Joint Optimization of Cooperative Communication and Computation in Two-Way Relay MEC Systems

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Abstract—**Considering two users exchange computational results through a two-way relay equipped with a mobile-edge computing server, we investigate the joint optimization problem of cooperative communication and computation, whose objective is the total energy consumption minimization subject to the delay constraint. To derive the low-complexity optimal solution, by assuming that the transmit power of the relay is given, we theoretically derive the optimal values of computation task partition factors. Thus, the optimal solution to the total energy consumption minimization problem can be found by one-dimensional search over the transmit power of the relay. Simulation results show that our proposed scheme performs better than that where all computational tasks are allocated to the relay or users.**

Index Terms—**Cooperative communications, delay constraint, mobile-edge computing (MEC), two-way relay.**

I. INTRODUCTION

Recently, new applications, such as face recognition, natural language processing, and virtual reality, trigger the research on mobile-edge computing (MEC) [1]–[5]. In [1], a power-constrained delay minimization problem in a single-user MEC system was studied. In [2], resource allocation under the delay constraint for a multiuser MEC system was investigated. In [3], a unified MEC-wireless power transfer (WPT) design was proposed, by considering a wireless powered multiuser MEC system. In [4], a joint cooperative communication and computation in a relay MEC system was put forward. In [5], for an unmanned aerial vehicle (UAV)-enabled MEC system, the joint optimization problem of UAV position, time slot allocation, and computation task partition was solved.

In this paper, we consider a computational result exchanging system over the wireless two-way relay channel. A typical scenario is mutual identity authorization by face recognition with help of a two-way relay equipped with an MEC server. Considering cooperative communication and computation, our aim is to minimize the total energy consumption at both users and the relay, subject to the delay constraint. The formulated problem is convex and can be solved by the interior point method. Since the interior point method has high computational complexity, we propose a low-complexity optimal solution in this paper. By assuming that the transmit power of the relay is given, we theoretically derive the optimal values of CT partition factors. With the obtained CT partition factors, we can find the optimal durations of offloading and computing. Therefore, the optimal solution to the total energy consumption minimization problem can be found by one-dimensional search over the transmit power of the relay.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Consider a computational result exchanging system over the wireless two-way relay channel. In the system, User 1 wants to share its computational results with User 2 and the results require some key parameters from User 2. User 2 also wants to share its computational results with User 1 and the results require some key parameters from User 1. We assume that the two-way relay is equipped with an MEC server and it has the global information to determine the amount of computation at both the relay and two users, respectively. We focus on a time block with duration T.

In the first time slot (TS) with duration τ_1, User 1 offloads all of the CTs with length L_1 in bits to the relay over the forward relay channel $h_{1,f}$. In the second TS with duration τ_2, User 2 offloads all of the CTs with length L_2 in bits to the relay over the forward relay channel $h_{2,f}$. The achievable data rate for offloading from User i, $i \in \{1, 2\}$, to the relay is expressed as

$$r_{i,f} = B \log_2 \left(1 + P_i |h_{i,f}|^2 / \sigma^2 \right) \qquad (1)$$

where B denotes the system bandwidth, P_i denotes the transmit power of User i, and σ^2 denotes the power of the additive Gaussian noise at both the relay and users. The duration and the energy consumption for offloading from User i are

$$\tau_i = L_i / r_{i,f} \text{ and } E_i = \tau_i P_i, \qquad (2)$$

respectively.

To reduce the computational delay, the two-way relay allocates CTs with length $(1 - \alpha_1)L_1$ to User 2 and CTs with length $(1 - \alpha_2)L_2$ to User 1 where $\alpha_i \in [0, 1]$ denotes the CT partition factor for User i, $i \in \{1, 2\}$. The remaining CTs $\alpha_1 L_1 + \alpha_2 L_2$ are computed at the relay. Specifically, the relay employs the physical-layer network coding to simultaneously broadcast CTs with length $(1 - \alpha_1)L_1$ and CTs with length $(1 - \alpha_2)L_2$ to two users over the backward channels in the third TS with duration τ_3. We assume that the relay employs the same coding scheme for the CTs to User 2 and User 1. Thus, we have

$$(1 - \alpha_1)L_1 = (1 - \alpha_2)L_2. \qquad (3)$$

By using the local information, User 1 and User 2 are able to decode the relaying CTs. The achievable data rate at User i, $i \in \{1, 2\}$, in the third TS is

$$r_{i,b} = B \log_2 \left(1 + P_r |h_{i,b}|^2 / \sigma^2 \right), \ i \in \{1, 2\} \qquad (4)$$

where P_r denotes the transmit power of the relay and $h_{i,b}$ denotes the backward relay channel from relay to User i. Since

the relay employs the same coding scheme for the CTs to User 2 and User 1, the duration and the energy consumption of the third TS are given by

$$\tau_3 = \max\{\tau_{1,b}, \tau_{2,b}\} \text{ and } E_3 = \tau_3 P_r, \tag{5}$$

respectively, where

$$\tau_{1,b} = (1 - \alpha_2)L_2/r_{1,b} \text{ and } \tau_{2,b} = (1 - \alpha_1)L_1/r_{2,b}. \tag{6}$$

At the fourth TS, the computing time and the energy consumption at each user are given by [3]

$$t_u = k(1 - \alpha_1)L_1/F_u = k(1 - \alpha_2)L_2/F_u, \tag{7}$$
$$C_u = k(1 - \alpha_1)L_1\eta_u F_u^2 = k(1 - \alpha_2)L_2\eta_u F_u^2, \tag{8}$$

respectively, where k denotes the number of CPU cycles for computing one bit, η_u denotes the effective capacitance coefficient at users, and F_u denotes the computational speed of users [3]. For the relay, since both the third and fourth TS can be used for computing, we have

$$t_r + \tau_3 = k(\alpha_1 L_1 + \alpha_2 L_2)/F_r \tag{9}$$

where t_r denotes the computing time of the relay at the fourth TS and F_r denotes the computational speed of the relay. The energy consumption at the relay is given by

$$C_r = k(\alpha_1 L_1 + \alpha_2 L_2)\eta_r F_r^2 \tag{10}$$

where η_r denotes the effective capacitance coefficient at the relay. After computing at the relay, the relay forwards the results to users. According to [3], the result forwarding time duration is relatively small and negligible.

Considering the whole computational result exchanging process, our aim is to minimize the total energy consumption at both users and the relay, subject to the delay constraint

$$\tau_1 + \tau_2 + \tau_3 + \tau_4 \leq T \tag{11}$$

where

$$\tau_4 = \max\{t_u, t_r\}. \tag{12}$$

The system energy consumption optimization problem is

$$\min_{\Theta} \mathcal{E} \tag{13a}$$
$$\text{s.t. } (3), \ 0 \leq \alpha_i \leq 1, \ i \in \{1, 2\}, \tag{13b}$$
$$(11), \ \tau_j \geq 0, \ j \in \{1, 2, 3, 4\}, \tag{13c}$$
$$P_i \geq 0, \ i \in \{1, 2\}, \ P_r \geq 0 \tag{13d}$$

where $\Theta = \{\alpha_1, \alpha_2, \tau_1, \tau_2, \tau_3, \tau_4, P_1, P_2, P_r\}$ and

$$\mathcal{E} = E_1 + E_2 + E_3 + 2C_u + C_r. \tag{14}$$

III. OPTIMAL SOLUTION

Substituting (2) into (1), we have

$$P_i = \gamma_{i,f}^{-1}\left(2^{\frac{L_i}{B\tau_i}} - 1\right) \geq 0, \ i \in \{1, 2\} \tag{15}$$

where $\gamma_{i,f} = |h_{i,f}|^2/\sigma^2$. Substituting (15) into $E_i = \tau_i P_i$ for $i \in \{1, 2\}$, we have

$$E_i = \tau_i \gamma_{i,f}^{-1}\left(2^{\frac{L_i}{B\tau_i}} - 1\right), \ i \in \{1, 2\} \tag{16}$$

which is a convex perspective function with respect to τ_i. Similarly, we have

$$E_3 = \tau_3 \gamma_b^{-1}\left(2^{\frac{(1 - \alpha_1)L_1}{B\tau_3}} - 1\right) \tag{17}$$

where $\gamma_b = \sigma^{-2}\min_i |h_{i,b}|^2$. Substituting (16) and (17) into problem (13), problem (13) is convex and can be solved by the interior point method.

Since the interior point method has high computational complexity, we propose a low-complexity optimal solution in this paper. To proceed, we have the following proposition.

Proposition 1: Denote the optimal solution to problem (13) as $\Theta^\star = \{\alpha_1^\star, \alpha_2^\star, \tau_1^\star, \tau_2^\star, \tau_3^\star, \tau_4^\star, P_1^\star, P_2^\star, P_r^\star\}$. For the optimal solution to problem (13), we have

$$\tau_1^\star + \tau_2^\star + \tau_3^\star + \tau_4^\star = T. \tag{18}$$

Proof: The proof is omitted for space limitation. ∎

From Proposition 1, we replace the constraint (11) in problem (13) with the following constraint

$$\tau_1 + \tau_2 + \tau_3 + \tau_4 = T. \tag{19}$$

In the following, assuming that the optimal value of P_r is given, we theoretically derive the optimal values of α_1 and α_2. In (12), we consider two cases, i.e., $t_u \geq t_r$ and $t_u \leq t_r$.

A. The Case When $t_u \geq t_r$

When $t_u \geq t_r$, using (3), we have

$$\alpha_2 = 1 - (1 - \alpha_1)L_1/L_2. \tag{20}$$

Since we assume that the optimal value of P_r is given, from (5) and (6), we obtain

$$\tau_3 = (1 - \alpha_1)L_1/r_b \tag{21}$$

where $r_b = \min\{r_{1,b}, r_{2,b}\}$. Substituting (7) and (9) into $t_u \geq t_r$, we have

$$\frac{k(1 - \alpha_1)L_1}{F_u} \geq \frac{k(\alpha_1 L_1 + \alpha_2 L_2)}{F_r} - \tau_3. \tag{22}$$

Substituting (20) and (21) into (22), after some mathematical manipulation, we have

$$\alpha_1 \leq 1 - \phi \tag{23}$$

where

$$\phi = \frac{k(L_1 + L_2)/F_r}{L_1\left(k/F_u + 1/r_b + 2k/F_r\right)}. \tag{24}$$

Given the optimal value of P_r, the objective function of problem (13) is rewritten as

$$\mathcal{E} = \Psi + \xi + \zeta \tag{25}$$

where $\Psi = (L_1 + L_2) \cdot (k\eta_u F_u^2 + P_r/(2r_b))$ is a constant and

$$\xi = E_1 + E_2 = \sum_{i=1}^{2} \tau_i \gamma_{i,f}^{-1}\left(2^{\frac{L_i}{B\tau_i}} - 1\right), \tag{26}$$
$$\zeta = \varphi(\alpha_1 L_1 + \alpha_2 L_2). \tag{27}$$

In (27), $\varphi = k\eta_r F_r^2 - k\eta_u F_u^2 - P_r/(2r_b)$.

Since $t_u \geq t_r$, from (7), τ_4, which is determined by t_u, is a monotonically decreasing function of α_1. Furthermore, from (21), τ_3 is a monotonically decreasing function of α_1. Because of (19), $\tau_1 + \tau_2$ is a monotonically increasing function of α_1. From (16), E_i is a monotonically decreasing function of τ_i for $i \in \{1, 2\}$. Therefore, $\xi = E_1 + E_2$ is a monotonically decreasing function of α_1.

In (27), if $\varphi \leq 0$, ζ is a monotonically decreasing function of α_1. Thus, $\mathcal{E}$ is a monotonically decreasing function of α_1. The optimal value of α_1 is $\alpha_1 = 1 - \phi$.

If $\varphi > 0$, ζ is a monotonically increasing function of α_1 whereas ξ is a monotonically decreasing function of α_1. The optimal value of α_1 is the solution to the following equation

$$\frac{\partial \xi}{\partial \alpha_1} + \frac{\partial \zeta}{\partial \alpha_1} = 0, \tag{28}$$

because in (25), Ψ is a constant. Substituting (20) into (27), we have $\zeta = \varphi(2\alpha_1 L_1 + L_2 - L_1)$. Taking the partial derivatives of ζ with respect to α_1, we have

$$\frac{\partial \zeta}{\partial \alpha_1} = 2\varphi L_1 > 0 \text{ and } \frac{\partial^2 \zeta}{\partial \alpha_1^2} = 0. \tag{29}$$

Taking the first-order partial derivative of ξ with respect to α_1, we have

$$\frac{\partial \xi}{\partial \alpha_1} = \frac{\partial \xi}{\partial \tau_1}\frac{\partial \tau_1}{\partial \alpha_1} + \frac{\partial \xi}{\partial \tau_2}\frac{\partial \tau_2}{\partial \alpha_1}. \tag{30}$$

From (26), we have

$$\frac{\partial \xi}{\partial \tau_i} = -\gamma_{i,f}^{-1} 2^{\frac{L_i}{B\tau_i}}\left(\frac{L_i \ln 2}{B\tau_i} - 1\right) - \gamma_{i,f}^{-1} \tag{31}$$

for $i \in \{1, 2\}$. To obtain $\partial \tau_1/\partial \alpha_1$ and $\partial \tau_2/\partial \alpha_2$, we substitute (7) and (21) into (19) and obtain

$$\tau_1 + \tau_2 = T - \omega(1 - \alpha_1)L_1 \tag{32}$$

where $\omega = 1/r_b + k/F_u$. Thus, we have

$$\frac{\partial \tau_i}{\partial \alpha_1} = \frac{\partial \tau_i}{\partial (\tau_1 + \tau_2)} \cdot \frac{\partial(\tau_1 + \tau_2)}{\partial \alpha_1} = \frac{\omega L_1 \cdot \partial \tau_i}{\partial(\tau_1 + \tau_2)} \tag{33}$$

for $i \in \{1, 2\}$. In the following, we need to obtain $\frac{\partial \tau_i}{\partial(\tau_1 + \tau_2)}$. Since τ_1 and τ_2 should be optimal solution to problem (13), if $\hat{\tau} = \tau_1 + \tau_2$ is given, problem (13) is reduced to

$$\min_{\tau_1, \tau_2} E_1 + E_2 \quad \text{s.t. } \tau_1 + \tau_2 = \hat{\tau}. \tag{34}$$

Problem (34) is convex, whose Lagrangian dual function is

$$\mathcal{L} = \sum_{i=1}^{2} \tau_i \gamma_{i,f}^{-1}\left(2^{\frac{L_i}{B\tau_i}} - 1\right) + \theta(\tau_1 + \tau_2 - \hat{\tau}) \tag{35}$$

in which $\theta > 0$ is an introduced Lagrangian variable. Using the Karush-Kuhn-Tucker (KKT) conditions, the optimal solution to problem (34) is

$$\tau_i = \frac{L_i \ln 2}{B\left(\mathcal{W}\left(\frac{\theta \gamma_{i,f} - 1}{e}\right) + 1\right)}, \quad i \in \{1, 2\}. \tag{36}$$

Taking the first-order partial derivative of τ_i with respect to θ,

we have $\partial \tau_i/\partial \theta = \vartheta_i$ where

$$\vartheta_i = \frac{L_1 \gamma_{i,f} \ln 2}{-B\left(\mathcal{W}\left(\frac{\theta \gamma_{i,f} - 1}{e}\right) + 1\right)^3 \cdot \exp\left(\mathcal{W}\left(\frac{\theta \gamma_{i,f} - 1}{e}\right)\right)}. \tag{37}$$

Thus, we have

$$\frac{\partial \tau_i}{\partial(\tau_1 + \tau_2)} = \frac{\partial \tau_i/\partial \theta}{\partial \tau_1/\partial \theta + \partial \tau_2/\partial \theta} = \frac{\vartheta_i}{\vartheta_1 + \vartheta_2}. \tag{38}$$

Substituting (38) into (33), we obtain

$$\frac{\partial \tau_i}{\partial \alpha_1} = \chi_i = \frac{\omega L_1 \vartheta_i}{\vartheta_1 + \vartheta_2}. \tag{39}$$

Substituting (31) and (32) into (30), we have

$$\frac{\partial \xi}{\partial \alpha_1} = \sum_{i=1}^{2} -\chi_i \gamma_{i,f}^{-1} 2^{\frac{L_i}{B\tau_i}}\left(\frac{L_i \ln 2}{B\tau_i} - 1\right) - \chi_i \gamma_{i,f}^{-1} < 0. \tag{40}$$

To obtain the solution to (28), we take the second-order partial derivative of ξ with respect to α_1 and obtain

$$\frac{\partial^2 \xi}{\partial \alpha_1^2} = \sum_{i=1}^{2} 2^{\frac{L_i}{B\tau_i}}\left(\frac{\chi_i L_i^2 (\ln 2)^2}{\gamma_{i,f} B^2 \tau_i^3}\right) > 0. \tag{41}$$

This shows that $\partial \xi/\partial \alpha_1$ is a monotonically increasing function of α_1. From (29), there exists at most one solution to (28). Substituting (29) and (40) into (28), we have

$$\chi_2 \gamma_{2,f}^{-1} 2^{\frac{L_2}{B\tau_2}}\left(\frac{L_2 \ln 2}{B\tau_2} - 1\right) = \lambda. \tag{42}$$

where $\lambda = 2\varphi L_1 - \chi_1 \gamma_{1,f}^{-1} 2^{L_1/(B\tau_1)}(L_1 \ln 2/(B\tau_1) - 1) - \chi_1 \gamma_{1,f}^{-1} - \chi_2 \gamma_{2,f}^{-1}$. We rewrite (42) as follows

$$\left(\frac{L_2 \ln 2}{B\tau_2} - 1\right) \cdot \exp\left(\frac{L_2 \ln 2}{B\tau_2} - 1\right) = \frac{\gamma_{2,f}\lambda}{e\chi_2}. \tag{43}$$

From the property of Lambert $\mathcal{W}$ function, we obtain

$$\tau_2^o = B^{-1}\left[\mathcal{W}\left(\frac{\gamma_{2,f}\lambda}{e\chi_2}\right) + 1\right]^{-1} L_2 \ln 2. \tag{44}$$

Substituting (44) into (32), we have

$$\alpha_1^o = 1 - (T - \tau_1 - \tau_2^o)/(\omega L_1) \tag{45}$$

where τ_1 is defined in (36). Therefore, if $\varphi > 0$, the optimal value of α_1 which minimizes $\mathcal{E}$ is

$$\alpha_1 = \min\{\max\{\alpha_1^o, 0\}, 1 - \phi\}. \tag{46}$$

B. The Case When $t_u \leq t_r$

In this case, from (23), we know $\alpha_1 \geq 1 - \phi$. Substituting (9) into (21), we have

$$\tau_1 + \tau_2 = T - k(2\alpha_1 L_1 - L_1 + L_2)/F_r. \tag{47}$$

From (47), $\tau_1 + \tau_2$ is a monotonically decreasing function of α_1. From (16), E_i is a monotonically decreasing function of τ_i for $i \in \{1, 2\}$. Therefore, $\xi = E_1 + E_2$ is a monotonically increasing function of α_1.

In (27), if $\varphi \geq 0$, ζ is a monotonically increasing function of α_1. Thus, $\mathcal{E}$ is a monotonically increasing function of α_1. The optimal value of α_1 is $\alpha_1 = 1 - \phi$.

If $\varphi < 0$, ζ is a monotonically decreasing function of α_1 whereas ξ is a monotonically increasing function of α_1. Using the similar method in Subsection III-A, we have

$$\frac{\partial \xi}{\partial \alpha_1} = \sum_{i=1}^{2} -\tilde{\chi}_i \gamma_{i,f}^{-1} 2^{\frac{L_i}{B\tau_i}} \left(\frac{L_i \ln 2}{B\tau_i} - 1 \right) - \tilde{\chi}_i \gamma_{i,f}^{-1} < 0 \quad (48)$$

and $\partial^2 \xi / \partial \alpha_1^2 > 0$, where $\tilde{\chi}_i = -\frac{2kL_1 \vartheta_i}{F_r(\vartheta_1 + \vartheta_2)}$ for $i \in \{1, 2\}$. The solution to (28) is

$$\tilde{\alpha}_1^o = - \left(T - \tau_1 - \tilde{\tau}_2^o - k(L_1 - L_2)/F_r \right) / \tilde{\omega} \quad (49)$$

where τ_1 is defined in (36), $\tilde{\omega} = -2kL_1/F_r$ and

$$\tilde{\tau}_2^o = B^{-1} \left[\mathcal{W} \left(\frac{\gamma_{2,f}\tilde{\lambda}}{e\tilde{\chi}_2} \right) + 1 \right]^{-1} L_2 \ln 2 \quad (50)$$

in which $\tilde{\lambda} = 2\varphi L_1 - \tilde{\chi}_1 \gamma_{1,f}^{-1} 2^{L_1/(B\tau_1)}(L_1 \ln 2/(B\tau_1) - 1) - \tilde{\chi}_1 \gamma_{1,f}^{-1} - \tilde{\chi}_2 \gamma_{2,f}^{-1}$. Thus, if $\varphi < 0$, the optimal value of α_1 which minimizes $\mathcal{E}$ is

$$\alpha_1 = \max\{\min\{\tilde{\alpha}_1^o, 1\}, 1 - \phi\}. \quad (51)$$

C. Summary of Algorithm

To solve problem (13), we perform one-dimensional search over P_r. Given P_r, we obtain $r_b = \min\{r_{1,b}, r_{2,b}\}$ by (5). When $\alpha_1 = 0$, from (19), we have

$$\tau_1 + \tau_2 = \hat{\tau} = T - \omega \min\{L_1, L_2\}. \quad (52)$$

When $\alpha_1 = 1$, from (47), we have $\hat{\tau} = T - k(L_1 + L_2)/F_r$. When $\alpha_1 = 1 - \phi$, we have $\hat{\tau} = T - \phi\omega L_1$. In the aforementioned three conditions, the optimal τ_1 and τ_2, expressed in (36), can be found by bisection search over θ such that $\tau_1 + \tau_2 = \hat{\tau}$ is satisfied.

When $\alpha_1 = \alpha_1^o$, combining (44) and (36), we have

$$\mathcal{W} \left(\frac{\gamma_{2,f}\lambda}{e\chi_2} \right) = \mathcal{W} \left(\frac{\theta\gamma_{2,f} - 1}{e} \right). \quad (53)$$

The right-hand side of (53) is a monotonically increasing function of θ. For the left-hand side of (53), we have

$$\frac{\partial \lambda}{\partial \tau_1} = \chi_1 \gamma_{1,f}^{-1} \tau_1^{-1} 2^{\frac{L_1}{B\tau_1}} \left(\frac{L_1 \ln 2}{B\tau_1} \right)^2 > 0. \quad (54)$$

Furthermore, from (36), τ_1 is a monotonically decreasing function of θ. Thus, the left-hand side of (53) is a monotonically decreasing function of θ. Solving (53) by the bisection search over θ, we can find the optimal τ_1 and τ_2.

Similarly, when $\alpha_1 = \tilde{\alpha}_1^o$, solving the following equation

$$\mathcal{W} \left(\frac{\gamma_{2,f}\tilde{\lambda}}{e\tilde{\chi}_2} \right) = \mathcal{W} \left(\frac{\theta\gamma_{2,f} - 1}{e} \right), \quad (55)$$

we can find the optimal τ_1 and τ_2.

After obtaining τ_1 and τ_2, we obtain τ_3 using (21) and then τ_4 using (19). The optimal transmit power of User 1 and User 2, i.e., P_1 and P_2, can be found by (15).

Comparing the five conditions of α_1, we obtain the optimal system energy consumption $\mathcal{E}$ given P_r. By performing one-dimensional search over P_r, we obtain the optimal solution to problem (13).
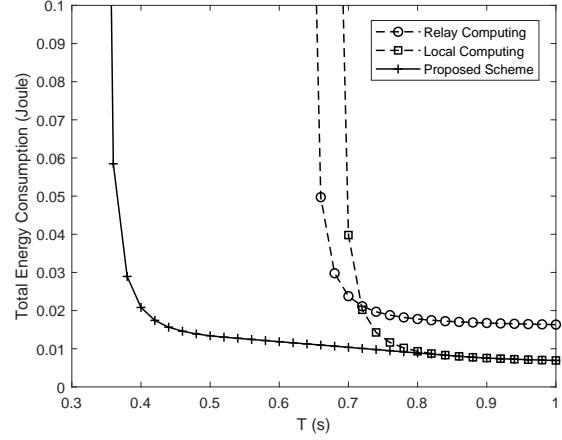

Fig. 1. Total energy consumption versus the delay constraint T; performance comparison of different schemes.

IV. SIMULATION RESULTS

In the simulations, both the forward and backward channels are modeled as independent Rayleigh fading with average power loss 10^{-6}. The power of the additive Gaussian noise at both the relay and users is 10^{-9} W [3]. The system bandwidth is 1 MHz. The length of CTs is $L_1 = L_2 = 1.8 \times 10^5$ bits. The number of CPU cycles for computing one bit is $k = 10^3$ cycles/bit. The effective capacitance coefficients are $\eta_u = \eta_r = 10^{-28}$ Joule/(cycles·Hz^2) [3]. The computational speed of users is $F_u = 0.3$ GHz and that of the relay is $F_r = 0.6$ GHz. In Fig. 1, we compare the total energy consumption of the proposed scheme with the "Relay Computing" and "Local Computing" schemes where the "Relay Computing" scheme means that all CTs are allocated to the relay, i.e., $\alpha_1 = \alpha_2 = 1$, and the "Local Computing" scheme means that all CTs are allocated to users, i.e., $\alpha_1 = \alpha_2 = 0$. From Fig. 1, it is found that our proposed scheme significantly outperforms the "Relay Computing" and "Local Computing" schemes.

V. CONCLUSION

In this paper, we have proposed a low-complexity algorithm to solve the total energy consumption minimization problem for a computational result exchanging system. Simulation results illustrate that our proposed scheme performs better than that where all CTs are allocated to the relay or users.

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