Incentive Mechanism Based Fair Computational Resource Allocation in Mobile Edge Computing

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Abstract

In this work, we consider the fair computational resource allocation in mobile edge computing (MEC). In MEC, each mobile user will upload its computational tasks to the MEC server which is attached at the base station through the radio access network to save local mobile energy consumption. In this scenario, each mobile user will try to get more computational resources from the MEC server to serve its computational tasks. In this resource competition, we have to guarantee the fairness among mobile users. To address the resource competition problem, we deploy an incentive mechanism (Kelly mechanism). The Kelly mechanism is a kind of an adaptive mechanism. In the Kelly mechanism, each mobile user serves as a buyer and the MEC server as a seller. The server allocates the computational resources (e.g., CPU) to each mobile user according to its bidding value. In the simulation results, we present that our proposed Kelly mechanism for computation resource allocation in mobile edge computing (MEC) outperforms equal computational resource sharing among mobile users.

Index terms – Mobile edge computing, computational resource allocation, incentive mechanism, Kelly mechanism.

1. Introduction

Nowadays, Internet of Things (IoT) becomes very popular where billions of devices (e.g., mobile devices, sensors, and small wearable devices etc.) will be connected to the internet via the wireless cellular networks [1]. Moreover, the limited battery lifetime and computational capacities of IoT devices become the significant challenges to deploy the IoT networks. The most auspicious solution to address the above challenges is deploying the concept of the mobile edge computing (MEC) [2] where edge server is attached at the base station (BS) and the computational tasks of the mobile devices are offloaded to the nearby cloud server (i.e., edge server) at the edge of the mobile cellular networks. After uploading the computational tasks to the edge server through the radio access network, the mobile server computes the computational tasks under its limited computational resource (i.e., CPU). After that, the server sends the output of the computational tasks to each corresponding mobile user. So, the allocation of computational resource of the mobile edge server to serve the offloading computational tasks of mobile users becomes a critical problem. To address the above problem, we propose the seller – buyers incentive mechanism (i.e., Kelly mechanism) [3] where each mobile serves as a buyer and the mobile edge server is the seller.

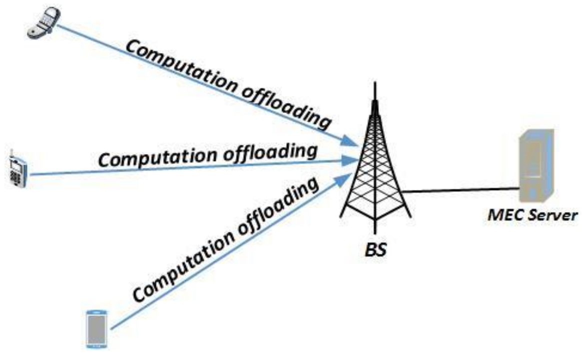

Fig. 1. A System Model

2. System Model and Problem Formulation

In our system model, we consider $U = \{1, 2, ..., U\}$ mobile users where each mobile user has its computational tasks and will upload to the server s via radio access network. Moreover, the server s has its limited computational capacity C_s to perform the computational tasks of mobile users. In our model, each mobile user will try to get more computational resource from the server.

Here, each mobile user submits the bidding value b_u to the server. Depending on the bidding value, the server allocates its computational resource r_u (i.e., CPU) to each mobile user and the server aims to maximize the social welfare of the computational resource competition game. Here, the social welfare means the sum of the valuation of the mobile users. Therefore, we can write the optimization problem of our resource competition game as follows:

$$\max \quad \sum_{u=1}^{U} v_u(r_u(b)) \tag{1}$$

subject to:

$$r_u(b) \cap r_s(b) = \varnothing, \text{ for } u \neq s, \text{ and } u, s \in U, \tag{2}$$

$$\sum_{u=1}^{U} r_u(b) \le C_s, \tag{3}$$

$$\text{var.} \quad r_u(b) \ge 0, \qquad \forall u \in U, \tag{4}$$

where constraint (2) ensures the isolation of computational resource among different users. Due to the limited computation resource of the server, constraint (3) guarantees that the allocated computational resource to all mobile users will not exceed the total computational resource capacity of the server. Solving the above optimization problem is not too much difficult if the server knows the valuation of the mobile users. However, the true valuation is the private information of the mobile users and they will not reveal it to maximize their utilities when the server requests to submit it.

The fraction of the computational resource allocated to each mobile user $u \in U$ is determined as follows:

$$r_u(b) = \frac{b_u}{\sum_{u=1}^{U} b_u} C_s, \qquad \forall u \in U, \tag{5}$$

where $\sum_{u=1}^{U} b_u$ is the total bidding value received by the mobile edge server. Then, the payoff (i.e., utility) function of each mobile user can be calculated as follows:

$$p_u(r(b)) = v_u(r_u(b)) - c_u(b), \qquad \forall u \in U, \tag{6}$$

where $c_u(b)$ is the cost function of mobile user u which depends on its bidding value. Moreover, the optimal bidding value of the user is as follows:

$$b_u = r_u(b) v'(r_u(b))(1-\beta_u), \qquad \forall u \in U, \tag{7}$$

where,

$$\beta_u = \frac{b_u}{\sum_{u=1}^{U} b_u}, \qquad \forall u \in U, \tag{8}$$

In the computational resource allocation game, each mobile user will choose its own strategy b_u to maximize the payoff $p_u(r(b))$ as:

$$p_u(b_u; b_{-u}) = v_u(r_u(b)) - c_u(b), \forall u \in U,$$

where b_{-u} is the strategy profiles of the other mobile users except user u. The strategy profile b_u^* is the Nash equilibrium of the resource competition game if the following relation is satisfied:

$$p_u(b_u^*; b_{-u}^*) \ge p_u(b_u; b_{-u}^*), \qquad \forall u \in U,$$

In order to analyze the equilibrium condition of the resource allocation game, we introduce $\mathrm{V}(r_u(b))$ as follows:

$$\mathrm{V}(r_u(b)) = \left(1 - \frac{r_u(b)}{C_s}\right) v(r_u(b)) + \frac{1}{C_s} \int_0^{r_u} v(z) d(z), \tag{11}$$

The efficient computational resource allocation among mobile users under the Nash equilibrium can be analyzed according to the following problem:

$$\max \quad \sum_{u=1}^{U} \mathrm{V}_u(r_u(b)) \tag{12}$$

subject to:

$$r_u(b) \cap r_s(b) = \varnothing, \text{ for } u \neq s, \text{ and } u, s \in U, \tag{13}$$

$$\sum_{u=1}^{U} r_u(b) \le C_s, \tag{14}$$

$$\text{var.} \quad r_u(b) \ge 0, \qquad \forall u \in U, \tag{15}$$

The Lagrangian function of (12) is as follows:

$$L(r_u, \lambda) = \sum_{u=1}^{U} \mathrm{V}_u(r_u(b)) + \lambda\left(C_s - \sum_{u=1}^{U} r_u(b)\right), \tag{16}$$

where $\lambda \ge 0$ is the Lagrangian multiplier for (14). By taking the first-order derivative of (16) with respect to the r_u and λ, we can express the KKT conditions as follows:

$$\frac{\partial L(r_u,\lambda)}{r_u(b)} = (1-\beta_u)v'(r_u(b)) - \lambda \le 0, \text{ if } r_u \ge 0, \quad \forall u \in U, \quad (17)$$

$$\frac{\partial L(r_u,\lambda)}{\lambda} = C_s - \sum_{u=1}^{U} r_u(b) \ge 0, \quad \text{if } \lambda \ge 0, \quad (18)$$

when $\lambda > 0$,

$$v'(r_u(b))(1-\beta_u) = \lambda \quad . \quad (19)$$

By solving (17), (18), and (19), the optimal computational resource allocation to each mobile user under the Nash equilibrium can be expressed as follows:

$$r_u(b) = \frac{b_u}{v'(r_u(b))(1-\beta_u)}, \qquad \forall u \in U \quad .$$

3. Simulation Results

In our simulation, we consider **3** mobile users within the base station coverage area with the different computation tasks and who want to upload their computation tasks to save their local mobile energy consumption. Fig.2. demonstrates the valuation achieved by the different mobile users. We can see that our proposed algorithm outperforms the equal sharing where equal sharing means we allocate the equal amount of computation resource to all mobile users. The reason is that different mobile users have different tasks (e.g., some mobile users need more computation resource because they have to compute heavy tasks). In this case, equal resource sharing to every user will not work efficiently.

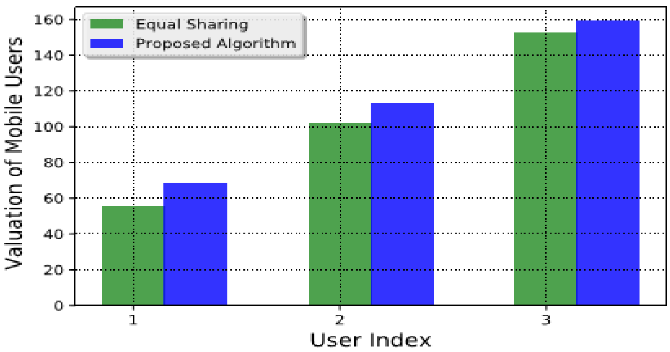

Fig. 2. Valuation of mobile users

Moreover, we present the amount of computation resource allocation to each user under our proposed algorithm (i.e., Kelly mechanism). In Fig.3, we observe that mobile user index "3" receives more computation resource compared with others. This is because mobile user "3" has to compute heavy computation task (i.e., higher bidding value) when compared with other mobile users.

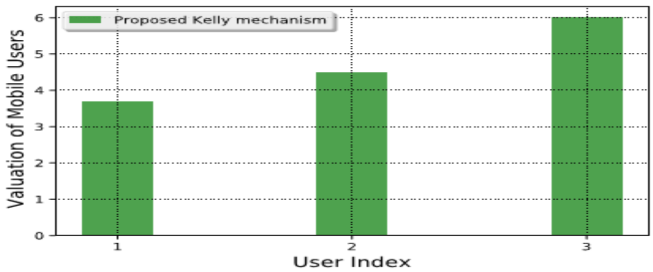

Fig. 3. Resource allocation to mobile users

4. Conclusion

In this paper, we consider computation resource allocation to mobile users depending on their bidding values. It is also sure that the user with the heavy tasks will give higher bidding value. After receiving bidding values from the mobile users, the edge server will do computation resource allocation among mobile users. From the simulation results, we observe that our proposed algorithm outperforms equal resource sharing.

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