



A Network Energy Efficiency Measurement Method for Cloud-Edge Communication Networks

Ningzhe Xing¹, Chuan Liu^{2,3}(✉), Rui Ma⁴, Jing Tao^{2,3}, Shidong Liu^{2,3}, and Yutong Ji¹

¹ State Grid Jibei Electric Power Company Limited, Beijing, China

² Global Energy Interconnection Research Institute Co., Ltd., Nanjing 210003, China

³ State Grid Laboratory of Electric Power Communication Network Technology, Nanjing 210003, China

⁴ State Grid Information and Telecommunication Branch, Beijing 100761, China

Abstract. In the process of network consumption management of traditional wireless communication network, it is impossible to timely adjust according to the network energy efficiency, and the communication effect between nodes is not ideal. Therefore, this paper proposes a dynamic edge-cloud architecture of wireless communication network based on Software defined networking (SDN) architecture. According to the proposed model, the energy consumption of wireless communication network is analyzed. From the point of view of node communication distance, the model of energy consumption regulating is constructed. The experimental results show that the proposed SDN-based edge-cloud model can improve the delay and throughput performance of the network, which indicates that the research of this paper is conducive to the sustainable development of wireless communication network.

Keywords: Software defined networking · Wireless communication network · Edge computing · Network energy consumption

1 Introduction

Recently, cloud computing technology has been greatly developed and applied. Due to its high efficiency and flexibility, cloud computing realizes the functions of computing, storage and network management in a centralized way, and provides services for users in the way of on-demand deployment. But with the development of mobile Internet, such as AR, VR, HD video, the rise of Live services, the centralized cloud computing architecture faces greatly challenge [1, 2]. Because the cloud server is often deployed far away from the end user, and with the increase of the number of users, the cloud computing network bandwidth will be seriously insufficient, and the robustness is poor. Therefore, the cloud computing network architecture is difficult to meet the needs of users for low latency and high reliability services [3, 4]. The mobile end devices access to the backbone network and connect to remote cloud server to obtain services.

For cloud computing, how to overcome the problems of high delay and low energy efficiency in traditional cloud computing architecture is the main challenge. The edge cloud framework enables collaboration between cloud and edge devices to make intelligent decisions related to charging and discharging of electric vehicles [1]. In addition to stable supply and demand, use software to define network convergence to achieve traffic balance. In [3], the author designs a software defined IOT management framework, which is based on a software defined network awareness architecture for edge computing multi domain wireless sensor networks. In [5], the author studies the scalability and resource allocation of wireless MEC, aiming to minimize the battery delay in the user equipment and the delay at the same time [6]. In [7], a new framework for joint optimization of energy consumption and computation of M2M communication in virtual cellular network based on MEC is proposed. In order to improve the computing capacity [8], MEC is introduced into M2M communication network. In [9], a SDN architecture for energy efficiency optimization in 5G Ethernet Passive Optical Network is studied. An open control layer framework based on SDN is proposed, which can prepare EPON backhaul to handle 5G applications and services. In [7], mobile edge computing is introduced into the virtual cellular network of M2M communication to reduce energy consumption, optimize the allocation of computing resources and improve the computing capacity [10]. The random-access process of MTCs is expressed as partially observable Markov process [11].

In order to solve the problems of high delay, network load and network energy consumption when traditional cloud computing architecture deals with large amount of data business, we analyze the problems existing in cloud computing architecture, proposes a SDN-based cloud-edge integration network architecture [12]. Mobile edge computing (MEC) offloads the business requirements and computing storage resources of traditional cloud computing data center to the edge of the network close to users, while devices on the edge side and cloud computing devices are used for collaborative energy efficiency optimization. [13, 14] MEC technology migrates the computing power to the mobile edge server close to the user. Compared with the cloud server's architecture far away from the user, mobile edge computing can significantly reduce the user's delay in communication and improve the service ability of cloud computing [15, 16]. MEC technology provides it and cloud computing capabilities for wireless access network (RAN) close to mobile users by deploying servers with computing and storage capabilities on the edge of the network.

2 Mathematical Model

SDN is an encouraging solution to the above problems, with the following advantages: 1) Cloud technology provides utilities with high computing power. In addition, the huge amount of data stored in the cloud can help users improve the demand side management services and participation, so as to realize efficient electricity consumption. 2) Through so-called cloud computing, the decentralization of cloud networks can be used to manage and control each microgrid in a distributed manner. 3) SDN technology adopts standards and introduces abstractions to centralize control and management of various types of common network equipment and multiple suppliers. 4) The hardware of SDN solves

the problem of managing different networks and reduces the energy consumption of network equipment. 5) Programmability of operators, enterprises, independent software vendors, and users using a common programming environment.

The SDN-MEC architecture of wireless communication network is shown in Fig. 1. As can be seen from Fig. 1, the SDN architecture is composed of three layers, namely the application layer, the communication layer and the node layer. The communication layer and the node layer are connected by a plane interface, and the communication adopts the OpenFlow protocol, with unified communication identification. Figure 1 shows the SDN architecture of wireless communication network.

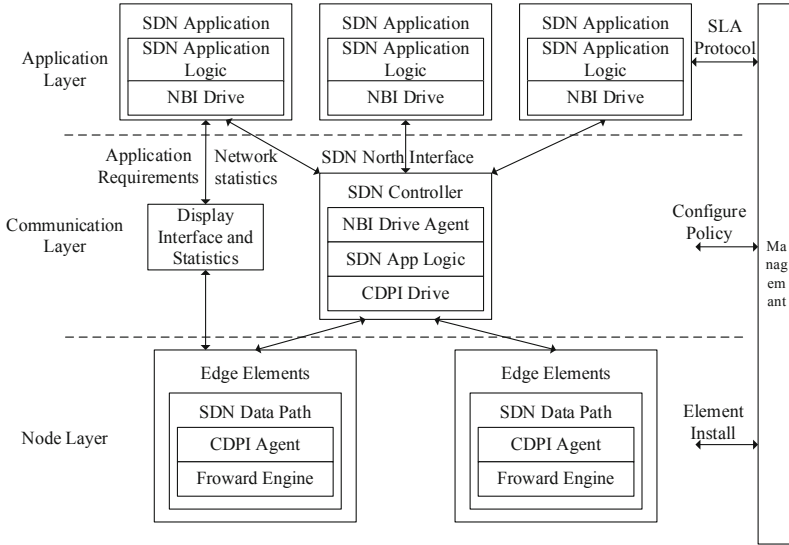


Fig. 1. SDN-MEC architecture of wireless communication network

As can be seen from Fig. 2, the SDN architecture consists of three layers: the application layer, the communication layer and the node layer. The communication layer and the node layer are connected through a plane interface. The communication adopts the OpenFlow protocol and the unified communication ID.

In the wireless communication network, cloud computing architecture is considered to be able to efficiently handle a large number of businesses. In the wireless communication network, the basic architecture of MEC is shown in Fig. 2.

As shown in Fig. 1, the edge cloud framework in the wireless communication network is mainly composed of MEC devices, mobile intelligent terminals and cloud data centers. The deployment of MEC devices is one of the major differences between edge cloud architectures and traditional cloud computing architectures.

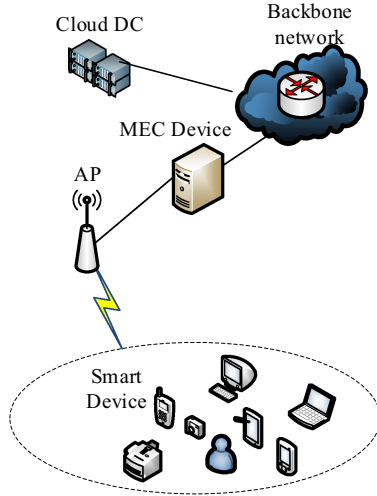


Fig. 2. MEC architecture in wireless communication network

2.1 Node Division and Dynamic Adjustment of Energy Consumption

Under the support of SDN architecture, network nodes can be divided to reduce the energy consumption of nodes. According to the SDN architecture, the wireless network can be divided into n regions, as shown in Fig. 3.

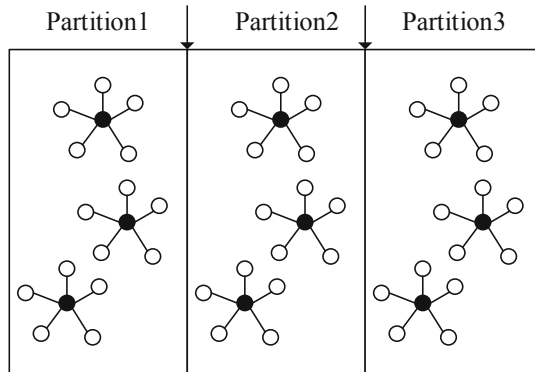


Fig. 3. Network node partition

Since the forwarding energy consumption between the first area and the tail area changes with the partition change, the regulation process is a dynamic regulation. Then, the forwarding energy consumption of the partition node i can be represented by E_r , and the energy consumption of the region node is equal to the energy consumed by all the packets fused in the partition as follows:

$$E_{ri} = \sum_j^{i-1} n_j E_r \tag{1}$$

where n_j is the number of nodes in partition j . Energy consumption E_{CH} in partition i can be expressed as:

$$E_{CHI} = E_{CH} + E_{ri} \quad (2)$$

Assuming that the energy consumption of packets forwarded by the first region in the SDN architecture partition is balanced, Eq. (2) can be written as follows:

$$E_{CHI} = E_{CH} + \frac{\sum_{k=1}^{i-1} n_j}{n_i} E_r \quad (3)$$

In order to ensure the connectivity of the communication network, the communication radius of the first region R_{CH} should be set to twice that of the communication radius R_{node} of other network nodes, so it can be approximately considered as follows:

$$\frac{E_r}{E_{node}} = 2 \quad (4)$$

Substitute Eq. (4) into Eq. (3) and then we get as follows:

$$E_{CHI} = E_{CH} + 2 \frac{\sum_{k=1}^{i-1} n_j}{n_i} E_{node} \quad (5)$$

On the basis of ensuring communication network connectivity, the dynamic regulation of energy consumption of nodes is completed.

Moreover, the number of nodes in SDN architecture partition is determined by the communication distance of the partition, and the network nodes with a large communication distance are relatively few. If the network nodes are uniformly distributed, then the node density can be expressed as

$$\rho = \frac{N}{S} \quad (6)$$

where N is the total number of network nodes; S is the network coverage area. If the communication distance of network nodes is assumed to be d , and the communication distance of adjacent nodes is smaller than or equal to d , then the number of adjacent member nodes is as follows:

$$n_{nei} = \rho \times d^2 \quad (7)$$

Each wireless communication node in the network has a communication distance identifier, and all nodes in the network have a communication distance identifier of 0. After a network node collects the broadcast message from the base station, the communication distance identifier of the wireless communication network node is 1.

The dynamic regulation model of wireless communication energy consumption is as follows: it is assumed that node b far away from node d sends a data packet, whose data

packet byte is 1, and is the associative property of sending data, then the communication data energy consumption is as follows:

$$E(l, d) = \begin{cases} n_{nei}(lE + l\varepsilon_{fs}) & d \leq d_0 \\ n_{nei}(lE + l\varepsilon_{mp}) & d > d_0 \end{cases} \quad (8)$$

where E is the energy consumption per bit of data sent or received; ε_{fs} and ε_{mp} are the amplification coefficients of sending and receiving respectively. When the energy consumption is high, the communication path will be redeployed, and when the receiving node is fixed, the sending node will choose a shorter path to realize the communication, thus completing the dynamic adjustment of the energy consumption of the partition communication distance.

2.2 The Network Performance Analysis

The SDN-MEC architecture is proposed above, and the scheme of node division and dynamic regulation of energy consumption is also proposed. This subsection analyzes the performance of business responses between nodes under the proposed architecture. In the SDN-MEC network architecture, in order to reduce the delay of business response, MEC technology is introduced to process the computation-intensive operations at the edge of the network. At the same time, SDN technology is introduced to realize the centralized control network and collect the global information of the network. In the real scenario, we consider a software-defined-cloud-edge computing architecture, composed of k MEC devices, and its network topology is denoted by graph $G = (V, E)$, V is the node set and E is the edge set. So $V = \{v_1, v_2, \dots, v_k, S, C\}$, where v_i is the MEC device, k is the number of device, S is the SDN controller, and C is the cloud platform. The computing capacity of each device v_i is denoted by c_{v_i} . The computing capacity of the cloud server is denoted by c_c . The edge set can be denoted by $E = \{e_{v_1v_2}, \dots, e_{v_iv_j}, \dots, e_{v_iv_c}, e_{v_jv_c}, \dots, e_{v_{k-1}v_k}\}$. $e_{v_iv_j}$ expresses the communication link between node v_i and v_j . $W_{v_iv_j}$ denotes the delay of node v_i and v_j .

In the process of business execution, the business $Task$ received by the MEC devices is first divided into many sub-tasks $Task_i$, and meets $Task_i = \delta_i Task$, where δ_i is the proportion of the sub-tasks in the total $Task$, and then the sub-tasks are unloaded to each MEC device for parallel preprocessing. Finally, the pre-processed result $Task_{pre}$ is sent to the cloud computing platform for decision making. Since the business response delay in distributed computing is equal to the maximum processing delay for all subtasks, the total business response delay in the SDN-MEC network architecture is represented as follows:

$$t = \max \left\{ \frac{\delta_i Task}{c_{v_i}} + W_{v_i, v_j} m_{v_i, v_j} \right\} + \frac{Task_{pre}}{c_c} + W_{v_i, c} \quad (9)$$

where $\frac{\delta_i Task}{c_{v_i}}$ is the computing time of subtask $Task_i$ in MEC device v_i , W_{v_i, v_j} denote the delay of node v_i and v_j , m_{v_i, v_j} denote the subtask assignment relationship of node v_i and v_j . When $m = 1$, subtask allocation relationship exists, and when $m = 0$, subtask allocation relationship does not exist. $\frac{Task_{pre}}{c_c}$ represents the delay in matching and identifying the

pre-processed result on the cloud. $W_{v_i,c}$ represents the communication delay when the pre-processed result is sent to the cloud server.

In order to optimize the delay of business response and achieve the goal of minimizing the delay of business response, an optimal set of task assignment coefficient δ_i is needed, so that the delay t in Eq. (9) is minimized. Therefore, the business response delay based on SDN-MEC network architecture can be expressed as follows:

$$\begin{aligned} \min \max \left\{ \frac{\delta_i T_{usk}}{c_{v_i}} + W_{v_i,v_j} m_{v_i,v_j} \right\} + \frac{T_{usk_{pre}}}{c_c} + W_{v_i,c} \quad i, j = 1, 2, \dots, k \\ \text{s.t. } m_{v_i,v_j} = \begin{cases} 1, & \delta_i \neq 0 \\ 0, & \delta_i = 0 \end{cases} \\ \sum_{i=1}^k \delta_i = 1 \end{aligned} \quad (10)$$

In the SDN-MEC architecture, the edge nodes are used to preprocess the business data, and the carrying capacity and transmission efficiency of the network are improved through the above analysis, which is conducive to the sustainable development of wireless communication network.

3 Simulation Analysis

3.1 Simulation Environment

This simulation platform is based on the SDN virtual environment composed by floodlight and mininet. The specific environment is one PC with 2.6 GHz CPU and 8 MB RAM. The software environment is 64-bit ubuntu 16.04 operating system with Floodlight, Mininet, and Iperf simulation tools. Floodlight is the current mainstream SDN controller, which is stable and easy to control SDN network flexibly.

3.2 Network Performance Evaluation

Then, we simulate and compare the time delay performance of SDN-MEC model, traditional cloud computing model, and single MEC device model. In the simulation, the MEC device v1 is selected as the single MEC device. The simulation results are shown in Fig. 4. When the number of user requests is less than 10, the time delay of SDN-MEC model is smaller than that of cloud computing model and single MEC device model, but the delay difference of the three scheme is not large.

Because the link bandwidth directly affects the data transmission delay, it will affect the business response delay. In addition, in the actual environment, the link bandwidth between the MEC device and the cloud server also changes in real time. Therefore, we study the impact of the uplink bandwidth of the cloud server on the SDN-MEC model's business response delay performance. When the number of user requests is 35, the uplink bandwidth of the cloud server varies between 5 Mbps and 45 Mbps. The simulation results are shown in Fig. 5. It shows that with the increase of link bandwidth, the business

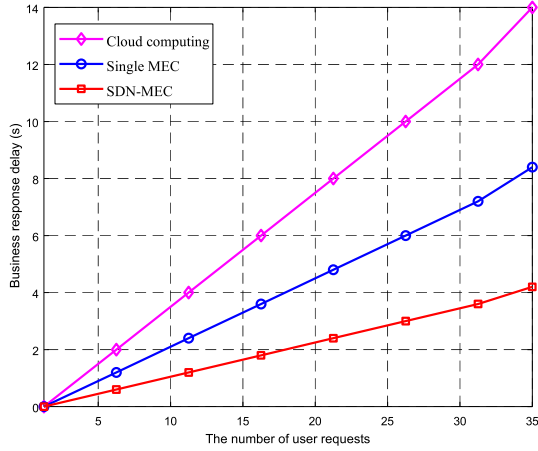


Fig. 4. The comparison of delay performance.

response delay of cloud computing model and single MEC model are gradually reduced, but the business response delay of SDN-MEC architecture is only slightly reduced. In cloud computing and single MEC model, the increase of link bandwidth will lead to the significant reduction of data transmission delay, so the business response delay will decrease with the increase of bandwidth. However, in the SDN-MEC architecture, the amount of pre-processed data is small. When the uplink bandwidth of the cloud server increases, the transmission of a small amount of data to the cloud server will not cause significant time delay reduction. Therefore, as the bandwidth of the cloud server link increases, the delay performance of the SDN-MEC architecture only decreases slightly. To sum up, when the uplink bandwidth of the cloud server is limited, the SDN-MEC architecture has more obvious advantages in reducing the delay of business response.

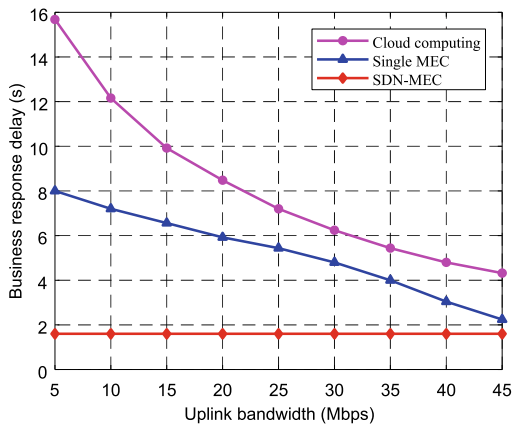


Fig. 5. The impact of uplink bandwidth on delay performance.

Next, the traffic scheduling performance of wireless cloud-edge communication network is simulated and analyzed. In the experiment, the stable traffic flow is simulated by Poisson distribution, while the emergent traffic flow is simulated by Random distribution. Figure 6 shows the network throughput as the network load increases. We can see that, as the network load increases, the network throughput of the three model continues to increase. However, in cloud computing architecture, when the network load exceeds 0.7, the network throughput declines. This is because the data flows are all pre-empting network resources without SDN controller co-processing, resulting in network congestion and throughput decline under high load conditions.

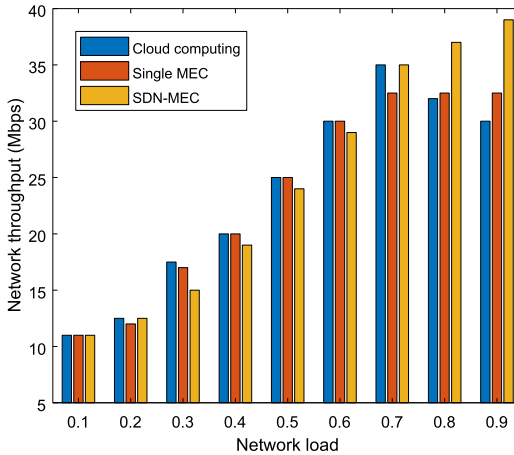


Fig. 6. The impact of network load on network throughput.

4 Conclusion

This paper proposes a SDN-MEC architecture for dynamic regulation of wireless communication network energy consumption. We analyze the energy consumption model and the node management under SDN controller. Moreover, we analyze the network performance under this framework. The experimental results show that the proposed method can effectively save energy, improve the performance of communication delay and network throughput, which indicates that the research of this paper is conducive to the sustainable development of wireless communication network.

Acknowledgements. This work was supported in part by the Science and technology program of State Grid “Research and Application of Key Technologies of Dynamic Resource Allocation Based on Cloud-Edge Collaboration” (5700-202014179A-0-0-00). The authors wish to thank the reviewers for their helpful comments.

References

1. Kaur, K., Garg, S., Kaddoum, G., et al.: Demand-response management using a fleet of electric vehicles: an opportunistic-SDN-based edge-cloud framework for smart grids. *IEEE Network* **33**(5), 46–53 (2019)
2. Jiang, D., Wang, Z., Huo, L., et al.: A performance measurement and analysis method for software-defined networking of IoV. *IEEE Trans. Intell. Transp. Syst.* (2020). <https://doi.org/10.1109/TITS.2020.3029076>
3. Mavromatis, A., Colman-Meixner, C., Silva, A.P., et al.: A software-defined IoT device management framework for edge and cloud computing. *IEEE Internet Things J.* **7**(3), 1718–1735 (2020)
4. Jiang, D., Huo, L., Zhang, P., et al.: Energy-efficient heterogeneous networking for electric vehicles networks in smart future cities. *IEEE Trans. Intell. Transp. Syst.* **22**, 1868–1880 (2020). <https://doi.org/10.1109/TITS.2020.3029015>
5. Kiran, N., Pan, C., Wang, S., et al.: Joint resource allocation and computation offloading in mobile edge computing for SDN based wireless networks. *J. Commun. Netw.* **22**(1), 1–11 (2020)
6. Jiang, D., Wang, Y., Lv, Z., Wang, W., Wang, H.: An energy-efficient networking approach in cloud services for IIoT networks. *IEEE J. Sel. Areas Commun.* **38**(5), 928–941 (2020)
7. Li, M., Yu, F.R., Si, P., Zhang, Y.: Energy-efficient Machine-to-Machine (M2M) communications in virtualized cellular networks with Mobile Edge Computing (MEC). In: *IEEE Transactions on Mobile Computing*, pp. 1541–1555 (2019)
8. Jiang, D., Wang, W., Shi, L., Song, H.: A compressive sensing-based approach to end-to-end network traffic reconstruction. *IEEE Trans. Netw. Sci. Eng.* **7**(1), 507–519 (2020)
9. Khalili, H., Khodashenas, P.S., Rincon, D., Siddiqui, S., Piney, J.R., Sallent, S.: Design considerations for an energy-aware SDN-based architecture in 5G EPON nodes. In: *Proceedings of ICTON, Bucharest*, pp. 1–4 (2018)
10. Jiang, D., Huo, L., Song, H.: Rethinking behaviors and activities of base stations in mobile cellular networks based on big data analysis. *IEEE Trans. Netw. Sci. Eng.* **7**(1), 80–90 (2020)
11. Jiang, D., Wang, Y., Lv, Z., Qi, S., Singh, S.: Big data analysis based network behavior insight of cellular networks for industry 4.0 applications. *IEEE Trans. Ind. Inform.* **16**(2), 1310–1320 (2020)
12. Moreno, R., Huedo, E., Montero, R.S., et al.: A disaggregated cloud architecture for edge computing. *IEEE Internet Comput.* **23**(3), 31–36 (2019)
13. Nguyen, D.M., Pham, C., Nguyen, K.K., et al.: Placement and chaining for run-time IoT service deployment in edge-cloud. *IEEE Trans. Network Serv. Manage.* **17**(3), 214–562 (2019)
14. Sun, H., Yu, H., Fan, G., et al.: Energy and time efficient task offloading and resource allocation on the generic IoT-fog-cloud architecture. *Peer-to-Peer Networking Appl.* **13**(2), 548–563 (2020)
15. Jiang, D., Huo, L., Lv, Z., Song, H., Qin, W.: A joint multi-criteria utility-based network selection approach for vehicle-to-infrastructure networking. *IEEE Trans. Intell. Transp. Syst.* **19**(10), 3305–3319 (2018)
16. Li, C., Sun, H., Tang, H., et al.: Adaptive resource allocation based on the billing granularity in edge-cloud architecture. *Comput. Commun.* **145**, 29–42 (2019)