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Multi-access edge computing in cellular networks

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Abstract Multi-access edge computing (MEC) is an extension of cloud computing technology to provide an application deployment platform close to the end users. This platform helps to deploy real-time, compute and resource-intensive applications like video caching, augmented reality, virtual reality, and Internet of Things at the edge. MEC enhances the performance of 4G and 5G networks since it achieves reduced application latency and optimizes the backhaul bandwidth utilization. Due to these benefits, MEC has become one of the key enablers of 5G technology. This paper covers evolution, architecture, current standardization activities, and use cases of MEC in cellular networks. The paper also emphasizes on how key enablers of 5G like software defined networking, network function virtualization, quality of service handling, and service based interface model will handle faster connectivity, huge data demand with less backhaul congestion, large number of devices and real-time applications as compared to MEC in 4G. Further, MEC deployment approaches in 4G and 5G are discussed, which play a vital role in achieving the requirement of 5G services.

Keywords MEC · LTE · 5G · SDN · NFV

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1 MEC introduction

The evolution of cloud computing provides a centralized infrastructure platform for application providers to host their services. Recent technological advancements lead to an increase in new low-latency and high throughput based mobile applications, but it may also lead to having high-end client devices. From an energy and resources perspective, mobile devices may not be able to handle these compute-intensive applications. To accommodate real-time compute and resource-intensive applications, edge computing technology in the form of cloudlet [1] offloads computation tasks to servers near the end users. Cloudlets achieve low latency by performing computation at the edge. With the same motive, in the telecommunication sector, the European Telecommunications Standards Institute (ETSI) introduced the concept of mobile edge computing in 2014 [2]. To leverage edge computing in any radio access network such as mobile network and wireless network, ETSI renamed MEC as multi-access edge computing in 2017. In cellular networks, edge computing is an extended version of cloud computing to bring cloud services at the edge. MEC helps to improve network flexibility to fulfill mobile data demand, high density of users, and real-time applications. Due to this, MEC becomes one of the key technology enablers for the 5G network. Plenty of real-time applications can host on the MEC platform, which helps the telecommunication sector to reduce CAPEX and OPEX.

As per ETSI, MEC is defined as the extension of IT services and cloud-computing capabilities at the edge of the mobile network in an environment that is characterized by proximity, ultra-low latency, and high bandwidth [2]. MEC platform is created not only for cloud computing capabilities for MEC usecases but also provides the real-

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time environment. The radio network information and location information of mobile devices from the 4G/5G core network is exposed to the MEC platform to improve the quality of experience and offer new location-based business models. The primary goal of edge computing is to reduce back-haul network congestion, to support low latency applications, and improve overall application performance. MEC framework helps to provide high throughput, interactive services, ultra-reliable communication, and connection in dense areas. The MEC architecture characterize by features such as proximity with one hop away, location-aware services, low latency, less network back-haul congestion, high reliability, and high availability.

1.1 MEC use cases

ETSI mainly classifies MEC use cases in three classes, which are consumer-oriented services, operator-oriented services, and network performance-oriented services. Augmented and virtual reality applications, eHealth services, and IoT services develop for consumer benefits. Operator oriented services help the organization to get insights from captured data for its future operations. Those services are video surveillance, video analytics, connected vehicles, etc. The last class of use cases based on improvements in network performance and quality of experience. Use cases of this class are content/video caching and location-aware video optimization, which reduce the load on back-haul network bandwidth. In [3], ETSI specified various MEC use cases with their technical requirements and benefits. MEC computation offloading usecases are briefly described in [4, 5].

1.2 MEC framework

ETSI has started to standardize framework specifications for MEC hosts so that any mobile operator or third-party application provider can deploy their MEC applications [6].

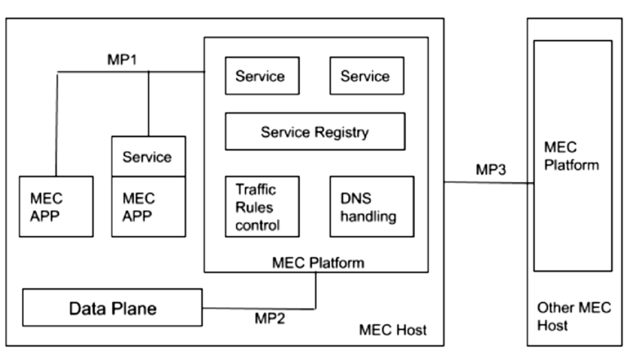

Fig. 1 MEC host framework

Figure 1 describes the framework details of the MEC host. MEC applications can communicate with the MEC platform via the MP1 interface. This communication can be for application registration, use of MEC services, and to interact with the cellular network for traffic influence. The MP2 interface of the MEC platform control/add traffic rules of the user data plane for MEC applications. Different MEC platforms can interact with each other about user and application mobility via the MP3 interface. The MEC platform does the activation and deactivation of traffic rules related to MEC applications and adds these rules to the user data plane. MEC platform has a Domain Name System (DNS) facility to add local DNS entries for MEC applications, which reduces DNS resolution time. Deployed MEC applications can use registered services such as location information and radio network information for better performance. ETSI also specifies the MEC platform deployment in a virtualized environment of a data center in [7].

2 MEC in 4G networks

Currently deployed 4G network can leverage the benefits of MEC by configuring data plane traffic to route requests to MEC applications. ETSI specified various MEC deployment options [8] inline with 3GPP specifications like Bump-in the wire approach, Distributed Evolved Packet Core (EPC), Distributed Serving or Packet Data Network Gateway (S/PGW), and Distributed Serving Gateway (SGW) with local breakout approaches. The Bump-in the wire approach can again have three deployment approaches. In the first approach, the MEC platform acts as part of a legacy S1-U interface (Reference point between the Radio Access Network (RAN) and the EPC). In this, user data traffic will encapsulate in GPRS Tunneling Protocol (GTP) packets. Because of it; this approach can have the overhead of GTP header processing. In the second approach, the base station locally routes IP packets to MEC applications by adding specific traffic filters. There is one more way in the Bump-in the wire approach where the MEC platform co-locates with Cloud-RAN, which ensures low latency due to the use of the same cloud infrastructure for MEC deployment at the RAN side. This approach also reduces the latency of MEC services while getting location information and radio network information from the RAN. ETSI described this specific approach as a perfect pairing of Cloud-RAN and MEC in [9]. In a distributed EPC approach, the MEC platform can connect EPC via the SGi interface (lies between the Packet Data Network Gateway (PGW) and the data network), and deploy EPC instances at the edge site.

In Distributed S/PGW approach, SGW and PGW network functions are deployed at the edge site and can use the SGi interface to connect with the MEC applications. The latter approach is Distributed SGW with local break out, in which the SGW network function has local traffic steering functionality to route traffic towards MEC application via the SGi interface. This approach mainly uses to route specific types of traffic to MEC applications using traffic filters.

Based on ETSI MEC deployment approaches for 4G, researchers have proposed the MEC implementation frameworks to integrate 4G and MEC applications. In the Bump-in-the wire approach, also known as the Middle-box approach [10], the MEC platform deploys on the S1-U interface, which lies between the RAN and 4G core network. This approach does not require any modifications to the 4G network. Additionally, all GTP control and data packets go to core network from RAN via the MEC platform. Hence, the introduction of the MEC platform creates two separate networks between RAN and EPC. Figure 2 shows the MEC framework in the Middlebox approach. The main modules in the MEC platform are packet forwarding module, GTP unpacking and repackaging module, and local DNS server. The packet forwarding module applies traffic filters based on the port and IP address of the destination. If a port address is 53, then it routes the packets to the local DNS server. If a packet destines for any MEC application, it would be forwarded to the corresponding MEC applications by un-packing the GTP header. Else, the packets are forwarded to the 4G core network.

To keep track of all the GTP packets routed via the MEC platform to the MEC applications, the packet details such as tunnel endpoint identifier (TEID) and IP address are saved in the form of a map. After processing requests by MEC applications, packets correctly forward after GTP packaging to the destined mobile device. Key benefits of this approach include a reduction in latency as MEC applications are at first hop after RAN and simpler management of forwarded data packets to applications. But this approach introduces control plane latency and raises security concerns as all packets route via MEC middle-box.

There is also one more implementation framework based on the local breakout approach [11]. In this approach, IP traffic intended to MEC applications is directly forwarded to the MEC server using the application-aware function at the RAN side. GTP packaging overhead comparatively less than the middlebox approach. Recently, the researchers leveraged the benefits of SDN with the help of an open virtual switch to develop an MEC platform [12]. In this SDN based approach, an open-source low-latency MEC (ll-MEC) platform is developed along with OpenAirInterface (OAI), which is an open-source LTE platform. SGW of LTE is configured in such a way that open virtual switch acts as a control and data plane separator. Data traffic does not route towards PGW as compared to regular LTE operation.

Additionally, using northbound redirection APIs of the ll-MEC platform, new traffic rules related to MEC applications can be added to the virtual switch. The main features of this approach are the separation of control and data plane functionality and support to add new traffic rules using northbound APIs. 3GPP considers the related approach in 5G specifications, which discuss in later sections. Along with the ll-MEC platform, FlexRAN APIs are also being developed to get radio network information from OAI-RAN components and used for RAN-aware video optimization usecase.

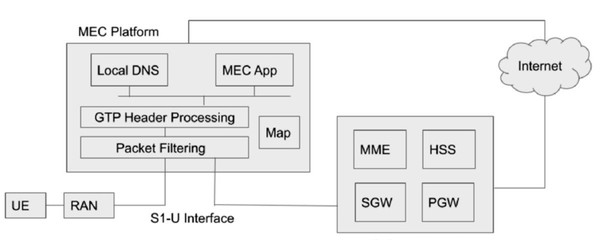

Fig. 2 Framework of middlebox approach in 4G network

3 MEC in 5G network

4G and its interaction with the MEC framework are discussed in the previous section in detail. However, recent technological advancements in the mobile industry, sensor devices, networking domains, data analytics, and cloud architectures have transformed the telecommunication industry. New applications lead to an increase in data demand, industrial machine-to-machine communications, real-time applications, and availability of computing capabilities near the user devices. The next-generation cellular radio access networks provide much needed enhanced connectivity, high data rate, high service availability, high user density, and low latency for real-time applications. Hence, 5G technology attracts research interest among leading researchers in the world.

5G use cases can broadly cluster into three categories based on key performance indicators and value propositions offered in various scenarios i.e., Enhanced Mobile BroadBand (eMBB), Ultra-Reliable Low Latency Communication (UR-LLC), and massive Machine Type Communications (mMTC). The exemplary use case in the eMBB category comprises data applications such as video surveillance, live event streaming, virtual reality, and augmented reality, which require a high data rate. The second category of applications includes real-time responsive systems such as autonomous cars, eHealth services, and connected vehicles, which require reliable and low-latency communication. Third category applications include use-cases such as a large number of sensor connections i.e., massive connectivity. The features of MEC fulfill the 5G use case requirements, such as reduced end-to-end application latency and bandwidth efficiency. Figure 3 generalizes the MEC deployment scenario at the edge i.e., near the RAN and its interaction with 5G core network to support various usecases.

3.1 MEC interaction with 5G core network

This section describes the communication of the MEC platform with 5G core services [13]. As per 3GPP specifications, the 5G network can be implemented as the reference-point or service-based architecture. In reference-point architecture, individual network functions interact with each other using a point-to-point logical communication link, whereas, service-based architecture is based on HTTP Request-Response or subscribe-notify model between two network functions. In the 5G network, the mobile devices would be registered to the core network initially and establish the Protocol Data Unit (PDU) sessions only when data services are required. The communication between 5G core network and MEC varies as per session establishment leading to two scenarios, such as existing sessions and future sessions. In the existing session scenario, the PDU session is already created with a 5G core network but not with the MEC platform i.e., User Equipment (UE) comes first condition. Whereas in future session scenarios, the MEC platform is connected to the core network first and then establishes the PDU session i.e., MEC comes first condition.

The current section illustrates MEC communication with a 5G core network in general irrespective of PDU session establishment. The MEC platform acts as an Application Function (AF) for 5G. If AF is trusted i.e., AF is part of the mobile operator, AF registers as one of the core network functions using Network Repository Function (NRF). AF interacts with Policy Control Function (PCF) by sending MEC application details like its routing information and data network name. PCF converts AF requests into policies and store it into the Unified Data Management (UDM) repository. PCF notifies the policy creation event to Session Management Function (SMF). SMF will use this information to add new traffic steering rules in selected available User Plane Function (UPF). If UPF is not available at a particular location, based on QoS and location constraints, SMF creates a new instance of UPF and adds new traffic rules so that the UE traffic route to MEC application locally. Figure 4 shows the interaction between registered trusted AF and core network modules to add new traffic rules in UPF.

If AF is an un-trusted or deployed by the third-party application provider, then AF interacts with Network Exposure Function (NEF) for traffic influence. To achieve low latency, NEF can also be deployed locally. After authorization of AF, NEF sends received traffic influence details to Unified Data Repository (UDR). If SMF is subscribed to UDR notifications, then SMF gets a new traffic update from UDR. As per data received, it adds new traffic rules in the available UPF or newly created UPF. During the PDU session establishment, SMF provides the IP address of respective UPFs for routing traffic locally to the MEC applications. The sequence diagram of this scenario is shown in Fig. 5.

3.2 MEC deployment scenarios in 5G

As per ETSI, MEC can deploy along with the base station, at aggregation point of small cells, or along with core network [14]. 5G core network can have single or multiple UPFs configured to steer data-plane traffic between MEC

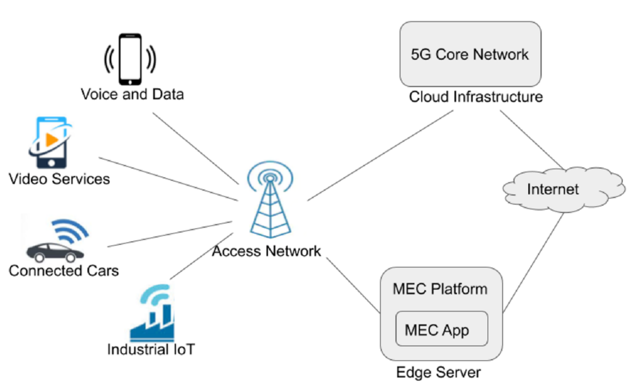

Fig. 3 MEC platform deployment in 5G network

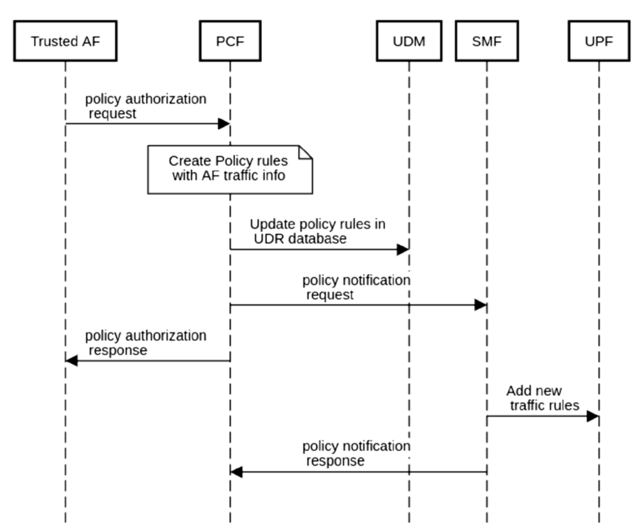

Fig. 4 Interaction between trusted AF and 5G core network

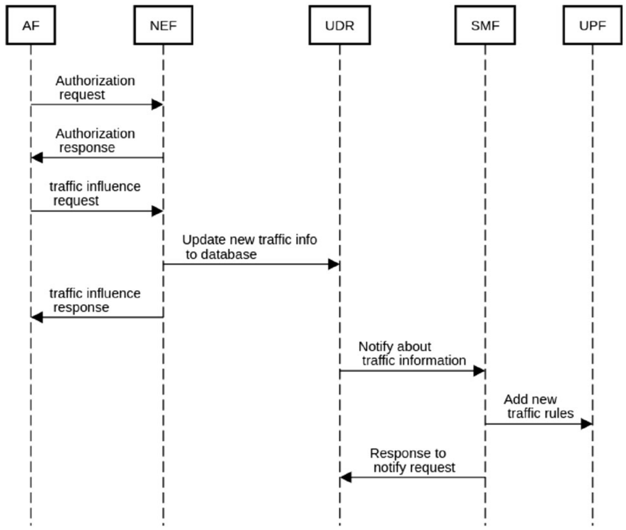

Fig. 5 Interaction between un-trusted AF and 5G core network

and data network. Alternatively, the MEC platform can deploy with local UPF and Local Area Data Network (LADN) provided by Public Land Mobile Network (PLMN). In single UPF configuration, data network and MEC platform can connect with only one UPF, which contains packet detection rules to route traffic to MEC or Internet/cloud. In multiple UPFs configuration scenarios, one UPF redirects traffic to MEC applications, and another one redirects to cloud/remote applications. Figure 6 summarizes all the deployment scenarios, as mentioned above.

4 Advancements in 5G from 4G

To cope up with new 5G requirements specified by IMT - 2020 [15] like 10 Gbps data rate, 1 ms end-to-end latency, high density of users, and 99.99 % service availability, 5G architecture is enhanced with new technical features. These new features help to reduce application latency, service

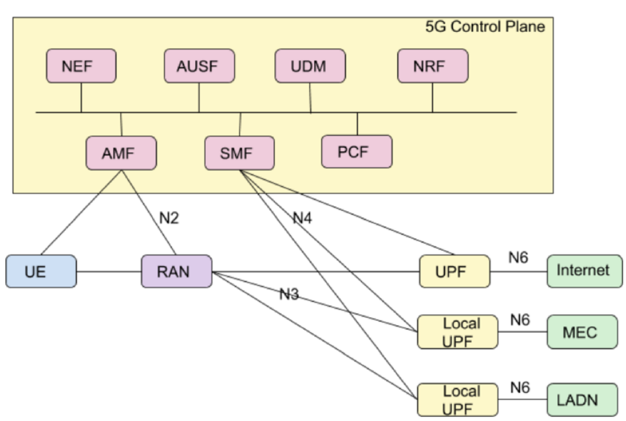

Fig. 6 MEC deployment scenarios in 5G network

downtime, and service deployment time in 5G to support real-time applications. Features like Control and Data Plane Separation (CUPS) framework, modular network functions, SDN, NFV, quality of service (QoS) handling and, network slicing are the enablers to achieve the above mentioned 5G requirements. Mao et al. [4] focuses on QoS requirements, mobility management, and network slicing features. These new underlying 5G core network features are discussed in terms of their impact on MEC deployment as follows:

4.1 CUPS framework

The current LTE setup is not fully separated in control and data plane functions due to tight coupling between SGW and PGW network functions. With the UPF introduction, 5G architecture separates the control plane i.e., signaling and user plane i.e., data traffic. In the 4G network, data traffic to the data network goes via SGW and PGW, but in 5G, it routes via UPF, which is 1-hop away from the RAN. The CUPS framework also helps to achieve the scalability of the data plane and deployment of local UPFs in a distributed fashion near to mobile devices, which enable reduced latency [16]. The use of the CUPS framework also achieves the scalability of the control plane.

4.2 Modularization of network functions

Due to the monolithic nature of LTE, there is always an inter-dependency between different network functions for smooth functioning. In 5G architecture, the functionality of LTE's Mobility Management Entity (MME) module can be segregated into Access Mobility Function (AMF) and SMF network functions for better scalability and independent development. In the same way, the MEC platform and MEC applications can host as different network functions. The service-based architecture [17] achieves the modularity of the network functions. Services are flexibly developed without creating any new interfaces to communicate between network functions. From the deployment perspective of a network function, any network function can deploy on dedicated bare-metal hardware, virtual machines, lightweight virtualized containers, or cloud infrastructure. Flexible deployment of network functions in virtualized infrastructure can further reduce service migration time and end-to-end application latency from the MEC perspective.

4.3 Use of NFV and SDN technologies

NFV facilitates flexible and scalable deployment of network functions in any data center. In contrast, SDN provides functionalities in terms of enormous traffic handling using the SDN controller by adding new traffic rules at any time. Christos et al. [18] surveys use of SDN and NFV in the 5G network. To handle the 5G requirements like a large number of session requests, scaling of core network functions based on traffic demand are achieved with the help of NFV technologies. SDN technologies manage load balancing between different network functions/MEC applications. These technologies help in easy and fast deployment of MEC components like MEC platform and MEC applications anywhere and at any time during service and user mobility to achieve high availability of edge applications.

4.4 Service continuity management

In 4G, anchors are maintained at PGW by saving UE's IP address and data network details during mobility events. For 5G, 3GPP specified three different session and service continuity (SSC) modes to handle MEC application or device mobility [19]. For any session, SSC mode applied during its establishment by SMF. In the first mode, the IP address of a mobile device remains the same at UPF anchor regardless of mobility. This mode performs the same as session continuity in LTE. In the second mode, the first session between source UPF gets discontinued and a new session created with target UPF in a new area. In contrast, in the third mode, the session is maintained between both source and target UPFs until a new session gets established in a target location to maintain uninterrupted service and improve the quality of experience.

4.5 Management of QoS requirements

In LTE, QoS is applied per bearer, which is used to route all types of traffic in the same manner, i.e., it does not distinguish different flows (services) in a bearer. In 5G, QoS requirements are applied to each service in a PDU session, so each service has its own QoS characteristics. Each MEC use case may have its specific QoS requirements. Low latency is required by mission-critical applications, whereas video streaming services require high bandwidth. To ensure QoS requirements of MEC user plane traffic, PCF provides QoS details and respective charging rules for associated PDU sessions with MEC. Figure 7 describes the handling of QoS requirements by the 5G core network and MEC application. The 5G network manages the QoS requirements between the UE and respective UPF. Deployment of the UPF should fulfill 5G QoS requirements. To achieve the MEC application's end-to-end QoS requirements, the application provider chooses an appropriate data center to deploy edge application. For this, the 5G core network communicates the QoS requirements of the MEC applications over the N6 interface to the MEC application provider.

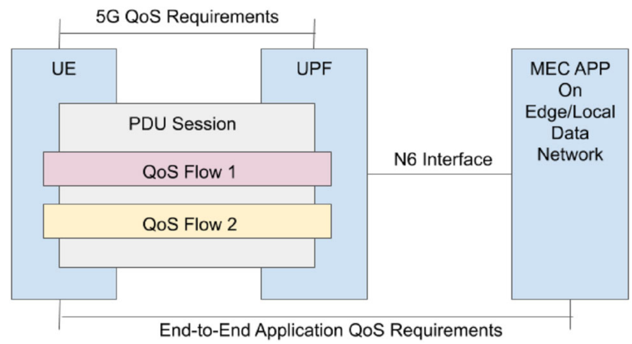

Fig. 7 QoS requirements of MEC application

4.6 Use of network slicing

Network slicing is one of the key features of the 5G network. It is a framework through which different virtualized logical networks are created on the top of physical infrastructure. It is mainly used for deploying various services having different requirements of network resources efficiently and in a seamless manner. The concept of network slicing and its key benefits, driving technologies, and standardization work is covered in [20]. Using a network slicing concept, a mobile operator/third-party application provider can deploy MEC applications as a part of network service by mentioning required configuration parameters in descriptor files. Due to this feature, application deployment becomes much easier, faster, and on-demand.

4.7 Integration of MEC with 5G core network

With the above mentioned underlying technologies to interact MEC applications with 5G core network, 5G also provides a mechanism for the MEC platform [19] to select required local UPF for traffic steering and interact with NEF/PCF to add new traffic influence rules in the UPF. Local traffic steering is achieved with the help of a local area network provided by PLMN or by adding traffic filters in UPF. Also, it takes the help of various SSC modes for service continuity in mobile scenarios. The core network exposes location information, radio network information, and IP address details of mobile devices for better performance of the MEC platform. 3GPP also adds the functionality of the data usage tracker in UPF for the charging of services.

5 3GPP service aspects on edge applications

Recently, 3GPP is working on application architecture for enabling edge applications [21]. This work emphasizes various issues that arise in MEC application architecture and its connectivity with end devices. Challenges from the

UE side comprise how it can configure, discover, select, register, get notifications to update about application mobility, and connect to any deployed MEC applications at edge data network. MEC application server's challenges are how to host multiple third party services at a single edge data network, discover and use capability exposure APIs provided by 5G core network, management of QoS requirements, and lifecycle management of various MEC applications. Application and user mobility-related challenges like relocation of application context are covered. Proposed solutions for the issues mentioned above are based on the service-based model, as it mainly uses as an architectural approach for cloud computing services. Also, the edge management and orchestration guidelines provided by 3GPP [22] highlight the UPF lifecycle management using NFV infrastructure, access provision of NEF to AF for interaction with the cellular network.

6 Conclusion

Multi-access edge computing technology has become an emerging research area in the telecommunication sector. This paper summarizes the evolution of edge computing, its architecture, and its use cases in cellular networks. It also discusses how underlying technologies such as SDN, NFV, network slicing, and CUPS framework helped 5G network to lower the end-to-end application latency, optimize the use of network resources, and improve quality of experience. This computing paradigm is especially useful while accommodating real-time, compute intensive, and resource sensitive applications. The paper also covers current MEC deployment frameworks in the 4G network and provides guidelines on deployment scenarios in 5G while interacting with the core network.

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