# A Distributed Resource Allocation Game with Task centric Association in MEC enabled Ultra-Dense Networks

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**Abstract**

Mobile Edge Computing (MEC) allows users to assign their tasks to servers which are co-located with base stations to provide low latency and computation reliability. In MEC enabled ultra-dense networks environment where the small cell base stations (SBSs) are densely deployed to satisfy the growing demand of users, it is critical to decide the user association. In traditional user association approach, Signal to Interference plus Noise (SINR) is mostly considered as the threshold. But, in MEC enabled networks, we also need to consider the parameters related to the user's task which have the high influence over the latency. In this paper, we consider the user association based on weighted SINR and the task size of users that include the input file, computing, output file size. Moreover, Augmented Lagrangian approach is used to propose the distributed resource allocation problem where users compete with each other over resources to minimize their latency.

## 1. Introduction

Mobile Edge Computing (MEC) has been a critical aspect in 5G since it brings computation resources near to users so that users can offload their computation and latency intensive tasks to MEC servers that are co-located with base stations. In MEC enabled ultra-dense networks where SBSs are closely located to each other, the user association decision is crucial because this decision directly affects the latency experienced by users. The latency is composed with three parameters, uplink, computation and downlink latency which is varied among users depending on their task requirements.

A comparison of solutions for MEC networks presented in recent works is made in [1] where authors also provided the open challenges and requirements for MEC. Authors in [2] proposed a Logic Based Benders Decomposition approach to offload and schedule the tasks. The task offloading for ultra-dense network is proposed in [3]. The authors solved the resource allocation problem and task placement problem by using optimization approaches. In our previous work [4], we only consider the resource allocation game for a single cell network.

In this paper, we consider the task assignment and resource allocation problem separately. Since the task assignment problem is combinatorial which is difficult to solve in polynomial time. Thus, we propose a heuristic approach where we consider not only the Signal to Noise (SNR) but also the task parameters in making the assignment decision. In addition, we formulate the resource allocation problem as Generalized Nash Equilibrium Problem where users compete with each other to minimize their latency. A distributed solution is proposed based on the Augmented Lagrangian approach as proposed in [5] so that users can handle their own resource allocation.

## 2. System Model

We consider an ultra-dense network where a user is allowed to access only one SBS. The task assignment and resource allocation decisions are made according to the parameters of users' tasks.

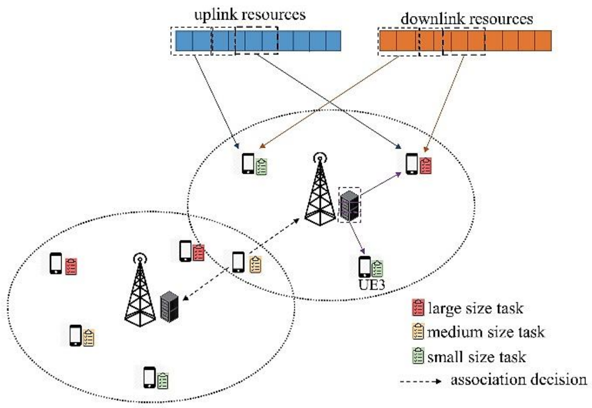


Figure 1. Task Association with Resource Allocation in MEC enabled Ultra-dense network

The Orthogonal Frequency Division Multiple Access is considered for both uplink and downlink transmission. The data rate for uplink transmission is

$$R_{ij} = \widehat{\omega}_{ij} \ \ \log_2(1+\frac{p_{ij}g_{ij}}{n_0}) := \ \ \widehat{\omega}_{ij}\gamma_{ij}$$

where $\widehat{\omega}_{ij}$ is the uplink bandwidth allocation. The data rate for downlink transmission is

$$R_{ji} = \widetilde{\omega}_{ij} \ \ \log_2\left(1+\frac{p_{ji}g_{ji}}{n_0}\right) := \ \ \widetilde{\omega}_{ij}\gamma_{ji}$$

where $\widetilde{\omega}_{ij}$ is the downlink bandwidth allocation, $\widehat{\omega}_{ij}$ is the uplink bandwidth allocation, $p_{ij}$ is the uplink transmit power of user $i$ to BS $j$, $p_{ji}$ is the downlink transmit power of BS $j$ to user $i$, $g_{ij}$ and $g_{ji}$ are the channel gain between BS $j$ and user $i$ for the uplink and downlink transmission, $\gamma_{ij}$ and $\gamma_{ji}$ are the uplink and downlink spectral efficiency of user $i$ when it is associated to BS $j$. We assumed that the MEC servers are set up with the multi-thread processing where multiple computation tasks can be processed simultaneously. Each task has three parameter which are $b_i$ (input file size), $c_i$ (computing size) and $r_i$ (the output result size).

### 3. Task centric User Association

In this section, we propose a task centric user association approach to minimize the latency of users. The end-to-end latency of user $i$ is calculated as

$$t_i = \ \sum_{j=1}^{N}\theta_{ij}(\frac{b_i}{\widehat{\omega}_{ij}\gamma_{ij}}+\frac{r_i}{\widetilde{\omega}_{ij}\gamma_{ji}}+\frac{c_i}{f_{ij}}) \qquad (1)$$

where $\theta_{ij}$ is the binary variable to decide whether user $i$ is associated to SBS $j$ or not. Since the latency, $t_i$, is influenced by both SNR, resource allocation and the parameters of the user's task, we propose a heuristic approach to find a SBS to minimize the latency. Thus, we define a rank of SBSs from the user's perspective which is calculated as follows.

$$\sigma_{ij} = \alpha_i(\gamma_{ij}+\gamma_{ji}) + (1-\alpha_i)\left(\frac{\widehat{\omega}_j^{max}}{\sum_{q\epsilon\Theta_j} b_q}+\frac{\widetilde{\omega}_j^{max}}{\sum_{q\epsilon\Theta_j} r_q}+\frac{f_j^{max}}{\sum_{q\epsilon\Theta_j} c_q}\right)$$

where $\Theta_j$ is the set of users who are likely to associate to SBS $j$ which means these are users within SBS $j$'s radius and $\widehat{\omega}_j^{max}$, $\widetilde{\omega}_j^{max}$, $f_j^{max}$ are the maximum uplink, downlink bandwidth and MEC server capacity of SBS $j$. The associated SBS can be calculated as.

$$n_i = \ \ argmax_j\{\sigma_{ij}\}$$

The association of user $i$ is calculated as $\theta_{in_i} = 1$.

### 4. Distributed Resource Allocation Game

As shown in fig (1), users associated to SBSs compete with each other to minimize their latency since the latency and resource allocated to users are inversely proportional to each other as shown in equation (1). Thus, we formulate the uplink, downlink and computing resource allocation as Generalized Nash Equilibrium problem since the resource allocation of one user is conflict to others'. The Augmented Lagrangian method is used to develop a distributed solution.

$$\min t_i + {}^{\rho}/_{2}\,(\|\widehat{\omega}_{ij}-\widehat{\omega}_{ij}^k\| + \|\widetilde{\omega}_{ij}-\widetilde{\omega}_{ij}^k\| + \|f_{ij}-f_{ij}^k\|)$$

s.t.

$$\widehat{\omega}_{ij} \le \widehat{\omega}_j^{max} - \textstyle\sum_{q\in\mathcal{U}_j, q\neq i}\widehat{\omega}_{qj}^k$$
$$\widetilde{\omega}_{ij} \le \widetilde{\omega}_j^{max} - \textstyle\sum_{q\in\mathcal{U}_j, q\neq i}\widetilde{\omega}_{qj}^k$$
$$f_{ij} \le f_j^{max} - \textstyle\sum_{q\in\mathcal{U}, q\neq i} f_{qj}^k$$
$$\widehat{\omega}_{ij}, \widetilde{\omega}_{ij}, f_{ij} \ge 0$$

Since the feasible set of each user is compact and convex, there is at least one Generalized Nash Equilibrium for this problem. $\widehat{\omega}_{ij}^k$, $\widetilde{\omega}_{ij}^k$, $f_{ij}^k$ are the resource allocation of user $i$ at previous iteration $k$. We use the cvxpy [6] to solve the above problem.

### 5. Evaluation Results

The Poisson Point Process model is used for the deployment of the MEC enabled ultra-dense network where the density of SBSs is 0.5/m$^2$ and users' density is 5/m$^2$. Transmit power of SBSs and users are 23dbm and 20dbm. The MEC server co-located with SBSs are equipped with 4GHz CPU. The input file, the result and computation size of users follow the uniform distribution which are [300, 800] KB, [0.2, 2.5] MB and [0.5, 1] GHz respectively.

The latency at different SBSs is shown in fig (2). For SNR based association where users are associated to the nearest SBSs, most of the users offload their tasks to SBS 11 which results in the highest latency at the SBS. In addition, users tend to associate to 4 SBSs in SNR based approach where users associate to 5 SBSs (4, 7, 9, 10, 11) in load centric solution. The highest latency achieved by load centric solution is significantly lower than SNR based approach.

Figure 3 shows the comparison of the total latency achieved by load centric and SNR based solution. The load centric solution provides the much lower latency compared to the SNR based solution.

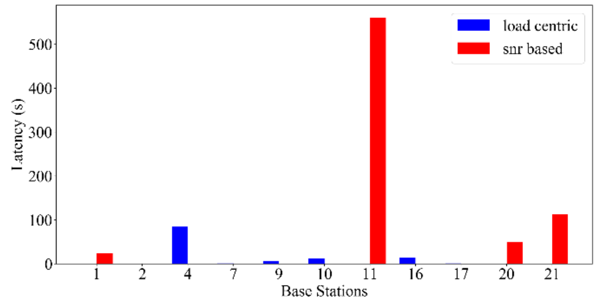


Figure 2. Latency at different SBSs

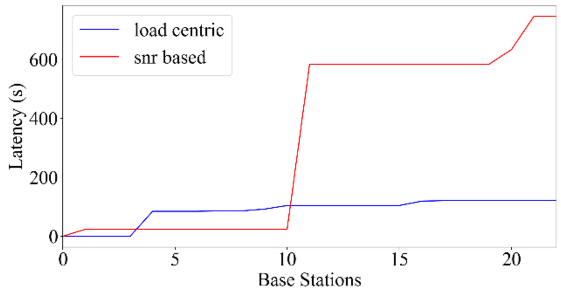


Figure 3. Latency comparison of Load Centric and SNR based approach

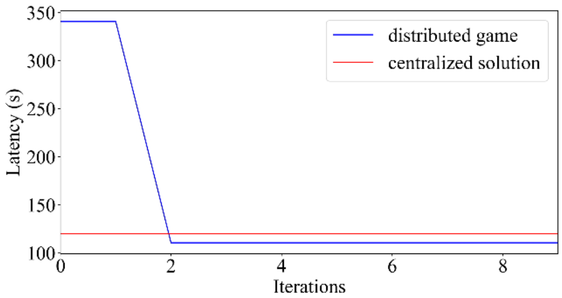


Figure 4. Convergence of the distribute game

The convergence of the distributed game solution is shown in fig 4. Due to the strong convexity of the objective function, the distributed game solution converges to a solution after the second iteration and achieve a slightly lower latency than the centralized solution.

## 6. Conclusion

In this paper, a heuristic approach is proposed to find the user association in the MEC enabled ultra-dense network where the latency of a user is affected by not only the SNR and resource allocation but also the task requirement of the user. The resource allocation problem is formulated as a distributed game which is solved using the Augmented Lagrangian method. In evaluation results, we prove that our heuristic association provides lower latency than SNR based approach. Users tend to associated to different SBSs. Moreover, the proposed game solution converges in a few iterations.

## Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2017R1A2A2A05000995). *Dr. CS Hong is the corresponding author

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