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Reducing interference effects in distributed D2D communication underlaying multicell cellular communication network using Soft Fractional Frequency Reuse

Misfa Susanto, Soraida Sabella, and FX Arinto Setyawan

Abstract—**The interests of researchers in expanding network capacity and enhancing network quality have risen as a result of the growing demands for mobile multimedia traffics in cellular communication networks. Device-to-Device (D2D) communication has become a promising technology to enhance spectral efficiency and network capacity. However, since D2D devices share the frequency bandwidth with the traditional cellular networks, it causes interference problems. This paper proposes a soft Fractional Frequency Reuse (FFR) scheme to resolve the interference problems in such D2D communications. Extensive simulation experiment has been carried out. The performance of the system with proposed scheme is compared to a baseline system. The simulation results show that the proposed scheme is able to increase the value of SINR and throughput, achieving the values from 19.8 dB to 20.7 dB and from 66.1 to 68.8 Mbp, respectively. For CUE the scheme is able to provide an increase of 15.5% for SINR and 15% increase for throughput on downlink transmission.**

Keywords—**D2D Communication; downlink transmission; FFR (Fractional Frequency Reuse); in-band D2D; multicell**

I. INTRODUCTION

THE need for improved communication devices to access the internet for higher data rate utilities, requires growing technological advances [1]-[2]. Some industry and academic experts anticipated that the data rate will increase by 1,000 times in the next decade due to the explosive demands on mobile data streams and the number of connected multi-media devices [3]-[5]. Device-to-Device (D2D) communications have recently received significant attention from academia and industries [6]-[7]. Originally designed for public safety scenarios, additional user- and network-oriented use-cases have quickly emerged [8]-[9]. D2D Communication is a feature of the fifth generation (5G) and beyond 5G of cellular networks which is regarded as two-tier networks. The device tier and the macro/micro cell tier are the two tiers in these networks. While D2D communication is supported by the device tier, conventional cellular communication is supported by the macrocell/microcell tier. D2D communication is defined as direct communication between two mobile users without passing through the Base Station (BS) or core network [10]-[11].

Enabling the D2D feature in typical wireless cellular communication networks faces the interference problems due to D2D communication shares the frequency spectrum with the typical cellular communication networks, i.e. in-band underlay D2D communications. Certainly, there are some research works considering the interference issues for D2D communication underlaying cellular communication network. Those research works deliberate the ICI (Inter-cell Interference) while solving the resource allocation problem for multi-cell D2D communications underlaying cellular networks which is called as in-band D2D communication. In-band D2D communication can either use a part of the cellular spectrum separately or in associated with other cellular users (reuse mode). Co-tier and cross-tier interferences are unavoidable in such communication networks, though, as a result of the constrained amount of available frequency spectrum [12]-[14].

Realizing these features will maximize the utilization of cellular network spectrum and hence achieving higher network throughput [15]. A method of interference management is needed to resolve these interference issues. Fractional Frequency Reuse (FFR) is one of the interference management techniques which are available in the literature. The inner (cell center) and the outer (cell edge) cells are the two distinct sections of the coverage area in FFR. The portion of the cell center that serves the users is assigned the same radio resources as in the other center of the cell. FFR presents a high fexibility for the researchers to design the bandwidth allocations according to their considered use-cases. Meantime, cell edges of the cells are allocated different radio resources [16]-[20]. DUE (D2D User Equipment) and CUE (Cellular User Equipment) simultaneously re-use a cell's radio resources. Therefore, despite the benefits of D2D technology, interference problems still need to be addressed. DUE (D2D User Equipment) and CUE (Cellular User Equipment) both utilize a cell's radio resources at the same time. Therefore, interference problems must still be resolved even though D2D technology has benefits. As there are more users (DUE and CUE), the

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interferences that are produced will increase. Problems with power allocation and network capacity optimization also occur, increasing system power consumption [21]. This paper aims to design a method of resource (frequency spectrum) allocation based on soft Fractional Frequency Reuse (FFR) for in-band D2D communication underlaying a cellular system on CUEs and DUEs side. The main contribution of this paper is a proposed soft FFR scheme which can improve the performance of DUE whereas still guarantees to not degrading the performance of CUEs.

The rest of this paper is structured as the following. Section of System Model and Description discusses the system model and explains the methods and scenarios that will be considered. Section of Simulation Settings, Parameters, and Results consists of the description of simulation settings, assumptions, parameters, and displaying the simulation results and its discussions comparing the performances for traditional in-band D2D communication underlaying cellular networks without and with the proposed soft FFR scheme. The performances of DUEs and CUEs are analyzed in this paper. The performance parameters are presented in terms of Signal to Interference plus Noise Ratio (SINR) and throughput. The paper is concluded in Conclusion section.

II. SYSTEM MODEL AND DESCRIPTION

The system considered in this paper is a multicell scenario consisting of three microcells. The DUE and CUE pairs are randomly distributed following a uniform distribution in each microcell. We consider Orthogonal Frequency Division Multiple Access (OFDMA) at the downlink transmission. In our system, we implement an underlay in-band, i.e., the D2D and microcellular systems share the same frequency band of B. As such, DUE and CUE will suffer the interferences caused by the same type of communications (co-tier interference) and by the different type of communications (cross-tier interference).

We first deliberate the traditional system, i.e. the system without any interference management method as illustrated in Fig. 1. Such system is referred to as baseline system in this paper. A number of CUEs and DUE pairs, N_C and N_D, are randomly deployed in each microcell area. In this scenario, we apply a Frequency Reuse Factor (FRF) of 1 for the microcellular network such that the overall available bandwidth is assigned to each microcell for uplink and downlink transmission. Whereas for D2D communications it is applied FRF of 3 without considering the location of DUE inside microcell area. By this setting, it can be seen that CUE is suffering interference not only caused by other eNodeBs (co-tier interference) but also by the presence of DUE (cross-tier interference). Whereas it is likely that DUE communications suffer the inferences caused by other DUE communications (co-tier interference) and by eNodeBs (cross-tier interference). Fig. 1 illustrates the interferences at the DUE receiver and CUE. Note that in that figure, it is shown for one DUE observed as an illustration accordingly.

B. *Proposed Fractional Frequency Reuse Scheme*

In this paper, we propose a Fractional Frequency Reuse (FFR) scheme to reduce the effects of interferences suffered by the DUEs meanwhile yet retaining the performance of CUEs is not degraded. Fig. 2 depicts the sub-bandwidth allocations for the proposed FFR scheme. The total bandwidth of B Hertz is divided into three sub-bandwidths of 0.33B Hertzh with different colors which each sub-bandwidths are assigned to be used for the communications of DUEs and from eNBs to CUEs according to the locations of DUEs and CUEs in each microcell area. Each microcell is virtually divided into two areas bordered by a circle with the radius of R_{inner}. The area that is inside of the inner of the circle is called as cell center area and the area out of the circle is referred to as cell edge area. Therefore, users (DUEs or CUEs) in cell center and cell edge areas are referred to as DUE/CUE center and DUE/CUE edge, respectively. At the top of Fig. 2, it is shown the division of system total bandwidth. The other parts of Fig. 2 depicts three sub-bandwidth assignments for each microcell of three microcellular network scenarios. For example, for microcell 1, the green sub-bandwidth is assigned to be allocated for the uses of DUE and CUE at the cell edge of microcell 1, DUE edge and CUE edge, accordingly. As the D2D communications share the same frequency spectrums, our system is under in-band underlay D2D communications. In addition, our FFR scheme is kind of soft FFR, since no strict limitation of the sub-bandwidth usages between cell edge and cell center areas.

The proposed FFR scheme was applied to drop the effect of interferences, especially for CUE on the cell edge areas. To clarify the distribution uses of the channels (sub-bandwidths) that have been described, Figs. 3 and 4 are the illustrations for network schemes with proposed FFR scheme on the cell center

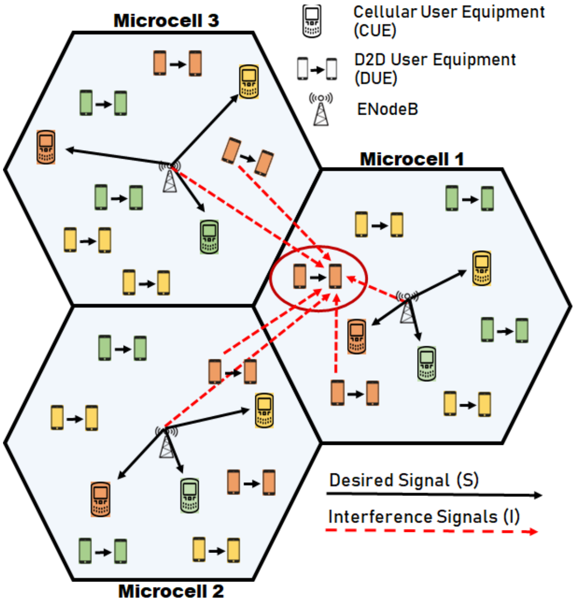
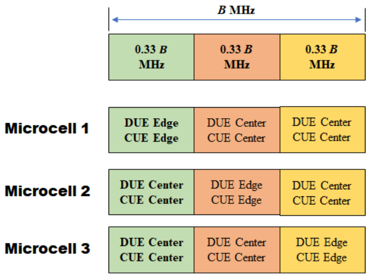


Fig. 1. Three microcells system of cellular communication network (traditional system) with interferences suffered at DUE side.



	B MHz		
	0.33 B MHz	0.33 B MHz	0.33 B MHz
Microcell 1	DUE Edge CUE Edge	DUE Center CUE Center	DUE Center CUE Center
Microcell 2	DUE Center CUE Center	DUE Edge CUE Edge	DUE Center CUE Center
Microcell 3	DUE Center CUE Center	DUE Center CUE Center	DUE Edge CUE Edge

Fig. 2. Sub-bandwidth allocations for DUEs and CUEs.

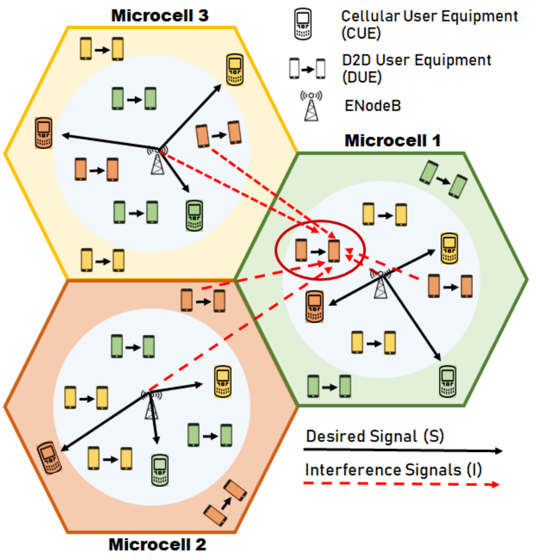


Fig. 3. Three microcells of cellular network with the proposed FFR scheme for observed DUE receiver at cell center.

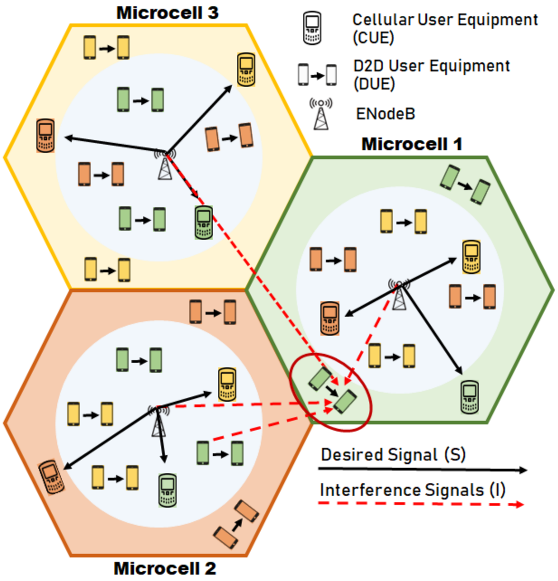


Fig. 4. Three microcells of cellular network with the proposed FFR scheme for observed DUE receiver at cell edge.

and edge. In those figures, the color indicators of user equipments (DUE and CUE) represent the sub-bandwidths used by the user. The same color means that it describes the use of the same sub-bandwiths, so that interference can still occur between CUE to DUE and from eNodeB (eNB) of other microcells, but not as bad as the traditional system in Fig. 1.

The interferences suffered by DUE that is located in the cell center and cell edge are described in Fig. 3 and Fig. 4, accordingly. Fig. 3 represents the illustration of proposed soft FFR scheme for the interferences suffered by DUE center. The circled DUE is the observed DUE receiver. The interferences that are suffered by the DUE center on microcell 1 are caused by eNB from microcells 1, 2 and 3, and by the DUEs center from microcells 1 and 2, and by the DUEs edge from microcell 3. Meanwhile, interferences suffered by the DUE edge in microcell 1 are illustrated in Fig. 4 in which the interferences are caused by eNBs of microcells 1, 2 and 3, and by the DUE edge in microcell 1, and by the DUE center of microcells 2 and 3.

C. *Channel Models*

This paper adopts the channel models used in the considered system as in [22]-[23]. Equations (1) and (2) from [23] are the path losses incurred by CUE (α_{CUE}) (downlink transmission) and suffered by DUE receiver (α_{DUE}), respectively. α_{CUE} and α_{DUE} are calculated in the dB units as the following [24].

$$\alpha_{CUE} = 140.7 + 36.7 * \log(d_{CUE}) \tag{1}$$

$$\alpha_{DUE} = 148 + 40 * \log(d_{DUE}) \tag{2}$$

where d_{CUE} and d_{DUE} are the distances between eNB and observed DUE receiver and between the observed DUE pair, respectively, both in km.

D. *Analysis of Signal to Interference plus Noise Ratio (SINR) and Throughput*

The Signal to Interference plus Noise Ratio (SINR) is analyzed both on the observed DUE receiver and CUE, because our concern is primaly to improve the performance of D2D communications without degrading the CUE performance. There are two types of interferences suffered by the observed DUE receiver in Figs. 1, 3 and 4. Both of them are caused by other DUE transmitters and by eNBs. The same intuitions are applied when the CUEs are observed. The observed CUE suffers two type interferences caused by the neighbouring eNBs and DUE transmitters in the same and other microcells. Consequently, the SINR at observed DUE and CUE can be calculated using (3) and (4).

$$\mathrm{SINR_{DUE}} = \frac{\mathrm{P_{rx\_DUE}}}{\sum_{i=1}^{m} \mathrm{I_i} + \sum_{j=1}^{n} \mathrm{I_j} + \mathrm{P_N}} \tag{3}$$

$$\mathrm{SINR_{CUE}} = \frac{\mathrm{P_{rx\_CUE}}}{\sum_{k=1}^{p} \mathrm{I_k} + \sum_{l=1}^{q} \mathrm{I_l} + \mathrm{P_N}} \tag{4}$$

where $\mathrm{P_{rx\_DUE}}$ and $\mathrm{P_{rx\_CUE}}$ denote the received powers at the observed DUE receiver and CUE, respectively, $\mathrm{I_i}$ and $\mathrm{I_j}$ are the i-th and j-th interference powers at the observed DUE receiver caused by the eNBs and other DUE transmitters, respectively, $\mathrm{I_k}$ and $\mathrm{I_l}$ are the k-th and the l-th interference powers caused by DUE transmitters and the neighboring eNBs, respectively, m and n are the number of interfering eNBs and other DUE transmitters, correspondingly, p and q are the number of interfering DUE transmitters and the neighboring eNBs, respectively, and $\mathrm{P_N}$ is the noise power.

TABLE I
SIMULATION PARAMETERS

No.	Parameters	Value
1	Number of microcells	3
2	Frequency reuse factor of microcell	1
3	Radius of microcell [25]	500 meters
4	Center boundary of microcell (R_{inner}) [25]	375 meters
5	Transmit power of microcell eNB [26]	36 dBm
6	Transmit power of DUE transmitter [27]	23 dBm
7	DUE pair distance [21]	10 meters
8	Number of DUE (each microcell), in steps	1 to 120 users
9	Number of CUE (each microcell), in steps	1 to 120 users
10	System Bandwidth (B)	10 MHz
11	Noise power [28]	-174 dBm/Hz
12	Simulation iteration	1000

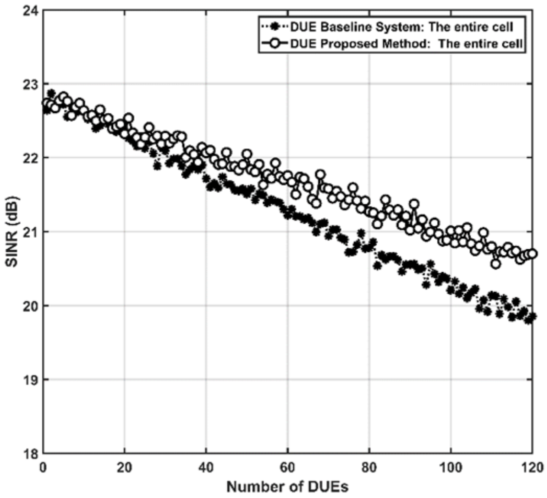


Fig. 5. The SINR simulation results versus number of DUE pairs in the whole cell area.

In this paper, the throughput performance is analyzed as well. The throughput is defined as the measured maximum channel capacity at the observation time and it can be calculated using equation (5) [24].

$$\text{Troughput (bps)} = \text{B}^* \log_2(1 + \text{SINR}) \qquad (5)$$

where B is the total system bandwidth, SINR is the measured SINR from SINR_{DUE} and SINR_{CUE}. Also, we analyze the Cumulative Distribution Function (CDF) for both SINR and throughput values.

III. SIMULATION SETTINGS, PARAMETERS, AND RESULTS

This section describes the parameters used in the simulation experiment and analysis. The simulation codes are written in MATLAB and the simulation experiments are carried out using Monte-Carlo simulation method. The parameters used will support the calculation needs to be analyzed, including SINR and throughput for the network system. The simulation results will be displayed in the form of a comparison graph between the results of the conventional system which is referred as a baseline system in this paper and the proposed system i.e., the system with the proposed soft FFR scheme, both at the terms of DUE and CUE performances.

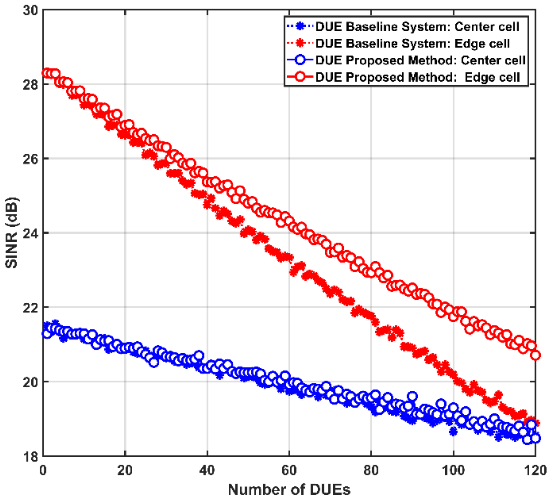


Fig. 6. The SINR simulation results versus number of DUE pairs in the center and edge of cells.

A. *Simulation Settings and Parameters*

We consider the impact of three omni microcells of an Orthogonal Frequency Division Multiple Access (OFDMA) cellular communication network at downlink transmissions. We consider two network scenarios. The first scenario is three microcells layout as shown in Fig. 1, i.e. the system without the proposed soft FFR applied in the system. As mentioned earlier, the system in Fig. 1 is referred to as a baseline system. The second scenario is three microcells layout with the proposed soft FFR applied. Both, in the network scenarios, a number of DUEs and a number of CUEs are randomly deployed in each microcell area. The total system bandwidth, *B* is set to 10 MHz. The frequency reuse factor (FRF) for the microcells is set to one. The transmit powers for eNB and DUE transmitter are set to 36 dBm and 23 dBm, respectively. The microcell's radius and distance between DUE pairs are 500 m and 10 m, accordingly. The inner (cell center) and outer (cell edge) cells are bordered by a circle with a radius of 375 m (R_{inner}). The noise power spectral density is set to -174 dBm/Hz. Each performance parameter is measured, collected and averaged after 1000 runs of the simulation program.

The simulation settings and parameters described are summarized in Table I. Each performance parameter is measured in effects of increasing of number of DUEs and number of CUEs. We measure two performance metrics on the observed DUE receiver and CUE, i.e. SINR and throughput. We present two performance metrics on the graphs in the following section. In the graphs of the simulation results, it is subsequently labeled as “Baseline System: The entire cell” and “Proposed method: The entire cell” for the system without and with the proposed soft FFR scheme, respectively. We present the graph for the cell center and cell edge areas according to the location of DUE and CUE as described earlier in this paper.

B. *Results and Discussion*

The results focus on downlink transmission of eNBs for CUE and DUE receivers. By analyzing them, it will be seen that the value generated by DUE is deployed in the cellular network, as well as the influence of CUE performances due to the presence of DUE in the system. Fig. 5 shows a comparison graph of SINR values for DUE. From that figure, at the number of D2D pairs equals to 120, it can be seen that the proposed method has a higher SINR value than the baseline system in which the baseline system achives the SINR value of 19.8 dB and the system with the proposed soft FFR scheme achieves the SINR value of 20.7 dB. It is 4.5% improved. When we notice more details of DUE locations in microcells area, similar trend of results is also gained as presented in Fig. 6 in which the system with proposed soft FFR scheme for the DUEs in the cell center or cell edge is higher than the baseline system. The comparative results between the system with and without the proposed soft FFR scheme show that for the number of DUE pairs equal to 120 the SINR values in the cell center slightly decrease from 18.55 dB to 18.47 dB whereas at the cell edge the SINR values increase from 18.8 dB to 20 dB.

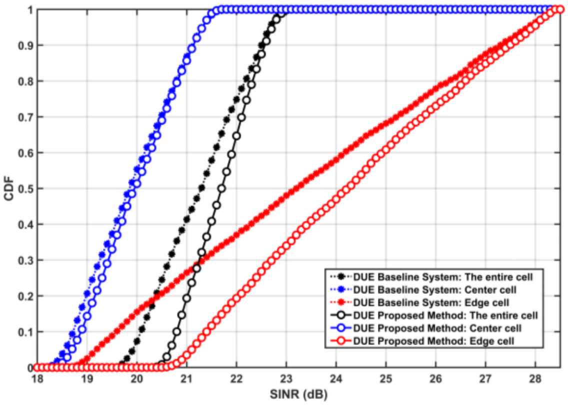


Fig. 7. The CDF of SINR results versus number of DUE pairs.

Cumulative Distribution Function (CDF) analysis of the SINR results based on Figs. 5 and 6 at the number of DUE pairs equal to 120 is shown in Fig. 7. When we consider an SINR value of 21 dB, from CDF graph it can be seen that there are 42% of SINR values for the baseline system that are less than 21 dB and 19% of SINR values for the system with proposed soft FFR scheme at the entire cell that are less than 21 dB. This indicates that the simulation results of the system with the proposed soft FFR scheme have a greater SINR distribution compared to the baseline system. The proposed soft FFR scheme guarantees higher number of D2D pairs that can gain better quality of services. Similarly, the CDF of SINR for the analysis of center and edge areas, SINR values that are less than 21 dB for the DUE pairs at cell center and cell edge areas for the baseline system, and the system with the proposed soft FFR scheme for the DUE pairs at cell center and cell edge areas are 87.5%, 27.5%, 86.7%, and 3.33%, respectively, for the number of DUE pairs equals to 120.

Figs. 8 and 9 represents a graph of throughput comparison values for DUEs. From Fig. 8, it can be seen that the system with the proposed soft FFR scheme has a higher throughput value than the baseline system. The systems without and with the proposed soft FFR scheme achieve 66.1 Mbps and 68.8 Mbps which is 4.1% improvement at the number of DUE pairs equals to 120. The same trend is also represented in Fig. 9. The throughput for the system with proposed soft FFR scheme at the cell center or cell edge of microcell areas demonstrates the increase value compared to the baseline system. The simulation results obtained for the throughput values at the cell center experience slightly decrease from 61.8 Mbps to 61.58 Mbps and at the cell edge increase from 62.9 dB to 68.9 Mbps, all of them for the number of DUE pairs equals to120.

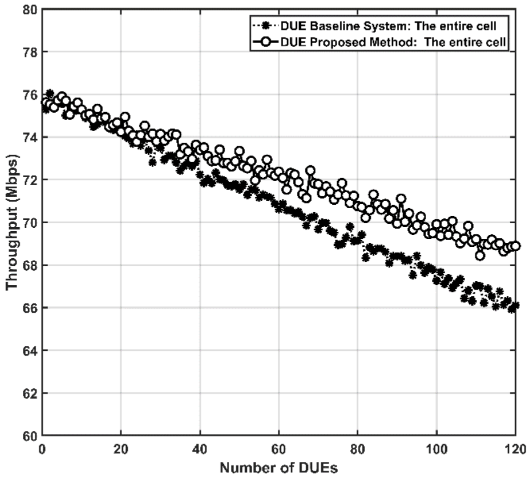


Fig. 8. The throughput simulation results versus number of DUE pairs in the whole cell region.

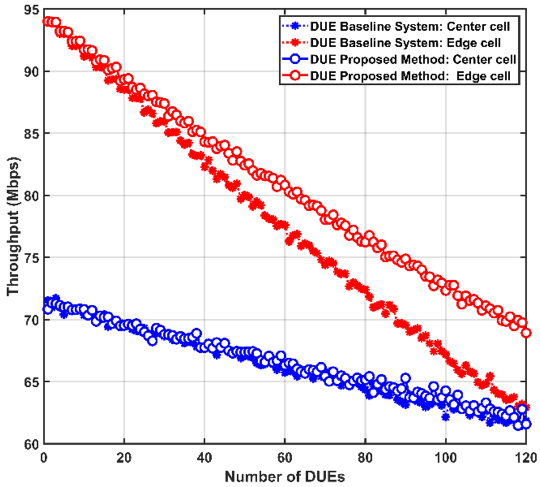


Fig. 9. The throughput simulation results versus number of DUE pairs in the cell center and cell edge.

The CDF analysis of throughput values is shown in Fig. 10. It shows that there are 43.3% and 21.6% throughput values for the system without and with proposed soft FFR scheme for the DUE pairs observed for entire cell at the throughput value of less than 70 Mbps. Likewise, for the analysis of the DUE pairs at cell center and cell edge areas, throughput values that are less than 70 Mbps for the baseline system at cell center and cell edge are 88.3% and 27.5%, and for the system with proposed soft FFR scheme at cell center and cell edge are 87.5% and 5%, all of them are the percentage of throughput values that are less than 70 Mbps. These values indicate that the throughput results of the DUE pairs for the system with the proposed soft FFR scheme contribute the higher throughput values than the baseline system.

We also evaluate the performance of CUE with the presence of DUE in the considered network scenarios. Figs. 11 and 12 show the simulation results for SINR values versus the number of CUEs. It can be seen from Fig. 11 that the simulation results show similar trends and values for the system with and without proposed soft FFR scheme. However, at the number of CUE equals to 120, the SINR value of the system with proposed soft

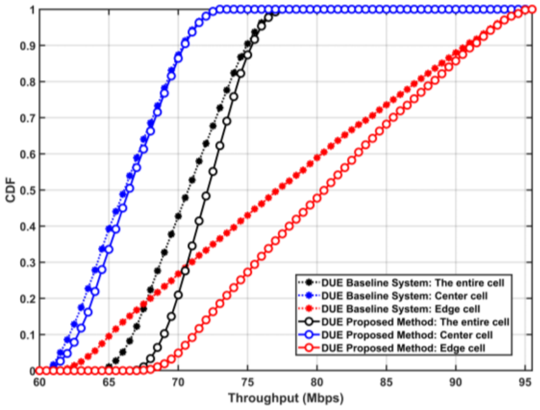


Fig. 10. The *CDF* of *throughput* results versus number of DUE.

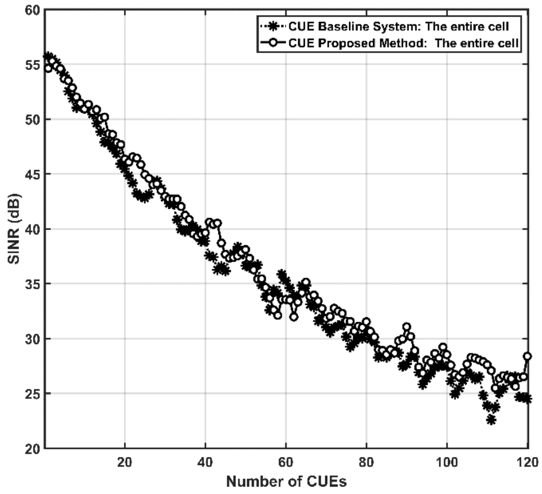


Fig. 11. The SINR simulation results versus number of CUE in the whole cell region.

FFR scheme gives a greater value than the baseline system. It is 24.5 dB and 28.3 dB for the systems without and with proposed soft FFR scheme, respectively, which is 15.5% improvement. Meanwhile, from Fig. 12, it can be seen that when analyzing the CUE at cell center for the systems without and with proposed soft FFR scheme, the SINR values attain a little decrease from 25 dB and 23.3 dB, respectively. So does the value of SINR at cell edge, the systems with and without proposed soft FFR scheme give the similar value that is 1.7 dB at the number of CUEs equals to 120. Nonetheless, the SINR values obtained in general can lead to the conclusion that the presence of DUE in a network scenario with the proposed soft FFR does not have a significant impact on the quality of service for CUE cellular users. The proposed soft FFR scheme could improve the performance of DUE without a degradation of CUE performance.

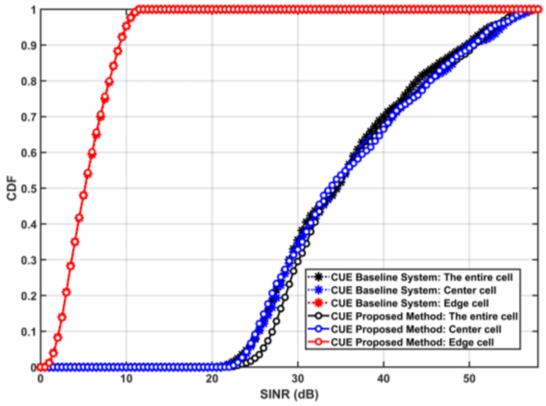


Fig. 13. The CDF of SINR results versus number of CUE.

More clear comparison of SINR performance can be seen in Fig. 13 which analyzes the CDF values of SINR. Generally, the system with proposed soft FFR scheme outperforms the baseline system. The CDF results of SINR for the CUE in entire cell areas are 70.8% for the baseline system and 67.5% for the system with the proposed soft FFR scheme considering the SINR value that is less than 40 dB. For the analysis at cell center and cell edge areas, the SINR values that are less than 40 dB for the baseline system at cell center and cell edge, and the system with proposed soft FFR scheme for cell center and cell edge are 66%, 100%, 67.5%, and 100%, respectively.

Figs. 14 and 15 indicate the results of CUEs throughput versus the number of CUEs. For the number of CUEs equals to 120, the system with proposed soft FFR scheme obtains the value of 94.3 Mbps and the baseline system achieves the value of 81.5 Mbps which is 15% improvement. Considering the throughput values for the CUEs at the cell center area of the system without and with proposed soft FFR scheme are 83.3 Mbps and 77.6 Mbps, respectively. Whereas the throughput values for the CUEs at the cell edge area of the system with and without proposed soft FFR scheme obtain 13.24 Mbps and 13.11 Mbps, accordingly.

Fig. 16 shows the CDF value of throughput. It can be seen that there are 75% throughput values for the baseline system and 72.5% for the system with proposed soft FFR scheme for the CUEs at the entire cell area considering throughput value of less than 140 Mbps. Throughput values that are less than 140 Mbps for the baseline system at cell center and cell edge areas are 72.5% and 73%, respectively, and for the system with proposed soft FFR scheme at cell center and cell edge area the CDF values are both 100%. As the conclusion, the quality of service of CUEs still obtains considerate results even though DUEs with in-band underlay sub-bandwiths deployed in the legacy cellular

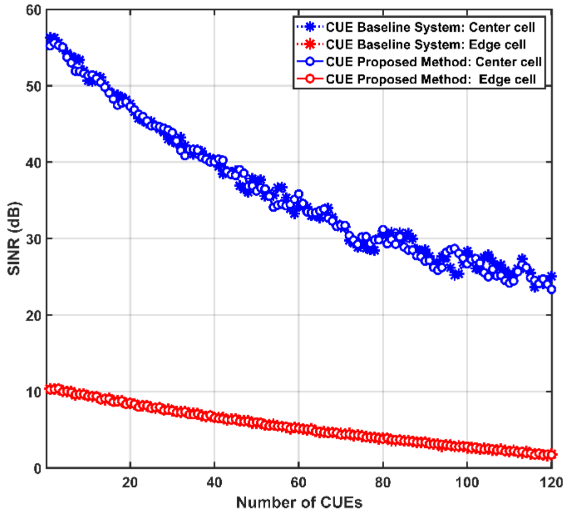


Fig. 12. The SINR simulation results versus number of CUE in the cell center and cell edge.

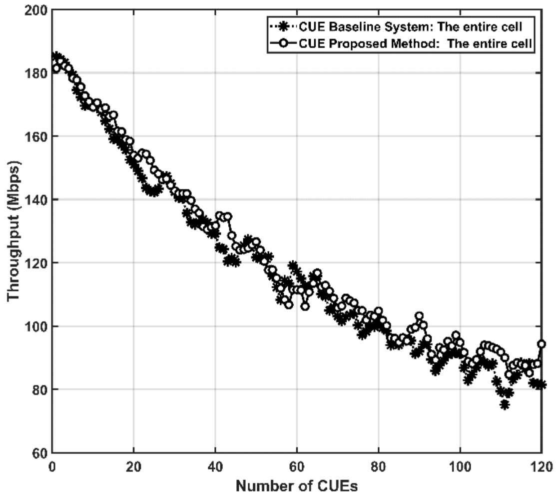


Fig. 14. The throughput simulation results versus number of CUE in the whole cell region.

TABLE II
COMPARISON OF PREVIOUS RESEARCH RESULTS

Ref.	Parameters	Value
[10]	Decomposition-based strategy for FFR heterogeneous networks.	The proposed method achieves a sum rate of up to 240 bits/s/Hz for femtocell users.
[19]	FFR method with three directional antennas.	The throughput achieved 1.5–2 times compared to the previous works of omnidirectional antenna.
[29]	FFR method with separating six zones and orthogonal frequency is allocated to each zone.	The throughput of the proposed scheme increases to 3.5 Mbps when cellular Tx power is 40 dBm.
[30]	Base stations are distributed to a hexagonal grid with poisson point processes.	FFR increases users link coverage probabilities while substantially lowering D2D sum-rate performance.
[31]	A sectorization multicell system using FFR method.	The proposed method increases throughput value to 17 Mbps at the number of DUEs pairs are 15 users.
[32]	Multicast D2D group with FFR method.	The sectorization proposed method achieves 7 Mbps and higher than without cell sectorization.

network. The proposed FFR scheme is feasible to support the realization of D2D communication implementation.

To compare our proposed soft FFR scheme to other related interference management schemes available in the literatures, we present other related literatures. Table II summarizes the results of the available literatures. As it can be noticed that our proposed FFR scheme expands the works of interference managements for D2D communications. Moreover, with the proposed soft FFR scheme, the SINR and throughput values for DUE and CUE are fairly adequate because the proposed method can boost DUE's performance parameters by up to 4.5% for SINR and 4.1% for throughput, and 15.5% for CUE compared to without proposed method.

IV. CONCLUSION

This paper proposes a soft FFR scheme for in-band D2D communications deployed in wireless cellular communication networks with multicell scenario of microcells. Three microcells of microcellular network at the downlink transmissions are considered in this paper. Each microcell area is randomly deployed the number of CUEs and DUEs. With the proposed soft FFR scheme, the total system bandwidth is partitioned into three sub-bandwidths and each sub-bandwidth is assigned for the usage of transmissions of eNB to CUE and the DUE transmitters to the DUE receivers according to the locations of CUEs and DUEs. The microcell area is divided into two areas, namely cell center and cell edge areas. The cell center and cell edge areas of each microcell are assigned the sub-bandwidths based on the proposed soft FFR scheme. Each sub-bandwidth is assigned to a different area which means that the different Frequency Reuse Factor (FRF) is applied to the cell center and cell edge areas. The proposed soft FFR scheme is examined through a simulation experiment. The MATLAB programming codes have been used to build a simulation program. The performance parameters in terms of SINR and throughput have been measured and collected through an extensive Monte-Carlo simulation experiment. All performance parameters show the consistent trends in the simulation results. Generally, the proposed soft FFR scheme provides better performance results compared to the baseline system. The proposed soft FFR scheme is able to increase the value of SINR and throughput including the improvement of SINR values from 19.8 dB to 20.7 dB with an increase of 4.5% and for throughput values from 66.1 Mbps to 68.8 Mbps with an improvement of 4.1%, for DUE analysis at the number of DUE pairs equals to 120. Likewise, the CUE performances provide valuable results even though there are DUEs deployed in the considered network system. CUEs analyzed are able to provide increase of 15.5% for SINR at the number of CUE equals to 120. The proposed soft FFR scheme is feasible to support in enabling D2D communications in legacy microcellular networks.

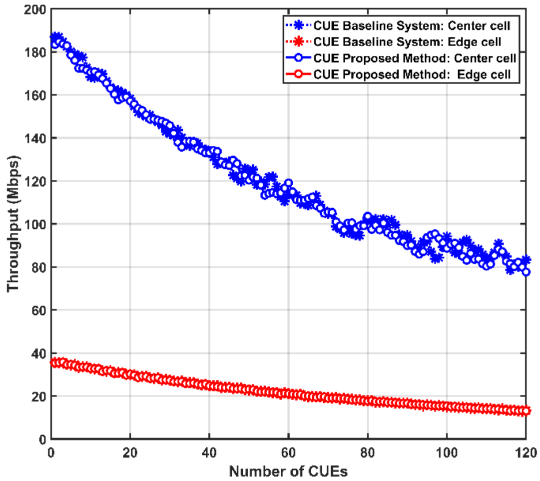


Fig. 15. The throughput simulation results versus number of CUE in the center and edge cell.

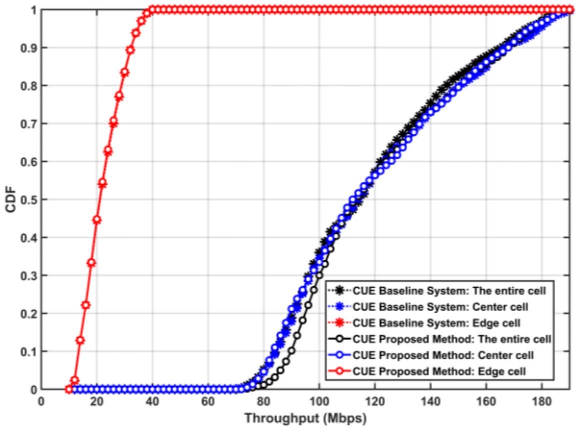


Fig. 16. The CDF of throughput results versus number of CUE.

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