Comparative Performance Evaluation of ICI Avoidance Frequency Reuse Techniques in OFDMA Cellular Downlink

Virpartap Singh
E.C.E Department
Punjab institute of technology, Kapurthala
Punjab, India
singhvirpartap@india.com

Gagandeep Kaur
E.C.E. Department
Punjab institute of technology, Kapurthala
Punjab, India
Gags_chemma1989@yahoo.co.in

***Abstract*—Orthogonal Frequency Division Multiple Access (OFDMA) technique is extensively deployed in existing and next generation cellular networks to reduce the intra cell interference and improve average network throughput. However, in OFDMA cellular networks Intercell Interference (ICI) still poses a real challenge that limits the system performance, especially for users located at the cell edge. Emerging technologies include multicarrier systems such as LTE and WiMAX for which effective management of intercell interference is of supreme concern in order to improve the performance of cell edges user. Hence, ICI avoidance is of paramount weightiness in dispose to enrich cell edge throughput. In this paper, we study the performance of ICI avoidance frequency reuse techniques in forthcoming OFDMA-based systems. We first develop a mathematical model for the calculation of Signal to Interference Noise Ratio (SINR) for each user in the cell and then calculate the throughput using the Shannon's formula. The allocation of transmit power and subcarriers to each cell in these techniques are fixed prior to network deployment. This limits the potential performance of these frequency reuse techniques. The simulation results show the comparative study of Reuse 1, Reuse 3, FFR and SFR in both cell center and cell edge performance.**

***Index Terms*—OFDMA Resource Allocation, Long Term Evolution (LTE), LTE Advanced (LTE-A), Frequency Reuse Technique.**

I. INTRODUCTION

The tremendous growth of mobile user data rate necessities on multimedia applications requires ever increased system capacity and wireless spectrum. The wireless spectrum to the systems is costly and limited. Thus high system capacity or spectrum efficiency has been the main design criterion for the next generation wireless cellular networks, such as 3GPP Long-Term Evolution (LTE) and LTE Advanced (LTE-A) [1],[2]. The downlink of both LTE and LTE-A is based on Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA technology has been widely applied in existing and next generation cellular networks, such as WiMAX and 3GPP LTE [1], [2]. Although intra-cell interference is avoided by orthogonal subcarrier allocation among users in each cell in OFDMA networks, inter-cell interference (ICI) exists when frequency bands are reused among different cells. The cell edge users are more susceptible to this inter-cell interference because, in addition to the high path loss, multiple strong interferences exist from nearby cells.

The aim is to efficiently use the available spectrum, which is achieved with a frequency reuse factor of 1 that is reusing the whole spectrum in each cell. This is called frequency reuse one approach (Reuse-l), since a band is reused over and over again across the cells. By using the same bands in different cells, the available spectrum can be reused, thereby improving spectral efficiency. However, a frequency reuse factor (FRF) of 1 certainly causes considerable intercell interference (ICI) by the signals transmitted on the same frequency from adjacent cells. In particular, the users at the cell edge experience high ICI. It is shown in [3] that higher frequency reuse improves average network throughput but reduces cell-edge throughput due to severe ICI.

To alleviate this problem, different interference mitigation techniques have been studied. According to standards and literature ICI techniques are categorized as: ICI cancellation, ICI randomization and ICI co-ordination/avoidance. In ICI cancellation the interference management is performed by detecting and subtracting the interfering signals from the desired signal [7]. In ICI randomization techniques, the interfering signals are randomized by cell-specific scrambling, cell-specific interleaving and frequency hopping to suppress interference and achieve frequency diversity gain [9]. In ICI avoidance techniques the principle of coordinating resource allocation between cells, the allocation of various system resources to users is controlled to avoid interference and improve SINR and system capacity [7], [8].

The fractional frequency reuse (FFR) scheme has recently been proposed as an inter-cell interference coordination (ICIC) technique in OFDM-based fourth generation (4G) wireless standards such as IEEE 802.16m [4] and 3GPP-LTE Release 8, with the aim to improve the performance of the cellular network by having each cell allocate its resources (e.g., time, frequency, and power) in a way in which ICI in the network is minimized [6]. The basis of the FFR scheme is to partition a cell into two or more regions: a cell centre region with lower ICI due to large separation distance between the user and interfering base station and a cell edge region, experiencing a higher ICI. Therefore, the cell center region is able to have a lower FRF while higher FRF for cell center region.

In this paper, we will compare the performance of four different frequency reuse techniques: reuse 1, reuse 3, fractional frequency reuse and soft frequency reuse. This paper presents a comprehensive assessment of ICI avoidance techniques, and evaluates the cell-edge, cell-center, and overall performance of the system in terms of the SINR, and throughput by adjusting different input parameters.

The remainder of this paper is organized as follows. In section II, the different frequency reuse technique in OFDMA cellular systems are discussed. In Section III the general system model is presented. Section IV includes cell partitioning and resource allocation. In section V simulation results are computed. Section VI eventually concludes the paper.

II. STATIC FREEQUENCY REUSE TECHNIQUES

A. REUSE-1

The simplest approach for efficient utilization of spectrum in a cellular OFDMA system is to use the whole available frequency spectrum in each cell within a network, frequency reuse factor (FRF) of 1. In this approach the entire available frequency spectrum is reused in each cell with equal power levels in their sub-carriers. Fig.2 shows the 7 cell layout with reuse-1 approach.

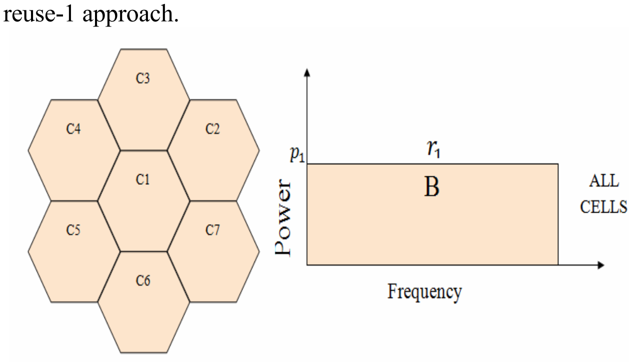

Figure 2: Reuse-1

Reuse-1 approach targets higher spectrum efficiency and system capacity by reusing the available frequency spectrum in all cells. However reuse-1 suffers from worst case of inter-cell interference levels. This interference reduces the SINR of users thus limiting the spectral efficiency and capacity of the users, especially which are located at the edges of cell.

B. REUSE-3

The inter-cell interference problem that occurs in reuse-1 is addressed by the frequency reuse-3 approach; that uses frequency reuse factor (FRF) of 3. In this approach the available frequency band is split into three orthogonal sub-bands (see fig.3). The adjacent cells use different frequency band to avoid interference to users in their respective cells.

Reuse-3 approach provides improved inter-cell interference. However, in this approach frequency spectrum is underutilized, only a part of the available spectrum is used by cell. This in turn will reduce the spectral efficiency and capacity of the system.

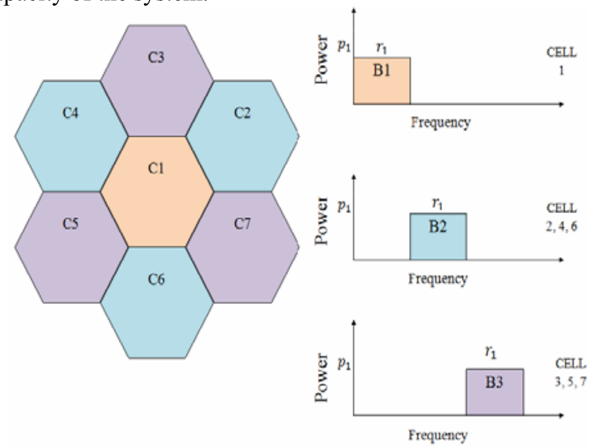

Figure 3: Reuse-3

Similarly Reuse-n approach can applied in the network, where n is FRF and described as, $n = i^2 + ij + j^2$ for $i, j \in N$.

Reuse-n provides improved ICI by increasing the FRF. In this approach each cell will have only a part of the available spectrum, thus interference avoidance comes at the cost of frequency spectrum [10].

C. FRACTIONAL FREQUENCY REUSE

To overcome the limitations of reuse-1 and reuse-3 i.e. low user throughput for users situated at the cell boundaries, fractional frequency reuse (FFR) approach is proposed. In FFR approach the whole spectrum is partitioned into two groups; the major group and minor group. The major group serves the cell center users with FRF of 1 and minor group serves the cell edge users with FRF of 3 [11] (see Fig.4).

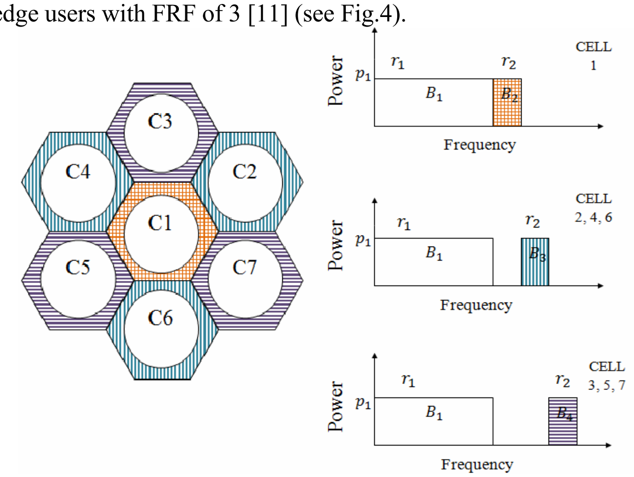

Figure 4: FFR

FFR approach is shown in Fig.4. As a result of splitting the spectrum for the major and minor regions of a cell so that the cell center users does not share any spectrum with the cell edge users, significant reduction in ICI, Particularly for users situated at the cell boundaries. However, the spectrum is underutilized in FFR approach since the users at the cell boundaries can only use a part of the total spectrum [12]. In addition, the implementation of a reuse factor at a cell edge results in lower system throughput.

D. SOFT FREQUENCY REUSE

Soft frequency reuse (SFR) approach has been proposed as an alternative for FFR approach [14]. In SFR the available frequency spectrum can be reused in each cell within a network. The cell is divided into two regions, major and minor regions. The major region subcarriers can serve the users located in both major and minor cell regions and in adjacent cells these sub-carriers are orthogonal. SFR approach is shown in Fig.6.

The minor region subcarriers have high power level than major group subcarriers in a cell and are used in adjoin cells only by major cell users with low power level. The ratio between major and minor region subcarrier transmit powers is referred to as power ratio [20].

SFR reduces inter-cell interference without reducing spectrum efficiency. SFR approach uses the whole spectrum in each cell thus increases the system capacity compared to that of PFR. The cell edge throughput achieved is better.

III. SYSTEM MODEL

The downlink transmission in OFDMA cellular network, for a user *u* using a resource block *b*, the associated Signal to Interference plus Noise Ratio (SINR) is given as

$$SINR_{u,b} = \frac{P_b^s \cdot G_b^s}{\sigma^2 + \sum_{i \in IC} P_b^i \cdot G_b^i}$$

Where P_b^s is the transmit power of the serving cell base station *s* on resource block *b*, G_b^s is the channel gain between user *u* and the serving base station *s*, and σ^2 is the thermal noise power. The set *IC* represents all the interfering base stations, i.e. base stations that are using the same resource block as user *u*. The number of interfering cells differs depending on the type of technique used. P_b^i is the transmit power of the interfering cell base station *i* on resource block *b*, G_b^i is the channel gain between user *u* and the serving base station s In this paper we consider only the path loss and small scale fading for simplicity. The channel gain is composed of the path loss between the base station and user *u* and is given as $PL[dB] = 137.3 + 35.2log10(d)$, where *d* is the distance, measured in kilometers, between a user and the center of the serving or interfering cell [15].

To calculate the user throughput Shannon's equation is used. Where $T_{u,b}$ is throughput of user *u* on resource block *b* with bandwidth *W*, and $SINR_{u,b}$ is the SINR of user *u* on *b*. and is given as

$$T_{u,b} = W.\log_2\left(1 + SINR_{u,b}\right)$$

For total number of users N in the network and K the total number of resource blocks. The overall system throughput can be expressed as

$$T_{total} = \sum_{u=1}^{N} \sum_{b=1}^{K} T_{u,b}$$

IV. CELL PARTIONING AND RESOURCE ALLOCATION

In this work, we focus on the OFDMA cellular system downlink. The given bandwidth is split into sub-carriers, each having sub-carrier spacing Δ f = 15 kHz. A resource block (RB) is the smallest resource assigned by a scheduler of a base station. An RB consists of 12 sub-carriers, therefore it has a total size of W = 180 kHz in the frequency domain and 0.5ms in the time domain. The more RBs a user gets, the higher the bit rate. A scheduling mechanism decides how many RBs a user gets at a given time.

One of the most important FFR system design parameters is the interior radius *r*, which determines the size of the frequency partitions. Additionally, since the cell partitions are based on the geometry of the network, knowledge of user locations is important. One practical method to determine user classifications is for each cell, the distance of the user from its base station. The base station then classifies users with distance grater than a pre-determined threshold as edge users, while users with distance lesser than the threshold are classified as interior users.

The total number of RBs available for a given cell varies according to the technique used. If K denotes the total RBs of an OFDMA system, then for Reuse-1, $K_c = K$. For Reuse-n, $K_c = \frac{K}{n}$. The number of RBs is proportional to the inner radius of a cell for FFR and SFR. The inner radius is used to distinguish between cell-center users and cell-edge users, and is given as $r = \alpha R$, where R is the radius of the cell, and α is ratio of the inner radius and the cell radius (0 < α < 1).

The number of inner and outer RBs for FFR can be determined as

$$K_{in} = K.\left(\frac{r}{R}\right)^2 \text{, and } K_{out} = \frac{K - K_{in}}{n}$$

Similarly for systems employing SFR,

$$K_{in} = K.\left(\frac{r}{R}\right)^2 \text{, and } K_{out} = K - K_{in}$$

For Reuse-1, the total number of RBs available is K with P_T total transmitting power. The power is evenly distributed among all RBs i.e. all RBs share equal power and is given as

$P_t = {P_T}/{K}$

For Reuse-n, the total number of RBs available in a cell is $K_c = {K}/{n}$, and the transmitted power on each RB is given as $P_t = \frac{P_T}{K_c}$. For FFR, the total number of RBs available in a cell is the sum of inner RBs (K_{in}) and edge RBs (K_{out}), $K_c = K_{in} + K_{out}$ Transmitted power on each RB is given as $P_t = {P_T}/{K_c}$. In SFR, outer RBs and inner RBs transmit at different power levels. If the power on outer RBs is denoted as P_{out}, and the power on inner RBs is denoted as P_{in}, then each can be calculated as

$$P_{out} = \frac{n\, P_T}{N\left(1 + \beta(n-1)\right)}$$
$$P_{in} = \beta P_{out}$$

Where n is the reuse factor, and β is defined as the power ratio. The power ration f has a range $0 < \beta \leq 1$. If β = 1, the technique becomes a Reuse-1 scheme where all the RBs, inner and outer, transmit using the same power level.

Table 1: SYSTEM PARAMETERS

Parameters	value
System bandwidth	10 MHz
Total number of RBs	50
RB size	180 KHz
Sub-carrier spacing	15 KHz
Channel model	Rayleigh
Path loss model	137.3+35.2*log10(d), d in km
Shadow fading	Log normal with 8 dB std. Dev.
Thermal noise power density	-174 dBm/Hz
Base station transmit power	45 dBm
Cell coverage	1.40 Km

V. SIMULATION RESULTS

In this section, we compare the system performance of the ICI avoidance frequency reuse techniques Reuse 1, Reuse 3, FFR and SFR.

A. Simulation Setup

We consider an OFDMA cellular network with 19 hexagonal cells. The total bandwidth of the system is 10 MHz; the spectrum is divided into 50 RBs each having a bandwidth of 180 KHz. The total transmit power is set to 45 dBm. The radius of each hexagonal cell in OFDMA cellular network is 1.40 Km. In network each cell is assumed to have a base station with an omni directional antenna at the center of a cell. All the base stations are operated by the OFDMA technology. There are 100 users randomly deployed in each cell. The inner radius for FFR and SFR techniques is discussed in section IV.

B. Results and Discussion

The cumulative distribution functions (CDF) for the system throughput and SINR is plotted to compare the performance of the four techniques.

The cell edge user and cell center user throughput and SINR is compared for the four techniques under different inner radius r values. The exterior radius R=1.40 Km is fixed and the inner radius r is varied and three different cases are presented. The values of r considered in this paper are 1.00 Km, 0.90 Km and 0.80 Km.

In Figure 5 and Figure 6 the comparison of the cumulative distribution functions (CDF) of the cell center throughput and cell edge throughput for the four techniques is shown with r=1.00 Km. Figure 7 and Figure 8 display the comparison of the cumulative distribution functions (CDF) of the cell center SINR and cell edge SINR for the four techniques respectively.

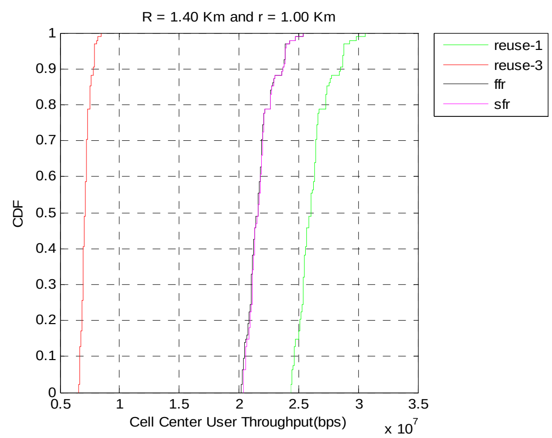

Figure 5: Cell center Throughput comparison for R=1.40 Km and r=1.00 Km

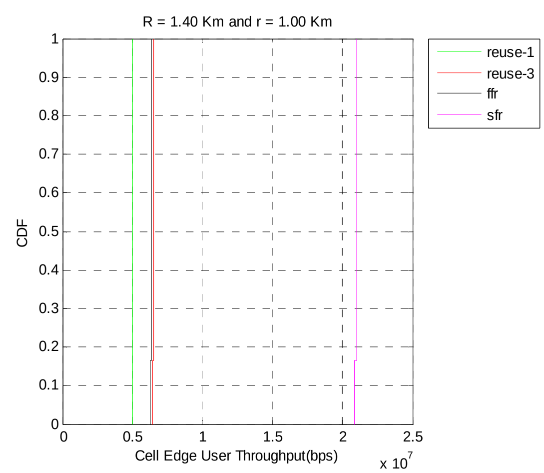

Figure 6: Cell Edge Throughput comparison for R=1.40 Km and r=1.00 Km

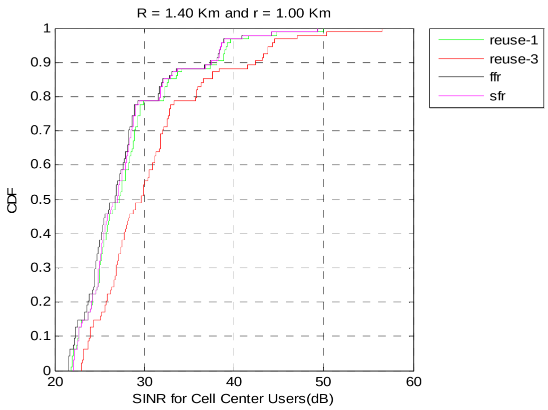

Figure 7: Cell Center SINR comparison for R =1.40 Km and r=1.00 Km

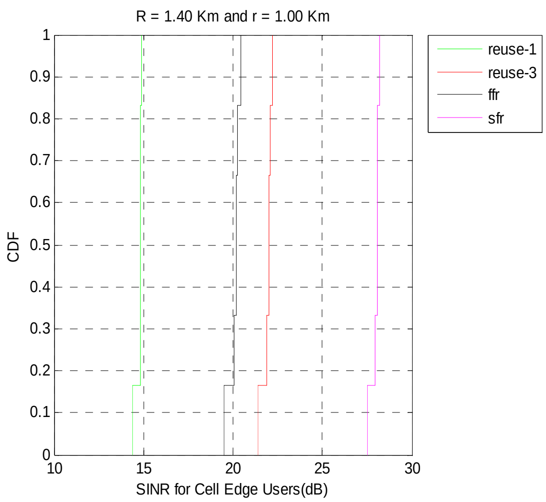

Figure 8: Cell Edge SINR comparison for R=1.40 Km and r=1.00 Km

In Figure 9 and Figure 10 the comparison of the cumulative distribution functions (CDF) of the cell center throughput and cell edge throughput for the four techniques is shown with r=0.90 Km. Figure 11 and Figure 12 display the comparison of the cumulative distribution functions (CDF) of the cell center SINR and cell edge SINR for the four techniques respectively.

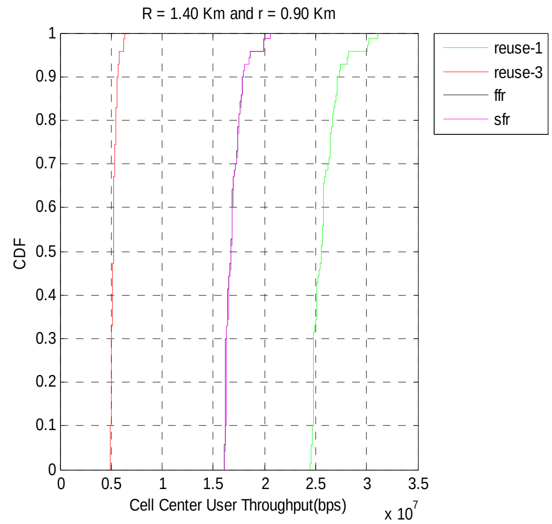

Figure 9: Cell center Throughput comparison for R=1.40 Km and r=0.90 Km

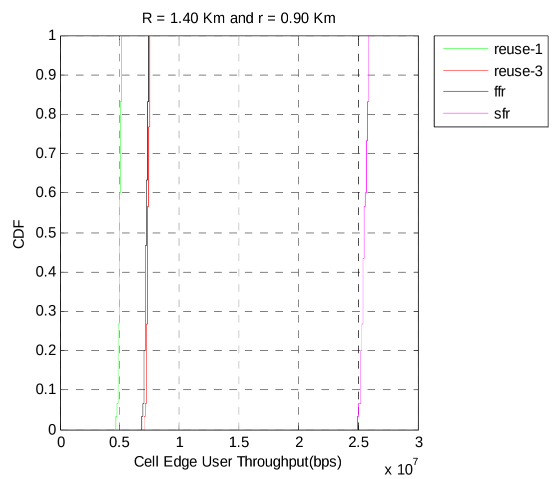

Figure 10: Cell edge Throughput comparison for R=1.40 Km and r=0.90 Km

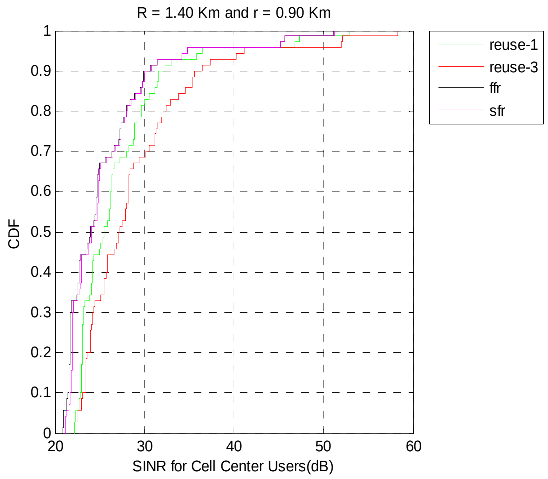

Figure 11: Cell Center SINR comparison for R =1.40 Km and r=0.90 Km

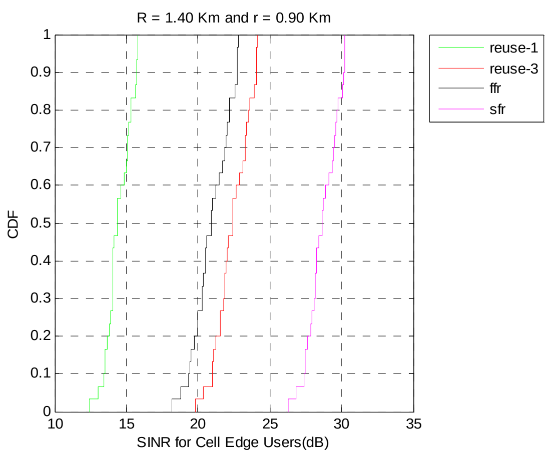

Figure 12: Cell edge SINR comparison for R =1.40 Km and r=0.90 Km

In Figure 13 and Figure 14 the comparison of the cumulative distribution functions (CDF) of the cell center throughput and cell edge throughput for the four techniques is shown with r=0.80 Km. Figure 15 and Figure 16 display the comparison of the cumulative distribution functions (CDF) of the cell center SINR and cell edge SINR for the four techniques respectively.

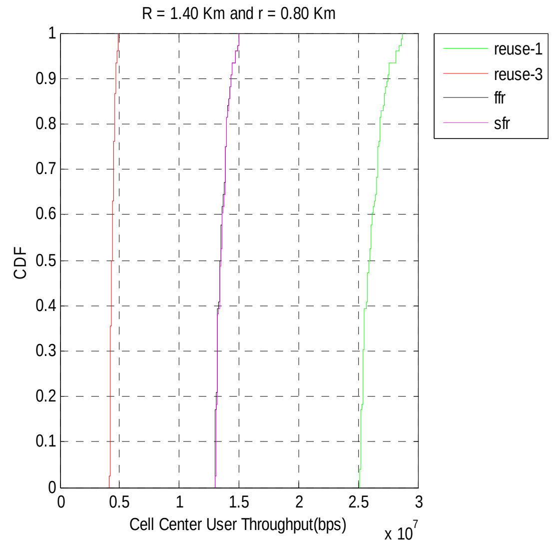

Figure 13: Cell center Throughput comparison for R=1.40 Km and r=0.80 Km

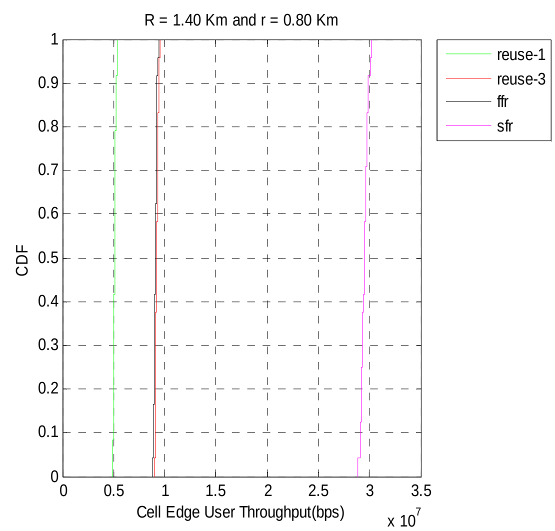

Figure 14: Cell edge Throughput comparison for R=1.40 Km and r=0.80 Km

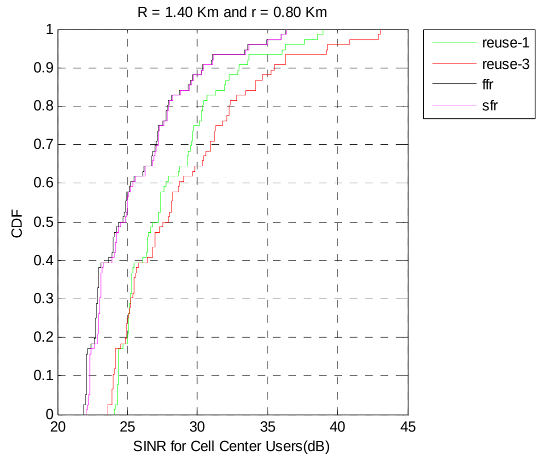

Figure 15: Cell Center SINR comparison for R =1.40 Km and r=0.80 Km

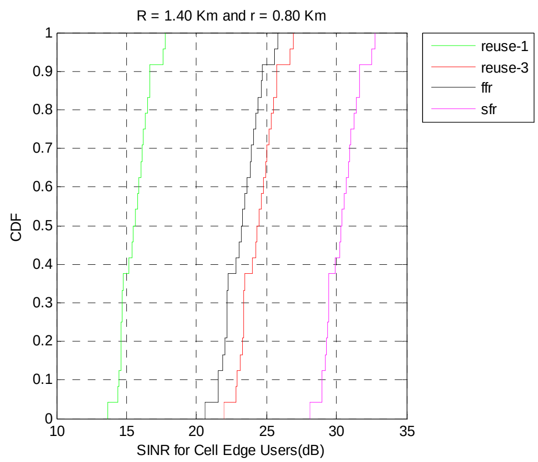

Figure 16: Cell edge SINR comparison for R =1.40 Km and r=0.80 Km

VI. CONCLUSION

In this paper we presented a comparative performance evaluation of the ICI avoidance techniques in OFDMA cellular downlink. Simulation results showed that reuse-1 suffers the most inter cell interference while the lowest in reuse-3. The cell center throughput and cell edge throughput results show that the Soft Frequency Reuse technique outperforms the Fractional Frequency Reuse technique. SFR has the highest SINR value among the other ICI avoidance techniques. SFR provides the greatest overall network throughput and highest cell edge user SINR, SFR balances the requirements of interference reduction and resource efficiency.

REFERENCES

[1] E-UTRA and E-UTRAN Overall description; stage2 (Release 8) 3GPP Technical Specification TS 36.300 V8.12.0.

[2] Requirements for future advancement for E-UTRA (Release 9) 3GPP Technical specifications TS 36.913 V9.0.0.

[3] Hujun Yin, Siavash Alamouti, “OFDMA: A Broadband Wireless Access Technology” Intel Cooperation 2200 Mission College Blvd, Santa Clara, CA 95054.

[4] S. Sesia, I. Tou fik, and M. Baker, “LTE-The UMTS Long Term Evolution: from theory to practice,” Wiley publishing, 2009.

[5] G. Fodor, Ch. Koutsimanis, A. Rcz, N. Reider, A. Simonsson, and W. Mller, “Inter-cell Interference Coordination in OFDMA Networks and

[6] in the 3GPP Long Term Evolution System,” Journal of Communications, vol. 4, no. 7, pp. 445-453, 2009.

[7] G. Andrea, Wireless Communications. New York: Cambridge University Press, 2005.

[8] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, S. Vrzic, “Interference coordination and cancellation for 4G networks”, IEEE Commun. Mag., vol.47, no.4, pp.74-81, Apr. 2009.

[9] M. Necker, “Interference Coordination in Cellular OFDMA Networks,” IEEE Network, vol.22, no.6, pp.12-19, Dec. 2008.

[10] 3GPP R1-060291, “OFDMA Downlink inter-cell interference mitigation,” Nokia, 2006.

[11] R. Y Chang, Z. Tao, J. Zhang, and C.-c. J. Kuo, "Dynamic fractional frequency reuse (D-FFR) for Multicell OFDMA networks using a graph framework," Wireless Communications and Mobile Computing, vol. 13, no. 1, pp. 12-27, 2013.

[12] M. Sternad, T. Ottosson, A. Ahlen, and A. Svensson, "Attaining both coverage and high spectral efficiency with adaptive OFDM downlinks," in Vehicular Technology Conference, 2003. VTC 20OJ-Fall. 2003 IEEE 58th, vol. 4, 2003, pp. 2486-2490 Vol.4.

[13] Ericsson, "R 1-0S0764: Inter-cell interference handling for E-UTRA," 3GPP TSG RA WG] Meeting #42, 2005.

[14] Samsung, R1-051341: Flexible Fractional Frequency Reuse Approach, 3GPP, Nov 2005, RAN WG1 Meeting 43: Korea.

[15] Huawei,"RI-0S0S07: Soft frequency reuse scheme for UTRAN LTE," 3GPP TSG RA WG] Meeting #42, May 2005.

[16] X. Zhang, C. He, L. Jiang, and J. Xu, “Inter-cell interference coordination based on softer frequency reuse in OFDMA cellular systems,” in Proc. 2008 Int. Conference on Neural Networks and Signal Processing, pp. 270–275.

[17] E. Haro, S. Ruiz, D. Gonzalez, M. Garcia-Lozano, and J. Olmos, “Comparison of Different Distributed Scheduling Strategies for Static/Dynamic LTE Scenarios,” Technical University of Wien, 2009.

[18] K. T. Kim and S. K. Oh, “An Incremental Frequency Reuse Scheme for an OFDMA Cellular System and Its Performance,” in Proc. IEEE Vehicular Technology Conf. VTC Spring 2008, 2008, pp. 1504-1508.

[19] Ki Tae Kim, Seong Keun Oh, Min Lee; “An Improved Incremental Frequency Reuse Technique Employing Maximally Orthogonal Fundamental Segments” Personal, Indoor and Mobile Radio communications, 2009 IEEE.

[20] Z. Xie and B. Walke, “Resource allocation and reuse for inter-cell interference mitigation in OFDMA based communication networks,” in Proc. 5th Annual ICST Wireless Internet Conf. (WICON), 2010, pp. 1-6.

[21] X. Yang, “A Multilevel Soft Frequency Reuse Technique for Wireless Communication Systems” IEEE Communications Letters, Vol. 18, N O. 11, November 2014.

[22] Manli Qian, Wibowo Hardjawana, Yonghui Li, Branka Vucetic, Xuezhi Yang,and Jinglin Shi, “Adaptive Soft Frequency Reuse Scheme for Wireless Cellular Networks” IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 64, N O . 1, JANUARY 2015.