Overview of Energy Consumption Optimization in Mobile Edge Computing

Bingyi Hu[1], Jixun Gao[2], Yanxin Hu[3a], Huaichen Wang[3b], Jialei Liu[3c*]

[1] School of Computer Science and Technology, Henan Polytechnic University, Jiaozuo 454000, China

[2] School of Computer, Henan University of Engineering, Zhengzhou 451191, China

[3] School of Software Engineering, Anyang Normal University, Anyang 455000, China

[1] hby1260464202@126.com , [2] gaojixun@haue.edu.cn , [3c*] jialeiliu@aynu.edu.cn

Abstract—The energy consumption of traditional mobile network is mainly reflected by task calculation and data transmission. The edge server in mobile edge computing is placed at the edge of the network closer to the mobile terminal device. When the computing resources of the mobile terminal device are insufficient, the task can be offloaded to the edge server for processing. This paper discusses the energy consumption optimization in the Mobile Edge Computing (MEC) system, which is composed of the edge server and mobile devices at the edge of the network. Firstly, the system model of MEC is elaborated. Secondly, the energy consumption optimization for mobile devices and base stations is studied. Which oriented to the mobile device energy consumption optimization is divided into multiple users - single MEC server scenarios of energy consumption optimization and multiple users - the energy optimization of MEC server scenario, and enumerate the oriented to the base station and a new method for the optimization of energy consumption for mobile equipment energy consumption optimization method, in addition to the insufficiencies of these methods and the prospect of the future are also explained.

Keywords-Mobile edge computing; task offloading; edge server; base station; mobile devices; energy consumption optimization

1. Introduction

With the continuous and rapid development of Internet of Things technology and 5G mobile communication technology [1], time-sensitive and computation-intensive computing tasks, including audio recognition, augmented reality and collaborative driving and other applications [2], have been gradually applied in our daily life, providing more convenient services for mobile users. However, such applications have problems such as large amount of data, time-delay sensitivity and excessive energy consumption. Cloud computing with centralized processing mode has been difficult to meet the demands of massive user data and long-distance transmission [3, 4]. Therefore, Mobile Edge Computing [5]

(MEC) was proposed to solve these problems. MEC places servers close to mobile users, which can significantly improve the quality of the mobile device experience and help reduce power consumption [6, 7]. MEC has been regarded as one of the key technologies in the 5G era by the European 5GPPP organization [8].

Nowadays, with the development of MEC technology, more and more attention has been paid to the energy consumption of MEC system. How to reduce the energy consumption of MEC system has become the goal pursued by many scholars. In this paper, the energy consumption optimization for mobile device terminal and base station is studied. In MEC system, users have high requirements for delay, so we combine delay to optimize the energy consumption of MEC system, so that the energy of MEC system can be fully utilized.

2. System Model

With the rapid development of computer technology, the types and functions of mobile terminal devices are becoming more and more diversified. If all the computing tasks on the mobile terminal devices are offloaded to the traditional cloud computing center for processing, it is easy to cause network congestions [9]. If the computing tasks are all processed on the mobile terminal device, the battery life of the mobile terminal device will decrease, which cannot meet the user's demand for the battery of the mobile device [10]. The introduction of MEC has solved these problems well.

The network model of the MEC system is shown in Figure 1. The MEC system includes a base station and an edge server and mobile devices deployed in the base station. From the figure, we can see that compared with the cloud data center, the edge server deployed on the base station and the base station is the distance of users is closer, which effectively reduces the delay of task transmission [11]. The MEC system offloads the computing tasks on the mobile terminal equipment to the edge server for computing, which greatly saves the computing and storage resources of the mobile equipment, reduces the energy consumption of the mobile equipment, and greatly improves user satisfaction. The reasonable deployment of edge servers on base stations and the reasonable utilization of edge server computing resources can effectively reduce the energy consumption of the servers [12]. Nowadays, with the development of MEC technology, people are paying more and more attention to energy consumption optimization in the MEC system [13].

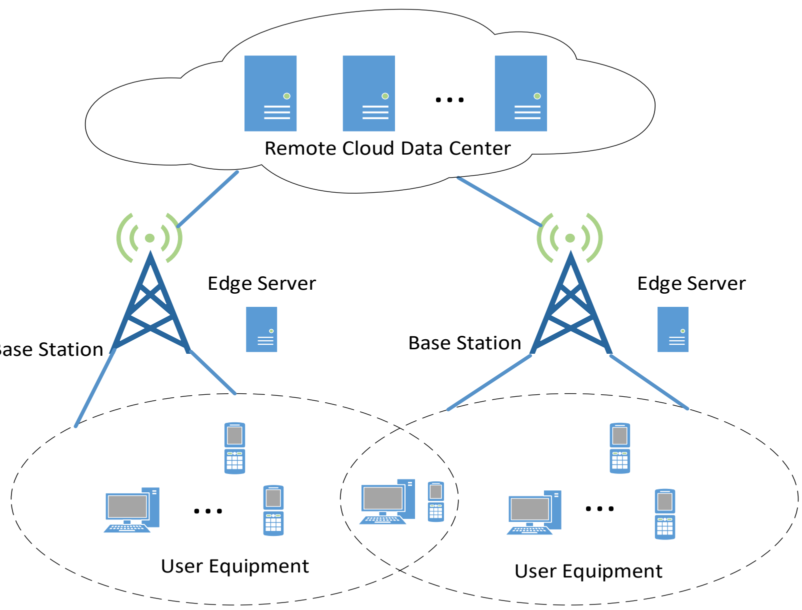

Fig.1 Network model of MEC system

3. Energy Consumption Optimization for Mobile Devices

Mobile devices in the MEC system can offload tasks to edge servers for processing, which effectively reduces the energy consumption of mobile terminals. This chapter studies the energy consumption optimization of mobile terminals in MEC based on the scenarios of multi-user-single-MEC server and multi-user-multi-MEC server respectively.

3.1. Energy Consumption Optimization Method Based on Multi-User-Single-MEC Server System

In the multi-user-single-MEC server scenario, there is only one MEC server, so the computing resources of the system and communication resources of the wireless channel are limited. Multiple users connected to the same MEC server compete for resources. In addition, since all users have self-interest, more resources will be wasted in the process of preempting computing resources. Therefore, how to optimize the energy consumption of mobile terminals in MEC is worth further study.

Literature [14] studied the joint allocation of computing and communication resources for the purpose of optimizing energy consumption in a multi-user-single- MEC server scenario in a cell. A greedy strategy and SMSEF algorithm are proposed to solve the problem, and it is compared with Priority-based algorithm and N-SMSEF algorithm. It is found that as the number of channels or the number of users increases, the SMSEF algorithm saves more energy than the other two algorithms.

In reference to the energy management problem of the MEC system, the literature [15] carried out research on the system energy consumption optimization problem in the scenario of a multi-user-single-MEC server equipped with energy harvesting equipment, and proposed an optimization algorithm based on the Lyapunov method and an alternative direction multiplication algorithm. The distributed optimization algorithm of ADMM achieves the optimization goal of minimizing system energy consumption under the condition of satisfying certain computing service quality and system queue stability.

Although the above two documents can optimize the energy consumption of the system, they do not consider the time delay problem. Most users in MEC also have relatively high requirements for time delay. In response to this problem, the following documents will consider time delay while optimizing energy consumption.

Literature [16] studied the centralized resource allocation by the MEC server in the multi-user-single-MEC server scenario. The goal is to minimize the total energy consumption of the system while meeting the task delay constraint. The optimal subcarrier allocation problem under the given task description and wireless channel conditions was mapped to a regression problem in machine learning, and an exhaustive search algorithm was used to construct a labeled data set, and then three sets of different regression models were trained, respectively It is a random forest, Xgboost, neural network, and predicts the allocation of sub-carriers on the test set. After obtaining the subcarrier allocation, calculate the resource allocation plan and the corresponding total energy consumption of the system according to the formula deduced in the preliminary conclusion [17]. The simulation experiment data shows that the distribution scheme obtained by the regression algorithm based on historical experience can obtain the system energy consumption close to the optimal solution.

Literature [18] proposed a system model for calculating migration energy optimization, including system model, migration model and migration time constraint model. The system model is a time division multiple access-based MEC migration system built in a cellular network environment. The system uses time slots as a mark to identify different user signals in the system. In any time slot, the base station is based on the time division multiple access to one of the users [19]. A subset of tasks are scheduled for complete or partial migration. Its core idea is to optimize the energy consumption in the multi-user computing migration system, and to balance the computing power of the system with the dynamic division of computing time as the constraint, to avoid the blind migration of a user in the multi-user migration system in order to save resources to ensure the system the total calculation time is the lowest. In addition, this document also proposes a Lagrangian-based energy consumption optimization model. According to the specific situation of the migration, the energy consumption of the terminal is divided into two parts: the local computing energy consumption and the computing migration energy consumption. The convexity proof of the energy consumption model is provided, the Lagrangian method is used to solve the model, and the optimal resource partitioning algorithm based on threshold is proposed [20].

In the multi-user-single-MEC server system proposed in this chapter, only one edge server is considered. If the MEC system wants to accommodate more users and provide more powerful MEC services, the resources of a single edge server are limited. Therefore, the following research can consider a multi-user-multi-MEC server system.

3.2. *Energy Consumption Optimization Method Based on Multi-User-Multi-MEC Server System*

There are multiple MEC servers in a multi-user-multi-MEC server system. The computing resources and communication resources of the wireless channel of the system are much more than that of a multi-user-single-MEC server system. This solves the problem of insufficient resources in a multi-user-single-MEC server system. Problems caused by use. Next, this chapter will study how to better optimize the energy consumption of the system in a multi-user-multi-MEC server system.

Aiming at the problem of how to make the time delay used in task execution shorter in the task offloading of MEC and how to further improve the energy efficiency of the MEC system, literature [21] proposed a computational offloading based on the population diversity-binary particle swarm optimization algorithm Strategy. This strategy needs to first establish the energy consumption model used by mobile terminal devices under multi-objective constraints when performing tasks, and then use the particle swarm optimization algorithm to turn the task unloading process into a particle optimization process, and finally Get the optimal unloading decision under the condition of seeking the lowest energy consumption [22]. Aiming at the problems of low energy efficiency of mobile terminal equipment and inflexible services due to the excessive concentration of computing tasks to be offloaded in the MEC system, the literature proposed a system energy efficiency optimization scheme based on energy harvesting. Under the condition that the unloaded transmission power is limited, it is necessary to analyze the state of energy collection and the power allocation of users, and then establish a joint optimization model for maximizing system energy efficiency [23]. In addition, the generalized fractional programming theory is used to transform the problem of unloading energy efficiency into a standard convex optimization problem, and then the objective function is iteratively optimized through the Lagrangian function to obtain the optimal energy index variables and power allocation.

In the multi-user-multi-MEC server system, there is still such a problem that the number of MEC servers cannot meet the needs of the mobile terminal, and the mobile terminal will compete for the MEC server, and the users in the multi-user system will interact with each other. Interference will increase the energy consumption of the system. Literature [24] proposed an energy efficiency optimization algorithm for mobile edge computing based on multi-dimensional games. An upper limit is set on the computing resources of the MEC server, and user queuing delay is added to solve the problem of insufficient energy efficiency of the mobile terminal in a resource-constrained multi-user system. The player of the game model in the algorithm is a mobile user, the decision space is a two-dimensional space composed of unloading decision and power control, and the revenue function is a function of energy efficiency and time delay. It is theoretically proved that the Nash equilibrium of the multidimensional game model exists and is unique.

Aiming at the problem of how to optimize the energy consumption in the process of system data offloading in MEC, literature [25] proposed an offloading strategy for minimizing the average energy consumption per unit data based on the optimal stopping theory. This strategy builds n task models for offloading data from mobile terminal equipment to m base stations. Combine local energy consumption, offload energy consumption and base station energy consumption for joint optimization. Then, the unconstrained problem without slack variables is obtained by defining the augmented Lagrangian function. Finally, the unconstrained problem is solved by an iterative formula and the solution of the original problem is further obtained to achieve the goal of minimizing the average energy consumption per unit data.

4. Energy Consumption Optimization Method for Base Station

The aforementioned research on energy consumption optimization in MEC mainly focuses on the research on energy consumption optimization of mobile terminals, while there are very few studies on energy consumption optimization of base stations. Only the joint optimization model in the literature [25] mentioned Base station energy consumption optimization. This chapter mainly considers how to optimize the energy consumption of the base station in the MEC system.

At present, there is not much research on task offloading between base stations in the MEC field. The network model mainly used in existing research is a fully connected base station model with a control center similar to cloud computing. In the MEC system through wireless communication, the establishment of a control entity or virtual control center requires a large amount of wireless data communication between base stations, which not only takes up a large amount of channel resources, but also increases the energy consumption of the base station.

Based on the above problems, the literature [26] combined with the dynamic voltage adjustment technology, proposed and solved the problem of minimizing the energy consumption of the base station group cooperative processing tasks, and effectively reduced the energy consumption of the base station group processing tasks. In view of the low load of the base station task queue, dynamic voltage adjustment technology is introduced, and the energy consumption model of the base station group cooperative processing tasks is established. The task offloading strategy and computing resource allocation plan are respectively given, and the threshold of urgent tasks is determined to minimize the energy consumption of the processing tasks of the base station group is the optimization goal, the task offloading strategy is designed using the most optimized method, and the computing resource allocation scheme is designed using the idea of dynamic programming. In view of the high load of the base station task queue, the dynamic voltage adjustment technology is also introduced, and the task offloading strategy and the computing resource allocation plan are jointly considered, and the corresponding energy consumption model of the base station group cooperative processing tasks is established, giving a wider range of tasks Unloading judgment conditions: Through the analysis of the task fragmentation processing algorithm, the energy consumption models of the base station group cooperative processing tasks are divided into two types, and the optimization goal is also to minimize the energy consumption of the base station group processing tasks, and two nonlinearities are established Problem, a load balancing algorithm and a breakpoint search algorithm are designed to solve the problem.

The following paper is devoted to discussing the energy consumption optimization problem of the edge server deployed. In the study of energy consumption optimization based on multiple edge servers, the problem of energy waste caused by unbalanced load of edge servers is considered. Literature [27] proposed an edge server collaboration-sleep mechanism, which combined the sleep mechanism with the edge server collaboration mechanism. In the edge server, an edge server is selected as the leader server and needs to process tasks for all mobile terminals in the range. However, when the computing resources of the leader server are insufficient, the task can be offloaded to the remaining edge servers as collaborator servers for processing. The collaborator server in the system has two states: dormant and active. In the dormant state, it consumes less energy. When in the active state, the collaborator server receives tasks and processes them. Under this mechanism, the state of the collaborator is determined by the state of the leader. To control. This document optimizes the energy consumption of multiple edge servers.

Literature [28] proposed an algorithm based on semi-definite relaxation (SDR) to solve the problem of new computing tasks and frequent switching between multiple tasks. In the fixed CPU scenario, an algorithm based on linear programming relaxation is used as an alternative to SDR. In the flexible CPU scenario, the algorithm based on exhaustive search is used as the benchmark, and then the algorithm based on SDR is applied to find the near optimal solution, thereby reducing the energy consumption and task delay of the mobile device to reach the minimum.

In a MEC system with multiple mobile users, multiple smart mobile devices need to offload computing tasks to one MEC server. In order to reduce the energy consumption of smart mobile devices, it is necessary to coordinately optimize offload selection, radio resource allocation, and computing resource allocation. Literature [29] describes the energy minimization problem as a mixed interleaved nonlinear programming (MINLP) problem, which is subject to specific application delay constraints. The branch and boundary (RLTBB) method based on the reconstruction linearization technique is proposed to solve this problem. The method can get the optimal or sub-optimal result by setting the solution accuracy. Literature [28] and Literature [29] mainly study the optimization of resource allocation to achieve the purpose of reducing energy consumption, but they do not consider the selection of the optimal number of servers to be turned on.

Literature [30] proposed a mobile caching network model called Cachin Mobile. In the CachinMobile network, mobile users first send request content to edge nodes through device-to-device (D2D) communication. If the requested content cannot be found in the neighboring edge nodes, it will request such content from the eNodeB. According to this idea, the optimal content placement strategy between user edge nodes is proposed to minimize transmission energy consumption. This document considers the joint optimization of CPU frequency, but does not consider the off-sleep mode strategy of edge servers. For ultra-dense networks, no matter how the network load fluctuates, all edge server nodes are always in working state, which makes the system energy consumption excessive.

Literature [31] proposed a framework for a sequence solution, based on the communication and computing energy consumption perception selection law to select the corresponding number of servers to work when the energy consumption is optimal. The disadvantage is that it does not consider the switching energy consumption caused by server state switching. State switching is too frequent, and its consequences will not only produce a large amount of switching energy consumption but also shorten the service life of the device.

Based on these problems, literature [32] proposed a server switch dynamic switching algorithm without delay constraints, in which the user connection and service configuration of adjacent base stations are considered in the algorithm. Since the number of users at different times in the network will continue to change, a linear regression prediction mechanism is used to predict the number of user requests for each service in the next time slice to calculate the utilization rate of the edge server in the next time slice. In addition, a system is also designed. This kind of user migration mechanism is used for the user's service migration. Through this strategy, the switching energy consumption of edge servers can be reduced while reducing network energy consumption. Literature [32] also proposed a server switch dynamic switching algorithm that includes delay constraints. The delay constraint is a key indicator in the algorithm design. When selecting the server shutdown link, each iteration must try to shut down a server, and make a decision on the premise that the delay constraints of all users can be guaranteed until there is no edge server. Closed, which effectively saves the energy consumption of the MEC system. In addition, when migrating the edge server to be shut down, the user preferentially selects the base station with the most remaining delay in the base station request candidate list for service request, so as to ensure that the user obtains the service in a short time.

5. Conclusion

With the rapid development of 5G technology and Internet of Things technology, the issue of energy consumption optimization in the MEC system has also been paid more and more attention. Consumption optimization methods. Although the methods listed above have achieved very good research results in many aspects, their application research still faces many deficiencies and challenges in many aspects:

(1) Although the multi-user-multi-MEC server system solves the problem of limited computing and communication resources in the multi-user-single-MEC server scenario, it still has some shortcomings. The research in the multi-user-multi-MEC server system mainly focuses on the problems related to MEC in the static environment. There is no consideration for user devices moving back and forth between multiple servers.

(2) During the research on energy consumption minimization under MEC environment, when the amount of data generated is large, a large amount of data cannot be unloaded to MEC server for processing because of the limitation of upper limit of link bandwidth under existing wireless network conditions. It is bound to affect the development of 5G network and user experience. Our future research

focus can be on improving the link bandwidth of hardware and combining hardware and software to better promote the development of network technology.

(3) The MEC system will generate more energy consumption with the improvement of the capacity of mobile terminals, edge servers and other devices. In the future, combined with the development of green energy such as solar energy in recent years, these devices can be designed to consume energy and obtain energy at the same time.

In this paper, energy consumption optimization methods in MEC system are summarized, the shortcomings of these methods are summarized and the future prospects are given. It is hoped that scholars can conduct more in-depth research in the future.

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