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Soft sectored fractional frequency reuse in LTE-advanced networks

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Abstract. Fractional Frequency Reuse (FFR) has been suggested as an Inter Cell Interference Coordination (ICIC) technique in Orthogonal Frequency Division Multiple Access (OFDMA), where the cell is separated into internal and external regions. The inner means that it is close to eNB, while the outer indicates closeness to the boundaries of the cell. The main idea of FFR is to divide the cell's bandwidth into partitions for reducing the cell interference from both inner users and the adjacent cells. The FFR has three main types including Strict FFR, Soft FFR and Sectored FFR (SFFR). This work proposes a hybrid Soft Sectored Fractional Frequency Reuse (SSFFR), which analyzes the uplink worst case Signal to Interference power Ratio (SIR). In addition, the effect of power control exponent, path loss exponent and inner radius are studied, and SSFFR is compared with SFFR. Simulation results show that, the higher SIR achieved by outer-SSFFR, enables to enhance the cell edge transmission through interference management.

1. Introduction

Cellular systems used to have weak spectral efficiency, but it is enhanced since the whole bandwidth is dedicated to every cell. However, this will increase interference among neighbouring cells, particularly at the outer region[1].

The ICIC technique is aimed at improving the network efficiency by allowing every cell to dedicate its resources in a way that reduces interference, while increasing spatial reuse [1, 2]. FFR has been proposed as an ICIC technique in OFDMA-based wireless networks, where the cell is partitioned into internal and external regions. The inner region is the closest to eNB, while the outer is closest to the cell edge. The entire bandwidth is separated into a few sub-bands, and each sub-band is dedicated to either the internal or the external region of the cell [1, 3]. The FFR has three main types including Strict FFR, Soft FFR and Sectored FFR (SFFR). [4,5,6,7], which will be explained in next subsections.



1.1. Strict FFR

The inner users has the same frequency (F1) while the outer users' bandwidth (F₂, F₃, F₄, F₅, F₆, F₇ and F₈) is separated over the whole cells based on a reuse factor (RF), so it requires a total of (RF + 1) sub-bands (Fig. 1). The inner users prevent to share any channel with outer users, that decrease interference for both but is less efficient in terms of resource utilization [1,3].

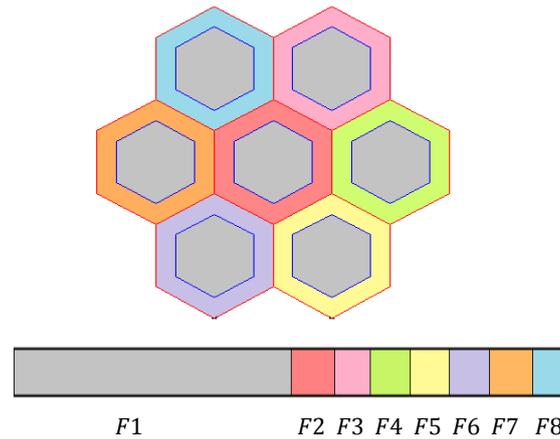


Figure 1. Strict FFR.

1.2. Soft Frequency Reuse

It utilizes a similar outer region bandwidth partition strategy as Strict FFR. Figure 2 illustrates a Soft Frequency Reuse, where the inner users are permitted to share sub-bands with outer users in other cells, and consequently they need to transmit at lower power than the outer users [1,8,9]. Each cell uses the whole frequency band, so it is more bandwidth effective compared to Strict FFR but it costs more interference to both inner and outer users [1,3,10].

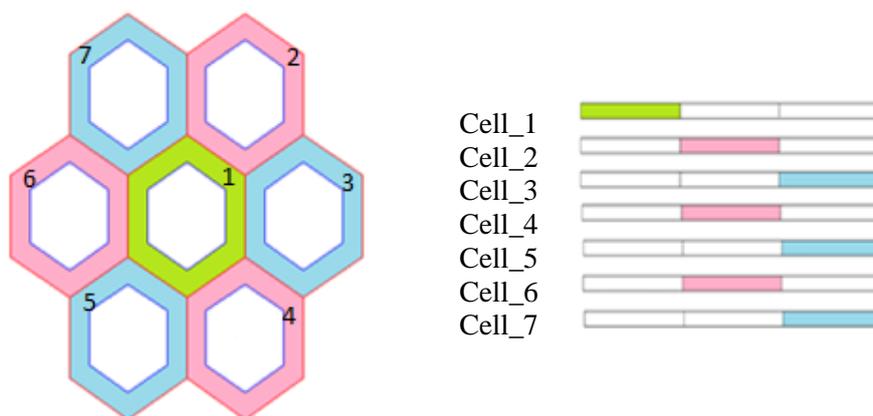


Figure 2. Soft Frequency Reuse.

1.3. Secteded FFR

The whole cell is divided into inner and outer regions, where the outer region is served by directional antenna [11, 12]. In SFFR with three directional antennas, the outer region is partitioned into three

sectors, each sector has a dedicated frequency (sub-band), while inner region can served by omnidirectional antenna as shown in Fig (3.a) or divided into sectors as shown in Fig (3.b). Each cell utilizes the entire frequency band with low transmission power for inner region, and with rather high transmission power for outer region [11, 13]. The main advantage of sectored FFR is the improved spectrum efficiency because of using the whole spectrum in a cell. Furthermore, it has no co-channel interference within the cell [11, 12, 14, 15].

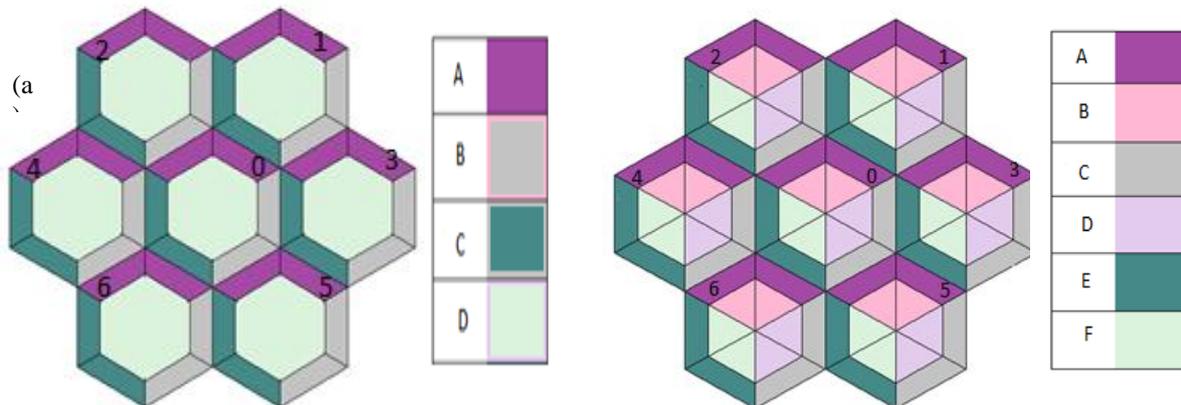


Figure 3. SFFR inner user served by a) omnidirectional antenna b) directional antenna.

Uplink analysis is more complicated than downlink analysis due to the following reasons; First, in downlink, interference comes from the static stations (eNB), while in uplink, interference comes from cell phones spread around the network. Second, the analysis of uplink uses position that depend on power control so transmit power is very changeable. Third, transmit power is very important for life-time of cell phones battery [4,16,17,18,19]. Huawei [20] proposed SFR, that uses hard limits on the spectrum utilization of every cell to reduce interference. However, there was no remarkable throughput enhancement. Partial Frequency Reuse (PFR) is presented in [21], it is a fixed frequency reuse which the sub-frequency is dedicated to a user, it cannot be re-allocated to another. Porjazoski, *et al* [22] calculated SIR as a function of the user position. Mao *et al* [23] decreased interference at the outer region by using a decentralized adaptive SFR. X. Mao[24] studied uplink and presented A traffic-adaptive SFR. It achieves better inner and outer user throughput in the downlink [25]. Elfadil *et al* [1] compared between SFR and Strict FFR with conventional system. It was found that Strict FFR has the best outer users' SIR, but conventional FFR has the best inner user's SIR Hashima *et al* [4] compared between the three main FFR schemes, where the results show that SFFR has the best performance but it caused more complexity.

2. Soft Sectored FFR (SSFFR)

This section describes the Soft Sectored FFR and calculates the worst SIR for the uplink. Figure-4 illustrates the idea of SSFFR in which the whole spectrum is evenly divided into six segments (A, B, C, D, E, and F). Each cell is divided into three sectors and each sector is additionally partitioned into inner and outer region, every inner or outer sector has a distinct sub-band, so SSFFR is more bandwidth effective compared to Strict FFR and soft FFR. Furthermore, it has no co-channel interference within the cell.

We study one sector which contains sub-band frequencies (A and B), then compare between SSFFR

and SFFR (at the same sub-band frequencies A and B) under the same condition. For simplicity, we assume that the whole network is consist of 7 cells. Each time/frequency sub-band is allocated to a single user per cell so for any transmitting mobile device (inner, outer) lying in the home-cell we consider 6 interfering mobiles that use the same frequency. The location of interfering mobiles is selected accurately to be the nearest position to the home eNB and has the highest power gain. The related SIR is given by the following equation[4]:

$$\text{SIR} = \frac{P_{tx} * \varphi_{BS} * d^{\alpha(\mu-1)}}{I_Z} \quad (1)$$

$$I_Z = \sum P_i (R_i^\alpha)^\mu d_i^{-\alpha} \quad (2)$$

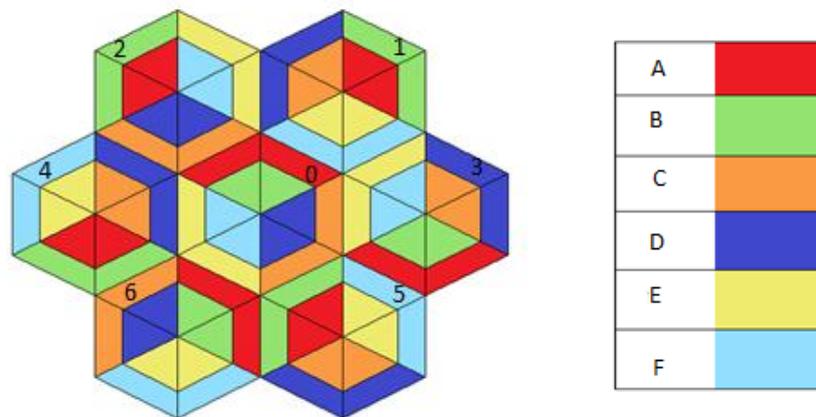


Figure 4. Soft Sectored FFR

The distance between any two adjacent eNBs is $\sqrt{3} R_C$, where R_C is the cell radius, φ_{BS} is the power gain of home eNB, and α denotes path loss exponent. i denotes interfering devices. d_i is the distance between an interfering device i and home eNB. R_i is the distance of an interfering device to its serving eNB. $\mu \in [0 : 1]$ is the power control exponent, the transmitted power of interfering device is denoted by P_i . It is assumed that the nearest interfering device must be connected to another cell and cannot be near to home eNB than the transmitter. $d_i > R$. [26].

3. Sectored FFR Versus Soft Sectored FFR

Both SFFR and SSFFR have high bandwidth utilization, but there is some difference between them. First, SFFR dedicated some frequency (F2, F4 and F6) for inner regions and the rest (F1, F2 and F3) for outer region, while SSFFR has more flexibility where the same sub-band frequency can be used for inner or outer users under one condition it can be in another cell. Second, the distribution of frequency in SFFR is uniform (similar) in every cell, but in SSFFR is rotated uniform distribution. Third, all of them have no co-channel interference within the cell, but SFFR has co-channel interference between adjacent sectors. For all of this, the SSFFR is able to enhance the cell edge transmission more than SFFR. The architecture of SFFR is shown in Fig. 3(b), while the SSFFR is shown in Fig. 4

4. Simulation and Results

The network is composed of 7 cells (SFFR, SSFFR) (Fig. 3(b), 4) there are 2 transmitter mobiles (inner and outer) where every one of them affected by 6 interfering mobiles, all of them is distributed in the worst position to calculate the worst SIR. The parameters' setting is referred to Table 1.

Table 1. Simulation Parameters

Parameter	Value
Outer cell radius (R)	1200 m
Inner cell radius (r)	800 m
Path Loss exponent (α)	4
BS transmission power for outer region (P_{BS_O})	49 dBm
BS transmission power for inner region (P_{BS_IN})	46 dBm
C2C Tx transmission power in outer region (P_{C2C_O})	25 dBm
C2C Tx transmission power in inner region (P_{C2C_INN})	24 dBm

Figures 5(a) and 5(b) show the relation between worst SIR of soft sectored FFR (outer, inner) region and α for different values of α . It can be seen that SIR of the outer region is greater than the inner region. Also cell_0 has the best SIR performance in the outer region. It shows that curve of cell.3.f1 (cell.3.f2) and cell.4.f2 (cell.4.f1) are overlapping (coincident) because cell.3 is just mirror of cell.4, every one of them has the same transmit power and the same interfering mobiles. Also it is clear that as α increases (attenuation increases), the SIR increases, because as α increases both the received signal and interfering signals powers decrease. However, the decrease in the interfering signal is more than that of received signal resulting in an increase of SIR. Because distance between any interfering device with home eNB is larger than distance between transmitter and home eNB.

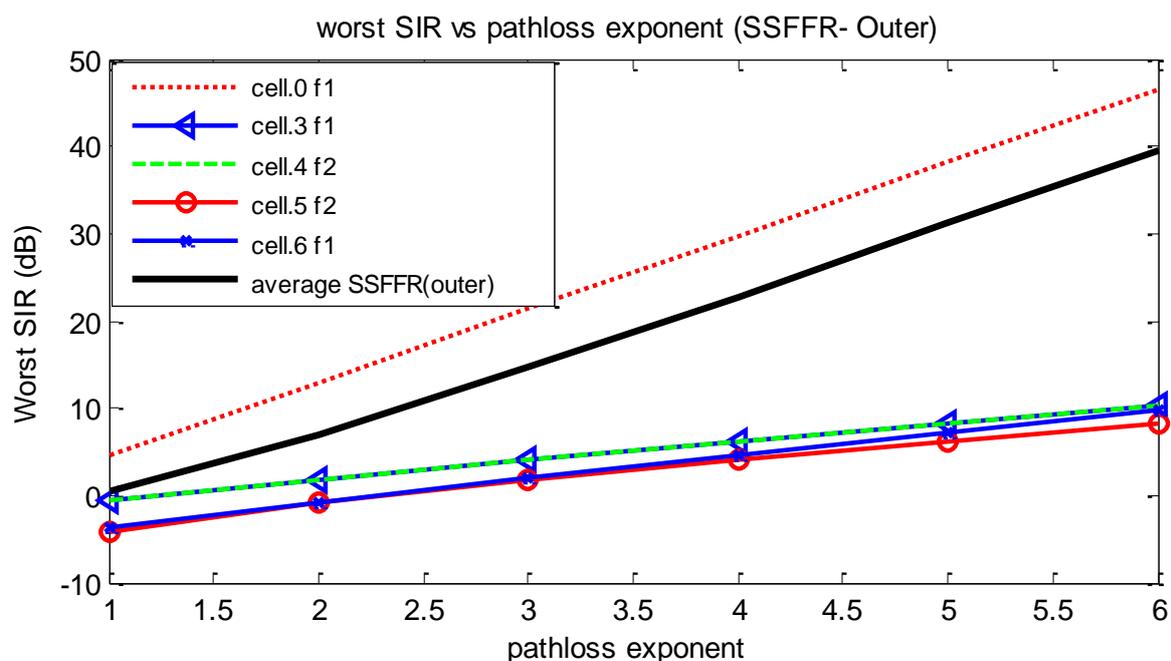


Figure 5(a). Worst SIR- outer Vs Pathloss exponent at power control ($\mu = 0.6$), $r/R = 2/3$

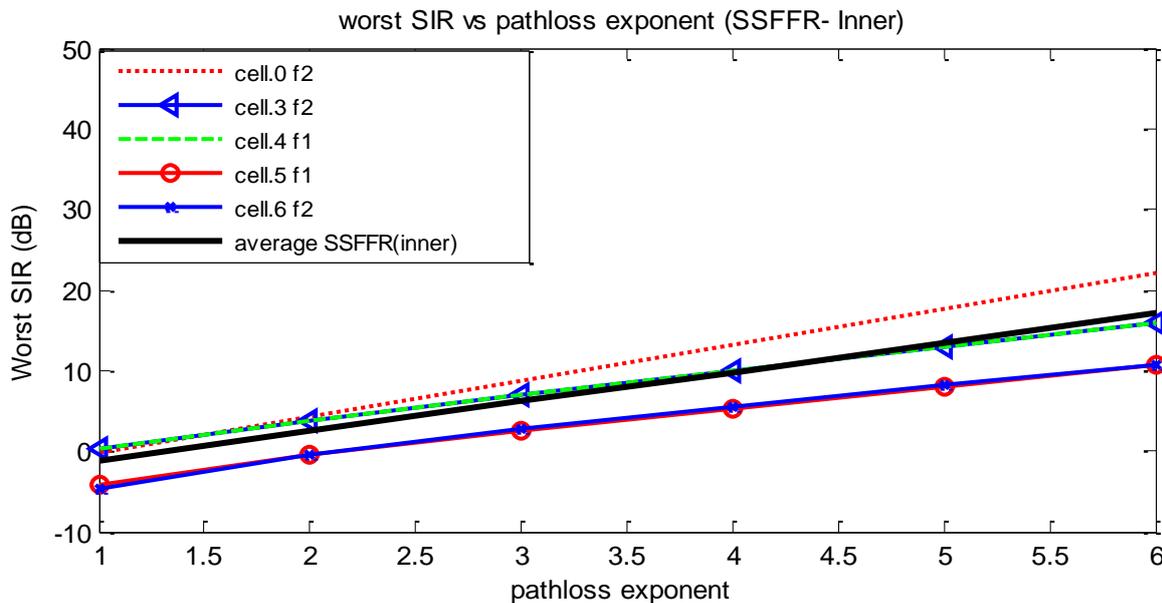


Figure 5(b). Worst SIR-inner vs path loss exponent at power control ($\mu = 0.6$), $r/R = 2/3$

Figures 6(a) and 6(b) preview worst SIR of Soft Sectored FFR (outer, inner) against power control exponent μ for different values from 0 to 1 at path loss exponent = 4. The main factor that affecting SIR is the distance between mobile to its serving eNB (transmitter, interfering mobile) is denoted by (R_t, R_i) . The simulation result shows that SIR increases in case of $(R_t > R_i)$ we can see that in cell.0.f1 (outer), decrease in case of $(R_t < R_i)$ such cell.3.f2 & cell.4.f1(inner) and has no effect when $(R_t = R_i)$ such cell.0.f2(inner). The relation between SIR and μ is drawn twice for $(r/R = 0.25)$ represented by solid lines, and $(r/R = 0.75)$ represented by dotted lines. The best SIR occurs for $(r/R = 0.25)$ while the lowest SIR value occurs when $(r/R = 0.75)$ SIR decrease because of the increased co-channel interference and increase distance between mobile to its serving eNB (R_{Tx} or R_i). It is clear that SIR of cell.0.f1 (outer) curve does not change due to the fixed position of T_x and interfering mobiles (because the interfering mobiles located next to their eNB so the change in inner radius has no impact of their position).

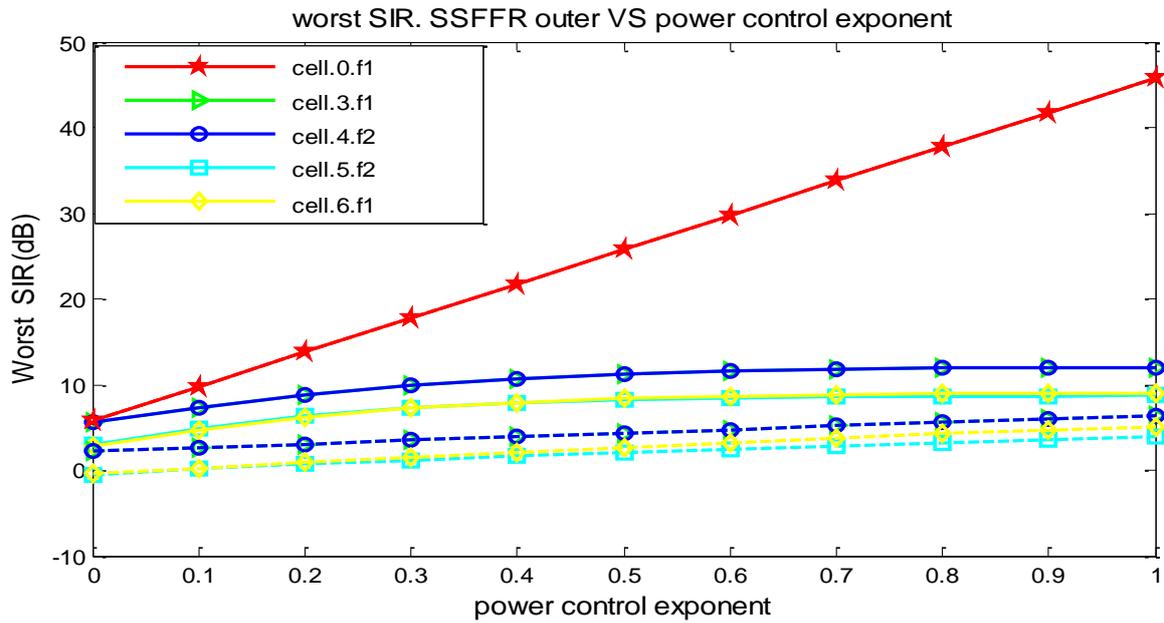


Figure 6(a). Worst SIR.SSFFR-outer vs Power control exponent; $r/R = 0.25$ (lines), $r/R = 0.75$ (dotted line)

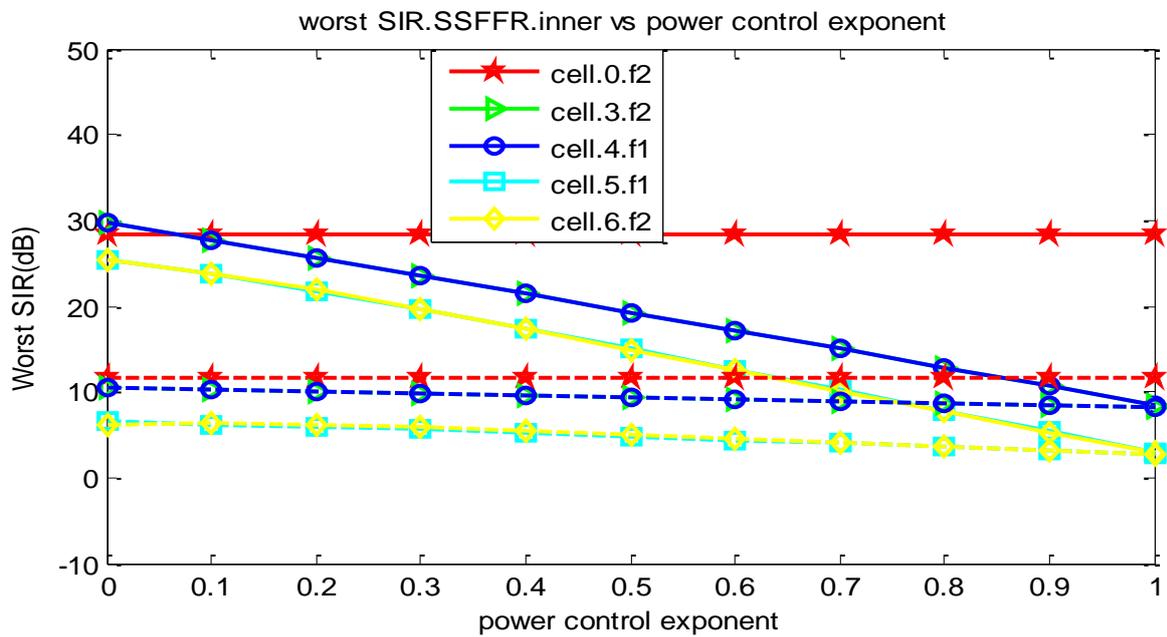


Figure 6(b). Worst SIR.SSFFR-inner vs Power control exponent; $r/R = 0.25$ (lines), $r/R = 0.75$ (dotted line)

Figure 7 shows average per-cell worst SIR (outer, inner) with pathloss exponent to compare between SSFFR and SFFR under the same condition. It is clear that outer SSFFR has the highest values of SIR while outer SFFR has the lowest values. It is clearly that SSFFR is able to enhance the cell edge transmission. On the other hand, Inner SFFR is better than SSFFR.

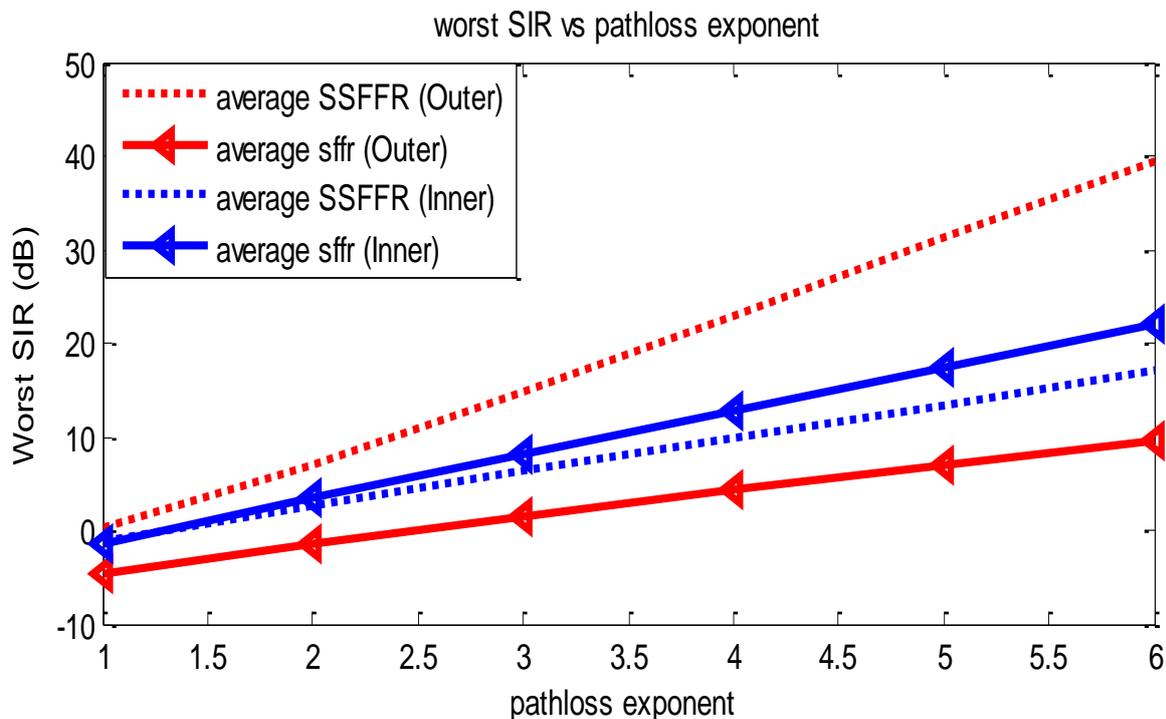


Figure 7. Worst SIR for all cells vs Pathloss exponent

Figure 8 shows CDF of call drop with average per-cell SIR (outer, inner) to compare between SSFFR and SFFR under the same condition. The reason behind using CDFs is to present the whole system performance regardless of the location of the user. The outer SSFFR is better than outer SFFR, due to the different distribution of sectorization for the same band (frequency) in each cell and the large distance between any interfering mobile and home eNB all of them are the main reason behind the less amount of co channel interference facing the outer users, while the inner SFFR is better than inner SSFFR because of the decreased co-channel interference from adjacent cells resulted from decrease interfering transmitted power for all interfering mobile (all of them are located in inner region and transmit inner power)

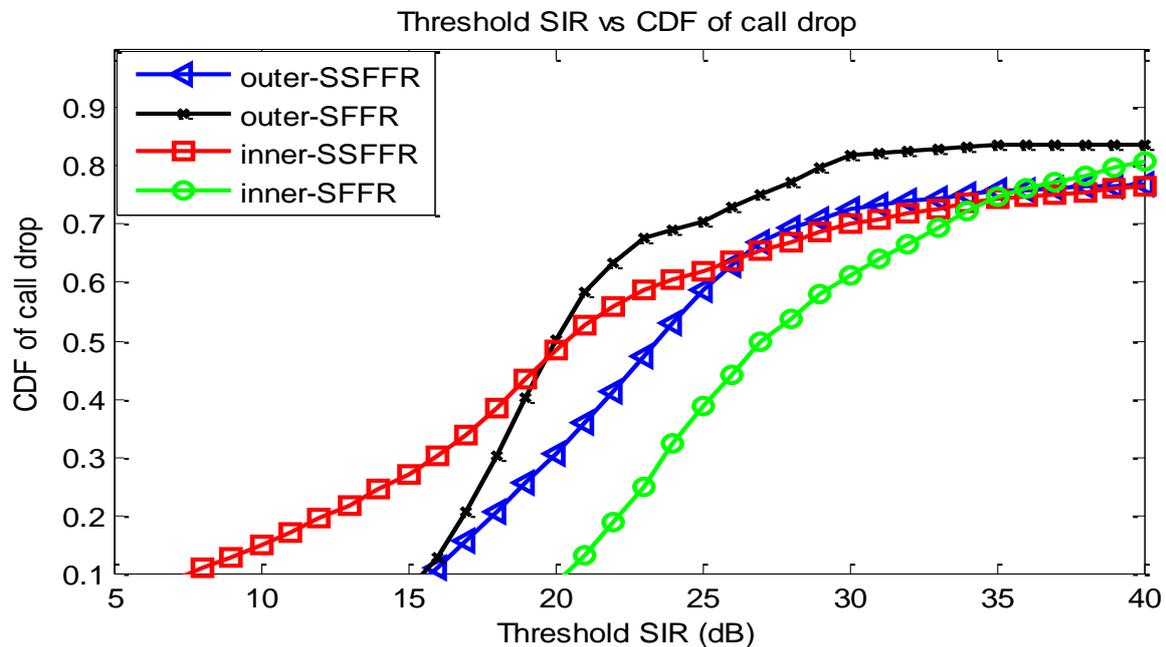


Figure 8. CDF vs threshold SIR

5. Conclusion

This paper proposed a hybrid Soft Sectored Fractional Frequency Reuse (SSFFR). It has no co-channel interference within the cell in addition to that it is able to decrease the adjacent cell sectors interference and consequently it is a great solution for the tradeoff between soft FFR and sectorized FFR. Simulation results show that the worst SIR depends on power control exponent, the path loss exponent, and the ratio of inner to outer radius. SFFR has been evaluated as a type of FFR in comparison with SSFFR. It is found that SSFFR is better than SFFR for outer region so it can enhance both the cell edge and adjacent sector transmission performance through interference management but these come at the cost of decreasing the SIR of inner region. Interference management using SSFFR for Device to Device will be a future work.

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