

Inter-Cell Interference Avoidance Techniques in OFDMA based Cellular Networks: A Survey

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Abstract – Orthogonal Frequency Division Multiple Access (OFDMA) technique is extensively deployed in existing and next generation cellular networks to reduce interference and improve average network throughput. The OFDMA cellular network suffers from inter-cell interference (ICI) and the users found at the cell boundaries are more prone from ICI problem. Effective management of ICI is of paramount importance in order to improve cell edge throughput. Inter-cell interference avoidance is a method to improve the overall performance of the network. This paper surveys key issues in managing interference by using static frequency reuse techniques and provide a summary of the current developments of an efficient interference avoidance technique to reduce ICI in OFDMA based cellular networks.

Index Terms – OFDMA; Frequency Reuse; Inter Cell Interference Coordination (ICIC); Long Term Evolution (LTE); LTE Advanced (LTE-A).

1. 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].

OFDMA also referred to as multiuser-OFDM, is being considered as the multiple access method for next generation cellular networks to deliver high level of spectral efficiency over wideband channels [3]. The intra-cell interference in the network is avoided by orthogonal subcarrier allocation among users in each cell. As frequency bands are reused among different cells in a network, therefore ICI exists and the users situated at the cell boundaries are more prone to inter-cell interference due to the existence of multiple interferences from close by cells.

In the downlink of emerging cellular systems such as LTE and LTE-A [1], [2], the OFDMA technology was preferred to diminish the effect of interference and to proficiently meet their high performance necessities. An OFDMA system divides the wireless spectrum into a number of channels and each channel is further divided into a number of consecutive

orthogonal OFDM sub-channels [4]. Basic structure of frames in OFDMA systems is shown in fig.1. The intra-cell interference present in the system is condensed to a huge extent by the orthogonality of sub-channels. Time is divided into slots consisting of few consecutive OFDM symbols. Resource block (RB) is the smallest resource unit that can be allocated to a user. In time domain, one time slot is a single channel RB. The number of consecutive time slots forms a frame and a number of consecutive frames form a super frame. The allocation of RBs to a single user at a time is application dependent. In a given cell, each resource block is assigned utterly to one user at any time. However, the same RB can be reused by adjoining cells for different users [5].

Even with almost no intra-cell interference, ICI still present a huge challenge, caused by collision between the RBs [5]. That limits the overall system performance, in particular for the cell edge users.

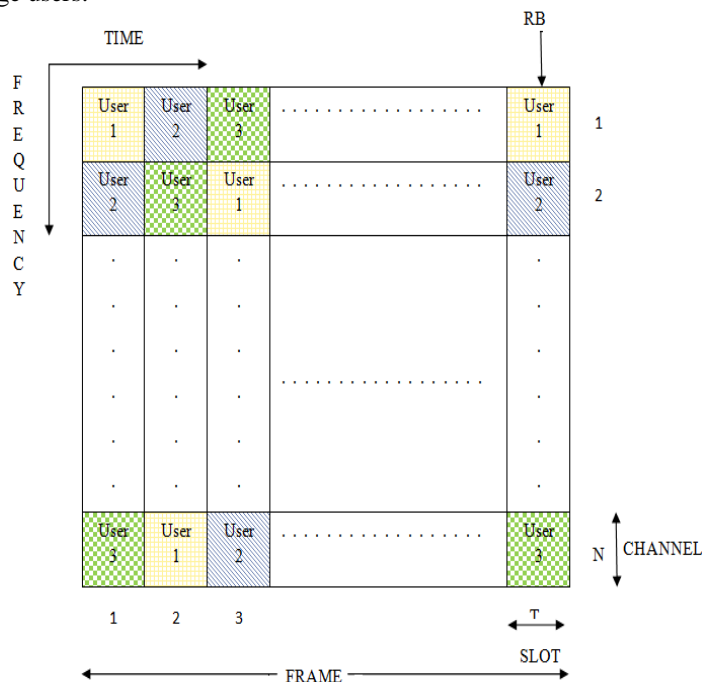


Figure 1: Basic Structure of Frames in OFDMA system.

Rest of the paper is arranged as follows. Section II describes system model for OFDMA cellular network; defining the essential parameters required for representation of inter-cell interference avoidance techniques. In Section III various inter-cell interference (ICI) avoidance techniques are explained. In Section IV comparison between various ICI techniques is evaluated and section V concludes the paper.

2. SYSTEM MODEL

In this paper we consider a hexagonal multi-cell OFDMA cellular network with C cells and K users. The total system frequency spectrum B MHz with N sub-carriers divided into a number of non-overlapping orthogonal frequency bands. In each the base station is placed at the center of the cell with transmit power P , serving a set of users within each cell.

Basic parameters used to develop the system model are as follows:

- $C = \{c_1, c_2, c_3, c_4, c_5, c_6, c_7\}$: The set of cells in a network.
- $B = \{B_1, B_2, B_3, \dots, B_i\}$: The set of channels (sub-bands) that compose the frequency spectrum in each cell.
- $P = \{p_1, p_2, p_3, \dots, p_q\}$: The set of power levels used within the sub-bands of a cell. Where $p_1 < p_2 < p_3 < \dots < p_q$.
- $R = \{r_1, r_2, r_3, \dots, r_s\}$: The set of concentric rings that compose the cell. Where $r_1 < r_2 < r_3 < \dots < r_s$.

All the static frequency reuse based approaches have to specify:

- The set of concentric rings that compose a cell, region in which the cell is divided (major region or minor region).
- The set of channels used in a cell.
- The region in which these set of channels is used.
- The transmit power at which each channel is working in a cell.

Thus, frequency reuse approach can be described using above parameters.

3. INTER-CELL INTERFERENCE AVOIDANCE TECHNIQUES

The spectrum available to the system is limited. Maximum system capacity is achieved when all the cells in a given coverage area uses all set of available channels, that is the use of same frequency bands in all the cells. In a network there are several cells that use the same set of frequency bands are called co-channel cells and the interference during transmission among signals from these cells is called co-channel interference or inter-cell interference (ICI) [6], [7]. According to standards and literature ICI techniques are

categorized as: ICI cancellation, ICI randomization and ICI coordination/avoidance. In ICI cancellation the interference management is performed by detecting and subtracting the interfering signals from the desired signal or by employing multi-user detection at the receiver to select 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 ICI problem can be treated by intelligent resource allocation, to control the use of frequencies over various channels in the network and the power levels between users in different cell regions. Various ICI avoidance techniques are as follow:

3.1. 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. The reuse-1 approach can be described as follows:

$$B = \{B_1\}, R = \{r_1\}, P = \{p_1\}.$$

All 7 cells in a network are identical, hence expressed as follows:

$$c_1 = c_2 = c_3 = c_4 = c_5 = c_6 = c_7 = \{B(p_1, r_1)\}.$$

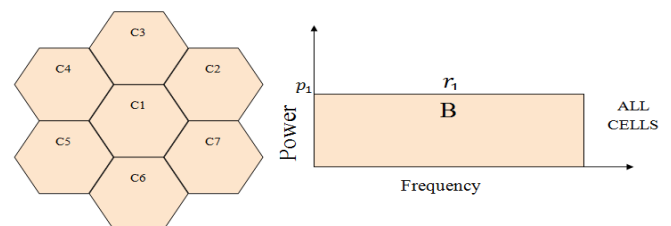


Figure 2: Reuse-1

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 edge of cells.

3.2. 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.

The parameters in this approach can be defined as:

$$B = \{B_1, B_2, B_3\}, R = \{r_1\}, P = \{p_1\}.$$

The 7 cells in a network can be expressed as follows:

$$c_1 = \{B_1(p_1, r_1), B_2(0,0), B_3(0,0)\}$$

$$c_2 = c_4 = c_6 = \{B_1(0,0), B_2(p_1, r_1), B_3(0,0)\}$$

$$c_3 = c_5 = c_7 = \{B_1(0,0), B_2(0,0), B_3(p_1, r_1)\}$$

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.

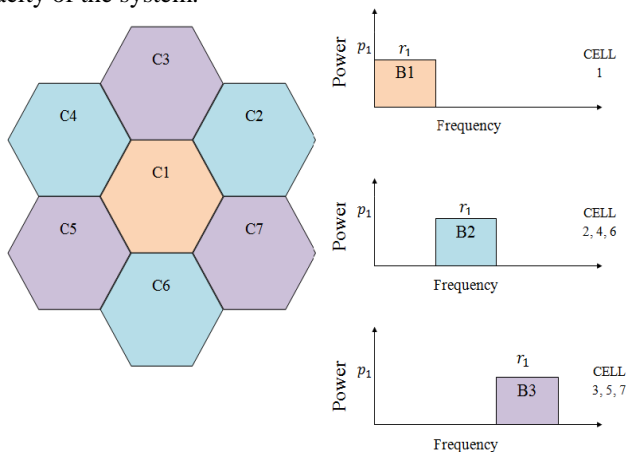


Figure 3: Reuse-3

This in turn will reduce the spectral efficiency and capacity of the system.

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

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].

3.3. 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).

FFR approach is shown in Fig.4. The parameters in FFR approach can be defined as:

$$B = \{B_1, B_2, B_3, B_4\}, R = \{r_1, r_2\}, P = \{p_1\}.$$

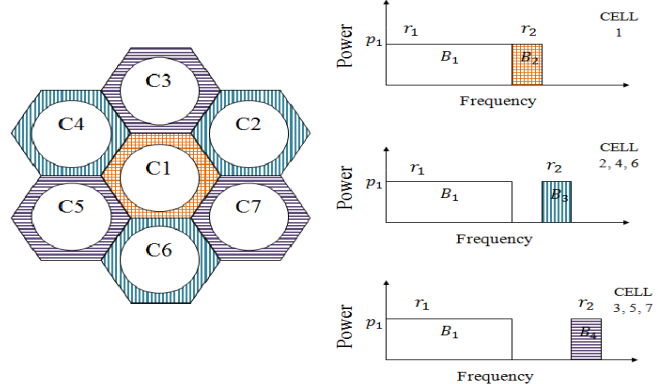


Figure 4: FFR

The 7 cells in a network can be expressed as follows:

$$c_1 = \{B_1(p_1, r_1), B_2(p_1, r_2), B_3(0,0), B_4(0,0)\}$$

$$c_2 = c_4 = c_6 = \{B_1(p_1, r_1), B_2(0,0), B_3(p_1, r_2), B_4(0,0)\}$$

$$c_3 = c_5 = c_7 = \{B_1(p_1, r_1), B_2(0,0), B_3(0,0), B_4(p_1, r_2)\}$$

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.

3.4. Partial Frequency Reuse

In partial frequency reuse (PFR) users at cell edge are fully protected from adjacent cells interference, hence known as FFR with full isolation [13]. In FFR, the idea is same as in PFR i.e. to apply FRF of 1 in the major region (cell center region) and FRF of 3 in the minor region (cell edge region) but the minor region sub-carriers are served with high power level. PFR approach is shown in Fig.5.

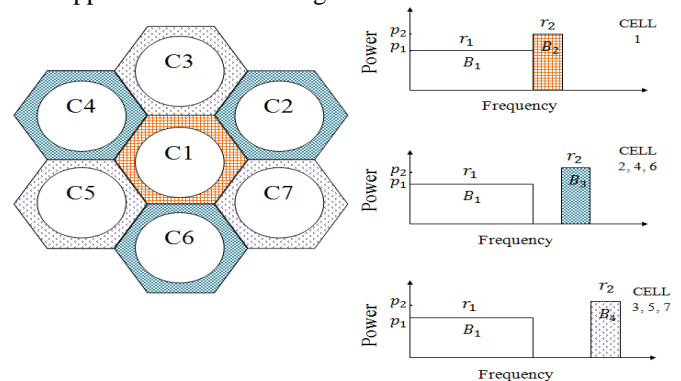


Figure 5: PFR

The difference between PFR and FFR is that in PFR the cell edge band (minor region) is transmitted with a higher power level whereas the cell center band (major region) is transmitted with a reduced power level. The parameters in PFR approach can be defined as:

$$B = \{B_1, B_2, B_3, B_4\}, R = \{r_1, r_2\}, P = \{p_1, p_2\}.$$

The 7 cells in a network can be expressed as follows:

$$c_1 = \{B_1(p_1, r_1), B_2(p_2, r_2), B_3(0,0), B_4(0,0)\}$$

$$c_2 = c_4 = c_6 = \{B_1(p_1, r_1), B_2(0,0), B_3(p_2, r_2), B_4(0,0)\}$$

$$c_3 = c_5 = c_7 = \{B_1(p_1, r_1), B_2(0,0), B_3(0,0), B_4(p_2, r_2)\}$$

PFR provides better ICI avoidance than FFR, as cell edge users are served with higher power levels as compared to cell center user, full isolation between adjacent cells. However, same problem is experienced in PFR as in FFR low cell edge throughput. Bandwidth is not fully utilized in each cell.

3.5. 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]. The parameters in SFR approach can be defined as:

$$B = \{B_1, B_2, B_3\}, R = \{r_1, r_2\}, P = \{p_1, p_2\}.$$

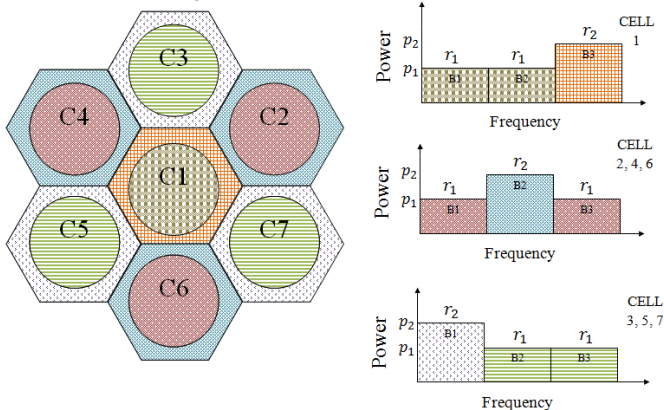


Figure 6: SFR

The 7 cells in a network can be expressed as follows:

$$c_1 = \{B_1(p_1, r_1), B_2(p_1, r_1), B_3(p_2, r_2)\}$$

$$c_2 = c_4 = c_6 = \{B_1(p_1, r_1), B_2(p_2, r_2), B_3(p_1, r_1)\}$$

$$c_3 = c_5 = c_7 = \{B_1(p_2, r_2), B_2(p_1, r_1), B_3(p_1, r_1)\}$$

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.

3.6. Soft Fractional Frequency Reuse

Soft fractional frequency reuse (SFFR) is an improved SFR approach. SFFR has been proposed to get better overall cell throughput [15]. In SFFR approach the whole spectrum is available in each cell. SFFR approach is more bandwidth efficient as it makes the use of frequency bands allocated to outer region in the inner region for different cells but with lower power level. SFFR approach is shown in Fig.7.

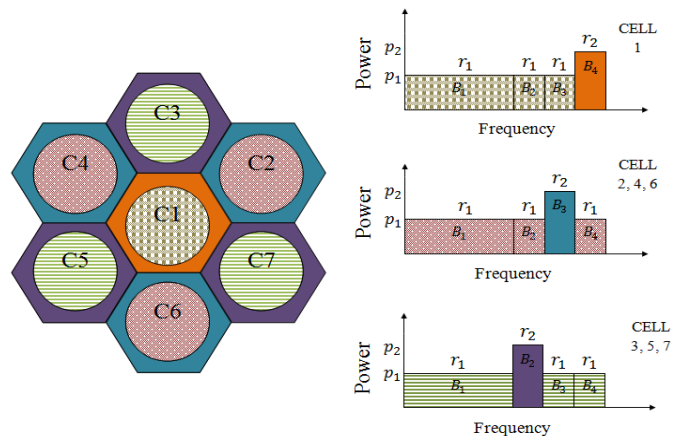


Figure 7: SFFR

SFFR and SFR are similar to each other as they both adopt varying power levels. Higher transmit power levels for the users situated in the cell minor region than that of cell major region users.

The parameters in SFFR approach can be defined as:

$$B = \{B_1, B_2, B_3, B_4\}, R = \{r_1, r_2\}, P = \{p_1, p_2\}.$$

The 7 cells in a network can be expressed as follows

$$c_1 = \{B_1(p_1, r_1), B_2(p_1, r_1), B_3(p_1, r_1), B_4(p_2, r_2)\}$$

$$c_2 = c_4 = c_6 = \{B_1(p_1, r_1), B_2(p_1, r_1), B_3(p_2, r_2), B_4(p_1, r_1)\}$$

$$c_3 = c_5 = c_7 = \{B_1(p_1, r_1), B_2(p_2, r_2), B_3(p_1, r_1), B_4(p_1, r_1)\}$$

In SFFR common sub-band is used for all cell center users, which increase the throughput of the cell center users. The transmit power level of cell center region does not have much impact on the overall system throughput. Whereas, the transmit power level in the minor region directly effects the throughput of that region and has inverse effect on the cell major region. As an outcome, cell edge region power level can be reduced according to necessities, while maintaining overall cell throughput [15].

3.7. FFR with multiple user class

In this approach different user classes are defined [16]. The cells are divided into number of concentric zones as shown in Fig.8, the whole spectrum available to each cell is divided into three sub-bands that are orthogonal to each other, served with three different transmit power levels.

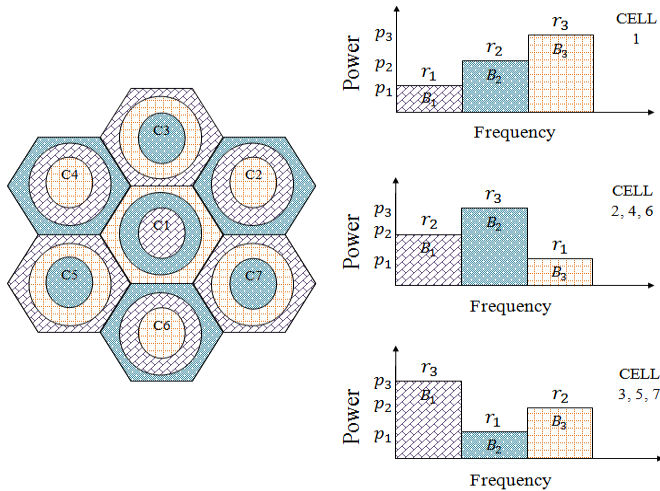


Figure 8: FFR with Multiple Classes

The parameters in this approach can be defined as:
 $B = \{B_1, B_2, B_3\}, R = \{r_1, r_2, r_3\}, P = \{p_1, p_2, p_3\}$.
 The 7 cells in a network can be expressed as follows:
 $c_1 = \{B_1(p_1, r_1), B_2(p_2, r_2), B_3(p_3, r_3)\}$
 $c_2 = c_4 = c_6 = \{B_1(p_2, r_2), B_2(p_3, r_3), B_3(p_1, r_1)\}$
 $c_3 = c_5 = c_7 = \{B_1(p_3, r_3), B_2(p_1, r_1), B_3(p_2, r_2)\}$

The cell center users are served with low power levels (p_1), cell middle users with power level (p_2) and cell edge user with higher power level (p_3). Increase in cell edge throughput as one third of the whole spectrum is available to cell edge users [19].

3.8. Incremental Frequency Reuse

In Incremental frequency reuse (IFR) the three adjoin cell-types in a network are considered. In this approach the resources are supplied by the three adjoin cell-types from distinct spots of the available frequency spectrum to their respective users [17].

Fig.9 shows a network with three cell-types (A, B, and C) of neighboring cells. In IFR approach the whole frequency spectrum is divided into 3 equal parts each containing one-third set of orthogonal sub-channels. First part is occupied by cells of type-A, then second by type-B and last segment by cells of type-C [17]. The succeeding sub-channels are allocated back to back along with the rise in traffic load until the entire frequency spectrum utilized [18].

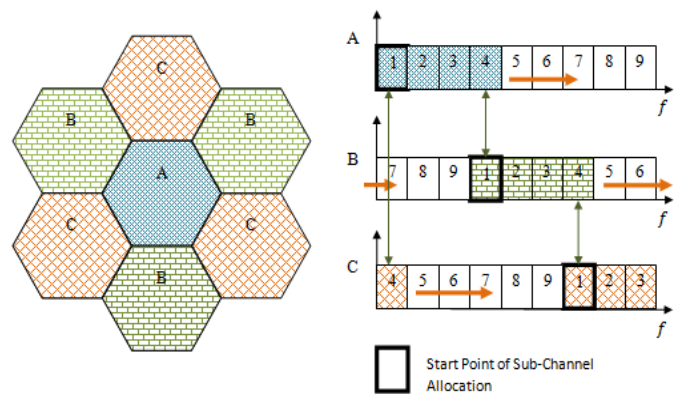


Figure 9: IFR

IFR reduces ICI effectively in case of low traffic load, thus enhances the system throughput. In a full traffic load situation, the IFR approach performs better over than the classical reuse approach. Hence, the spectral efficiency can be improved by IFR approach [17].

3.9. Enhanced Fractional Frequency Reuse

Enhanced fractional frequency reuse (EFFF) approach proposed in [19], [20], tries to heighten the system capacity particularly in case of heavy traffic load. EFFF was proposed to overcome the limitations of the SFR and IFR.

Fig.10. shows EFFF approach. In EFFF a network with three adjoin cell-types is defined and in each cell type a section of the frequency spectrum is reserved, called primary segment. The remaining sub-channels are called secondary segment [20].

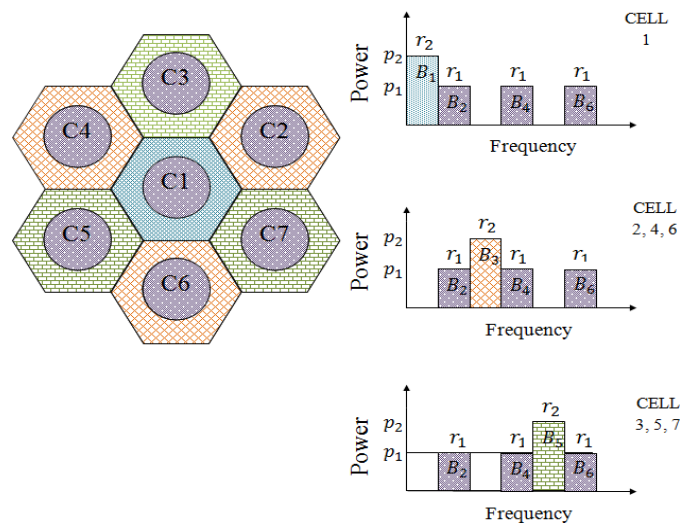


Figure 10: EFFF

The parameters in EFFF approach can be defined as follows:
 $B = \{B_1, B_2, B_3, B_4, B_5, B_6\}, R = \{r_1, r_2\}, P = \{p_1, p_2\}$.

The 7 cells in a network can be expressed as follows:

$$\begin{aligned}
 c_1 &= \{B_1(p_2, r_2), B_2(p_1, r_1), B_3(0,0), B_4(p_1, r_1), B_5(0,0), B_6(p_2, r_2)\} \\
 c_2 = c_4 = c_6 &= \{B_1(0,0), B_2(p_1, r_1), B_3(p_2, r_2), B_4(p_1, r_1), B_5(0,0), B_6(p_2, r_2)\} \\
 c_3 = c_5 = c_7 &= \{B_1(0,0), B_2(p_1, r_1), B_3(0,0), B_4(p_1, r_1), B_5(p_2, r_2), B_6(p_2, r_2)\}
 \end{aligned}$$

The primary segments between different cell-type are orthogonal; the primary segment of a cell-type is also available in secondary segment of other two cell-types.

For each cell-type the primary segment is divided in reuse-1 and reuse-3 part [19].

ICI is reduced as the adjoining cell in a network does not use reuse-3 part of the primary segment. An enhancement in the spectrum efficiency is expected by using inference awareness mechanism on the secondary segment.

3.10. Multi-Level Soft Frequency Reuse

Multi-level soft frequency reuse approach is proposed in [19], in which the whole frequency band is divided into several parts. On each part SRF-2 (Soft frequency reuse with 2 levels) is applied.

SRF-4 is shown in Fig.11. The frequency band is divided into six equal parts. In each cell four levels are defined; the frequency bands used in cell levels and the power at which the sub-channels are served [19].

The parameters in SFR-4 approach can be defined as:

$$\begin{aligned}
 B &= \{B_1, B_2, B_3, B_4, B_5, B_6\}, R = \{r_1, r_2, r_3, r_4\} \\
 P &= \{p_1, p_2, p_3, p_4\}
 \end{aligned}$$

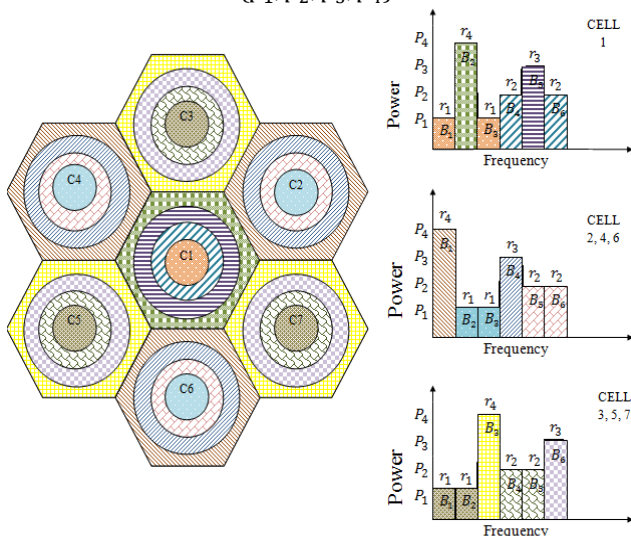


Figure 11: ML-SFR

The 7 cells in a network can be expressed as:

$$c_1 = \{B_1(p_1, r_1), B_2(p_4, r_4), B_3(p_1, r_1), B_4(p_2, r_2), B_5(p_3, r_3), B_6(p_2, r_2)\}$$

$$\begin{aligned}
 c_2 = c_4 = c_6 &= \{B_1(p_4, r_4), B_2(p_1, r_1), B_3(p_1, r_1), B_4(p_3, r_3), \\
 &B_5(p_2, r_2), B_6(p_2, r_2)\} \\
 c_3 = c_5 = c_7 &= \{B_1(p_1, r_1), B_2(p_1, r_1), B_3(p_4, r_4), B_4(p_2, r_2), \\
 &B_5(p_2, r_2), B_6(p_3, r_3)\}
 \end{aligned}$$

ML-SFR approach is a refinement of SFR-2, Improved cell and overall spectrum efficiency. This approach is a key candidate for the future OFDMA based cellular networks.

4. COMPARISON BETWEEN VARIOUS ICI AVOIDANCE TECHNIQUES

In this section comparison of various ICI avoidance techniques is evaluated. The parameters taken in consideration for comparison are overall system throughput and cell edge throughput.

ICI Avoidance Techniques	PARAMETERS	
	Overall system throughput	Cell edge throughput
Reuse-1	Lowest	Lowest
Reuse-3	Low	Low
FFR	Medium	Medium
PFR	Medium	High
SFR	High	Highest
SFFR	Highest	Medium
FFR with multiple user class	Medium	Highest
IFR	Medium	Medium
EFFR	High	High
ML-SFR	Highest	Highest

Table 1: INTER-CELL INTERFERENCE AVOIDANCE TECHNIQUES

5. CONCLUSION

In this paper we describe inter-cell interference (ICI) avoidance techniques for OFDMA cellular networks. Many frequency reuse techniques to diminish the effect of ICI are studied, that most likely mitigates the ICI by intelligent resource allocation of downlink such as frequency bands and transmits power resources. Frequency reuse techniques are suitable for networks with evenly distributed loads. In

practical no particular ICI avoidance technique is a best solution, the technique should be chosen according to the necessities of the network. Hence, it is required to choose the efficient interference avoidance technique that heightens both the overall and cell edge throughput of the system.

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. Toufik, and M. Baker, "LTE-The UMTS Long Term Evolution: from theory to practice," Wiley publishing, 2009.
- [5] G. Fodor, Ch. Koutsimanis, A. Racz, N. Reider, A. Simonsson, and W. Mller, "Inter-cell Interference Coordination in OFDMA Networks and in the 3GPP Long Term Evolution System," Journal of Communications, vol. 4, no. 7, pp. 445-453, 2009.
- [6] G. Andrea, Wireless Communications. New York: Cambridge University Press, 2005.
- [7] 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.
- [8] M. Necker, "Interference Coordination in Cellular OFDMA Networks," IEEE Network, vol.22, no.6, pp.12-19, Dec. 2008.
- [9] 3GPP R1-060291, "OFDMA Downlink inter-cell interference mitigation," Nokia, 2006.
- [10] 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.
- [11] 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 2003-Fall. 2003 IEEE 58th, vol. 4, 2003, pp. 2486-2490 Vol.4.
- [12] Ericsson, "R 1-0S0764: Inter-cell interference handling for E-UTRA," 3GPP TSG RA WG1 Meeting #42, 2005.
- [13] Samsung, R1-051341: Flexible Fractional Frequency Reuse Approach, 3GPP, Nov 2005, RAN WG1 Meeting 43: Korea.
- [14] Huawei, "R1-0S0S07: Soft frequency reuse scheme for UTRAN LTE," 3GPP TSG RA WG1 Meeting #42, May 2005.
- [15] 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.
- [16] 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.
- [17] 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.
- [18] 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.
- [19] 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.

- [20] X. Yang, "A Multilevel Soft Frequency Reuse Technique for Wireless Communication Systems" IEEE COMMUNICATIONS LETTERS, VOL. 18, N O. 11, NOVEMBER 2014.
- [21] Manli Qian, Wibowo Hardjawana, Yonghui Li, Branka Vucetic, Xuezhong 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.

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