Matching Subcarrier Resource Allocation and Offloading Decision

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Abstract: One of the main attributes of the heterogeneous cellular network is the composition of different cell sizes. From such heterogeneity, expanded network capabilities had sprouted with extensive computing power consumption and ultra-low latency constraints. Using a heterogeneous network will provide multiple paths in which the users' data can flow through the network depending on the users' available resources, remaining energy, etc. In this paper, we study the heterogeneous network model, which contains MeNB, SeNB, and Femtocells, and we propose a matching subcarrier resource allocation and offloading decision (MSRAOD) algorithm. MSRAOD aims at recourse allocation optimization to minimize the total energy consumption of mobile users' devices with acceptable latency requirements of the applications. We have evaluated MSRAOD through simulation, and when compared to non-optimized data offloading, the MSRAOD algorithm significantly enhances the average energy consumption of mobile users. Such results provide a promising roadmap towards the implementation of such an algorithm in offloading-heavy applications.

Keywords: Heterogeneous networks, Energy optimization, small cells, Femtocell, Macrocell, Mobile Edge Computing.

1. Introduction

Despite the several benefits of 5G technology, like high data rate and low latency communication, there is a need to cope with the increased mobile/battery-powered devices demand for high data rates and low latency applications. One of the prominent solutions for such demand in 5G networks is mobile edge computing, which will allow mobile users to upload a portion or all their applications to powerful nearby edge servers located in the base station or access point under network resource constraints. Such servers should be able to process all of the users' data [1]. From the users point of view, this remote data processing can enhance mobile users' energy consumption and increase the achievable processing power. However, mobile users have to upload data to the edge servers for processing. Hence, the energy consumed during data uploading and the latency constraints are optimized to enhance mobile computation offloading (MCO) [2].

In this work, we propose matching subcarrier resource allocation and offloading decision (MSRAOD) algorithm for heterogeneous network model containing Macro-cells (MeNB), Small-cells (SeNB), and Femtocells. The main optimization goal is to minimize mobile users' total energy consumption with acceptable latency requirements for remote processing applications. The proposed MSRAOD algorithm manages the resource allocations among users based on the optimum offloading ratio that can enhance the minimum computation power for mobile devices. We propose MSRAOD to achieve the minimum total energy consumption for mobile users by considering resource allocations, partitioning decisions, and subcarrier assignments optimization. We investigate the performance of the proposed resource allocations optimization algorithm by comparing the MSRAOD algorithm with a random algorithm under three cases:

- Case 1: A single subcarrier use for multiple users, where all users are assigned to the same subcarrier.
- Case 2: The number of subcarriers is less than the number of users (note that case 1 is a particular case of case 2)
- Case 3: The number of subcarriers equals the number of users.

Our proposed algorithm results show that the proposed algorithm enhances the average energy consumption of mobile users in the heterogeneous network for the three cases. Moreover, MSROAD efficiency is especially prominent for the first two cases.

The rest of this paper organize as follows: In Section 2, a summary of previous works is provided. In Section 3, the proposed Matching Subcarrier Resource Allocation and Offloading Decision technique is introduced, and MSRAOD Algorithm is described. In Section 4, MSRAOD performance evaluation is discussed. Finally, the paper is concluded in Section 5.

2. Literature Review

Minimum energy consumption for mobile users has been identified as one of the main optimization problems in MCO [3]-[7]. Therefore, several scholars have addressed power and resource allocation optimization of wireless cellular networks. To achieve this optimization, computation resources and offloading MCO decisions were the main constraints in the optimization process.

Ito *et al.* proposed a bandwidth allocation scheme based on collectible information to meet the requirements of each flow in mobile edge computing [6]. Energy-aware edge server placement is studied in [5] to find a more effective placement scheme with low energy consumption. Wei et al. investigate the scene where multiple mobiles upload tasks to a mobile edge computing MEC server in a single cell [8]. They defined allocating the limited server resources and wireless channels between mobiles as the main challenge in the optimization study. They proposed the select maximum saved energy first (SMSEF) algorithm to formulate and optimize the energy consumption in the process.

El Ghmary proposed a heuristic solution to solve a complex decision problem that jointly optimizes the computing resources and the trade-off between the energy consumption and the processing time in a MEC node [9]. In [9], they consider a multitasking offloading environment with a single user in order to optimize the communication resources, the local frequency of the smart mobile device (SMD), and the frequency of the Edge Node (EN). They introduced the available energy of SMD as a constraint. Moreover, they introduced the Edge server's frequency as a decision variable in their optimization problem.

In previous works on MCO, the offloading decision making using the wireless transmission depends on the amount of application data and computation of user applications that need to be processed. Thus, all data need to be sent to process remotely or is processed locally. The allocation of available computation resources for all users in the network needs powerful management for these pooled resources in the system. Therefore, having powerful management is a must to achieve the offloading performance optimization for all mobile users assigned to the wireless subcarrier and the users required to process the MCO. Most of the literature mentioned above focuses on the single-cell system without latency constraint for partial offloading optimization.

This work provides a partially offloading ratio mechanism to enhance the minimum consumption power for all network users by using offloading optimization performance technique that balances the computation loads in servers and mobile devices. In addition, it arranges the subcarrier resources between all users in the network.

3. Matching Subcarrier Resource Allocation and Offloading Decision

In this section, matching subcarrier resource allocation is presented. The network model is a heterogeneous network with one MeNB cell, I_s SeNBs, and I_f Femtocells co-located as shown in Figure.1. An MEC server connected at the MeNB [6], and another server is at a Femtocell access point. All I_s SeNB are connected to the MEC server through MeNB cell by RF mmW. The Femtocells, on the other hand, are connected the MEC server by wired optical fiber backhaul.

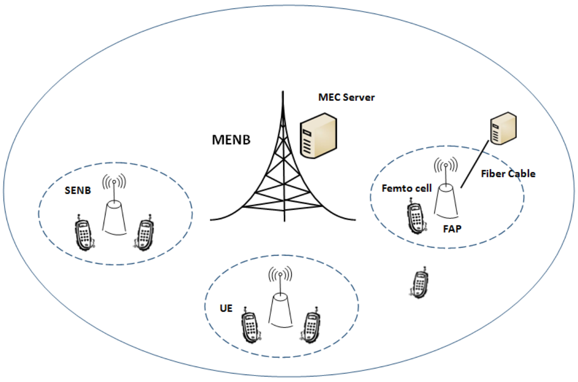

Figure 1. Heterogeneous networks.

3.1 Matching Subcarrier Allocation

Let I represents a set of all cells in the system. M_m represents a set of mobile user devices associated with MeNB. M_{si} represents a set of the mobile user devices associated with SeNB, and M_{fi} represents a set of mobile user devices associated with Femtocells. Assume that user m has challenging computation and latency constraint application that partition into a profile with two factors: (B_m, L_m^{Max}), where B_m is the amount of computation input data, and L_m^{Max} is the maximum tolerable latency for completing the application. The computation workload Q_m formula given by $Q_m = \alpha_m B_m$, is assumed to be the computer processing unit cycles, where the value of α_m depends on the application nature. The user device application can fully partition λ_m: $(0 \le \lambda_m \le 1)$, as the ratio of locally executed portion to the application's total computation load without loss. For user devices, the computational speed is F_m^l central processing unit CPU cycles/sec. The CPU's computational power formula is given by $\kappa (f_m^l)^3$, where κ is the conversion coefficient depending on chip architecture [3]. So, the local computation time and energy for application m in user device is given by:

$$t_m^l = \alpha_m \lambda_m, \tag{1}$$

and

$$E_m^l = \kappa \alpha_m \lambda_m B_m (F_m^l)^2, \tag{2}$$

respectively.

Subcarriers resource is denoted by K, and each subcarrier has the same bandwidth W. We use $x_{m,k}$ to denote the subcarrier assigned to user or not where

$$x_{m,k} = \begin{cases} 1, & assigned \\ 0, & not\ assigned. \end{cases}$$

The heterogeneous networks have multiple paths system; our model has three traffic paths for each user:

i) The MeNB user: Having direct path from MeNB cell, and there are two types of indoor or outdoor users [10]:

- Outdoor path loss MeNB user is given by:

$$PL_{OM}(dB) = 15.3 + 37.6\log_{10} d_m + L_{ow}, \tag{3}$$

where L_{ow} denotes the outdoor wall penetration loss, and d denotes the distance in meters.

- Indoor path loss for MeNB users is given by:

$$PL_{IM}(dB) = 15.3 + 37.6L\log_{10} d_m. \tag{4}$$

ii) The SeNB user: Having a path from MeNB through SeNB and two indoor or outdoor users.

- Outdoor path loss for SeNB users is given by:

$$PL_{OS}(dB) = 30.6 + 37.6(\log_{10} d_{ms} + \log_{10} d_s) + L_{ow}. \tag{5}$$

- Indoor path loss for SeNB users is given by:

$$PL_{IS}(dB) = 30.6 + 37.6(\log_{10} d_{ms} + \log_{10} d_s), \tag{6}$$

where d_{ms} is the distance between MeNB and SeNB and d_s denotes the distance in meters between the user and SeNB.

iii) The Femtocells user: Having a direct path from Femtocell, and there are two types of indoor or outdoor users [10].

- Outdoor path loss Femtocell user is given by:

$$PL_{OF}(dB) = max(15.3 + 37.6\log_{10} d_f, 38.46 + 20\log_{10} d_f) + 0.7 r_{2D,indoor} + 18.3 n^{((n+2/n+1)-1)} + q * L_{iw} + L_{ow}. \tag{7}$$

- Indoor path loss Femtocell user:

$$PL_{IF}(dB) = 38.46 + 20\log_{10} d_f + 0.7 r_{2D,indoor} + 18.3 n^{((n+2/n+1)-0.46)} + q * L_{iw}, \tag{8}$$

where n denotes the number of doors through which signal penetrate to or from the Femtocell, q is the number of walls that separate the user from Femtocell, $0.7 r_{2D}$ is the penetration loss induced due to walls inside the apartment, L_{iw} is the penetration loss of the wall separating apartments, d_f denotes the distance in meters between user and Femtocell.

The channel gain is changed and related to user path loss location. The channel gain is given by:

$$G = 10^{-PL/10}. \quad (9)$$

Considering an OFDMA system in heterogeneous networks, SINR is reduced when subcarriers are reused by users associated with different cells in the system to avoid ICI between users. The SINR for each user in the network calculates as following formulas to varying types in subcarrier k.

SINR MeNB cell user in subcarrier k is given by:

$$SINR_{GM}^{k} = (\sum_{S_i \in S} \sum_{n \in M_i^s} x_{n,k} P_{SeNB,k} G_{n,SeNB,k} + \sum_{F_i \in F} \sum_{n \in M_i^f} x_{n,k} P_{Femto,k} G_{n,Femto,k}), \quad (10)$$

$$SINR_{MeNB}^{k} = \frac{P_{MeNB_i,k} G_{m,MeNB_i,k}}{N_{of} + SINR_{GM}^{k}}. \quad (11)$$

SINR SeNB cell user in subcarrier k is given by:

$$SINR_{GS}^{k} = (\sum_{F_i \in F} \sum_{n \in M_i^f} x_{n,k} P_{Femto,k} G_{n,Femto,k} + \sum_{n \in M_{MeNB}} x_{n,k} P_{MeNB,k} G_{n,MeNB,k} + \sum_{S_j \in Sj \neq i} \sum_{n \in M_j^s} x_{n,k} P_{SeNB,k} G_{n,SeNB,k}), \quad (12)$$

$$SINR_{SeNB}^{k} = \frac{P_{SeNB_i,k} G_{m,SeNB_i,k}}{N_{of} + SINR_{GS}^{k}}. \quad (13)$$

SINR Femtocell user in subcarrier k is given by:

$$SINR_{GF}^{k} = (\sum_{S_i \in S} \sum_{n \in M_i^s} x_{n,k} P_{SeNB,k} G_{n,SeNB,k} + \sum_{n \epsilon M_{MeNB}} x_{n,k} P_{MeNB,k} G_{n,MeNB,k} + \sum_{F_j \epsilon FJ \neq i} \sum_{n \in M_j^f} x_{n,k} P_{Femto,k} G_{n,Femto,k}), \quad (14)$$

$$SINR_{Femto}^{k} = \frac{P_{Femto_i,k} G_{m,Femto_i,k}}{(N_{of} + SINR_{GF}^{k})}. \quad (15)$$

The capacity of MeNB user in subcarrier k is given by:

$$C_{m,MeNB}^{k} = W Log_2(1 + \alpha SINR_{m,MeNB,k}) bit/sec \quad (16)$$

The capacity of SeNB user in subcarrier k is given by:

$$C_{m,SeNB}^{k} = W Log_2(1 + \alpha SINR_{m,SeNB,k}) bit/sec. \quad (17)$$

The capacity of Femtocell user in subcarrier k is given by:

$$C_{m,Femto}^{k} = W(Log_2(1 + \alpha SINR_{m,Femto,k})) bit/sec. \quad (18)$$

The total transmission rate of MeNB user is given by:

$$C_m^{MeNB} = \sum_{k \in K} x_{m,MeNB}^{k} C_{m,MeNB}^{k}. \quad (19)$$

The total transmission rate of SeNB users is given by:

$$C_m^{SeNB} = \sum_{k \in K} x_{m,SeNB}^{k} C_{m,SeNB}^{k}. \quad (20)$$

The total transmission rate of Femtocell users is given by:

$$C_m^{Femto} = \sum_{k \in K} x_{m,Femto}^{k} C_{m,Femto}^{k}. \quad (21)$$

Based on the above equations, the time and energy consumption for uploading application m to its associated MeNB cell can express as:

$$t_{mMeNB}^{U} = \frac{(1-\lambda)B_m}{C_m^{MeNB}}, \quad (22)$$

$$E_{mMeNB}^{U} = P_m^{MeNB} \frac{(1-\lambda)B_m}{C_m^{MeNB}}, \quad (23)$$

and hence,

$$E_{mMeNB}^{U} = P_m^{MeNB} t_{mMeNB}^{U}. \quad (24)$$

Similarly, the time and energy consumption for uploading application m to its associated SeNB can be expressed as:

$$t_{mSeNB}^{U} = \frac{(1-\lambda)B_m}{C_m^{SeNB}}, \quad (25)$$

$$E_{mSeNB}^{U} = P_m^{SeNB} \frac{(1-\lambda)B_m}{C_m^{SeNB}}, \quad (26)$$

and hence,

$$E_{mSeNB}^{U} = P_m^{SeNB} t_{mSeNB}^{U}. \quad (27)$$

The time and energy consumption for uploading application m to its associated Femtocell can express as:

$$E_{mFemto}^{U} = P_m^{Femto} t_{mFemto}^{U} = P_m^{Femto} \frac{(1-\lambda)B_m}{C_m^{Femto}}. \quad (28)$$

The application process concludes to process locally and remotely. The remote process time depends on server CPU speed, So assuming high-speed multi-core CPU servers located at the network edge connected with MeNB or Femtocell can execute multiple applications in parallel. Assume f_m^S denotes the processing speed for application m at the MEC server. The remote execution time for application m is given as:

$$t_m^P = \frac{\alpha_m(1-\lambda_m)B_m}{f_m^S}, \quad (29)$$

and the total time for remote processing of application m can express as:

$$t_m^R = t_m^U + t_m^P. \quad (30)$$

Our objective is to achieve the minimum energy consumption of all mobile users in the network, under latency constraint is given by:

$$\min_{[\lambda_m],[x_{m,k}]} \sum_{m \epsilon M} E_m^L + E_m^U, \quad (31)$$

where

$$M = M_{MeNB} + M_{SeNB} + M_{Femto}, \quad (32)$$

$$t_m^U = t_{mMeNB}^{U} + t_{mSeNB}^{U} + t_{mFemto}^{U}, \quad (33)$$

and

$$E_m^U = E_{mMeNB}^{U} + E_{mSeNB}^{U} + E_{mFemto}^{U}. \quad (34)$$

The offloading ratio under latency constraints is given by:

$$\lambda_m^{\min} = \max\left\{0,1 - \frac{L_m^{\max}}{B_m(\frac{1}{W_m} + \frac{\alpha}{f_m^S})}\right\},$$

and

$$\lambda_m^{\max} = \min\left\{\frac{f_m^L L_m^{\max}/B_m}{B_m \alpha_m}, 1\right\}.$$

Since the objective function in the m^{th} subproblem is a linear function of λ_m, the optimal solution m can be derived as [3]:

$$\lambda_m^* = \begin{cases} \lambda_m^{\min}, & if W_m \geq \frac{P_m}{\kappa \alpha_m (f_m^L)^2} \\ \lambda_m^{\max}, & if W_m < \frac{P_m}{\kappa \alpha_m (f_m^L)^2} \end{cases}.$$

MeNB, SeNB, and Femtocells are available for all mobile users; hence, we consider three sets of mobile users, MeNB set, SeNB set, and Femtocell set. As the portable user path sets and subcarriers set K are allocated for this path as two disjoint sets to maximize energy consumption benefits for all mobile users in the network under latency constraints.

i) First path: If subcarrier k is assigned to mobile user m in MeNB, then we say k and m are matched with each other, a matching pair (m, k) where

$$m \in M_{MeNB} \;\; and \;\; (m, k) \cup \phi_{MeNB}.$$

ii) Second path: If subcarrier k is assigned to mobile user m in SeNB cell, then we say k and m are matched with each other, a matching pair (m, k) where

$$m \in M_{SeNB} \;\; and \;\; (m, k) \cup \phi_{SeNB}.$$

iii) Third path: If subcarrier k is assigned to mobile user m in a Femtocell, then we say k and m match with each other, a matching pair (m, k) where

$$m \epsilon M_{Femto} \;\; and \;\; (m, k) \cup \phi_{Femto}.$$

Each mobile user tries to select a path and a subcarrier to achieve the minimum path loss and maximum signal power, enhancing maximum SINR, maximum uplink transmission rate, minimum upload time, and maximum upload ratio portion from the application. Then, it achieves the minimum local energy consumption for users. Finally, it achieves the minimum total energy consumption for all network users. Therefore, we use a matching game to detect the best path for the mobile user m in subcarrier k, and we can enhance the minimum total energy consumption for all network users.

3.2 MSRAOD Algorithm

This section proposes the MSRAOD algorithm to achieve the minimum total energy consumption for mobile users. The mobile users attend the network and compete for available subcarriers. Every user tries to assign to the best cell and upload its application to a server to reduce the local process. Nevertheless, such a process is done under latency constraints and competition between users. The optimization algorithm proposes to enhance the minimum average energy between mobile users depending on their locations in the network and the distance between users and each cell in the system via calculate the SINR, then make the matching decision between users and subcarrier then assigns them to the best cell. The process of the MSRAOD algorithm is given in Algorithm 1.

Algorithm 1: MSRAOD algorithm

```
for i ∈ I do
    for m ∈ M do
      for k ∈ K do
        Calculate (C_{m,MeNB,k}, C_{m,SeNB,k}, C_{m,Femto,k})
        Find (MAXC_{m,k})
      end for
    if MAXC_{m,k} = C_{m,MeNB,k} then
      K_max = k_m
    end if
   if E_m^U < E^L then
    (m, k_m) and m ∈ M_MeNB
   end if
   if MAXC_{m,k} = C_{m,SeNB,k} then
    K_max = k_s
   end if
   if E_s^U < EL then
    (m, k_s) and m ∈ M_SeNB
   end if
   if MAXC_{m,k} = C_{m,Femto,k} then
    K_max = k_f
   end if
   if E_f^U < E^L then
    (m, k_f) and m ∈ M_Femto
   end if
   UPDATE (SINR_MeNB, SINR_femto, SINR_SeNB)
  end for
end for
set all (m, k_m) for I_MeNB, m ∈ M_MeNB
set all (m, k_f) for I_femto, m ∈ M_femto
set all (m, k_s) for I_SeNB, m ∈ M_SeNB
for m ∈ M_MeNB do
  Calculate C_m^MeNB
  Update λ_m
end for
for m ∈ M_SeNB do
  Calculate C_m^SeNB
  Update λ_m
end for
for m ∈ M_Femto do
  Calculate C_m^Femto
  Update λ_m
end for
Calculate min ∑ (E_m^u + E_m^L)
End
```

The optimization algorithm assigns every user to the best cell, which gives the user the maximum SINR. As a result, the optimization leads to achieving a maximum data rate for the user to enhance the whole offloading portion, which is the optimization factor. The user is competing to earn the maximum offloading portion that gives him the ability to process his applications remotely on the edge server that minimizes the local energy process and the energy consumption.

4. Performance Evaluation

This section evaluates the proposed algorithm performance by comparing three different cases in which the number of subcarriers given for each user is changed. To the best of our knowledge, no previous research has been done to achieve the minimum total energy consumption for mobile users in a heterogeneous network containing Femtocells. Therefore, we compare the MSRAOD algorithm with a random algorithm, random subcarriers matching, and users randomly assigned. In our heterogeneous network, we assume that there are one MeNB, two SeNB, and two Femtocells, and we assume that there are ten mobile users are to be served. The simulation results are calculated using the built-in Matlab version R2020a and Table 1 shows the simulation parameters used in the simulation results.

Table 1: Simulation parameters of MSRAOD algorithm.

Parameter	Value
α_m	100
f_m^L	$400 * 10^6$
f_m^S	$800 * 10^6$
B_m	$2 * 10^6 bits$
n	1
q	1
L_{ow}	20
L_{iw}	5
κ	10^-24
W	$180 * 10^3 Hz$
N_{of}	10^{-17}
L_{max}	$0.6s$
P_{user}	$1watt$
P_{MeNB}	$5watt$
P_{SeNB}	$3watt$
P_{Femto}	$2watt$

The ten mobile users that proposed to attend the network will compete for available subcarriers. The ten users are randomly distributed, and the distances between the users and each cell are calculated in the network. The optimization algorithm uses the network location and distances between users and cells in the system to calculate the SINR and then

make the matching decision between users and subcarriers. As a result, each user is assigned to the best cell.
In our work, we assume three special cases of the number of subcarriers in order to show the enhancement of the proposed optimization algorithm.

First case: a single subcarrier is considered. Every user must match this subcarrier and interfere with the other users assigned to the other system's cells. The algorithm calculates the best SINR for each user according to its location and assigns them to cells accordingly. Figure 2 shows the total energy per user in a single subcarrier scenario. Here, seven users are assigned to SeNB, three are assigned to Femtocells, and no one is assigned to MeNB. The figure shows that the energy is linearly increasing when the number of users increases. That occurs as the algorithm assigns the user with maximum SINR at the beginning, so it arranges the user in ascending order starting from the user with minimum energy consumption.

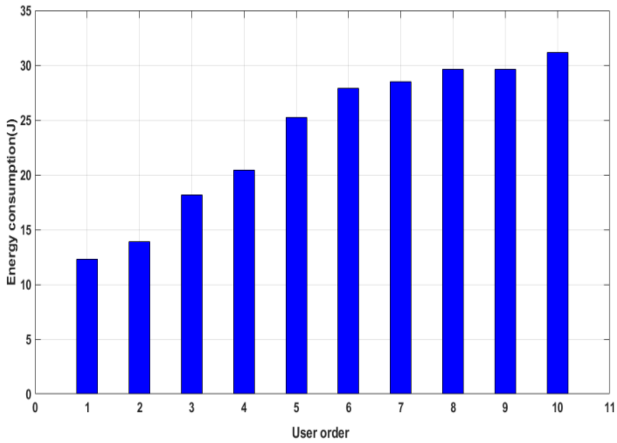

Figure 2. Energy consumption of users in a single subcarrier scenario.

Second case: the number of subcarriers equals half the number of the users (i.e., 50% of the number of users). Every user is assigned to one of the subcarriers. The algorithm allows low interference with the other users assigned to other cells in the system. The algorithm tries to calculate the best SINR for each user under its location and then assigns each user to a cell. Figure 3 shows the total energy per user in a five subcarriers scenario using the random algorithm as well as the MSRAOD algorithm. Using the MSRAOD algorithm, four users are assigned to SeNB, five users are assigned to Femtocells, and only one user is assigned to MeNB. The figure shows that the energy consumption for the first nine users can upload the maximum portion of their data when they enhance the maximum data rate, then they have minimum energy consumption. The last user interferes with another user and has a high path loss position. So it has a lower offloading portion of its data with the high local process and high energy consumption. In addition, the figure shows that the random algorithm, where each user is randomly assigned to a subcarrier, has six users offloading their applications data to MEC.

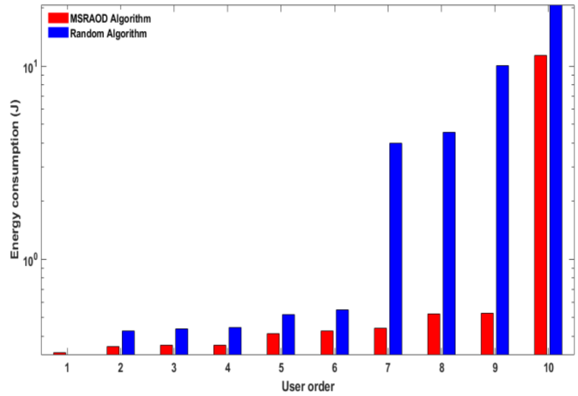

Figure 3. Energy consumption of users in a five subcarriers scenario.

Third case: the number of subcarriers equals the number of users (i.e., 100% of the number of users). Similar to the second case, the MSRAOD algorithm allows low interference with the other users assigned to other cells in the system. Figure 4 shows the total energy per user in a ten subcarriers scenario using the random algorithm and the MSRAOD algorithm. Using the MSRAOD algorithm, eight users are assigned to SeNB, two users are assigned to Femtocells, and no one is assigned to MeNB. As shown in the figure, the energy consumption using the MSRAOD algorithm is less than one joule for all ten users. That is because every user is assigned to a different subcarrier, and there is no interference with other users. All users can upload their applications to the remote process in MEC. In contrast, only six users can offload their application data to MEC using the random algorithm.

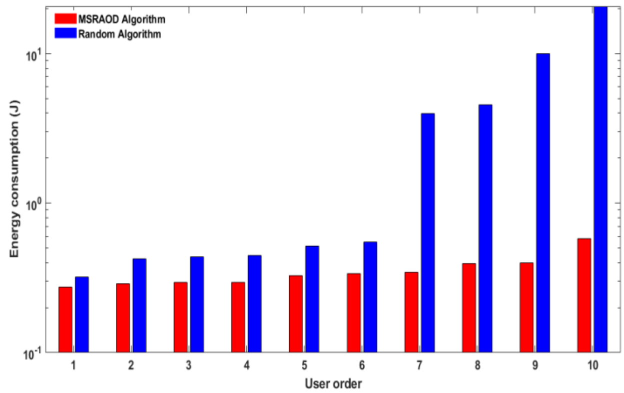

Figure 4. Energy consumption of usres in a ten subcarriers scenario.

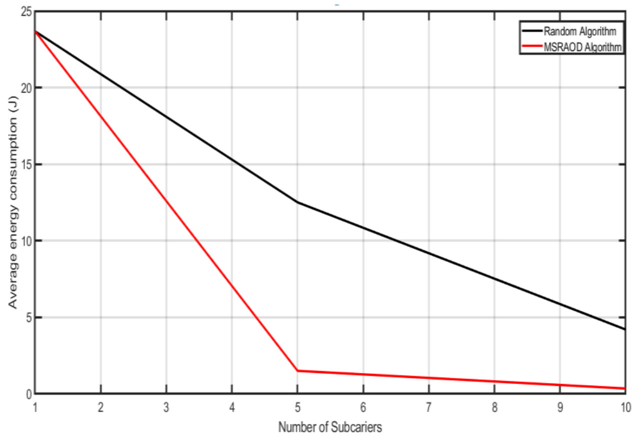

Figure 5. Average energy consumption vs. the number of subcarriers.

Finally, Figure 5 shows the average energy consumption versus the number of subcarriers over 100 runs using the random algorithm and the MSRAOD algorithm. The figure shows that the average energy consumption using the MSRAOD algorithm exponentially decreases when the number of subcarriers increases, whereas it linearly decreases using the random algorithm. In addition, the figure shows that the maximum average users' energy consumption is reached when the subcarrier is equal to one. Also, the minimum average users' energy consumption is achieved when the number of subcarriers is equal to the number of users.

5. Conclusions

In this work, we propose resource allocation optimization MSRAOD algorithm for heterogeneous networks. The proposed algorithm achieves maximum data rate and minimum energy consumption for users' devices. Simulation results of three special cases of the subcarriers numbers are obtained using the proposed MSRAOD algorithm and random algorithm. The results show that there is an improvement in using the proposed algorithm over the conventional random algorithm. Besides, the results show that the average energy consumption is exponentially decreasing as the number of subcarriers increases using the MSRAOD algorithm while it is linearly reducing using the conventional random algorithm.

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