Mobile Edge Computing services with QoS support for beyond 5G Networks – Use Cases

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4 authors, including:

Tomislav Shuminoski
Ss. Cyril and Methodius University in Skopje

Bojana Velichkovska
Ss. Cyril and Methodius University in Skopje

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David Nunev[1] Tomislav Shuminoski[2] Bojana Velichkovska[3] Toni Janevski[4]
[1]Virtual1
Skopje, R.N. Macedonia
[2,3,4]Ss. Cyril and Methodius University,
Faculty of Electrical Engineering and Information Technologies
Skopje, R.N. Macedonia
davidnunev@yahoo.com[1] tomish@feit.ukim.edu.mk[2] bojanav@feit.ukim.edu.mk[3] tonij@feit.ukim.edu.mk[4]

***Abstract*—This paper presents a novel research in intelligent multi-access QoS mobile edge computing (MEC) for beyond 5G services. Also, the improved advanced QoS model and architecture for beyond 5G systems and services are proposed. The proposed model combines the most powerful features of both Cloud and Edge computing, independent from any existing and future Radio Access Technology, leading to high performance utility networks with high QoS provisioning for any used multimedia modern service over present and future mobile and wireless networks and systems. Moreover, the proposed architecture will allow applications and network services to be executed at the edge part of the network, giving lower end-to-end delay for the end-user services and applications. Finally, this paper gives an overview of the existing Mobile Edge Computing technologies and several use cases. Undoubtedly, MEC is an innovative network paradigm going beyond 5G to cater for the unprecedented growth of computation demands and the ever-increasing computation quality of user experience requirements.**

Keywords*—Aggregation; Cloud; Edge Computing; Machine Learning; Quality of Service; Vertical Multi-Homing.

I. INTRODUCTION

The emerging future Mobile Broadband Internet applications require high demands for improved Quality of Service (QoS), which would be supported by services that are orchestrated on-demand and are capable of adapt at runtime, depending on the contextual conditions, in order to provide reduced latency, high bandwidth utilization, high mobility, high scalability, and real time execution with cloud computations. Recent years show increased interest in transferring computing from Clouds towards the network edges or Mobile Edge Computing (MEC). The 5G is an emerging technology that is growing exponentially, supporting many advance services, concepts and networks. Consequently, the 5G is including within this paradigm called Mobile Edge Computing. As 5G is already deploying in many countries round the globe, millions of new devices are deployed and will play part in various present and future networks and architectures that will benefit from the advantages that 5G offers. This means that the number of services offered by cloud and service providers will increase exponentially and all of that data could be overwhelming even for the cloud's (almost) unlimited resources. On the other side, the existing cloud computing (CC) solutions, cannot completely fulfill and cannot effectively cope with all these requirements and demands. Therefore the MEC concepts and sometimes Fog Computing appeared to resolve these challenges [1]. These concepts distribute computing, data processing, and networking services close to the end users, where computing and intelligent networking can best meet user needs. MEC and Fog Computing provide an infrastructure where distributed edge and user devices collaborate with each other, as well as, with the CC centers, in order to carry out computing, control, networking, and data management tasks. Also, there are significant disparities between MEC and CC systems in terms of computing, data storage, distance to end users and end-to-end latency. MEC has the advantages of achieving lower latency due to the shorter distances, saving energy for the mobile devices, supporting context aware computing and enhancing the privacy and security for mobile applications. Both MEC and CC in the core of their networks are using Network Virtualization, which is a powerful combination of SDN (Software-defined networking) and NFV (Network functions virtualization) infrastructure. In this paper, the user-centric approach is accepted as a basis for our work on Mobile Edge Computing system model, where the future the Mobile Terminals (MTs) would have access to different radio access technologies at the same time and should be able to combine different flows from different technologies using advance QoS algorithms within the Cloud orchestrator for used multimedia services, using vertical multi-homing and multi-streaming performances [2], [3].

II. FUNDAMENTALS AND BACKGROUND OF MEC

The tremendous interest and developments of mobile broadband Internet networks, undoubtedly lead to intensive research works towards advanced mobile and cloud computing algorithms and frameworks for high level of QoS provisioning in each core and access network. At the first place, the main motivation for our proposed intelligent multi-access QoS provisioning framework could be found in [2-6]. Device-centric multi-RAT architectures, native support of machine-to-machine communications and smarter devices are part of the main trend for 5G [6-8]. Moreover, our framework and design of a novel MT with Mobile Fog CC support is a next step from previous works on adaptive QoS provisioning in heterogeneous wireless and mobile IP networks [5, 6]. Those papers were introducing a framework adaptive QoS provisioning module that provides the best QoS and lower cost for a given multimedia service by using one or more radio access technologies (RATs) at a given time. A key concept that allows highlighting the potential of CC environment is orchestration that aims to coordinate the execution of a set of virtualized services within the same process. The orchestration concept has been widely studied in the context of Web services [9]. Recently it was extended in the CC domain, in order to perform an optimization and management of both physical and virtual resources in complex, federated or multi-cloud environments.

Furthermore we are giving an overview of fundamentals for MEC and MEC in 5G.

The key idea of MEC is in providing an Internet broadband service environment and cloud-computing capabilities at the edge of the mobile network part, within the RAN and in close proximity to MTs. In the foreseeable future, MEC will open up new markets for different industries and sectors by enabling a wide variety of 5G use cases, e.g., Internet of Things / Internet of Everything, Industry 4.0, Vehicle-to-everything (V2X) communication, smart city, Tactile Internet and etc. According to the ETSI [10], [11] white paper MEC can be characterized by some features, namely on-premises, proximity, lower latency, location awareness, and network context information.

Furthermore, there are several use cases for MEC [12]:

- *RAN-Aware video Optimization:* Video is currently taking half of mobile network traffic and set to exceed 70% of traffic over the next couple of years. Providing throughput guidance information is one of the MEC use cases. The proposed solution is to use MEC technology to inform the video server on the optimal bit rate to use given the radio conditions for a particular stream.
- *Video Analysis Service:* Many recognition type application could benefit from the MEC architecture, mostly by the proximity of the computation that is executed at the edge devices. Whenever some video data needs to be analyzed, it can be sent to the MEC server and only needed data can be sent to the centralized cloud. The system benefits of low latency and avoids the problem of network congestion.
- *Augmented Reality Service:* Augmented Reality (AR) is a live view of a real world environment whose elements are supplemented by computer generated inputs such as sound, video, graphics or other data, A MEC based AR application system should be able to distinguish the requested contents by correctly analyzing the input data and then transmit back the AR data back to the end user.
- *Enterprise and Campus Networks:*In large enterprise organizations, there is a desire to process users locally rather than backhaul traffic to centralized mobile core just so that it can send the data back again. This could be for services as simple as access to corporate intranet, (4k video training to a mass of employees at the same time) or more advanced services such as security policy, location tracking and asset tracking services.
- *IoT Applications:* MEC can be used to process and aggregate the small packets generated by IoT services before they reach the core network. Much of the data generated in a smart building is inherently local and involves D2D communication, so the benefits of this would be from moving the local computing and security, tracking, climate control to the edge servers and process and work with that data closer to the user without significant latency.

Furthermore, there are also many benefits in cooperation of MEC with SDN. The benefits of programmable networks align with the MEC requirements, and the recent form of SDN has the ability to mitigate the barriers that prevent Mobile Edge Computing to reach its full potential. All data flow management, service orchestration and other management tasks are done by the central SDN controller that is transparent to the end-user. Moreover, MEC will fit into the 5G concepts and what specifications have been developed based on the industry consensus. The 3GPP clarified how to deploy MEC in and seamlessly integrate MEC into 5G, which can be illustrated in [10]. Actually, the architecture comprises two parts: the 5G service-based architecture (SBA) and a MEC reference architecture. The network functions defined in the 5G architecture, and their roles can be briefly summarized as: Access and Mobility Management Function (AMF); Session Management Function (SMF); Network Slice Selection Function (NSSF); Network Repository Function (NRF): supports the discovery of network functions and services; Unified Data Management (UDM); Policy Control Function (PCF); Network Exposure Function (NEF); Authentication Server Function (AUSF); User Plane Function (UPF).

The MEC orchestrator (MECO) is the core component of the MEC system level, which maintains information on deployed MEC hosts (i.e., servers), available resources, MEC services, and topology of the entire MEC system. The MECO is also responsible for selecting of MEC hosts for application instantiation, onboarding of application packages, triggering application relocation, and triggering application instantiation and termination. The host level management consists of the MEC platform manager and the virtualization infrastructure manager (VIM). The MEC platform manager carries out the duties on managing the life cycle of applications, providing element management functions, and controlling the application rules and requirements. The MEC platform manager also processes fault reports and performance measurements received from the VIM. Meanwhile, the VIM is in charge of allocating virtualized resources, preparing the virtualization infrastructure to run software images, provisioning MEC applications, and monitoring application faults and performance. Finally, the MEC host comprises a MEC platform and a virtualization infrastructure. New functional enablers were defined in [13] to integrate MEC into the 5G.

III. INTEGRATED 5G AND MEC ARCHITECUTRE AND USE CASES

For supporting the large scale of network connections, 5G uses the tremendous computation and storage resources from remote datacenter and utilizes NFV and SDN technologies to virtualize the network resources for achieving an end-to-end optimized system for service provisioning. However, one issue that 5G network suffers from is the high latency, which could not meet the requirements of the emerging IoT applications. For solving this issue, MEC can be deployed in 5G gNB to eliminate the latency in the core network transmission, enhancing the service provisioning capability of 5G network for small-scale and ultra-low-latency services and application scenarios. As shown in Fig. 1, the future 5G mobile communication network will be a heterogeneous communication network that includes both the centralized Base Station (BS) and multiple distributed BSs. For integrating the MEC and 5G networks, Fig. 1 shows a multi-level computing network that provides edge computing and cloud computing functions. Within this architecture (also presented in [13]), MEC computing resources are allocated in LTE eNB, 5G gNB, super 5G BS, the edge of core networks to provide the computing and storage resources for end-users. To emphasized, there are many benefits of employing MEC into IoT systems, including but not limited to, lowering the amount of traffic passing through the infrastructure and reducing the latency for applications and services.

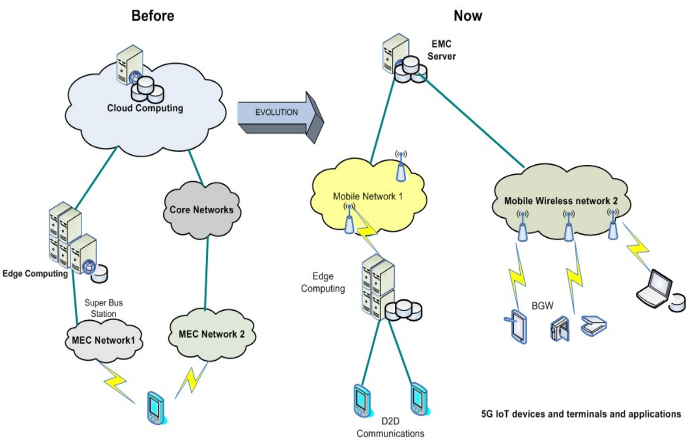

Fig. 1. A 5G combined with MEC.

Among these, the most significant is the low latency introduced by MEC which is suitable for 5G Tactile Internet applications requiring round-trip latency in the millisecond range. MEC technologies are envisioned to work as gateways placed at the middle layer of IoT architecture which can aggregate and process the small data packets generated by IoT services and provide some additional special edge functions before they reach the core network; hence, the end-to-end latency can be reduced.

In addition, based on the context and platforms of MEC, artificial intelligence (AI) or ML (Machine Learning) on the edge can gain the huge benefit to realize distributed IoT applications and intelligent system management, which is now considered as a part of beyond 5G standardization. Inversely, IoT also energizes MEC with mutual advantages. In particular, IoT expands MEC servies to all types of smart objects ranging from sensors and actuators to smart vehicles. Integrating MEC capabilities to the IoT systems come with an assurance of better performance in terms of quality of service and ease of implementation.

Furthermore several use cases for MEC and 5G IoT collaboration and integration are summarized.

Use case A: Security, safety, data analytics

Security and safety has become one of the most important verticals for IoT. The developments in technology with ever increasing amount of data from sensors and high resolution video cameras create the need for scalable, flexible and cost-economic solution to analyze the content in real time. MEC can host the analytics applications close to the source and enable increased reliability, better performance and significant savings by processing huge amounts of data locally. Enhanced video analytics enables creating and using rules for different events to trigger alerts and forwarding actions. Real time video analysis can be used to identify and classify objects (person, specific object), create rules for observation areas of interest, define and use event based rules (entering/exiting area, leaving/removing object, loitering) and counting objects (number of people, objects). The solution is flexible to deploy by enabling the video processing and analytics application running at optimum location based on technical and business parameters [12].

Use case B: Vehicle-to-Infrastructure communication

Digitalization of the services is progressing with enormous speed and automotive sector is one area where the new technologies are shaping the whole industry. Self-driving cars have been already demonstrated by both traditional automotive and new internet players. The work on future 5G system is being currently conducted by various organizations globally and the digitalization in the automotive industry is clearly reflected in the use cases and the requirements. IoT is a key driver for the next generation technology and the most of the use cases appear to focus on connected cars. Connected cars is not only about self-driving capability, but many other use cases exist. In general, all use cases related to smart transportation are of course in strict relation with the already mentioned Internet of Things paradigm. These use cases are not only considered from a theoretical point, of view, but early experimental activities are already taking place in these years. MEC is the ideal solution and has been identified as a key component to support these ultra-low latency scenarios as it enables hosting applications close to the users at the edge cloud and therefore providing the shortest path between the applications.

Use case C: Computation offload into the edge cloud

Applications running on MTs may want to offload parts of the computations into the cloud for various reasons, such as availability of more computing power or of specific hardware capabilities, reliability, joint use of the resources in collaborative applications, or saving bitrate on the air interface. The computation offload is particularly suitable for IoT applications and scenarios where terminals have limited computing capabilities, i.e. in those cases where M2M devices have severe low power requirements, in order to guarantee high batteries lifetime. Such offload may happen statically (server components are deployed by the service provider proactively in advance) or dynamically (server components are deployed on demand by request from UE). Also in this use case, applications benefit from low delay provided by MEC.

Use case D: Smart home and smart city

One of the most important use cases of IoT is smart city and its important subset smart home/building. Recently, the MEC contexts and novel 5G technologies have been enabled to emerge the judicious edge big data analysis and wireless access for IoT systems to further improve the urban quality of life for citizen with many aspects including security, privacy, energy management, safety, convenient life, etc...By leveraging the fog-enabled cloud computing environments, the novel implemented smart home systems can reduce 12% utilized network bandwidth, 10% response time, 14% latency and 12.35% in energy consumption. For monitoring and controlling the smart home/buildings, innovative analytics on IoT captured data from smart homes was presented in [14] employing the fog computing nodes. This fog-based IoT system can address the challenges of complexities and resource demands for online and offline data processing, storage, and classification analysis in home/building environment.

For the smart city use cases, the security and privacy aspects were considered in [15] where a blockchain-based smart contract services for the sustainable IoT-enabled economy is proposed for smart cities by employing AI solutions in processing and extracting significant event information at the fog nodes, and then utilizing blockchain algorithms to save and deliver results.

Use case E: Wearable IoT, AR and VR

The newly emerging applications corresponding to mobile AR, VR, and wearable devices, e.g., smart glasses and watches, are anticipated to be among the most demanding applications over wireless networks so far, but there is still lack of sufficient capacities to execute sophisticated data processing algorithms. To overcome such challenges, the emergence of MEC and 5G techniques would pose the longer battery lifetime, powerful set of computing and storage resources, and low end-to-end latency. Sharing this view, [16] presented Outlet system to explore the available computing resources from user's ambience, e.g., from nearby smart phones, tablets, computers, Wi-Fi APs, to form a MEC platform for executing the offloading tasks from wearable devices. Promising performance achieved by Outlet, e.g., mostly within 97.6% to 99.5% closeness of the optimal performance, has demonstrated the advantage of enabling edge computing technique into wearable IoT systems. Applying MEC on VR devices, [17] presented an effective solution to deliver VR videos over wireless networks minimizing the communication-resource consumption under the delay constraint. This work also demonstrated the interesting tradeoffs among communications, computing, and caching. In [18], a novel delivery framework enabling field of views caching and post-processing procedures at the mobile VR device was proposed to save communication bandwidth while meeting low latency requirement. Impressively, an implementation of MEC concepts over Android OS and Unity VR application engine in [19] enabled to reduce more than 90% computation burden, and more than 95% of the VR frame data being transmitted to MTs by letting MEC servers adaptively store the previous results of VR frame rendering of each user and considerably reuse them for others to reduce the computation load

Use case F: Tactile Internet

Tactile Internet is defined by the ITU as the next evolution of IoT that combines ultra-low latency with extremely high availability, reliability and security. Encompassing human-to-machine and machine-to-machine interaction, Tactile Internet will combine multiple technologies including 5G and MEC, i.e., 5G may be employed for the data transmission with low delay and high reliability while MEC efficiently exploit computing resources close to the end users for better QoE. The applications related to Tactile Internet can be automation, robotics, tele-presence, tele-operation, AR, VR. The following summarizes the recent works focusing on the technical aspects involving to the MEC implementation in Tactile Internet. An energy-efficient design of fog computing networks will support low service response time of end-users in Tactile Internet applications and efficiently utilize the power of fog nodes. The trade-off between the latency and required power was presented and then extended to fog computing networks leveraging cooperation between fog nodes. We can exploit the MEC systems including cloud, decentralized cloudlets, and neighboring robots equipped with computing resource collaborative nodes for computation offloading in support of a host robot's task execution. MEC based collaborative task execution scheme outperforms the non-collaborative scheme in terms of task response time and energy consumption efficiency. Recently, in [20] designed a hybrid edge caching scheme for Tactile Internet which can reduce latency and achieve better performance in overall energy efficiency than existing ones.

IV. SYSTEM ARCHITECTURE AND MODEL FOR BEYOND 5G MOBILE EDGE COMPUTING SERVICES

The Fig. 2 depicts the system architecture and usage scenario for our proposed intelligent multi-access QoS mobile edge computing framework for beyond 5G services, using heterogeneous environment orchestrated services. First, the main characteristics of our proposed edge MT with incorporated advanced QoS user-centric ML module (AQA) with vertical multi-homing and multi-streaming features are illustrated in [6], and and with ML being an essential tool for data intelligence it guarantees improvement of services [21]. The Cloud server placed in the core part of the network is in constant communication with the MEC Radio Access Network (MECRAN) servers in which are placed the multimedia broadband orchestrators wich orchestrates the MECs. Moreover, each MT used in the above scenario is multi-RAT node, with several (n) RAT interfaces. The advanced QoS routing algorithm is set within the AQA module on IP layer in both MT as edge device in one side, and the MECRAN server in the another side. Also in the edge devices (MTs) there is a orchestrator agent which collect the QoS parameters of interest and sends to the ochestrator manager in the MECRAN. Here, the QoS parameters of interests are: service price per RAT, MT velocity, MT battery level, MT latency (from MT to MECRAN), detected signals strength, response time, availability, maintainability and etc. If the MECRAN orchestrated-service manager is overloaded, he can send part of his work for processing to the local edge agents in the heterogeneous environment or to the Cloud server in the core or to global Cloud Server Farm. However, part of the optimizations in selecting the most appropriate RAT for a given services/service are done in the service orchestrator agent, but mostly all those optimizations are done in the service orchestrator manager in MECRAN, by starting the AQA module with Machine Learning (ML) algorithm. On a transport layer, the most suitable protocols which are used here are: Stream Control Transmission Protocol (SCTP) [22], Datagram Congestion Control Protocol (DCCP) [23]. Also, on the other end of the connection must be installed SCTP/DCCP on its transport layer in order to have successfully established SCTP/DCCP association.

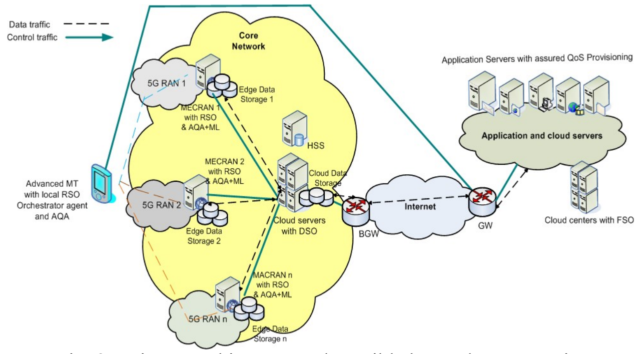

Fig. 2. Sistem architecture and possible beyond 5G scenario.

Furthermore, one of the advantages of our framework is the following: it is defined independently from different RATs, implemented on IP Network Layer. This advanced MT is using Multi-RAT interfaces and is able to provide intelligent QoS management and routing over variety of heterogeneous RATs at the same time. Moreover, the services orchestrator with help of AQA module is able to combine simultaneously several different traffic flows from different multimedia services transmitted over the same or different RAT channels, ML to understand traffic activity, and therefore, improve upon existing services, as well as optimize the chosen traffic flows accordingly to resources. The final aim is in achieving higher throughput, higher access probability ratio and optimally (regarding the resources) using the heterogeneous RAT resources. Our proposed architecture incorporates the above model, which consists of several levels: Regional Service Orchestrator (RSO), Domain Service Orchestrator (DSO) and Global Service Orchestrator (GSO). The RSOs are located at the edges of the MECRANs and at the advanced MTs, enabling semi-autonomous operation of the different Regions. Due to the advanced MT proximity, this provides quicker distribution of the load, lower latency and higher scalability. The DSOs are located in the cloud computing data centers, in the core networks. Each DSO is responsible for their domain/s and supervises the RSOs below. Like that global mechanisms are provided in order to enable intra-domain cooperation between different regions.

At the top of the architecture are located the GSOs, which allow a fruitful interaction between different cloud and fog domains. The GSO enables the management functionality between different cloud and fog domains and, similarly to the DSOs, it should be properly adapted to operate in a global Cloud environment. GSO communicate with other GSOs and like that global mechanisms are provided that enable cooperation among different cloud computing Domains (e.g. under the administration of different authorities). These global mechanisms also enable the creation of a Multi-Domain Mobile Cloud Environment able to support service ubiquity.

The process of establishing a tunnel to the Cloud Server in the core, for routing based on the QoS policies and QoS requirements per service; are carried out immediately after the establishment of peer-to-peer connection between the MT services orchestrator agent with MEC features and MECRAN server on the other side. The MT and MECRAN/Cloud server with vertical multi-homing and multi-streaming features and service orchestrator, with ML within, are able to handle simultaneously multiple radio network connections and speed up the transfer of the multimedia services. Moreover, by transmitting each object of each service in a separate stream, the highest level of satisfied end-users is achieved. In that way, by using our proposed MT with AQA with ML algorithm within, instead of creating a separate connection for each object as in TCP, makes use of network capacity aggregation, multi-streaming and multi-homing feature to speed up the transfer of the target multimedia service over separate streams over different RATs. So, all mobile broadband services are going over MECRAN and MEC agent in the user's MT (in the downstream direction) and vice versa (in the upstream direction). Also, in comparison with all related works, we must to emphasize that our advanced QoS framework for mobile broadband with MEC and ML is implemented on IP level in the Cloud-servers, MECRAN servers and in the edge (MT) sides.

V. CONCLUSION

In this paper overviewed MEC essence, provides existing use cases of MEC with 5G, and proposes a novel beyond 5G framework for MEC for mobile broadband Orchestrated-services in heterogeneous RATs. According to the analysis, our proposed framework with MEC orchestrated-services is expected to perform fairly well under a variety of network conditions and optimally utilized the resources due to the used ML algorithm and MEC processing. In that manner, efficient and QoS-based usage of available mobile resources, plus efficient MEC orchestrated-services performances are most essential for provision of seamless mobile broadband Internet services. The proposed model combines the most powerful features of both Cloud and Edge computing, independent from any existing and future Radio Access Technology, leading to high performance utility networks with high QoS provisioning. Undoubtedly, MEC is an innovative network paradigm to cater for the unprecedented growth of computation demands and the ever-increasing computation quality of user experience requirements. It aims at enabling Cloud Computing capabilities and telecommunication services in close proximity to end users, by pushing abundant computation and storage resources towards the network edges. The direct interaction between MTs and edge servers through wireless and mobile communications brings the possibility of supporting applications with ultra-low latency requirement, prolonging device battery lives and facilitating highly-efficient network operations.

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