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Efficient radio resource allocation scheme for 5G networks with device-to-device communication

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ABSTRACT

A vital technology in the next-generation cellular network is device-to-device (D2D) communication. Cellular user enabled with D2D communication provides high spectral efficiency and further increases the coverage area of the cell, especially for the end-cell users and blind spot areas. However, the implementation of D2D communication increases interference among the cellular and D2D users. In this paper, we proposed a radio resource allocation (RRA) algorithm to manage the interference using fractional frequency reuse (FFR) scheme and Hungarian algorithm. The proposed algorithm is divided into three parts. First, the FFR scheme allocates different frequency bands among the cell (inner and outer region) for both the cellular and the D2D users to reduce the interference. Second, the Hungarian weighted bipartite matching algorithm is used to allocate the resources to D2D users with the minimum total system interference, while maintaining the total system sum rate. The cellular users share the resources with more than one D2D pair. Lastly, the local search technique of swapping is used for further allocation to minimize the interference. We implemented two types of assignments, fair multiple assignment, and restricted multiple assignment. We compared our results with existing algorithms which verified that our proposed algorithm provides outstanding results in aspects like interference reduction and system sum rate. For restricted multiple assignment, 60-70% of the D2D users are allocated in average cases.

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1. INTRODUCTION

An exponential boost in the subscriber base and multimedia services are evident in the last two decades which motivated the development of new technologies such as massive MIMOs, small cells and millimeter waves in order to boost the speed and data rate, and decrease the latency of the system [1]-[4]. One of the key technology being discussed under 3rd generation partnership program (3GPP) is device-to-device (D2D) communication. This new paradigm enables two devices to connect to one another without transversing from the evolved node base station (eNb). This delivers high system throughput, low load at the eNB, improvement in spectral efficiency, and low consumption of transmit power, all of which are desirable features of long tern evolution-advanced (LTE-A) [5]-[9]. Figure 1 shows the D2D communication in multi-tier cells in HetNets.

The spectrum allocation in D2D communication is categorized into two modes: underlay and overlay. The main objective of underlay communication mode is to permit the D2D users to reuse of cellular user resource. Deployment of such communication mode improves the spectrum efficiency, energy efficiency as well as coverage area, but increases the interference among cellular and D2D users, and between D2D users which becomes a burden on the network [10]-[12]. Overlay communication mode grants the D2D users to share the orthogonal resources of the cellular users in a way that the spectrum is divided to optimally allocate resources among the cellular and the D2D users. Although there is minimal interference in this mode, there is a wastage of the spectrum if proper radio resource allocation (RRA) scheme is not implemented in the network [10], [12]-[14].

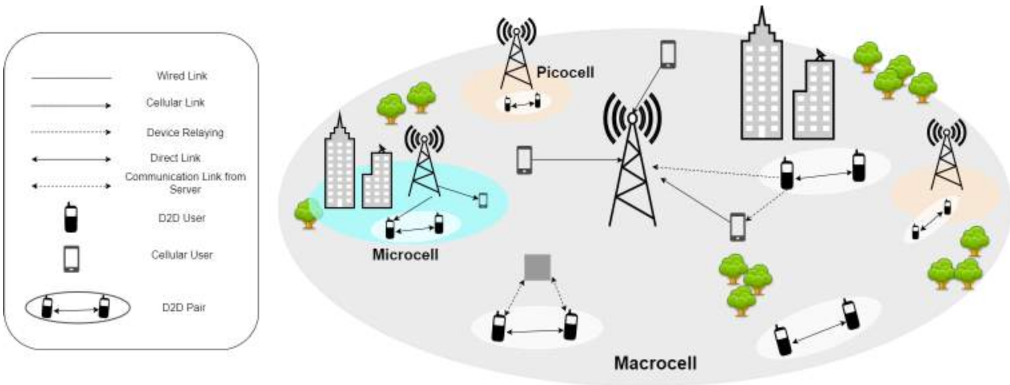


Figure 1. D2D communication in multi-tier cells in heterogeneous networks

Interference management is the main motivation when considering the underlay spectrum [15]. The reuse of the spectrum by D2D pairs interposes and imposes interference towards the eNb and the cellular users. The cellular users can also introduce the interference towards the D2D pairs which affects the efficiency and connectivity between D2D links. This interference relies on the shared channel of the cellular users which is in downlink (DL) and uplink (UL) phases. The assignment of the channel, therefore, is compulsory for interference management in D2D communication.

Currently, numerous open-ended projects are in progress which are considering distinct aspects of the D2D communication like increasing the sum rate of the system, minimizing the system interference, and maintaining the transmit power of the D2D transmitter [16]-[19]. Nevertheless, the cellular users are preferred over the D2D users by the network provider to lower the interference caused to the cellular users [20]. In order to resolve this concern, an effective RRA technique must be executed for assignment of resource blocks (RBs) to the D2D pairs. The proposed algorithms in the recent research of RRA concluded that when the resources of the cellular user is shared with D2D pairs, the sum rate of the user is improved [21]-[23]. However, these techniques may also minimize the system's total sum rate [24]-[25].

Considering all the work done previously, this paper aims to manage the interference in the underlay spectrum D2D-aided cellular networks. The system model aims to opportunistically assigns radio resources such that; i) The cellular network maintains the system's target sum rate, ii) The system reduces the interference. The major contributions of this paper are as follows:

a. We implemented fractional frequency reuse (FFR) scheme in the D2D-aided cellular network with seven cells for the purpose of allocating cellular users resources to the D2D pairs with minimum interference.
b. We considered fair as well as restricted multiple assignment schemes. In the fair multiple assignment, the system allocates all the D2D users present in the system at that moment to cellular users while in the restricted multiple assignment, the D2D users will be blocked in case the total sum rate of the system is lesser than the target sum rate.
c. We implemented a Hungarian-weighted bipartite matching allocation algorithm for one-to-one matching to mitigate the interference further while maintaining the sum rate. In the case where the sum rate is

not maintained, we applied one-to-many matching to increase the sum rate. Finally, we applied a local technique known as swapping to improve the result from the previous phase.

This paper is further organised as follows: Section 2 gives an overview of resource allocation in D2D-aided cellular network and framework of the proposed algorithm. Section 3 discusses the simulation outcomes for performance evaluation, in various aspects, of the algorithm proposed. Lastly, section 4 presents the conclusion of this paper.

2. OVERVIEW OF RESOURCE ALLOCATION IN D2D-AIDED CELLULAR NETWORKS

The main aim of resource allocation in D2D communication is to distribute the cellular user resources to D2D users efficiently and effectively. This section shows the proposed system model of resource allocation.

2.1. D2D communication system model

In our system model scenario, underlay D2D-aided cellular network was deployed, that reuses the frequency spectrum of the cellular users in the UL communication. The eNb and the D2D receiver will encounter the interference by the D2D transmitter and the cellular users, respectively. We considered seven hexagonal cells with a eNb situated in the centre of each cell. For the reduction of interference, FFR scheme is also considered. Each cell is partitioned into outer and inner cell regions. The frequency band, F, is divided into four segments: F_1, F_2, F_3, and F_4 with each segment corresponding to a bandwidth: f_1, f_2, f_3, and f_4, respectively. The eNb assigns the resources to the each device present in the cell's inner and outer region with the frequency reuse factor (FRF): 1 and 3, respectively.

The system supports the cellular and D2D users, where the cellular users are $>$ the D2D devices. To minimize the interference caused by the neighboring cells, F_1 frequency is utilized by the cellular users present in the cell's inner region while F_2, F_3, or F_4 is used by the cellular user present in the cell's outer region. The set of the cellular users are labeled as N =$\{n_1, n_2, n_3, ..., n_n\}$ while the set of D2D pairs are defined as R =$\{r_1, r_2, r_3, ..., r_n\}$. Tables 1 and 2 shows the parameters considered and list of abbreviations used in the paper, respectively. RRA for D2D users is implemented in different ways based on the position of the users.

Table 1. Simulation parameters

Parameter	Value
Radius of the cell	1 km
Cellular users	250
FRF - inner region	1
FRF - outer regionF	3
D2D pairs	10 - 200 (increment of 20)
Distance between D2D pairs (max)	15 meters
Bandwidth, B	180 kHz
Base station transmission power	46 dBm
D2D user transmission power	20 dBm
Cellular user transmitting power	20 dBm
Frequency	1.7 GHz
Target Sum rate	Sum rate (optimal achievable) [9]
AWGN	-174 dBm

2.1.1. Outer region-D2D users

In the outer part of the cell, the D2D pairs are assigned to reuse the cellular users' resources that are currently present in the cell's inner part only. Only F_1 can be utilized by the D2D users present in the cell's outer region. The interference to these D2D pairs are from all the cellular and D2D users present at the cell's outer and inner region (co-channel interference), respectively.

2.1.2. Inner region-D2D users

In the inner part of the cell, the D2D pairs currently present in the experience interference from three regions; i) From the co-channel D2D pairs in the same cell, ii) the co-channel D2D pairs in the inner part of the two third of the other cells and iii) the co-channel cellular users present in the outer part of the one third of the other cells. In this work, Rayleigh fading model was considered. Orthogonal channels and separate RBs for each cellular user were implemented. We expressed cellular and D2D pairs as n_i and r_j, respectively. Note: $1 \leq i \leq n$ and $1 \leq j \leq r$.

Table 2. Table of abbreviation

Abbreviation	Description
d	distance between the D2D transmitter and receiver
f_c	transmission frequency
$P^{m,n}$	path loss between device: m and n
m and n	the transmitting device and receiving device respectively
Int	system interference
TS	system sum rate (total)
$W_{i,j}$	a binary channel allocation decision matrix
P_i^n	cellular user transmitting power
$P^{r_j t})$	D2D user transmitting power
$ChannelGain^{n_i,eNB}$	channel gain (cellular user to the base station)
$ChannelGain^{r^{j^t},eNB}$	channel gain (interference by the D2D transmitter to the base station)
$ChannelGain^{r^{j^t},r^{j^r}}$	channel gain (D2D transmitter - D2D receiver)
$ChannelGain^{n_i,r^{j^r}}$	the channel gain (cellular user and - D2D receiver)
B	bandwidth of the channel
υ_{n_i,r_j}	SINR (eNB)
$\upsilon_{n_i,0}$	SINR for the cellular users who are allowing the sharing of resources with any D2D user,
υ_{r_j,n_i}	SINR for D2D receiver when reusing the resources)

Path loss model used is (1):

$$P = 36.7\log_{10}(d) + 26\log_{10}(f_c) + 22.7 \tag{1}$$

Achievable channel gain for the transmission can be written as (2):

$$ChannelGain^{(m,n)} = 10^{(-P^{m,n}/10)} \tag{2}$$

2.2. Problem formulation

The FFR scheme using the assignment algorithm for the UL RRA is proposed. The assignment scheme indicates the assignment of each D2D pair with a resource of the cellular user. In (3) shows the objective of our paper, which is to mitigate the interference of the system concerning the constraints (4), (5), (6) and (7).

$$minimize \sum_{i=1}^{k}\sum_{j=1}^{l} Y_{i,j} Int_{n_i,r_j} \tag{3}$$

subject to,

$$TS \geq Targetsumrate, \tag{4}$$

$$\sum_{j=1}^{l} W_{i,j} \leq 2; \quad \forall\, n_i \in N \tag{5}$$

$$\sum_{i=1}^{k} W_{i,j} = 1; \quad \forall\, r_j \in R \tag{6}$$

$$\sum_{i=1}^{k} W_{i,j} \leq 1; \quad \forall\, r_j \in R \tag{7}$$

$$W_{i,j} = \begin{cases} 1 & r_j \text{ reused the resource of } n_i \\ 0 & r_j \text{reused the resource of } n_i \end{cases} \tag{8}$$

Although the existing algorithms deal with the same problem formulation, they consider only a single cell interference and use one D2D user that reuses the resource of one cellular user in order to avoid the generation of higher interference. The cellular users can share the resources to a maximum of two D2D pairs as depicted in constraint (5). A single cellular user must share the resource to the D2D user as present in constraint

(6). D2D pair can reuse the resource of one cellular user only, or else, the D2D pair will not be assigned to any resource as shown in constraint (7). In our system, we present two types of assignments, fair and restricted. Constraint (5) declares that the system implies fair multiple assignment of RRA, where all the D2D pairs are assigned to cellular users, which indicates the fairness feature of the system.

However, in some cases the constraint (5) does not satisfy, thus constraint (6) presents the restricted multiple assignment where the system assigns the D2D users with cellular user resources only if the sum rate is maintained. Hence, the D2D pair is allocated resource blocks of the cellular user or they remain unassigned to satisfy the total system sum rate. Signal to interference plus noise ratio (SINR) for the uplink, at the eNB, while the D2D pairs reused the cellular users RBs is (9),

$$\upsilon_{n_i,r_j} = \frac{P^{n_i} ChannelGain^{n_i,eNB}}{\delta + P^{r_{j^t}} ChannelGain^{r^{j^t},eNB}}, \tag{9}$$

The cellular users who are sharing of resources, the SINR is:

$$\upsilon_{n_i,0} = \frac{P^{n_i} ChannelGain^{n_i,eNB}}{\delta}, \tag{10}$$

In (11), the SINR at the D2D receiver is shown in cases where the D2D user reused the resources.

$$\upsilon_{r_j,n_i} = \frac{P^{r_{j^t}} ChannelGain^{r^{j^t},r^{j^r}}}{\delta + P^{n_i ChannelGain^{n_i,r^{j^r}}}}, \tag{11}$$

The total interference that is produced in the system when RBs are shared to the D2D users is presented in (12).

$$Int_{n_i,r_j} = P^{r_{j^t}} ChannelGain^{r^{j^t},eNB} + P^{n_i} ChannelGain^{n_i,r^{j^r}} \tag{12}$$

Using the Shannon capacity formula, we calculated the system sum rate (13), in cases when D2D pairs reused the resource.

$$SRt_{n_i,r_j} = Blog_2(1 + \upsilon_{n_i,r_j}) + Blog_2(1 + \upsilon_{r_j,n_i}) \tag{13}$$

The sum rate when the resources are not reused is:

$$SRt_{n_i,0} = Blog_2(1 + \upsilon_{n_i,0}) \tag{14}$$

Taking (13) and (14), we measured the overall system sum rate.

$$TS = \sum_{i=1}^{k}(1 - \sum_{j=1}^{l} W_{i,j}) SRt_{n_i,0} N_{n_i} + \sum_{i=1}^{k}\sum_{j=1}^{l} W_{i,j} SRt_{n_i,d_j} N_{n_i} \tag{15}$$

2.3. Proposed resource allocation algorithm for D2D communication

In this paper, we proposed the RRA assignment using the FFR scheme followed by the Hungarian weighted bipartite matching approach for mitigation of interference in the system. In this part, we displayed the calculation of the FFR, the development, and calculation of the weight bipartite matching graph, and the algorithm proposed for both, fair multiple assignment as well as restricted multiple assignment. The graph compromises of two disjoints. The sets of vertices are N =$\{n_1, n_2, n_3, ..., n_n\}$ and R =$\{r_1, r_2, r_3, ..., r_n\}$. Shannon capacity sum rate and interference in the system are the edge between both the vertices.

The D2D pairs and the cellular users are the columns and rows for the weigh matrix, respectively, We included n x n matrix called A. Only a square matrix is considered in the weight bipartite matrix. The cellular user $>>$ the D2D users hence, we introduced dummy D2D users that will not influence the final assignment of the allocation.

For the fair multiple assignment, the initial m columns represent the interference that is introduced because of the resource sharing between D2D pairs and cellular users. The remaining dummy pairs is assigned zero value so that it does not match the final allocation. For the restricted multiple assignment, the remaining D2D pairs are assigned zero value, so that it does not match the final solution.

Likewise, the weight matrix for the sum rate maximization, we included a matrix: m x m called B. For the fair multiple assignment, the first m columns presents the system sum rate when the D2D pair reuse the resource of the cellular user. The remaining dummy pairs are assigned with the value of the sum rate calculated in (14), which implies that the sum rate will not affect the final allocation. For the restricted multiple assignment, the remaining D2D pair is assigned the value of the sum rate calculated in (14). This ensures that the matching is avoided with the dummy pairs.

Algorithm 1 RRA-part one

1: Assigning $N(n_1, n_2, ..., n_n)$, $R(r_1, r_2, ..., r_n)$ and $Targetsumrate$
2: Consider matrix A$[n, n]$ and matrix B $[n, n]$ as weight matrix for the weight bipartite matching
3: $A_{i,j}$=SR_{n_i,r_j}
4: $B_{i,j}$=I_{n_i,r_j}
5: **for** all $i \in C$ **do**
6:     **for** all$j \in D$ **do**
7:         Measure the interference
8:     **end for**
9: **end for**
10: Measure TS using Hungarian Minimization Algorithm $(B_{i,j})$
11: **if** $TargetSumrate \leq TS$ **then**
12:     Allocate r_j to n_i to all values of $(B_{i,j})$
13: **else**
14:     Allocate 2 D2D users to 1 cellular user
15:     Measure new TS
16: **end if**
17: **if** $TargetSumrate \leq TS$ **then**
18:     Assign $r_j ton_i$ to all the values of $(B_{i,j})$
19: **else** {Measure the TS through bipartite weight $A_{i,j}$ for specific fair or restricted multiple assignment}
20: **end if**
21: **if** $TargetSumrate \leq$Hungarian Maximization Graph(A$_{i,j}$) **then**
22:     Allocate r_j to n_i for all the values of $(A_{i,j})$
23: **end if**

2.3.1. Interference minimization using FFR

In the first part of the algorithm, we developed a RRA algorithm for D2D communication using FFR. In every cell, an eNb is deployed. Every cell is then divided into the inner and outer parts. The cellular user present in the inner part used one part of the frequency band while the users in the outer part used the remaining one third.

Taking the location of the D2D pair in the cell, the resources are allocated. The outer part's D2D user reuse the resource of the cellular user present in the inner part and vice versa. The frequency allocation is described in section 2.1.

2.3.2. Minimizing interference in the system using Hungarian approach

Firstly, two sets of disjoint value are used as follows: $N(n_1, n_2, ..., n_n)$ and $R(r_1, r_2, ..., r_n)$. The total interference in the system was measured using these disjoint values. A matrix A was created in the third line. We ran the Hungarian algorithm to measure the total interference. The edges of the weight presents the interference of the system when D2D users reuse the resources of cellular users. The calculation of the interference is done based on the selection of assignment, that is, fair or restricted multiple assignment. According to the Hungarian algorithm, the D2D pairs are then assigned to the cellular users.

This result is considered the final allocation unless the sum rate is not achieved. Thus, in the next phase, we use Hungarian maximization to increase the system sum rate. This is done to check the allocation for any assignment where the sum rate is increased. We introduce a matrix B to measure the maximum sum rate. The Hungarian algorithm then allocates the D2D to the cellular users if the sum rate is maintained.

Assuming that the target sum rate is $<=$ to the acquired sum rate, we will take the result as the final allocation, otherwise, we confirm that there is no solution. The allocation is then passed to the next part of the algorithm, where the initial allocation is further checked to reduce the system interference. After multiple sharing, if the sum rate is still less, the Hungarian maximization algorithm is implemented. This calculates the highest sum rate for that case to get the optimal solution. In case of an optimal solution, we consider this as the final allocation else the previous allocation is considered final. The algorithm is shown in algorithm: RRA-part one.

2.3.3. Minimizing interference in the system using swapping approach

After the initial assignment of the D2D users, we propose a local swapping approach technique to minimize the interference further. In this part, we considered two D2D-cellular user's allocations and swap the D2D pairs to check for the interference, for example, two user n_1, n_2 and r_1, r_2. We swap the D2D pairs with each other and measured the interference of the system and achieved sum rate. If the interference is minimized, the system ensures that the sum rate is greater than or equal to the target sum rate. If both, interference and the sum rate, assignment is done as follows: n_1 to r_2, and n_2 to r_1. This allocation is considered final, otherwise, the allocation in the previous step is considered as the final solution. This is shown in algorithm for swapping approach-part two.

Algorithm 2 Algorithm for swapping approach-part two

for entire $N_{i,j}$ and $R_{i,j}$ **do**
  swapping $n_i r_i$ and $n_j r_j$ to $n_i r_j$ and $n_j r_i$
  Measure the interference
end for
if $TargetSumrate <=$ update sum rate **then**
  Allocate n_i to r_j and n_j to r_i
  Revise the updated system interference
end if

3. PERFORMANCE EVALUATION

3.1. Previous algorithms for performance observation

The same problem formulation is used in MIKIRA [24]. The authors used knapsack based interference aware RRA. MIKIRA satisfies the constraints, but the assignment is not fair for the D2D user. Once the sum rate is maintained, the system blocks the RRA for the D2D pairs, hence leaving a great number of D2D pairs unassigned. TAFIRA [25] is an algorithm using the same problem formulation. The authors developed the auction-based algorithm. Although the interference is minimized and the sum rate is maintained, there are instances where the algorithm fails to provide any feasible solution, although the solution exists. D2D pairs are randomly assigned to cellular users without implementing any interference management schemes.

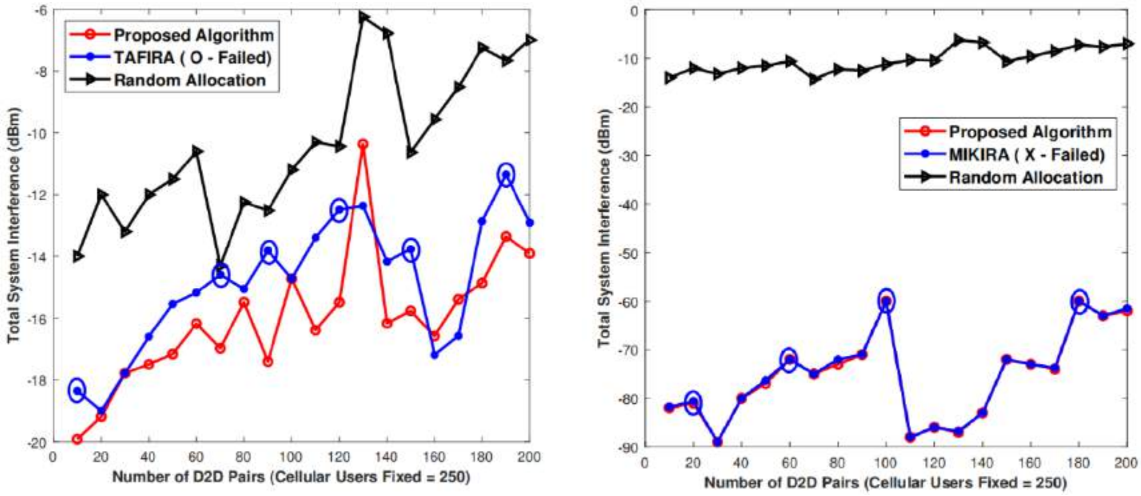
3.2. System description

The parameters shown earlier is followed for the system setup. We manipulated with several parameters to verify the results. In the setup, we used 7 cells. Each cell radius is 1000 m. In 15 m was the maximum distance between the D2D link (long distances minimize the benefits of implementing D2D communication). Using [9], we calculated the target sum rate. However, the network provider can set there own target sum rate. The result of multiple iteration's averages was used for each result. We fixed the cellular user to 250 for all the scenarios. However, we varied the cellular users to verify the results. It was observed that the results were consistent.

3.3. System interference performance of D2D communication without FFR scheme

Below are the results that present the comparison between the existing and the proposed algorithm. In Figures 2(a) and 2(b), a comparison of the results of our proposed algorithm of only one cell is shown. The results are compared without FFR.

Figure 2(a) presents that the system interference of our algorithm is much lesser than TAFIRA. When the number of D2D pairs were 10, the total system interference of our algorithm was -20 dBm, while for TAFIRA and random allocation, the interference is -18 dBm and -14 dBm, respectively. As the number of D2D pairs is increased, it can be observed that the interference is increased as well. However, throughout the graph pattern, it can be noted that in most cases our algorithm outperforms other algorithms. The circles in the TAFIRA show the instances where there exist a feasible results but the TAFIRA failed to allocate the D2D users while maintaining the sum rate. In the proposed algorithm, all the D2D users were assigned resources. In Figure 2(b), the graph shows the comparison of interference of restricted multiple assignment, MIKIRA, and random allocation. The results prove that even without FFR, the proposed algorithm is showing better results than the existing algorithms. The marked circles show that MIKIRA does not provide feasible solutions even when the solutions exist. These results prioritize our algorithm since our algorithm assigns the D2D pair for all the existing solutions.



(a) (b)

Figure 2. Interference in the system, (a) proposed algorithm vs fair multiple assignment, (b) proposed algorithm vs restricted multiple assignment

3.4. System sum rate performance of D2D communication with FFR scheme

In Figures 3(a) and 3(b), the results show the normalized system sum rate of our algorithm. The comparison in this section evaluates that the system sum rate has boosted when the number of D2D pairs was increased from 10 to 200. Our algorithm outperformed TAFIRA and random allocation algorithm for the fair multiple assignment (where we ensure that all the D2D users are assigned to one cellular user) and MIKIRA and random allocation algorithm for the restricted multiple assignment (where we ensure that the D2D users are assigned to one cellular user if the sum rate is maintained else the D2D pair remains unassigned). The difference between the sum rate between our algorithm and TAFIRA is very high. In Figure 3(a), for 10 D2D pairs, the normalized system sum rate is 1, while for TAFIRA and random allocation algorithm normalized sum rate is 0.924 and 0.917, respectively.

Furthermore, in many instances, TAFIRA and MIKIRA failed to allocate the feasible solution even when the solution existed. In some cases, D2D pairs remain unassigned to any cellular users because sharing of those resources with the D2D pair decreases the sum rate. The simulation ran multiple times and it is noticeable that for restricted multiple assignment, Figure 3(b), about 60 to 70% of D2D pairs are allocated in average cases. It is also noted that the fair multiple assignment provides much higher interference than restricted multiple assignments. This is due to the fact that in restricted multiple assignment some of the D2D pairs are not allocated to the cellular users, hence minimizing the system interference. The shape of the graph is not smooth because of the random distribution of users around the cell. An average for 20 runs was done to plot the graph on a single case scenario. The single plot presents multiple cases.

3.5. Performance of D2D pair allocation

We further analyzed our system to check for the allocation of D2D links in the restricted multiple assignment. In Figure 4(a) (see in appendix), we compared the results with MIKIRA and our proposed algorithm, with and without FFR scheme. It can be noted that in all the cases, our algorithm with FFR assigned more D2D pairs to the cellular user, while maintaining the sum rate and decreasing the interference, than MIKIRA. In all the cases, even the algorithm without FFR shows higher results.

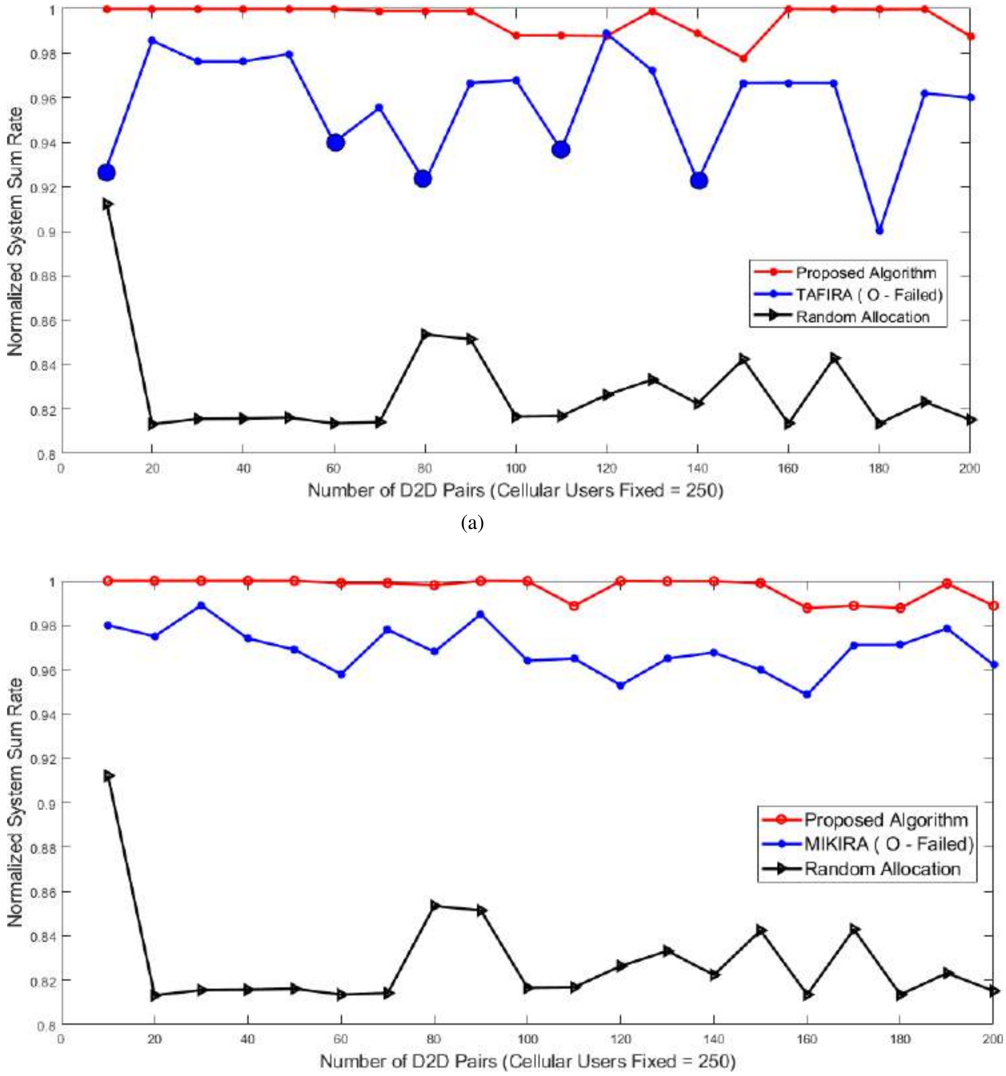


Figure 3. Total sum rate, (a) proposed algorithm vs fair multiple assignment, (b) proposed algorithm vs restricted multiple assignment

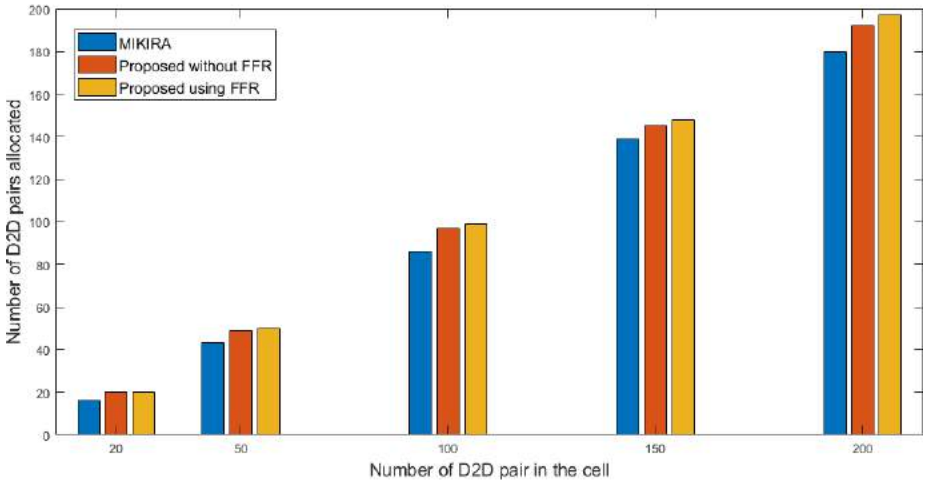
3.6. Performance of D2D pair allocation at the cell-edge

In Figure 4(b) (see in appendix), we analyzed the cell-edge D2D pairs to verify the performance of the system. We increased the D2D pairs present at the cell-edge to compare the results of RRA. The graph shows that our algorithm always allocates most of the D2D pairs with our proposed algorithm with FFR scheme. For all the cases, the allocation of our algorithm without FFR is still higher than MIKIRA. This shows that our algorithm shows superior results for the cell-edge D2D pairs.

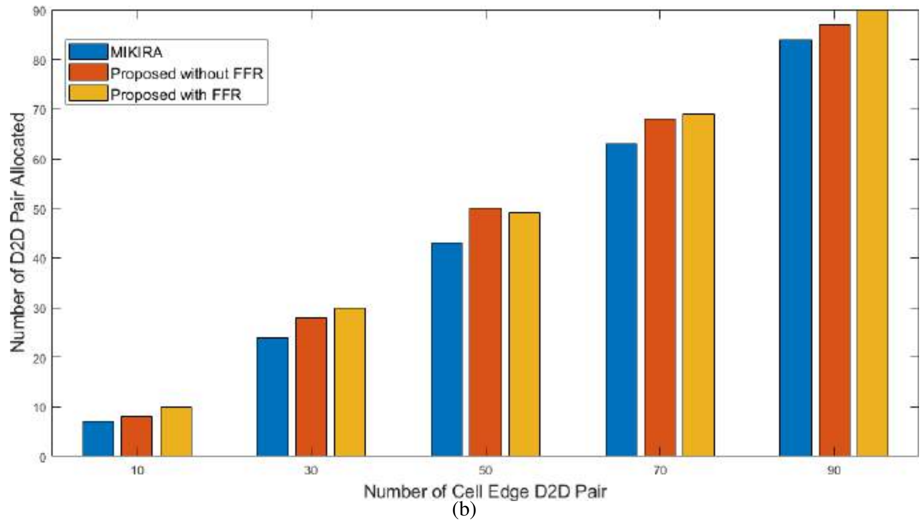
4. CONCLUSION

D2D communication is a technology with great importance for future communication networks. However, interference management is crucial for introducing this paradigm into the market. Various algorithms are proposed for minimizing interference, increasing the data rate, and improving spectral efficiency. RRA algorithm using the FFR scheme along with the Hungarian minimization/maximization algorithm for mitigation of the interference while controlling the sum rate is proposed in this paper. We used fair multiple assignment and restricted multiple assignment to allocate the D2D users to the resources of the cellular users. The simulation results shows that FFR greatly influence the throughput of the system. The proposed algorithm minimized the interference while the sum rate was maintained. Most of the cell-edge users were covered when FFR scheme was applied with our proposed algorithm unlike conventional algorithms. For the future work, we plan on assigning multiple D2D pairs to one cellular user and one D2D pair to multiple cellular users to further increase the sum rate. However, this will require complex interference management techniques.

APPENDIX



(a)



(b)

Figure 4. Comparison of proposed restricted multiple assignment and MIKIRA, (a) D2D users, (b) cell Egde D2D users

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