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Development of an Improved Hybrid Soft FFR – ABS Scheme to Mitigate Inter-Cell Interference in Heterogeneous Networks

Lawal F*, Usman AD and Sani SM

Department of Communications Engineering, Ahmadu Bello University, Zaria, Nigeria

Abstract

Interference management in Device-to-Device (D2D) communication underlying cellular networks is an important criterion for successful and beneficial deployment of D2D communication. Several efforts are still being made by researchers to satisfactorily resolve the technical challenges that are associated with deploying D2D communication. The use of interference avoidance schemes like Frequency reuse is a popular proposal with promising results. In this paper, we developed an Improved Soft Fractional Frequency Reuse (FFR) and Almost Blank Sub-frame schemes to mitigate inter-cell interference. In our proposed scheme, Cellular user equipment (CUEs) are regarded as aggressor interfering with D2D user equipment (DUEs) as they are using the same resource as the cell edge area. The aim is to improve Signal to Interference and Noise Ratio (SINR) of the D2D user equipment pair in communication.

Keywords: Fractional frequency reuse; Almost blank sub-frame; Device-to-Device; Signal to interference and noise ratio; Heterogeneous network

Introduction

In the conventional uplink communication, all communications has to pass through a Base station (BS) which is also called evolved NodeB (eNB). With the improvement of communication and advent of D2D communication, devices in close proximity can communication without having to transverse through the eNB [1]. This feature will greatly benefit the drive to meet the increasing demand for mobile data and ability of mobile network providers to cope with the increasing need for flexibility and increase mobility [2] of users. The benefits of D2D communication are improving system spectral efficiency by reusing cellular uplink resources, reducing communication delay, facilitate new services such as machine-to-machine communication, location based services and improving system capacity [3]. To successfully adapt D2D communication in cellular network, challenges such as device discovery, mode selection, Quality of Service (QoS) synchronization and interference management has to be resolved. The most critical of these challenges being interference as it affects the overall performance of the cellular network and also the D2D devices. Figure 1 illustrates a D2D network scenario.

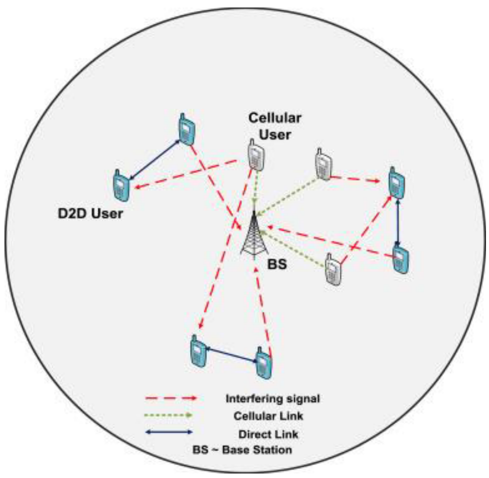

Figure 1: Device to device communication [3].

Several research efforts have been made both in academia and in industry to address the issue of interference in D2D communication undelaying cellular network. Frequency reuse scheme is a promising interference avoidance method that has gained a lot of interest because of it enables simultaneous transmission demands, thus improves system efficiency. Soft Fractional Frequency Reuse (FFR) is used as an interference management method between CUEs and DUEs. An eNB can manage the interference between CUE and DUE pairs using soft FFR. D2D pairs are allowed to use any partition of frequency (Fc, F1, F2, and F3), except that which is allocated to its CUE in the same area. In this way, D2D pairs can reuse the same frequency with CUEs located in the neighboring sectors and avoid interference from CUEs in the same sector. However, D2D pairs located at the cell edge area can experience serious interference from CUEs of neighbor sectors because those are allowed to use any frequency, except the one allocated to CUEs in the same sector [4]. Resource allocation for cellular user equipment and D2D pairs is shown in Table 1.

ABS is a technique based on adaptive resource partitioning in the time domain as can be seen in Figure 2. In Figure 2, sub-frames 2, 3, 4, 6, 7, and 8 are ABS, where the aggressor nodes do not send data signals to avoid interference to victim nodes. During ABS, the aggressors can transmit only control signals such as Cell-specific Reference Signals

Area	Partition	Freq.	CUE	D2D
Cell-Center	s_o	F_c	F_c	F1, F2 and F3
Cell-Edge	s_1	F_1	F_1	Fc, F2 and F3
Cell-Edge	s_2	F_2	F_2	Fc, F1 and F3
Cell-Edge	s_3	F_3	F_3	Fc, F1 and F2

Table 1: Resource allocation for cellular user equipment and Device-to-Device pairs.

***Corresponding author:** Lawal F, Department of Communications Engineering, Ahmadu Bello University, Zaria, Nigeria, Tel: +2348065212477; E-mail: flawal99@gmail.com

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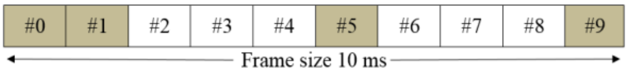

Figure 2: Frame structures with ABS [5].

(CRSs) [5]. In Figure 1, sub-frames 0, 1, 5, and 9 are not blank, which are reserved to transmit Primary Synchronization Signals (PSS), Secondary Synchronization Signals (SSS), SIB-1, and paging.

In literature [6], the use of strict Fractional Frequency Reuse (FFR) scheme are was proposed by the authors to reduce inter-cell interference, results shows however that throughput degrades. In Dongyu and Wang [7] they proposed FFR to mitigate cell edge interference although, interference from other parts of the cell was not considered during simulation. Several other works [8-10] considered FFR scheme to improve throughput and mitigate interference in D2D communication with varying degrees of success. Elfadil et al. [11] proposed FFR and Soft FFR to increase cell edge SINR. A Soft Partial Frequency Reuse scheme is developed by Gajewski [12] for improvement of physical resource utilization. An effective hybrid mechanism of Soft fractional frequency reuse and Almost Blank Sub-frame scheme was developed in a study [13], the scheme improved SINR and less interference at cell edge areas. According to the proposed scheme DUEs would benefit from silent time of the CUEs in ABS time to transmit its own data with less interference. Our work therefore aims to develop a modified Soft FFR-ABS scheme that will increase throughput and reduce interference while improving SINR.

Materials and Method

To develop the improved Soft FFR-ABS scheme, first a system model consisting CUEs and DUEs with a spectrum sharing D2D enable cellular network is obtained. The features of the scheme include;

a. An eNB operated soft FFR with the cell divided into four different sectors of S0, S1, S2, and S3 checks the location of CUEs and allocates frequency to the CUEs.

b. ABS configuration of eNB if the eNB receives a D2D connection request from DUE-Txi to DUE-Rx j and lists CUEs whose distance to the DUE-Rx j is less than the minimum ABS distance.

c. eNB then sends control signals including the improved ABS pattern for the DUE-pair i,j.

d. Data transmission by DUEs and CUEs, where the eNB checks the DUE-pair i,j and the set for the DUE-pair i,j and the CUEs in the should be silent during Alost Blank sub-frames.

Then a simulation of the developed scheme simulated using Matlab 9.2 (R2017a).

Mathematical Modeling

A mathematical model of the system is developed as follows:

Channel and link distance models

The channel and link distance models are defined by signal power. The received power of CUE, $P_{j,c}^{CUE}$, from CUE j to eNB, can be derived as follows:

$$P_{j,c}^{CUE} = G_{j,c}^{CUE} P^{CUE} \tag{1}$$

Wher $G_{j,c}^{CUE} = \left| H_{c,j}^{CUE} \right|^2$. Similarly, the received signal power of DUE-Rx i to DUE-Rx j, $P_{i,j}^{D2D}$, can be defined as follows:

$$P_{i,j}^{D2D} = G_{i,j}^{D2D} P^{D2D} \tag{2}$$

$$\text{Where } G_{i,j}^{D2D} = \left| H_{i,j}^{D2D} \right|^2 \tag{3}$$

Signal-to-interference-plus-noise-ratio (SINR) model

The SINR of DUE-Rx j from DUE-Txi with the conventional FFR can be expressed as follows:

$$SINR_{FFR}^{D2Dn} = \left. \frac{P_{i,j}^{D2D}}{\gamma^2 + \sum K \epsilon K_{tx}^{n}, k \neq i \; P_{k,j}^{D2D} + \sum_{k\epsilon} c^n P_{k,j}^{CUE}} \right|_{i,\, j \epsilon F_n} \tag{4}$$

Similarly, the SINR of CUE with the conventional FFR can be defined as:

$$SINR_{FFR}^{CUEn} = \left. \frac{P_{i,c}^{CUE}}{\gamma^2 + \sum K \epsilon K_{tx}^{n}, \; P_{k,c}^{D2D} + \sum_{k\epsilon} c^n P_{k,c}^{CUE}} \right|_{i,\, \epsilon F_n} \tag{5}$$

Thus, the SINR of DUE-Rx j from DUE-Txi in the FFR-ABS can be defined as follows:

$$SINR_{ABS}^{D2Dn} = \left. \frac{P_{i,j}^{D2D}}{\gamma^2 + \sum K \epsilon K_{tx}^{n}, k \neq i \; P_{k,j}^{D2D} + \sum_{k\epsilon} c^n, \; K \notin ABS_j^{CUE} P_{k,j}^{CUE}} \right|_{i,\, j \epsilon F_n} \tag{6}$$

Note that CUE k does not interfere with DUE-Rx j in ABS_j^{CUE}. In the same way, the SINR of CUE in the FFR-ABS can be described as follows:

$$SINR_{ABS}^{CUEn} = \left. \frac{P_{i,c}^{CUE}}{\gamma^2 + \sum K \epsilon K_{tx}^{n}, K \notin ABS_c^{DUE} P_{k,c}^{D2D} + \sum_{k\epsilon} c^n P_{k,c}^{CUE}} \right|_{i,\, \epsilon F_n} \tag{7}$$

Optimal ABS ratio

In FFR-ABS, a part of CUEs have ABS applied and others operate by the FFR method. The nodes that are on the ABS scheme have to transmit data on their sub-frames only. Thus, the total data rate of FFR-ABS is as follows:

$$R_{total}^{ABS} = \beta \left(Pr_{ABS}^{D2D} \sum R_{ABS}^{D2D} + \left(1 - Pr_{ABS}^{D2D}\right) \sum R_{FFR}^{D2D} \right) + \left(1 - \beta\right), \left(Pr_{ABS}^{CUE} \sum R_{ABS}^{CUE} + \left(1 - Pr_{ABS}^{CUE}\right) \sum R_{FFR}^{CUE} \right) \tag{8}$$

Where,

$$Pr_{ABS}^{D2D} = \frac{n\left(U_{c \in C} ABS_c^{D2D}\right)}{n(K)} \; and \; Pr_{ABS}^{CUE} = \frac{n\left(U_{j \in k} ABS_j^{CUE}\right)}{n(C)}$$

System Model

The system model is developed as proposed in a study [13], to achieve this, a cellular network with 7 cells is used with each cell divided into two broad areas namely; central area and cell edge area. The central area has a Frequency Reuse facto (FRF) of one 91) and the edge area has a FRF of three (3). The entire frequency band is then partitioned into four parts Fc, F1, F2 and F3 as illustrated in Figure 3.

The D2D pairs are considered as victims while the CUEs are considered aggressors, so that the interference by the CUEs on the D2D pairs can be mitigated intermittently by the ABS.

For the Non-ABS sub-frames,

$$SINR = \frac{P_{dt} * G_{dtdr}}{\sigma^2 + \sum I_d^{in} + \sum I_c^{out}} \tag{9}$$

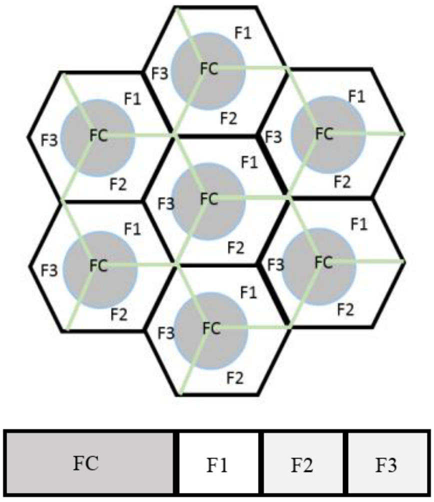

Figure 3: System cell model with cell parts divided.

Then for the ABS sub-frames the model is;

$$SINR = \frac{P_{dt} * G_{dtdr}}{\sigma^2 + \sum I_d^{in}} \tag{10}$$

Developed Improved Scheme

The developed scheme consists of three phases: soft FFR, ABS, and data transmission. In phase 1, an eNB operates soft FFR. The eNB divides its own cell into four different sectors like S0, S1, S2, and S3. Then, it checks the locations of CUEs and allocates frequency to CUEs through the soft FFR method. Phase 2 is an ABS configuration by the eNB. If the eNB receives a D2D connection request from DUE-Txi to DUE-Rx j, it lists CUEs whose distance to the DUE-Rx j is less than D_{max}^{ABS}. The list is a set ABS_j^{CUE} of CUEs that should be silent on ABS sub-frames for the DUE-pair i, j. The eNB then sends control signals including the ABS pattern for the DUE-pair i, j. The final phase is data transmission by DUEs and CUEs. In this phase, the eNB checks the DUE-pair i, j and the set ABS^{CUE} for the DUE-pair i, j. The CUEs in the set should be silent during ABS sub-frames. In the developed scheme, the CUEs that cause severe interference are selectively chosen to be silent in ABS to minimize the throughput loss. A flowchart illustrating the overall scheme developed is shown in Figure 4.

Simulation and Evaluation

The model developed for this work was simulated in Matlab environment, using Matlab R2017a version. The simulation parameters used is shown in Table 2.

To evaluate the performance of the improved FFR-ABS scheme, computer simulations of scheme is carried out, using Matlab software. The simulation parameters as shown in Table 2 provides assumptions and parameter values as referenced from a study [13]. The main criterion for an eNB to allow a piece of user equipment to operate in either cellular or D2D mode is the location of the sender and receiver in reference to the eNB. Therefore, Pathloss measurement helps in determining the connection mode of the EUs. The Path-loss model used here is modelled according to micro-urban models in the International Telecommunication Union Radio-Communication Sector (ITU-R) reports 2017 [14]. The expression for the path-loss models are shown below.

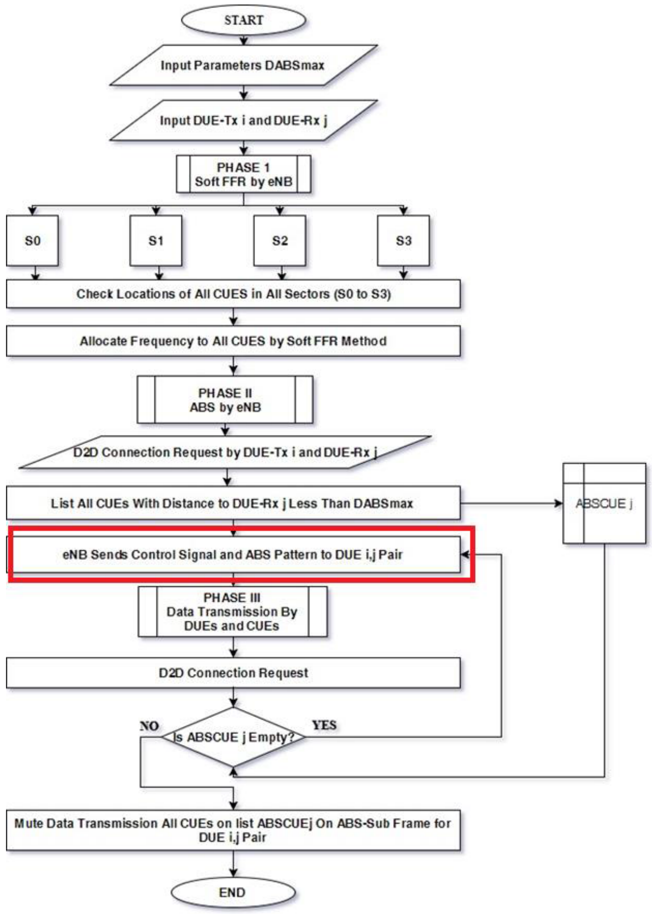

Figure 4: Flowchart of developed improved FFR-ABS scheme.

Parameter	Assumption
Cellular Layout	Hexagonal grid, 7 cells sites
Cue Transmit Power	24 dBm
Due Transmit Power	20 dBm
Noise Power Density	-174 dBm
Bandwidth	10 MHz
Cell Radius	500 m
ABS Pattern Period	10 ms
Carrier Frequency	2 GHz
Number of CUEs	10
Number of DUEs	20
Distance between D2D	20-60 m
Traffic Pattern	Full buffered

Table 2: Developed scheme simulation parameters.

$$(NLOS\,100\%)PL_{D2D} = 24.82 + 35.31 \times \log_{10} d \quad (NLOS\,80\% + LOS\,20\%)PL_{D2D} = 28 + 40 \times \log\_10d$$

$$(NLOS\,100\%)PL_{eNB} = 31.25 + 33.76 \times \log_{10} d$$

$$(NLOS\,80\% + LOS\,20\%)PL_{eNB} = 30.35 + 36.7 \times \log_{10} d$$

Where d is the distance between transmitter and receiver in meters.

NLOS (Non-Line of Site); LOS (Line of Site).

Result and Discussion

The evaluation during simulation considered two key parameters namely throughput and Signal to interference and Noise Ratio (SINR).

These parameters where considered under three scenarios which are;

1. Path-loss
2. Transmission Power
3. Traffic Load.

The results show significant improvement on the parameters considered. Figure 5 below presents the developed system model.

Path-loss

The first scenario – Different path-loss – here the performance of the scheme was evaluated using Matlab, first evaluation of isolated D2D pair at cell edge area when D2D pair shares resources with CUE located in a neighboring cell. In the scenario, it is assumed that a target DUE_R is located 20 m from its corresponding DUE_T, and its power was set to 20 dB corresponding to 100 mW. The locations of the interferers which are all user equipment (DUEs and CUEs) are randomly assigned between 20 to 60 meters. Figures 6 and 7 show the SINR and the received throughput at the target DUE_R (DUE-receiver).

Transmission power level

To evaluate the performance of the developed scheme under varying transmission power levels for CUE and DUE in the network, firstly the scheme is evaluated with all DUEs having the same transmission power levels set at 20 dBm equivalent to 100 mW, all DUEs in the network are set to this power level, even those located at difference distances. All the CUEs are set to same transmission power level of 250 mW equivalent to 24 dBm. The results of the Signal to Noise Interference Ratio and also throughput for the target DUE_R are presented in Figure 8 for SINR and Figure 9 for throughput.

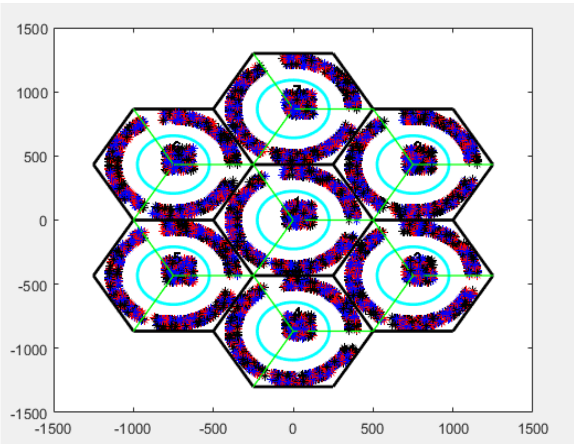

Figure 5: System model network with 7 – Cell hexagonal structure.

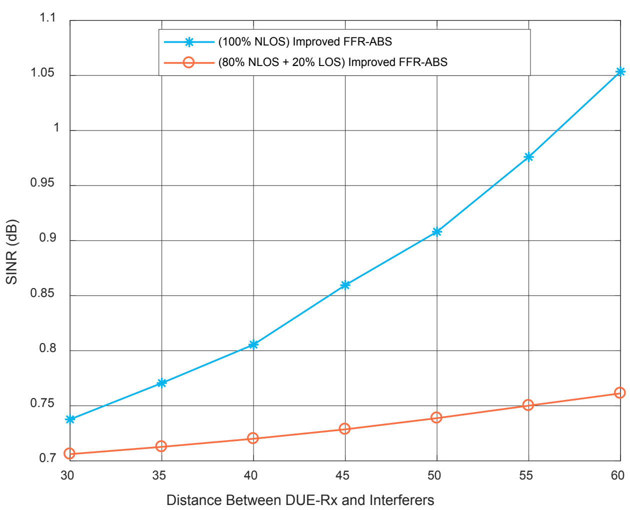

Figure 6: Signal to interference and noise ratio received at target DUE_R for the developed scheme.

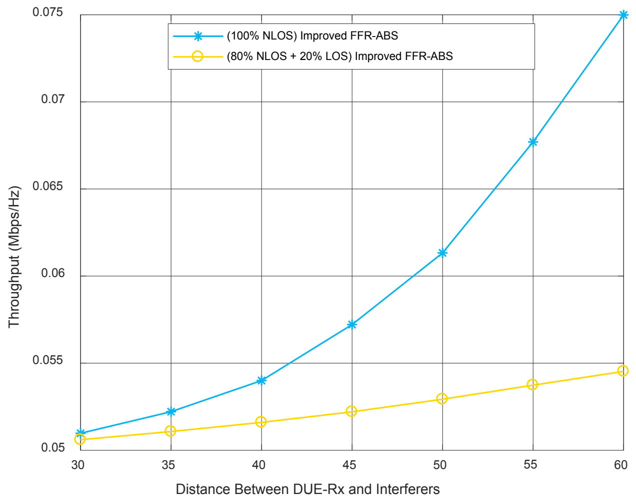

Figure 7: Throughput received at target DUE_R for the developed scheme.

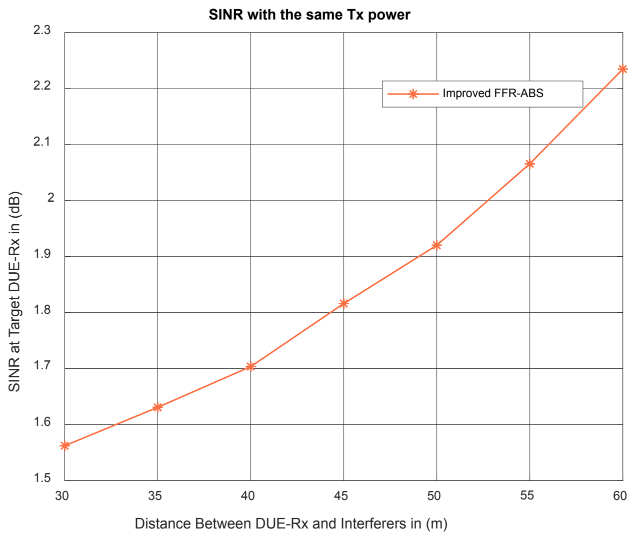

Figure 8: Signal to noise interference ratio at the target DUE_R with same CUE and DUE transmission power levels.

Different traffic loads for CUE and DUE

In this scenario, a traffic load of low, medium, and high in CUEs and DUEs was considered. For high traffic loads real time video streaming can be considered, for medium and low traffic loads web browsing and voice call can be examples respectively. According to a study [15], traffic loads can be assigned 242 kbps, 100 kbps, and 12 kbps for high, medium, and low traffic loads respectively. Figure 10 shows the Cumulative Distribution Function (CDF) of throughput based on

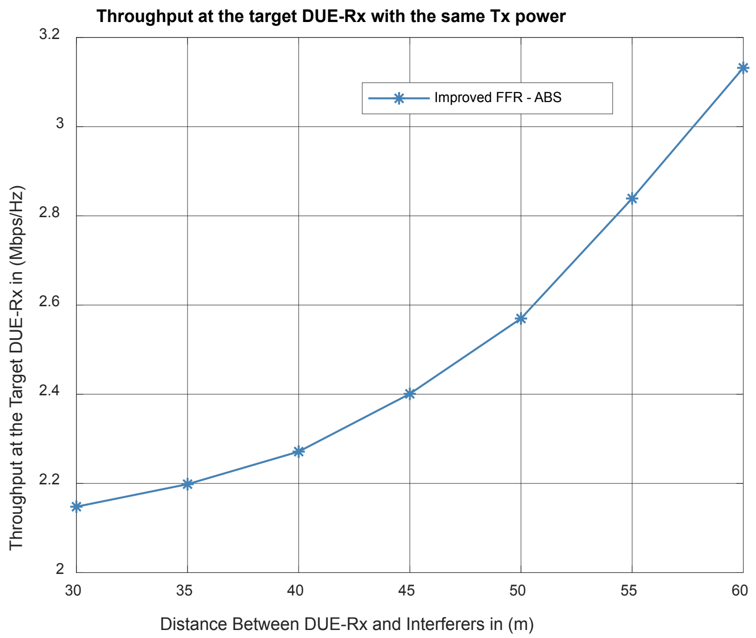

Figure 9: Throughput at the target DUE_R with the same transmission power level for DUE and CUE.

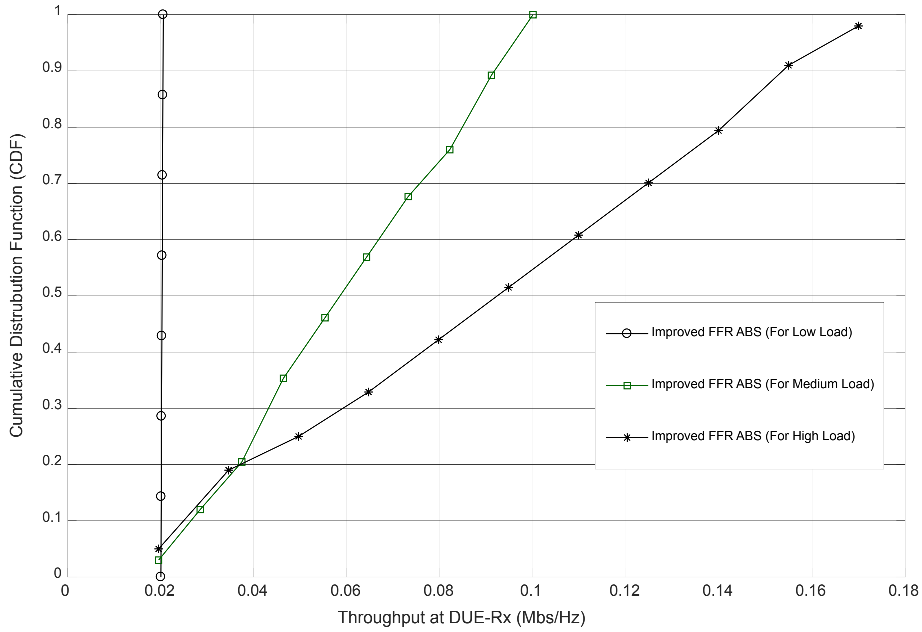

Figure 10: Cumulative distribution function (CDF) of throughput based on traffic loads.

traffic loads. In the improved FFR-ABS scheme, interferences from nearby CUEs can be ignored because the CUEs are muted in ABS.

The overall results obtained from our developed improved Soft Fractional Frequency Reuse and Almost Blank Sub-frame scheme shows significant improvement in terms of Throughput and Signal to interference and noise ratio.

Conclusion

The effect of Interference in D2D communication underlying LTE cellular network is a bottle neck for achieving the full benefit of D2D communication, attempts are still being made to enhance the system and reduce the interference. The work in a study [13] provides one such attempt and serves as a basis for this work. With the limitations observed in their work which is mainly slight increase in performance of the system when compared to other conventional interference mitigation schemes. Then this work was proceeded to develop an Improved Hybrid FFR-ABS scheme for D2D interference mitigation, in the developed scheme, distance between CUEs and DUEs are considered as vital parameters. The results obtained from simulation using Matlab R2017a, indicates that the developed scheme has higher throughput and Signal to Noise Interference ratio and also better interference mitigation from neighboring CUEs on the D2D cell edges areas. This improved scheme can be further extended to minimize intra-cell interference caused by co-channel D2D pairs.

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