New Research Directions for Green Mobile Cloud Computing

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1 Introduction

Whenever, we integrate more than one technological paradigms, then several issues appear. In mobile cloud computing (MCC), we have discussed issues such as mobility, reliability, security, and network connectivity. As we are focusing green mobile cloud computing (GMCC), meeting the criteria of energy-efficiency is a mandate in this case. This chapter discusses the following topics as future research areas in GMCC:

- Energy harvesting in MCC
- Entropy-based GMCC
- Green Vehicular MCC
- Green Mobile Crowd Sensing
- Green Edge and Fog Computing
- GMCC-based Smart applications
- Geographical Location Aware Mobile Recommender System
- Nature Inspired Optimization Algorithms for GMCC

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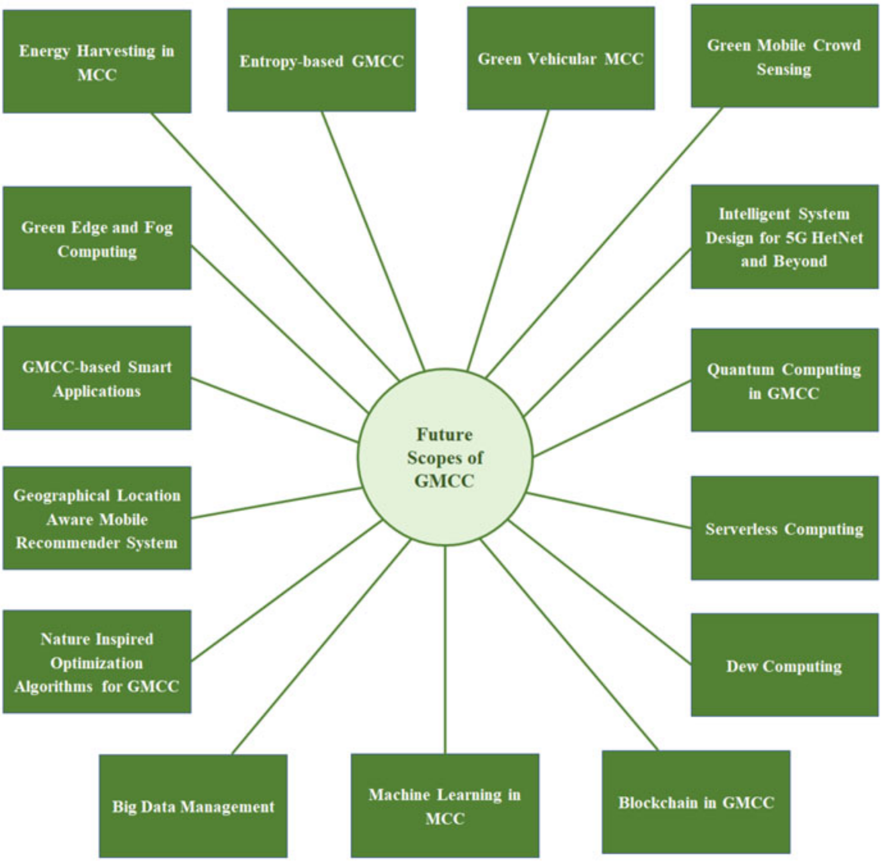

Fig. 1 Future research directions of GMCC

- Big Data Management
- Machine Learning in MCC
- Blockchain in GMCC
- Dew Computing
- Serverless Computing
- Quantum Computing in GMCC
- Intelligent System Design for 5G HetNet and Beyond

A pictorial view of these research directions in GMCC is shown in Fig. 1. We will discuss them in the rest of the chapter.

2 Energy Harvesting in MCC

In energy harvesting, the renewable energy sources such as solar and wind are used as the source of power supply. The work in [1] discussed on the use of solar photovoltaic and biomass resource-based hybrid power supply for the base stations in a cellular network. The renewable sources were used to charge the cloud-enabled small cell base stations in [2]. In [3], its authors integrated MCC with microwave power transfer for computation inside the passive low-complexity devices like sensors, wearable devices etc. In a single-user system, a base station either transfers power or offloads computation from a mobile device to the cloud [3]. The mobile device uses harvested energy for computing given data either locally or by offloading [3]. In [4], its authors considered simultaneous wireless information and power transfer technique to multi-user computation offloading problem in mobile-edge-cloud computing paradigm. Here, energy-limited mobile devices harvest energy from ambient radio-frequency signal [4]. In MCC, the renewable energy sources can be used as a source of power supply to the cloud servers. For the energy-limited mobile devices also energy harvesting can be used [4].

3 Entropy-Based GMCC

The cloud service providers offer three types of services: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). In a multi-agent network, multiple agents are present within a location. Now a situation may arise when a single agent is unable to solve all the problems. In such situations, intelligent cloud entropy management is required, which is composed of functions, algorithms and methods. Here, fractional entropy and Tsallis entropy can be used [5]. On the other hand, the developers can consider functional and non-functional aspects of quality of service (QoS) while looking for the services fulfilling the requirements like reliability, security, delay, throughput etc. For weightening each aspect entropy was used [6]. Now different users have different requirements, for example, some users require game offloading, some users require web service. As the users' choices vary, the offered services also differ. In most of the situations, users' choices are unpredictable. When huge number of requests of same priority arrive at the same time and they require same resource, then how these all requests will be fulfilled is a challenging research area. Users have to state the level of their QoS requirement and they also consider how much they pay. Now the capacity of the system of the services is required to determine. For this purpose Tsallis entropy can be used [7]. For the user it is tough to decide the QoS requirement level for the requested cloud service. In such a case, fractional entropy based boundary value problem can be used for the multi-agent system [8].

4 Green Vehicular-MCC

While people travel sometimes the vehicles get stuck into the traffic. Accessing Internet service at this time is a popular option for entertainment. In this case, vehicular adhoc network [9, 10], mobile network and cloud computing are integrated to introduce vehicular-MCC. The location of the vehicles are required to update to the cloud for tracking a vehicle when required. This feature can greatly contribute towards efficient rescue operations after any type of accidents or natural disasters. Nowadays most of the users have smart phones which offers a rich sensing platform. The sensing platform contains built-in sensors which detect light, temperature, accelerometers, Global Positioning System (GPS), etc. The vehicular users can monitor the surrounding circumstances, collect information and share it on social networking sites, for example, if an accident has occurred, the vehicular user can inform about it on social network. The other persons then may avoid this route if they are in hurry to reach their destinations.

5 Green Mobile Crowd Sensing

In mobile crowd sensing, a user observes his or her surroundings and collect information, which he or she shares on social domain or with the service providers by using mobile device [11]. Here, a sensing platform is provided with the mobile device to collect data from the surroundings. In mobile crowd sensing, various types, of data are gathered such location information, traffic condition, noise level, etc. The users share these data with others. These data are aggregated inside the cloud and processed for further knowledge extraction and then delivered. Route planning is a popular example of mobile crowd sensing, where based on the GPS information of the mobile device, an optimal route to the destination is determined. Urban sensing [12], participatory sensing [13], corresponding big data management [14], energy-aware crowd sensing [15], use of blockchain in crowd sensing [16], are significant research directions of GMCC.

6 Green Edge and Fog Computing

In mobile edge computing, either the edge server or cloudlets are used to bring resources at the network edge to provide faster service provisioning to the users [17]. Fog computing refers to a distributed computing model that offers a virtualized environment providing computation, storage, and network services between data centers and end devices [18–20]. In fog computing, the intermediate devices between the end node and cloud servers participate in data processing [21]. Fog devices can be used for computation offloading also [22]. Fog computing supports computational resources, protocols for communication, integration with cloud, interface heterogeneity and distributed data analytics to fulfill the necessity of the applications requiring low latency. Power efficiency, security, reliability and resource management are promising research directions of edge and fog computing.

7 GMCC-Based Smart Applications

Smart and low power system design is another promising research direction of MCC. In retail, health care, home monitoring, agriculture, MCC can play an important role. The sensor nodes will be used to collect the object status, and the collected data will be stored and processed inside the cloud. The intended user can access the information using his/her mobile device. The work in [23] proposed a smart retailing system using fog-cloud paradigm. In [24], the fog-cloud paradigm was used for storing and analyzing health data. In [25], edge-fog-cloud paradigm was used in healthcare. In [26], the mobility information of the users was stored and analyzed inside the cloud to guide him/her regarding the nearby the health center or the optimum route to reach the nearby health center when the user is inside a vehicle. The design of MCC-based energy-efficient smart applications is another future research direction of GMCC.

8 Geographical Location Aware Mobile Recommender System

Mobile recommender system refers to the software tools and methods which offer suggestions to the mobile users [27, 28]. Recommender system is one type of information retrieval system that offers recommendations in terms of personalized information. For the non-experienced mobile users, this recommender system helps a lot when a decision has to be taken by the user, for example, appearance of e-commerce websites during the Internet access. The mobile users can access the recommender system anytime anywhere as a mobile application. The georecommendation system can suggest the mobile user regarding various places to visit based on the present geographical location of the user, for example, to suggest the nearby shopping mall, food court, cinema hall, etc. based on the present geographical location of the user.

9 Nature Inspired Algorithms for GMCC

In future generation mobile network, nature inspired algorithms [29] can be used for optimizing energy, throughput, latency, etc. For optimized resource allocation, nature inspired algorithms can be used. In offloading, to select the optimal path towards the device that will execute the application, the nature inspired algorithms can be used. The work in [30] proposed a handoff management strategy based on the bird flocking. In [31] based on the feeding nature of octopus, power-efficient cellular network designing was proposed. The work in [32] proposed an intelligent offloading strategy based on ant colony optimization. The work in [33] used a metaheuristic artificial bee colony optimization method to deal with the workload of the edge server under the limitations of low latency and fast response time. In MCC environment, nature inspired algorithms can also play a significant role for optimizing the energy consumption.

10 Big Data Management

With the explosive increase in the number of mobile subscribers and growing use of the Internet access has resulted in huge volume of data generation. The big data analytics and management [34, 35] is a major research direction of MCC. Integration of Internet of Things (IoT) [36, 37] and MCC has directed towards various research scopes such as energy-efficiency, security, etc. in big data management. Nowadays, the use of blockchain has gained popularity in data analytics and management [38].

11 Machine Learning in MCC

Machine learning has opened a new way to find solutions regarding various problems, such as, scheduling, computation offloading, spammer identification, etc. The work in [39] proposed a distributed computation offloading method using machine learning. The work in [40] proposed a context-sensitive offloading system to get the benefit of machine learning reasoning schemes and robust profiling system for taking offloading decisions with better accuracy. The work in [41] proposed a framework that provides an online training method for the machine learning-based runtime scheduler for dynamically adapting scheduling decisions by observing the previous offloading decisions along with their correctness. The work in [42] considered the execution of machine learning applications to the cloud for improving the energy-efficiency of mobile device and improving the performance by reducing execution time. The work in [43] used a machine learning algorithm to identify spammer in industrial MCC. For cyberattack detection in mobile cloud environment, a deep learning-based framework was proposed in [44]. The use of machine learning for attaining energy-efficiency in MCC is another future research direction.

12 Blockchain in GMCC

For dealing with information security in mobile cloud infrastructure a building information modelling (BIM) system was proposed in [45]. This model facilitates BIM data audit for historical modifications by blockchain in mobile cloud with sharing of big data. The work in [46] proposed a privacy preserving user authentication protocol using blockchain for distributed mobile cloud environment. The work in [47] proposed a cloudlet management scheme using blockchain for multimedia workflow. For blockchain-based authentication of mobile devices a secure authentication management human-centric scheme was proposed in [48]. The work in [49] proposed an electronic health records sharing framework integrating blockchain and decentralized interplanetary file system on a mobile cloud platform. The use of blockchain in GMCC is another future research direction.

13 Dew Computing

Dew computing has opened a new window towards centralized-virtualization-free computation, that allows to scatter multi-typical data into the low-end devices [50]. Dew computing relies on micro-services in vertical, heterogeneous, and distributed way [50]. Dew computing allows data accessibility even when continuous Internet connectivity is unavailable [50]. There are several advantages of dew computing, such as, self-augmentation, self-healing, transparent, self-adaptive, scalability, user-programmability, etc. [50]. Dew computing can perform complex tasks in its vicinity [50]. However, to attain this feature, dew computing requires an advanced modular architecture that can adapt the related features of dew computing-ecosystem [50]. The use of dew computing in IoT was explored in [51–53]. Energy-efficient dew computing is another future research direction of GMCC.

14 Serverless Computing

The term ‘serverless computing’ has been invented by the industry to refer a programming model and architecture executing small code snippets inside the cloud without control over the resources on which the code is executed [54]. Various cloud service providers, such as, Microsoft, Google, IBM, Amazon, etc. have released serverless computing abilities [54]. In serverless computing the servers are required, however, the developers do not concern regarding the server management [54]. The serverless platform handles the decisions like the number and capacity of servers, and the server capacity is provisioned according to the workload-based requirement [54]. The work in [55] designed a serverless computing platform. It was implemented in .NET deployed in Microsoft Azure, and utilized Windows containers as function execution environments. The design of serverless computing platform for energy-aware MCC is another future research direction.

15 Quantum Computing for GMCC

The integration of quantum computing with cloud is another emerging research direction. The use of quantum computing can provide solutions towards various issues of cloud, such as, security, backup, processing, and vicinity [56]. However, the integration of these two systems is not an easy task [56]. The work in [56] used quantum cryptography and quantum computing to improve the security in cloud computing. The work in [57] discussed on cloud quantum computing. The work in [58] proposed an approach named QuCloud to map quantum programs in cloud environment. The integration of quantum computing with GMCC is another future research direction.

16 Intelligent System Design for 5G HetNet and Beyond

Next generation mobile network will comprise of different categories of base stations like macrocell, microcell, picocell, femtocell, cloud-enabled small cells, Wi-Fi access point, etc. Such a heterogeneous network requires proper deployment strategies in order to achieve energy-efficiency, high data rate, low latency, etc. [59, 60]. Efficient and intelligent resource allocation methods are also required for this heterogeneous mobile network. In next generation mobile network, most of the application processing and data storage will occur inside the cloud. Hence, intelligent big data management and analysis inside the cloud for such heterogeneous networks is a crucial research area. On the other hand, the edge-fog-cloud paradigm is one of the key element of future generation mobile network. Resource allocation, energy-efficiency, security, reliability, etc. are various domains in MCC, which seek significant research contributions.

17 Summary

In this chapter we have highlighted the future research directions of green mobile cloud computing. Energy-efficiency is one of the signficant challenge of MCC to provide an eco-friendly system. Hence, we have considered the energy-efficiency as one of the core aspects in research directions along with mobile crowd sensing, vehicular MCC, edge and fog computing, smart applications, etc. We also covered other research directions of MCC such as mobile recommender system, intelligent system design, use of nature inspired algorithms, big data management, and energy harvesting.

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