Power Optimization in Wireless Powered Based Mobile Edge Computing

Xiaohan Xu[1], Qibin Ye[1], Weidang Lu[1](✉), Hong Peng[1], and Bo Li[2]

[1] College of Information Engineering, Zhejiang University of Technology, Hangzhou 310023, China
{luweid, ph}@zjut.edu.cn

[2] School of Information and Electrical Engineering, Harbin Institute of Technology, Weihai 264209, China
libo1983@hit.edu.cn

Abstract. Mobile edge computing (MEC) can meet the requirements of high-bandwidth and low delay commanded by the boost developing of mobile network and shorten the network load. This paper investigates a wireless powered MEC system consists a single antenna AP, and two single antenna mobile devices, which are powered by wireless power transmissions (WPT) from AP. In order to settle the users' near-far influence, the system will let the mobile devices closer from the AP mobile devices as a relay for unloading. The Objective of this paper is to minimize the transmission energy of the AP, taking into account the restraints of the computing task. Our solution is divided into two steps: first, the mathematical model of the problem is listed, and then the optimal solution of each feasible scheme is discussed in a classified manner, and the minimum transmission power of AP is obtained through comparison. Simulation results show that collaboration can reduce energy consumption and improve the user performance.

Keywords: Mobile edge computing · User cooperation · Wireless power transfer

1 Introduction

With the boost developing of communication technologies, a lot of smart mobile devices have been spread all over our life, gesture recognition, virtual reality (VR) and augment reality (AR), as well as smart home. These are computation-intensive applications, when they run, they require a lot of computing and storage resources and use electricity very fast. To solve these problems, MEC came into being, which mainly migrates heavy computing tasks to MEC servers at the wireless access points to improve mobile services capability [1]. MEC technology provides IT and cloud computing capabilities for mobile communication wireless access networks, enabling wireless networks with low latency and high bandwidth, thus solving the problem of heavy computing tasks [2].

MEC effectively integrates wireless network and Internet, and adds calculation, storage, processing and other features at the edge of wireless network. Computing

X. B. Zhai et al. (Eds.): MLICOM 2019, LNICST 294, pp. 186–195, 2019.
https://doi.org/10.1007/978-3-030-32388-2_16

offloading in MEC has the characteristics of ultralow latency and good network scalability. MEC can be studied from two different systems, single-user [3, 4] and multi-user [5–8]. In [3], the energy-optimal execution of mobile equipment and cloud computing is in random wireless channel by using Lagrange multiplier method, and the system is single-user. Computation offloading use a Markov decision process method to solve two-timescale stochastic optimization problem, and the system model is a multi-user in [5]. Later in [6], a MIMO system is studied, which several mobile users request computation unloading to a public cloud server grounded on a novel continuous convex approximation technology. The resource sharing problem was considered by proposing a framework in order to sustain mobile applications in a mobile cloud computing environment was addressed in [7]. Random joint wireless and computer resource governance were considered for multi-user MEC systems in [8].

There are some difficulties in making the best of the computing power at the edge. Lacking power provision is an important limitation for battery-based equipment that will stop when the battery uses up. So it is meaningful to use WPT technology to allow mobile equipment to be charged far, without having to deal with battery [4, 9–12]. In particular, WPT, represented by wireless powered communication networks (WPCN), has been recognized as a significant example of furnishing durative for mobile communications. The synergistic study of WPT and MEC was conducted in [4], which is a represent of a wireless powered system. In this paper, binary offloading is studied in order to improve the property.

However, WPCN is vulnerable to what is known as the “double near and far” effect, since users farther away from the AP obtain less energy and need to communicate over longer distances [9, 10]. User collaboration has been widely studied to improve the transmission rate under bad channel. Especially [11, 12] concentrate on the impact of collaboration among near-far users and manage to further the function of WPCNs.

In this paper, we investigate how MEC systems powered by wireless perform computation-intensive tasks between two near-far users, powered entirely by AP throughout the entire process. Therefore, our goal is to minimize the transmission energy of AP and combine the power distribution. Our contributions are summarized as follows:

Aiming at the double near-far influence in WPT-MEC system, a block-based time division protocol is raised. We proposed the problem of minimizing the transmitted energy of AP, and compared the transmitted power of two users by comparing two different situations. The total transfer energy of AP is minimized when the delay is satisfied. Simulation products prove the explanation of the designed program. The results show that the program can take the full advantage of the cooperation between near-far users to process intensive tasks.

2 System Model and Problem Formulation

2.1 System Model

As shown in Fig. 1, we are considering building a wireless powered MEC system with a single antenna AP, including two single antenna mobile devices, expressed as D_1 and D_2. They both work on the same frequency band and D_1 needs to complete computationally intensive latency critical tasks. A block-based TDMA structure is employed in which each block has a duration of T seconds. AP powers D_1 and D_2 in the downlink through the WPT during each block. The two devices use the harvested energy to complete the computing task of D_1 in a partially offloading manner [13].

Since local computing and WPT can be done at the same time, when considering that two users are transmitting in half-duplex mode, the wireless communication for offloading and the WPT are not overlapping. Therefore, the harvest-then-transmit protocol proposed in [9] is applied to our model, but we call it the harvest-then-offload protocol for wireless powered computation offloading.

Assuming the AP can obtain accurate data on all channels and task related parameters through feedback, then AP can make the best offload decision to optimally allocate radio and computational resources. And our goal is to minimize the transfer energy of the AP to complete the calculation tasks.

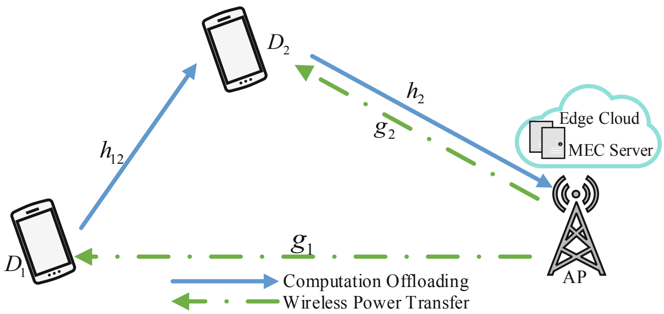

Fig. 1. The model for the two-user WPT-MEC system.

Computation Task Model

The user D_1 has a task in each block, which we can use a parameter tuple $\langle I, C, O, T \rangle$ to represent, where I indicates the size of the input computation data, C is the amount of computing resources needed to calculate 1-bit input data, O is the output data size and T is the maximum tolerable latency. In [14], we can obtain the information of I and C. In this article, we assume users D_2's and D_2's the maximum tolerable delay time T is the same.

User Collaboration Model for Calculate Offloading

Because of the double-near-far effects in WPCN, collaboration between near and far users can improve computing performance during offloading. Without loss of generality, we assume d_1, d_2 and d_{12} are expressed as the distances between AP and D_1, AP and D_2, D_1 and D_2, respectively, with $d_2 \leq d_1$. Besides, we must have $d_{12} \leq d_1$. Only than the cooperative communications are useful. Table 1 shows the time division structure of a single block.

Table 1. The time division structure of the harvest-then-offload protocol.

$T/3$	$T/3$	$T/3$
AP $\rightarrow D_1, D_2$	$D_1 \rightarrow D_2$	$D_2(D_1) \rightarrow$ AP
WPT	Computation Offloading	

In the first period $T/3$ (WPT), AP transmits wireless power to both D_1 and D_2 with power P_0, and thus the energy harvested by each device is given by

$$E_i = \frac{T}{3} v_i g_i P_0, i \in \{1, 2\} \tag{1}$$

where g_i is power gain from the AP to D_i and $0 < v_i \leq 1$ is the energy conversion efficiency of D_i.

After that, D_1 transmits its information with power p_1 by using the energy harvested in the second period $T/3$, and D_2 decodes received signals from D_1. During the last period $T/3$, D_2 will relay the D_1's data information with power p_2 to the AP by using its harvested energy. We define a power allocation vector as $\mathbf{p} = [p_1, p_2]$. With a given $\mathbf{p}$, at the AP and D_2, the smaller value between the decoded data sizes should be the offloaded data size of D_1 at the AP for remote computation, i.e.

$$L_1(\mathbf{p}) = \min\{L_{1,12}(p_1), L_{1,2}(p_2)\} \leq I \tag{2}$$

where $L_{1,12}(p_1)$ and $L_{1,2}(p_2)$ denote the D_1's offloaded data size from D_1 to D_2 and from D_2 to the AP, respectively, which are given by

$$L_{1,12}(p_1) = \frac{T}{3} r_{1,12}(p_1) = \frac{T}{3} B \log_2\left(1 + \frac{p_1 h_{12}}{N_2}\right) \tag{3}$$

$$L_{1,2}(p_2) = \frac{T}{3} r_{1,2}(p_2) = \frac{T}{3} B \log_2\left(1 + \frac{p_2 h_2}{N_0}\right) \tag{4}$$

where $r_{1,12}(p_1)$ and $r_{1,2}(p_2)$ are the transmission rates for offloading D_1's data information. In expressions, h_{12} and h_2 are the channel gains from D_1 to D_2 and from D_2 to AP, respectively. Also, the channel bandwidth denote B. At the AP and D_2, the receiver noise power are N_0 and N_2, respectively, and we assume that $N_0 = N_2$ without loss of generality.

The energy required to receive the calculations returned from the AP can be ignore. Therefore, D_1 and D_2 are used to calculate the energy consumption of the offloading, which can be regarded as the energy consumed for wireless transmissions, which can be given by

$$E_{\text{off},i}(\mathbf{p}) = \frac{T}{3} p_i, i \in \{1, 2\} \tag{5}$$

Local Computing Model

Given a power allocation vector $\mathbf{p}$, we will know the offloaded data sizes $L_1(\mathbf{p})$, so the data $I - L_1(\mathbf{p})$ of tasks should be computed locally at D_1. We assume that the D_1's computing resources of the CPU is limited and the frequency is f. In order to meet the constraint $(I - L_1(\mathbf{p}))C/f \leq T$ of latency, so D_1's offloaded data should be a minimum size of $L_1(\mathbf{p}) \geq M^+$ with $M = I - fT/C$, $(x)^+ = \max\{x, 0\}$. At D_1, the energy consumption of the CPU for local calculation can be expressed as $Q = \kappa f^2$, where κ is the effective capacitance coefficient. Hence, the locally calculated energy consumption of D_1 can be denoted as

$$E_{\text{loc},1}(\mathbf{p}) = (I - L_1(\mathbf{p}))CQ \tag{6}$$

2.2 Problem Formulation

Based on the model, D_i' s saving energy can be expressed as

$$E_{s,1}(P_0, \mathbf{p}) = E_1 - E_{\text{off},1}(\mathbf{p}) - E_{\text{loc},1}(\mathbf{p}) = \frac{T}{3} v_1 g_1 P_0 - \frac{T}{3} p_1 - (I - L_1(\mathbf{p}))CQ \tag{7}$$

$$E_{s,2}(P_0, \mathbf{p}) = E_2 - E_{\text{off},1}(\mathbf{p}) = \frac{T}{3} v_2 g_2 P_0 - \frac{T}{3} p_2 \tag{8}$$

Furthermore, the APTEM problem can be formulated below

$$\begin{aligned} &\min_{P_0 > 0, \mathbf{p}} \; P_0 T \\ \text{s.t.} \quad & M^+ \leq L_1(\mathbf{p}) \leq I, \; T \geq 0, \; p_1 \geq 0, p_2 \geq 0, \\ & E_{s,1}(P_0, \mathbf{p}) \geq 0, \; E_{s,2}(P_0, \mathbf{p}) \geq 0. \end{aligned} \tag{9}$$

3 Optimal Solution

Here, we can find that for the different value of $L_1(\mathbf{p})$ in (2), the APTEM problem for minimizing AP's transmit energy has different form. Thus, we should analyze the constraint of the APTEM problem as well as the different value of $L_1(\mathbf{p})$ to obtain the optimal solution.

3.1 Condition 1

If $L_{1,2}(p_2) < L_{1,12}(p_1)$, obviously, we have that $L_1(\mathbf{p}) = L_{1,2}(p_2)$. Furthermore, combining the constraints of the problem, we can rewrite the constraints as the follow:

$$N_0\left(2^{\frac{3}{B}\left(\frac{I}{T}-\frac{f}{C}\right)}-1\right) \le p_2h_2 \le N_0\left(2^{\frac{3I}{BT}}-1\right) \tag{10}$$

$$P_0 \ge \frac{1}{v_1g_1}\left(p_1 + \frac{3}{T}ICQ - BCQ\log_2\left(1+\frac{p_2h_2}{N_0}\right)\right) \tag{11}$$

$$P_0 \ge \frac{p_2}{v_2g_2} \tag{12}$$

Moreover, we also find $L_{1,12}(p_1) \le I$ from (2), then we have

$$p_2h_2 \le p_1h_{12} \le N_2\left(2^{\frac{3I}{BT}}-1\right) \tag{13}$$

In order to analysis in the inequality group, we define a function

$$f(\mathbf{p}) = p_1 - BCQ\log_2\left(1+\frac{p_2h_2}{N_0}\right) \tag{14}$$

Obviously, $f(\mathbf{p})$ is monotonically increasing when $p_1 \ge 0$, and it is also monotonically decreasing when $p_2 \ge 0$. Thus, the optimal P_0 is given by

$$P_0 = \max\left\{\frac{1}{v_1g_1}\left(\frac{N_2}{h_{12}}\left(2^{\frac{3I}{BT}}-1\right)+3Qf\right), \frac{N_0}{v_2g_2h_2}\left(2^{\frac{3I}{BT}}-1\right)\right\} \tag{15}$$

3.2 Condition 2

If $L_{1,2}(p_2) \ge L_{1,12}(p_1)$, obviously, we have that $L_1(\mathbf{p}) = L_{1,12}(p_1)$. With the similar analysis as above, we can rewrite the constraints of the problem as the follow:

$$N_2\left(2^{\frac{3}{B}\left(\frac{I}{T}-\frac{f}{C}\right)}-1\right) \le p_1h_{12} \le N_2\left(2^{\frac{3I}{BT}}-1\right) \tag{16}$$

$$P_0 \ge \frac{1}{v_1g_1}\left(p_1 + \frac{3}{T}ICQ - BCQ\log_2\left(1+\frac{p_1h_{12}}{N_2}\right)\right) \tag{17}$$

$$P_0 \ge \frac{p_2}{v_2g_2} \tag{18}$$

$$p_1h_{12} \le p_2h_2 \le N_0\left(2^{\frac{3I}{BT}}-1\right) \tag{19}$$

In this condition, for analyzing, we redefine the function

$$f(p_1) = p_1 - BCQ\log_2\left(1 + \frac{p_1 h_{12}}{N_2}\right) \tag{20}$$

By deriving the function $f(p_1)$ and making $f'(p_1) = 0$, we can find that $f(p_1)$ gets the minimum $f(p_1^*)$ when $p_1^* = BCQ/\ln 2 - N_2/h_{12}$. Besides that, $f(p_1)$ is an increasing function when $p_1 \in (BCQ/\ln 2 - N_2/h_{12}, \infty)$, and $f(p_1)$ is a decreasing function when $p_1 \in (0, BCQ/\ln 2 - N_2/h_{12})$. Thus, we should analyze the constraint of p_1^* to obtain the optimal value of P_0.

Condision 2.1

When $p_1^* \in \left[\frac{N_2}{h_{12}}\left(2^{\frac{3}{B}\left(\frac{I}{T}-\frac{f}{C}\right)} - 1\right), \frac{N_2}{h_{12}}\left(2^{\frac{3I}{BT}} - 1\right)\right]$, the optimal P_0 is given by

$$P_0 = \max\left\{\frac{N_2}{v_1 g_1 h_{12}}\left(2^{\frac{3I}{BT}} - 1\right), \frac{1}{v_1 g_1}\left(\frac{N_2}{h_{12}}\left(2^{\frac{3}{B}\left(\frac{I}{T}-\frac{f}{C}\right)} - 1\right) + 3fQ\right), \frac{N_0}{v_2 g_2 h_2}\left(2^{\frac{3I}{BT}} - 1\right)\right\} \tag{21}$$

Condision 2.2

When $p_1^* \in \left(\frac{N_2}{h_{12}}\left(2^{\frac{3I}{BT}} - 1\right), \infty\right)$, the optimal P_0 is given by

$$P_0 = \max\left\{\frac{1}{v_1 g_1}\left(\frac{N_2}{h_{12}}\left(2^{\frac{3}{B}\left(\frac{I}{T}-\frac{f}{C}\right)} - 1\right) + 3fQ\right), \frac{N_0}{v_2 g_2 h_2}\left(2^{\frac{3I}{BT}} - 1\right)\right\} \tag{22}$$

Condision 2.3

When $p_1^* \in \left(0, \frac{N_2}{h_{12}}\left(2^{\frac{3}{B}\left(\frac{I}{T}-\frac{f}{C}\right)} - 1\right)\right)$, the optimal P_0 is given by

$$P_0 = \max\left\{\frac{N_2}{v_1 g_1 h_{12}}\left(2^{\frac{3I}{BT}} - 1\right), \frac{N_0}{v_2 g_2 h_2}\left(2^{\frac{3I}{BT}} - 1\right)\right\} \tag{23}$$

4 Simulation Results and Discussion

Here, computer simulation is used to study the performance of the offloading scheme by combining user collaboration and optimizing the power allocation for wireless power.

Unless otherwise stated, the simulation parameters are set as follows. It is assumed that the uplink and downlink channels are reciprocal, and thus $g_1 = h_1, g_2 = h_2$. The power gain of the channel is modeled as $h_j = d_j^{-\alpha^2}$, $j \in \{1, 2, 12\}$. For distance d_i in meters with the same path-loss index $\alpha = 2$. At the AP and D_2, the noise power is assumed as $N_2 = N_0 = 10^{-9}$ W. The bandwidth $B = 10$ MHz, the distance $d_1 = 10$ m, $d_2 = 6$ m. For D_1, the CPU frequency $f = 0.2$ GHz and the number of CPU cycles required per bit of data is 1500cycles/bit. Then we set $v_i = 0.8$ and $\kappa_i = 10^{-28}$, $i \in \{1, 2\}$.The figures by simulations are modeling the real heterogeneous computing scenarios.

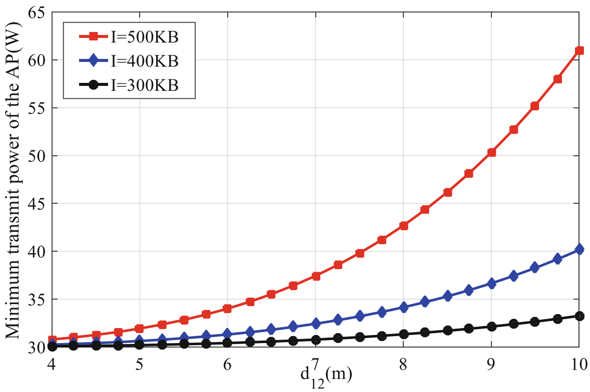

Fig. 2. Minimum transmit power of the AP versus d_{12}

Figure 2 shows the minimum transmit power P_0 of the AP versus d_{12}. We can easily find that P_0 increases with the farther distance between D_1 and D_2. Besides that, we can know that with I larger, the P_0 becomes larger. Further, when the d_{12} is increased from $d_{12} = 4\,\text{m}$ to 10 m, we can find that before $d_{12} = 7\,\text{m}$, the P_0 grows slowly but rapidly increases after $d_{12} = 7\,\text{m}$. And more, when the amount of tasks is small, the P_0 increases gently in the case of increasing d_{12}, but when the amount of tasks increases, the P_0's growth range becomes larger.

Figure 3 shows the minimum transmit power P_0 of the AP versus I. The distance between D_1 and D_2 remains unchanged, $d_{12}= 6\,\text{m}$. The task quantity of D_1 is $I \in [100, 600]$KB. We can easily find that P_0 increases with the larger I. Besides that, we can know that with T smaller, the P_0 becomes larger. And more, the P_0 is small when $I \leq 350\,\text{KB}$ but then the growth rate of P_0 increasingly. Especially, when $T = 0.15\,\text{s}$, the P_0 of AP increases more rapidly.

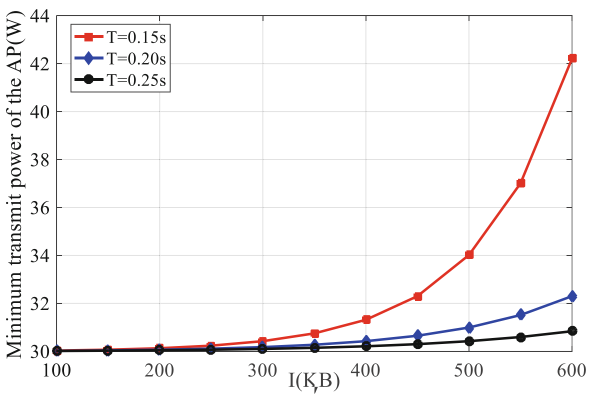

Fig. 3. Minimum transmit power of the AP versus I

5 Conclusion

In the article, we study the application of collaborative communication in computational offloading, where the AP acts as an energy source through the WPT and as a MEC server to help remote mobile terminal devices to complete their computationally intensive delay critical tasks. The block-based harvest-then-offload protocol is used to cooperatively calculate the power allocation of the offload, to achieve the purpose of minimizing the transmit energy of the AP for completing the computation task of the user. Simulation results revealed that utilizing cooperation can decrease the energy consumption and improve performance of users.

References

1. Yang, L., Cao, J., Yuan, Y., Li, T., Han, A., Chan, A.: A framework for partitioning and execution of data stream applications in mobile cloud computing. ACM SIGMETRICS Perform. Eval. Rev. **40**(4), 23–32 (2013)
2. Patel, M., Naughton, B., Chan, C., Sprecher, N., Abeta, S., Neal, A.: Mobile-edge computing introductory technical white paper. In: White Paper, Mobile-edge Computing (MEC) Industry Initiative, pp. 1089–7801(2014)
3. Zhang, W., Wen, Y., Guan, K., Kilper, D., Luo, H., Wu, D.O.: Energy-optimal mobile cloud computing under stochastic wireless channel. IEEE Trans. Wireless Commun. **12**(9), 4569–4581 (2013)
4. You, C., Huang, K., Chae, H.: Energy efficient mobile cloud computing powered by wireless energy transfer. IEEE J. Sel. Areas Commun. **34**(5), 1757–1771 (2016)
5. Liu, J., Mao, Y., Zhang, J., Letaief, K.B.: Delay-optimal computation task scheduling for mobile-edge computing systems. In: 2016 IEEE International Symposium on Information Theory (ISIT), pp. 1451–1455. IEEE (2016)
6. Sardellitti, S., Scutari, G., Barbarossa, S.: Joint optimization of radio and computational resources for multicell mobile-edge computing. IEEE Trans. Sig. Inf. Process. over Netw. **1** (2), 89–103 (2015)
7. Kaewpuang, R., Niyato, D., Wang, P., Hossain, E.: A framework for cooperative resource management in mobile cloud computing. IEEE J. Sel. Areas Commun. **31**(12), 2685–2700 (2013)
8. Mao, Y., Zhang, J., Song, S.H., Letaief, K.B.: Stochastic joint radio and computational resource management for multi-user mobile-edge computing systems. IEEE Trans. Wireless Commun. **16**(9), 5994–6009 (2017)
9. Ju, H., Zhang, R.: Throughput maximization in wireless powered communication networks. IEEE Trans. Wireless Commun. **13**(1), 418–428 (2014)
10. Ju, H., Zhang, R.: User cooperation in wireless powered communication networks. In: 2014 IEEE Global Communications Conference, pp. 1430–1435. IEEE (2014)
11. Chen, H., Li, Y., Rebelatto, J.L., Uchoa-Filho, B.F., Vucetic, B.: Harvest-then-cooperate: wireless-powered cooperative communications. IEEE Trans. Sig. Process. **63**(7), 1700–1711 (2015)
12. Liang, H., Zhong, C., Suraweera, H.A., Zheng, G., Zhang, Z.: Optimization and analysis of wireless powered multi-antenna cooperative systems. IEEE Trans. Wireless Commun. **16**(5), 3267–3281 (2017)

13. Mao, Y., You, C., Zhang, J., Huang, K., Letaief, K.B.: A survey on mobile edge computing: The communication perspective. IEEE Commun. Surv. Tutorials **19**(4), 2322–2358 (2017)
14. Cuervo, E., Balasubramanian, A., Cho, D.K., Wolman, A., Saroiu, S., Chandra, R., Bahl, P.: MAUI: making smartphones last longer with code offload. In: Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services, pp. 49–62. ACM (2010)