Introduction to Mobile Edge Computing

Anwesha Mukherjee, Debashis De, Soumya K. Ghosh, and Rajkumar Buyya

Abstract Fifth generation mobile networks aim to use multi-tier heterogeneous cellular networks integrated with cloud computing to provide users with low latency and energy-aware service. However, for high bandwidth and low latency services, edge/fog computing comes into the scenario. In edge/fog computing, the intermediate devices between end users and cloud participate in processing and storage of data as well as execution of applications. Mobile edge computing provides cloud computing services at the edge of mobile network, which facilitates the developers, service providers as well as the users. Internet of Things (IoT) has become a principle component to design smart technological solutions for our daily life. For low latency and high bandwidth services, edge computing assisted IoT has become the pillar for the development of smart home, smart health etc. This chapter will discuss the overview of mobile edge computing along with its real time applications.

Keywords Mobile edge computing · IoT · Power · Latency

A. Mukherjee (✉)
Department of Computer Science, Mahishadal Raj College, Mahishadal, West Bengal, India
e-mail: anweshamukherjee@ieee.org

D. De (✉)
Centre of Mobile Cloud Computing, Department of Computer Science and Engineering, Maulana Abul Kalam Azad University of Technology, Kolkata, West Bengal, India
e-mail: dr.debashis.de@ieee.org

S. K. Ghosh
Department of Computer Science and Engineering, Indian Institute of Technology (IIT) Kharagpur, Kharagpur, West Bengal, India
e-mail: skg@cse.iitkgp.ac.in

R. Buyya
Cloud Computing and Distributed Systems (CLOUDS) Laboratory, School of Computing and Information Systems, The University of Melbourne, Melbourne, VIC, Australia
e-mail: rbuyya@unimelb.edu.au

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1 Introduction

Mobile phones have become essential commodity in our daily life. With the advancement in wireless network, the number of mobile phone users have increased drastically. Moreover mobile phone usage is not limited within voice call and SMS service, but also has become a most popular equipment of accessing Internet anytime anywhere. Different mobile apps are nowadays available for online shopping, health monitoring, playing game, watching video etc. Fifth generation mobile network aims to use multi-tier heterogeneous cellular network integrated with cloud computing to provide users latency and energy-aware service [1, 2]. However, for high bandwidth and very low latency services, edge/fog computing comes into the scenario. In edge/fog computing the intermediate devices between end users and cloud participate in processing and storage of data as well as execution of applications [3–8]. Multi-Access Edge Computing which is formerly known as Mobile edge computing (MEC) [3] provides the cloud computing services at the edge of mobile network, which facilitates the developers, service providers as well as the users. In MEC the operators can open their Radio Access Network edge to the authorized third parties in order to provide rapid and flexible deployment of interactive services and applications for the users. Computations are performed usually at the local network edge in edge computing instead of putting it to the remote cloud, that in turn reduces the latency. The network providers meet the customers' demand of good coverage and high bandwidth through the help of MEC. MEC enables Information Technology (IT) and Cloud Computing facilities at the edge of the network. The objective of MEC is to minimize the congestion, reduce latency, and provides better Quality of Service (QoS) by accomplishing the related processing tasks closer to the end user. MEC can be implemented as cellular base stations which in turn can offer rapid application deployment. In [4] the authors have defined MEC as:

> MEC is a new network paradigm that provides information technology services and cloud computing capabilities within the mobile access network of mobile users and has become a technology.

MEC is a principle component for fifth generation (5G) network [4, 9]. As MEC is located close to the mobile users and within the Radio Access Network (RAN), low latency and high bandwidth access can be provided [4]. Hence, the QoS is improved. Moreover, service deployment and caching at the edge of the network helps to efficiently handle user requests and minimize congestion. In mobile edge computing computations are performed at the edge of the network, which helps to minimize the latency.

The MEC can be partitioned into three management systems (MS) [10]: (i) hosting infrastructure, (ii) application platform, and (iii) application. The first one contains a virtualization manager and virtualization layer. The second one offers traffic control, service registry, communication services and RAN information services. The third one serves as a virtualized machine for applications. Before getting deeper into the architecture of MEC, we will discuss few models closely related to MEC.

- Mobile cloud computing: Mobile devices usually have resource limitation, for which they may not be able to store huge volume of data or perform exhaustive computation. To solve the shortcomings, MCC has been developed. Mobile Cloud Computing (MCC) is a paradigm where the computations and storage take place inside the cloud instead of the mobile device [4, 11–15]. The user accesses the data from the cloud whenever required. Similarly when a computation has to be executed, that also is performed inside the cloud and the user gets the result. However, long distant cloud servers may increase the latency and the mobile device's power consumption, which may be crucial for real time application with hard deadline. In such situation it can be fruitful to bring the computation and storage facilities at the edge of the network.
- Fog computing: In case of the fog computing, the intermediate devices between end node and cloud servers, for example switch, router etc. takes part in data processing [8, 16–21]. These devices are known as fog devices. Edge devices in this case serve as a connecting devices with the end nodes. Fog computing is very much related to IoT nowadays. The data collected using IoT devices are preliminarily processed inside the fog device before being forwarded to the cloud. This in turn helps to reduce latency and improve the QoS subsequently.
- Cloudlet: A computer or a cluster of computers which offers the cloud services to the users by acting as an agent, is referred as cloudlet [22–27]. The cloudlet contains cache copies of the data stored inside the cloud. When a user requests to access to the data, the cloudlet meets the requirement. As a result the latency is reduced and the QoS is enhanced. However, cloudlet is mainly popular with wireless access environment.

The concept of MEC is much broader which makes it applicable for Wi-Fi as well as mobile network. Here, we will discuss on the use of cloudlet as well as cellular base station with edge server to depict the scenario of MEC.

2 Architecture of MEC

Mobile edge computing architecture contains the following components [4]:

- Mobile device
- Cellular base station (in case of cellular network)
- Cloudlet (in case of Wi-Fi)
- Edge Server
- Core network
- Cloud

In case of cellular network cellular base station is used along with an edge server. In this case it has to be noted that small cell with storage and computational ability

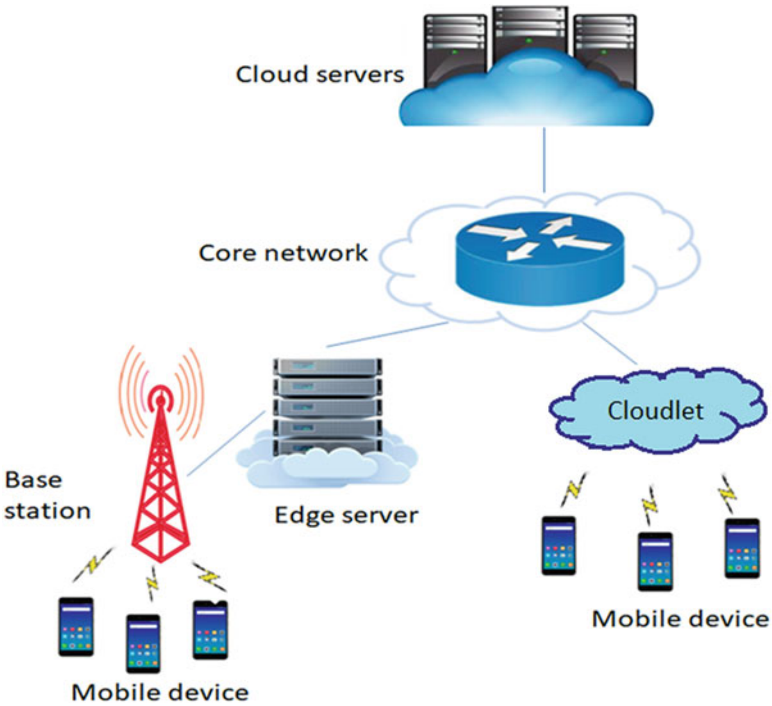

Fig. 1 Architecture of mobile edge computing

has been studied in few existing works [19, 21, 28–32]. In case of Wi-Fi i.e. Wireless Local Area Network (WLAN) or Wireless Metropolitan Area Network (WMAN), cloudlet is used. As cloudlet itself offers the storage and computation facilities, it can act as edge server. The MEC architecture is presented in Fig. 1. As observed from the figure, the mobile devices are connected with the base station (cellular network) or cloudlet (WMAN/WLAN). The base station is connected with edge server. The edge server is connected with the cloud through the core network.

The mobile device users or mobile users and edge server are the key components of MEC, on basis of which two categories of services come [4]:

- Mobile user oriented service
- Edge server oriented service

For the first category, mobile users request for offloading data and/or computation. For the second category, resource management is crucial. Mobile user oriented service mainly deal with offloading. Offloading is of two types [4]:

- Data offloading: User requests for storing data.
- Computation offloading: User requests for execution of a computation.

Edge server oriented service mainly deal with resource allocation and management. Load balancing is a vital issue when multiple users generate request. In such situations, efficient resource management is required.

2.1 Edge Server Placement

For cellular network, it is assumed that the edge servers of MEC are placed in the location of the base station [4]. For WLAN/WMAN, the edge servers are the cloudlets [4]. In WLAN, the number of mobile users is relatively less due to the small network coverage, whereas in WMAN has large number of mobile users due to its large network coverage. Hence, multiple cloudlets are to be placed at different locations. The mobile device access the cloudlet through an access point. If a cloudlet is co-located with an access point, the mobile users under that AP can get minimum cloudlet access delay. Otherwise, the mobile user under that access point if sends some request that will be relayed to nearby cloudlets, which can cause cumulative delay for multi-hop relays. Hence, the cloudlet placement is promising when a number of access points are present. This leads to two optimization problems [4]: cache placement [33] and server placement [34], both of which can be dealt with through a direct reduction to the capacitated K-median problem [35]. Nevertheless, this problem differs; here the assumption is that either there is no limitation in capacity of caches/servers or all the caches/servers have identical capacities though the capacity of each cloudlet may differ and different user requests also may need different resources for computation. This problem has been described as a new capacity cloudlet placement problem in [36]. Here, the objective is to put the cloudlets in such a way that the average access delay between the users and cloudlets can be minimized. To address this issue an effective heuristic solution with good scalability has been proposed in [36]. Another method for cloudlet placement and user allocation under them has been discussed in [24]. The selection of cloudlet while multiple cloudlets are available has been studied in [25, 26]. A location-aware service deployment method has been proposed in [37], where K-means is used. Here, the mobile users are divided into multiple clusters depending on their geographic location and the service instances are deployed to edge servers nearest to the mobile user clusters. The problem of access point ranking has been addressed in [38]. An adaptive integrated access point ordering scheme has been proposed in [38], where the connection features of the access point are analysed.

2.2 Resource Allocation

For the cellular base station based MEC framework, resource allocation and computation offloading both are considered. In MCC, the computation is executed inside the cloud and result is sent back to the mobile device. In MEC the offloading takes place usually inside the edge servers. In [39] the trade-off between latency and reliability in case of task offloading has been studied. A mobile user divides a task into subtasks and offloads those subtasks to multiple edge servers to reduce latency and offloading failure probability. For multi-user environment energy-efficient resource allocation has been discussed in [40], where the authors have considered computation-efficient models for negligible and non-negligible base station execution durations. A total weighting and energy consumption minimization problem has been developed for each model through optimal allocation of communication and computing resources. Computation offloading and interference management have been simultaneously taken into account in [41]. In this work physical resource block allocation, offloading decision and computation resource allocation are considered as optimization problems. Multi-access feature of 5G network has been considered in [42] to develop an energy-efficient computation offloading strategy, which can reduce energy consumption under delay constraint through the integration of radio resource allocation and optimized offloading. In [43] optimal resource allocation has been discussed to reduce the total energy consumption of multi-antenna access point under the respective computation latency constraint. In [44] a wireless network has been considered where each cellular base station is equipped with an edge server, which can assist the mobile user in performing computationally intensive tasks by offloading. The task offloading and resource allocation can be considered jointly in problem formulation to maximize the offloading profit for the user by reducing delay and energy consumption.

In cloudlet based MEC system the allocation of mobile user tasks is a promising issue while multiple cloudlets are present. In [45] a mixed integer linear programming optimization model has been discussed, where two types of cloudlets is used: local and global. When a mobile user asks for a service and the local cloudlets are unable to provide the service, then global cloudlet is used to handle this. In [46] the deployment of server by maintaining QoS and low cost has been highlighted. To solve this problem a low-complexity heuristic algorithm has been proposed. For low-latency and energy-efficiency, a joint optimization method has been proposed in [47]. In this work the bandwidth and resource allocation model are formulated as a Stackelberg game and an iterative algorithm has been used to get Stackelberg equilibrium [47]. Virtual machine (VM) migration is also a prime issue as the user is mobile. In [48] the mobile users get services from a cloudlet as an intermediate node. In [49] the authors have focused on reducing on-grid power consumption of cloudlet using migration. In [50] user mobility based VM migration has been performed between cloudlets. In [51] the VM migration problem has been considered as one-to-one contract game and a learning-based price control scheme has been proposed for better resource management. Two dynamic proxy VM migration schemes have been discussed in [52] to reduce the latency and energy consumption. The problem of dynamic service migration has been considered in [53], where a sequential decision making problem has been formulated based on Markov Decision Process.

3 Latency in MEC

In MEC, the storage and computation execution takes place inside the edge device. To calculate the latency the data transmission, propagation, computation execution and queuing latencies are calculated. During offloading the user device's power consumption is also calculated.

The data transmission latency in MEC is given as [25],

$$L_t = \sum_{i=1}^{h} \left(1 + U_{fi}\right) \frac{D_{tui}}{R_{ui}} + \sum_{j=1}^{k} \left(1 + D_{fj}\right) \frac{D_{tdj}}{R_{dj}}, \tag{1}$$

where U_{fi} is the failure rate in uplink, D_{tui} is the data amount transmitted in uplink, R_{ui} is the data transmission rate in uplink, between the communicating devices for hop i, D_{fj} is the failure rate in downlink, D_{tdj} is the data amount transmitted in downlink, R_{dj} is the data transmission rate in downlink, between the communicating devices for hop j, h is the number of hops in uplink and k is the number of hops in downlink.

The computation execution latency is given as [25],

$$L_c = \frac{I}{S}, \tag{2}$$

where I is the number of instructions to be executed for the computation and S is the instruction execution speed of the computing device (Edge server/cloudlet).

The propagation latency is given as [25],

$$L_p = \frac{D_p}{S_p}, \tag{3}$$

where D_p is the distance covered between the requesting and serving node, and S_p is the propagation speed.

If the queuing latency is denoted by L_q, the total latency is given as [25],

$$L = L_t + L_c + L_p + L_q. \tag{4}$$

The user device's power consumption during data transmission is given as [25],

$$\begin{aligned} P_t = {} & P_a \cdot \left(\left(1 + U_{fi}\right) \tfrac{D_{tu1}}{R_{u1}}\right) + P_i \cdot \left(\sum_{i=2}^{h} \left(1 + U_{fi}\right) \tfrac{D_{tui}}{R_{ui}}\right) \\ & + P_i \cdot \left(\sum_{j=1}^{k-1} \left(1 + D_{fj}\right) \tfrac{D_{tdj}}{R_{dj}}\right) + P_a \cdot \left(\left(1 + D_{fk}\right) \tfrac{D_{tdk}}{R_{dk}}\right), \end{aligned} \tag{5}$$

where P_a and P_i represents the mobile device's power consumption in active and idle modes respectively. For the first hop the communication takes place from the user to the next node in case of uplink. Hence, in this case the mobile device's power consumption in active mode is considered. Similarly, in case of downlink in case of the last hop (kth hope) the result is received by the mobile device. Thus, in this case the mobile device's power consumption in active mode is considered. In rest cases the mobile device's power consumption in idle mode is considered.

The user device's power consumption during computation is given as [25],

$$P_c = P_i \cdot L_c. \tag{6}$$

As the computation takes place inside the edge device, the power consumption of the mobile device in idle mode is considered.

The user device's power consumption during propagation is given as [25],

$$P_p = P_i \cdot L_p. \tag{7}$$

The user device's power consumption during queuing period is given as [25],

$$P_q = P_i \cdot L_q. \tag{8}$$

The total power consumption of the mobile device i.e. user device is then given as [25],

$$P = P_t + P_c + P_p + P_q. \tag{9}$$

In Fig. 2a and 2b the latency in computation offloading and user device's power consumption during that period, while using MEC and MCC are compared. This is observed that by bringing the computation at the network edge the latency is delivering the result to the mobile user has been reduced by ~45% and power consumption of the user device by ~35% than the mobile cloud computing framework.

In Table 1 three codes have been considered which are offloaded using MEC and MCC. The latency and user device's power consumption during that period are shown. From the experimental results it is observed that MEC reduces the latency by ~40% and user device's power consumption by ~30% with respect to MCC.

From the theoretical and experimental results we observe that MEC reduces the latency and power consumption of the user device than MCC in case of computation offloading.

4 Applications of MEC

There are several applications of MEC discussed as follows.

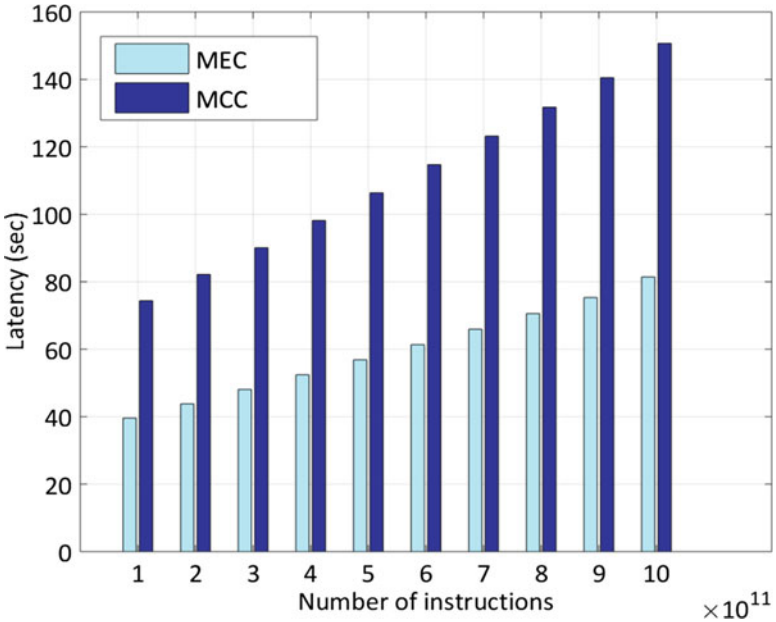

Fig. 2a Latency in MEC and MCC

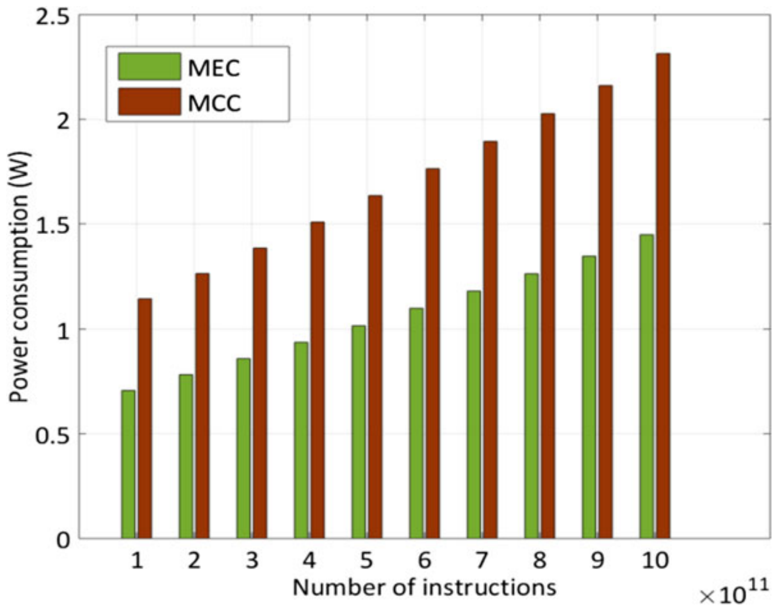

Fig. 2b Power consumption in MEC and MCC

Table 1 Latency and power consumption in code offloading

Device details	Code	Latency (sec)		Power consumption (W)	
		MEC	MCC	MEC	MCC
(i) User device: Asus ZenFone 5, RAM: 2 GB, storage: 16 GB, processor: Intel Atom Z2560 1.6 GHz. (ii) Edge server/cloudlet: Intel(R) Xeon(R) CPU E5-2667 0 @ 2.90GHz (Octa Core). (iii) Cloud server: Intel(R) Xeon(R) CPU ES-2667 0 @ 2.90 GHz (Hexa Core)	Matrix multiplication of order 100×100	2.7	4.5	0.15	0.22
	Creation of text file	5.01	8.35	0.25	0.36
	8-Queens puzzle	2.5	4.17	0.12	0.17

- **MEC in IoT**: IoT is an emerging research field nowadays. Use of MEC in IoT can enhance the QoS by bringing computation resources nearby the network edges [4]. It will offer scalable IoT framework for time critical applications. In IoT-MEC, the data collected using IoT devices get partially processed inside the edge devices, which makes the system faster, energy-efficient and reduces the network operation cost [4, 20]. A mobile edge IoT framework has been proposed in [52], where computing and storage resources are pushed nearby the IoT devices. Another approach EdgeIoT has been proposed in [54], where the data streams has been identified at the mobile edge.
- **MEC in video streaming**: To improve the Quality of Experience (QoE) of video streaming in smart cities a method has been proposed in [55], where users' mobility pattern have been followed and "Follow Me Edge" concept has been implemented. This method reduces the network traffic as well as the delay.
- **MEC in computation offloading**: Computation offloading between the wearable devices and cloud has been analysed in [56]. The convergence of cloud computing and mobile computing depends on high bandwidth edge to edge network. Edge and fog device based computation offloading has been discussed in [19]. It has been shown in [19] that the use of edge and fog computing has reduced the delay and power consumption with respect to the cloud based system.
- **MEC in UAV**: The use of UAV (Unmanned Aerial Vehicle) can strengthen the coverage of relay services for the mobile users in limited infrastructure wireless systems [4]. Based on UAV a MCC framework has been considered in [57], where the mobile UAVs have computing ability to offer computation offloading facilities to the mobile users. This in turn reduces energy consumption meeting the QoS requirements. Here, offloading has been done through uplink and downlink communications between the UAV and the mobile users. This has solved the problem of joint optimization of the bit allocation in uplink and downlink communications. An edge computing based RAN framework has been proposed in [58], where the fronthaul and backhaul links are mounted on the UAVs, which provides faster response time and flexible deployment.

- **MEC in smart healthcare**: In smart health care health sensor devices capture the health status, and the sensor data are stored and processed inside the cloud servers. After processing the data, the health status of the user can be detected. In [59–62], use of fog computing for health care has been discussed. In [20] the use of edge/fog framework in time-critical applications has been shown, where health care has been considered as a case study. By bringing the processing facility closer to the network edge, the delay which is a vital parameter for health care, can be reduced.
- **MEC in smart home**: In [32] the use of fog computing in smart home has been demonstrated. By bringing the computing and storage resources nearby the network edge, the delay, jitter, and energy consumption of the user device can be reduced.
- **MEC in retail**: In [31] a retail application has been discussed based on fog computing, which reduces the delay and energy consumption. The MEC can be used in retail which can improve the energy-efficiency and reduce the delay by pushing the computing and storage resources nearby the network edge.
- **MEC in agriculture**: In [63] the use of edge computing in agriculture has been discussed. The use of MEC in water monitoring system in case of agricultural domain has been explored in [64]. Edge computing can have various **prospects** like safety traceability of products, identification of pest, unmanned agricultural machinery etc. The use of edge computing in agricultural IoT has been demonstrated in [65].

5 Challenges in MEC

Though the use of MEC has provided various advantages like low latency, low power consumption etc., still several challenges remain. The selection of edge device to meet different service requirements of multiple mobile users is a key factor, for which novel strategy is required. Moreover, edge devices have limited resources. Therefore, low-complexity edge device placement and scheduling become vital when large numbers of mobile users are present. Furthermore, the request of mobile user variable, therefore dynamic strategy is required which will deal with user requirements. Instead of these challenges, there are several other issues discussed as follows.

- **Security**: The security threats and challenges in the edge-cloud computing framework has been studied in [66]. In [67] the authors have proposed a fog based storage framework to deal with cyber threat. As a large number of mobile users are present, then privacy is another important issue. Here, the assessment of each mobile node is also very important [68] along with the assessment of invulnerability [69]. In [70] an intrusion detection system has been discussed based on decision tree. A pre-processing algorithm has been designed in [70] to digitize strings in a given dataset and after that the whole data is normalized. Then a decision tree based scheme has been used for the intrusion detection system.

- **Resource management**: Resource allocation and management is another major factor in MEC. Though several schemes have been proposed for deployment of cloudlets for optimal service provisioning, still resource management is a vital challenge in MEC. As multiple users are present and their requirements are also different and most importantly the users have mobility, the resource allocation, release, VM migration, delivery of required service with minimal latency are key challenges.
- **Energy consumption**: In few existing works [19–21] it has been shown that the use of edge/fog based framework has reduced the power consumption of the user device. However, the energy consumption of the overall paradigm is also crucial. Another factor is decision making regarding offloading to edge/fog or cloud; whether partial offloading will be done or multi-level full offloading will be done that is also important to reduce the total energy consumption of the paradigm.
- **Mobility based service provisioning**: The service provisioning becomes a challenge when the customer is mobile. Here the devices have mobility and frequently change their locations in many cases. In such a scenario, tracking the mobility of the user is very important to deliver the required service. The use of artificial intelligence can play a vital role in this case. Several approaches on trajectory analysis exist [71–77]. The integration of these methods with service provisioning can open a new era in MEC.
- **User allocation based edge-cloud placement**: In order to improve the service quality and reduce the cost simultaneously, edge-cloud placement is an important factor. To deal with this challenge, user location can be considered and based on the location mobile users can be allocated to the edge-clouds [78]. This can be treated as a multi-objective optimization problem where the aim is load balancing and reduce the communication delay of the users.
- **Edge-based smart wearable system for maintenance in communication network**: The shortcomings of existing communication system are shortage of real time operation and data interaction maintenance. The decision making and execution process might suffer from inconvenient information interaction and shortage of field links. Use of edge computing can provide a smart wearable maintenance system for communication network [79]. An edge computing based IoT platform can provide real time guidance that can help to enhance the efficacy and quality of on-site maintenance.

Not only the issues discussed above, there are other challenges also like billing, simulation tool designing etc. For cloud computing simulation tools are already available in MATLAB, Python etc. Cloudsim [80, 81] is a popular simulator for cloud computing. EdgeCloudSim [82] has been built on Cloudsim to provide necessary functionalities for edge computing. For fog computing, iFogSim [83, 84] simulator is present. Resource allocation in fog computing considering user mobility has been studied in [85], where MyiFogSim has been built as an extension of iFogSim. To effectively promote MEC development and standardization of experimental design, a simulator is required that will provide the computation, storage and networking facilities at the edge to the mobile users.

6 Summary

This chapter has discussed the architecture and working model of mobile edge computing. The use of edge computing provides lower latency and power consumption of the user device with respect to the cloud only system in case of computation offloading, which we have shown in theoretical and experimental results. The applications and challenges of mobile edge computing are also discussed.

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