Fractional Frequency Reuse Scheme With Two and Three Regions For Multi-cell OFDMA Systems

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***Abstract*—The co-channel cell interference (CCI) becomes the major performance degradation factor for multi-cell OFDMA systems. In this paper, we propose two fractional frequency reuse (FFR) schemes that can efficiently avoid the CCI in the cell edge: scheme I where each cell is divided into two regions: the central region and the edge region. In the central region, the frequency reuse is set to 1. In the edge region, according to a difference-set and using the sectorization technique, the FFR of $3/7$ and $4/7$ have been applied. In the scheme II, each cell is partitioned into three regions: the central region, the middle region and the edge region. The FFR of 1, $2/3$ and $3/7$ are used correspondingly to the three regions. In two proposed schemes, an optimal dimension of the central region has been achieved by maximizing the average to variance ratio. In the cell edge of two proposed schemes, by using the difference-set notion and adding more antenna, the FFR of $3/7$ and $4/7$ can provide more diversity gain in selecting the serving sector than the classical schemes with reuse 1 and 3. Simulation results show that the proposed scheme is a powerful solution for CCI avoidance in the edge of the cell.**

***keywords*- Fractional Frequency Reuse, OFDMA, Co-channel Cell Interference.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is one of the promising modulation technique for next generation of mobile communication systems due to its ability to combat the inter-symbol interference (ISI) resulting from the frequency selective fading. However, OFDM is very sensible to co-channel interference (CCI) from neighboring cells caused by the use of the same frequency channel. To combat the effect of the (CCI) in the cell edge, several frequency reuse schemes have been studied such as [1] when a cooperative scheme using a frequency reuse factor (FRF) equal to 1 can achieve an average (CCI) level in the cell edge almost similar to (CCI) of the non-cooperative scheme with FRF=3. In [2] an efficiency reuse of the radio spectrum has been achieved through a set of specific segment allocation sequences. However, these schemes suffer from complexity and need further investigation for implementation. While the traditional FRF's are fixed at 1, 3 or 7, some of fractional number like $4/7$, $3/7$ and $2/3$ are used in [3] and [4]. In this paper, we propose two fractional frequency reuse schemes: scheme I and scheme II. The main contribution given by the two proposed scheme is the exploitation of the notion of difference-set [5] with the sectorization technique. More exactly, in [3], the FFR of $3/7$ and $4/7$ are adopted with difference-set in each cell but without sectorization. The performance of the scheme II is compared with the scheme given in [4] where the FFR of $1/3$ has been applied in the cell edge. Also, the proposed scheme can achieve an optimal dimension of the central region by maximizing the average to variance ratio of the received SINR. Numerical results show that the proposed FFR scheme has better performance than the classical frequency reuse scheme where the frequency reuse is set to 1 and the scheme given in [3] and [4].

The remainder of this paper is organized as follows: In section II, the system model is introduced. The parameters for switching between different regions are given in section III . Simulation results are shown in section IV and we conclude in section V.

II. SYSTEM MODEL

We consider a multi-cell OFDMA system with 19-cell structure. The cell of our interest is the cell 0 when the considered user moves away from the base station.

A. Channel model

The channel model considered in this paper consists into mobile wireless channel with L moving scatters. The Fourier transform of the channel response is the time varying frequency response which can be described as

$$H(t,f)=\sum_{l=0}^{L-1} h_l(t)\exp\left(-j2\pi f\tau_l\right) \qquad (1)$$

where h_l and τ_l are respectively the complex amplitude and the time delay of the l^{th} path.

The frequency response at subcarrier m of the k^{th} OFDM symbol corresponding to user n can be expressed as

$$H(kT_s,mw_f)=\sum_{l=0}^{L-1} h_l(k\Delta t_s)exp(-j2\pi mw_f\tau_l) \qquad (2)$$

where Δt_s and $w_f=\Delta t_s^{-1}$ are respectively, the OFDM symbol duration and the subcarrier spacing. For simplicity, we denote $H(k\Delta t_s,mw_f)$ as $H_{n,m}$. The pathloss model considered in our study is the cost-Hata model, so the decibel pathloss and shadow attenuation of user n at the distance d_n from the serving base station can be written as [7]

$$\begin{aligned} PL_{dB}(d_n) &= 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t) \quad (3)\\ -a(h_m) &+ (44.9 - 6.55\log_{10}(h_t)log_{10}(d_n)) + SH_\sigma(dB) \end{aligned}$$

where f_c, h_t and h_m are respectively the carrier frequency, the base station antenna height, the mobile antenna height. $a(h_m)$ is the correction factor for the mobile antenna hight and it given by

$$a(h_m) = [1.1\log_{10}(f_c) - 0.7]h_m - 1.56\log_{10}(f_c) - 0.8 \quad (4)$$

The shadowing fading term $SH_\sigma(dB)$ denotes a log-normal distribution with a standard deviation σ.

The channel gain between the serving base station and user n on subcarrier m can be formulated as

$$g_{n,m} = 10^{-PL_{dB}(d_n)/10}|H_{n,m}|^2 \quad (5)$$

The signal to interference plus ratio (SINR) for mobile n on subcarrier m is given by the following formula

$$SINR_{n,m} = \frac{g_{n,m}p_{n,m}}{N_0 w_f + \sum_{i=1}^{I} g_{i,n,m}p_{i,n,m}} \quad (6)$$

where $p_{n,m}$ is the transmit power of useful signal for mobile n on subcarrier m, $p_{i,n,m}$ and $g_{i,n,m}$ are respectively the transmit power and the channel gain of the interfering signal from the i^{th} co-channel cell for the considered mobile n on subcarrier m. I and N_0 are respectively the number of co-channel cells and the power spectrum density of additive white Gaussian noise (AWGN). Using the shannon's theorem, the average spectral efficiency of user n on subcarrier m can be formulated as

$$SE_{n,m} = log_2(1 + \frac{SINR_{n,m}}{\beta}) \quad (7)$$

where β is the SNR gap related to the target BER given by the following expression

$$\beta = \frac{-1.5}{Log(5BER)}. \quad (8)$$

B. Difference Set

let $\Omega = \{0, 1, 2, ..., M\}$ a set.

1) Definition: Let D_S a subset of Ω which contains N elements and $0 < N < M$. D_s is called a (M,N,K)-difference set if the set $\{a - a', a \neq a', a, a' \in \Omega\}$ contains each non zeros element of Ω exactly K-times.

2) Lemma 1: If D_s is an (M,N,K)-difference set in a set Ω, then the set defined as $D'_s = \{D_s + a(modM), a \in \Omega\}$ is symmetric of D_s.

3) Lemma 2: Let S_1 and S_2 two different subsets $\in D'_s$, there exist precisely K-elements that are common between S_1 and S_2.

4) examples: Let (7,3,1)-difference set. If we choose arbitrarily the subset $(1, 2, 4)$ and we apply the lemma 1, we can find the subsets $(2, 3, 5)$, $(3, 4, 6)$, $(4, 5, 7)$, $(5, 6, 1)$, $(6, 7, 2)$ and $(7, 1, 3)$ that satisfy the lemma 2. Indeed, there is exactly a single common element between two any arbitrarily subsets. In the other way and as shown in [3], using the (7,3,1)-difference set, the number of shared channels between any two neighboring cells is fixed to 1. Also, with (7,4,2)-difference set and by the arbitrary selection of the subset (1,2,3,5), the following subsets $(5, 6, 7, 2)$, $(4, 5, 6, 1)$, $(3, 4, 5, 7)$, $(2, 3, 4, 6)$, $(7, 1, 2, 4)$ and $(6, 7, 1, 3)$ satisfy the property of lemma 2 and can maintain a fixed number of shared channel between two neighboring cell equal to 2.

C. scheme I : Reuses (1, 3/7) and (1,4/7)

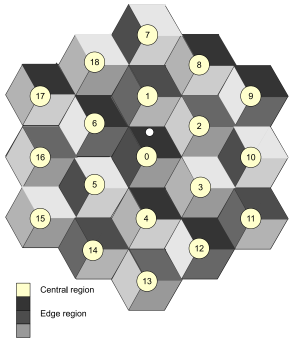

Fig. 1. Multi-cell OFDMA system with reuses 1, and 3/7

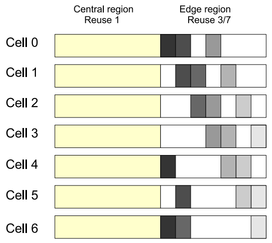

Fig. 2. Frequency band partitioned with reuses 1, and 3/7

In this scheme, the total bandwidth is divided into two parts corresponding to the two regions as shown in Fig.2. In the central region, the reuse pattern is set to 1 and the mobile station is subject to the interference of 18 sectors, so the received SINR follows the equation (6) with $I = 18$. In the edge region, by dividing the corresponding bandwidth into seven breakdowns and using the (7,3,1)-difference set, the FFR of 3/7 can be achieved. This reuse with 3-sectored cell provides a significant reduction into number of interfering sectors (cell 4 and cell 12). In the same way, if the edge region is partitioned into four sectors and using the (7,4,2)-difference set, the FFR of $4/7$ can be applied. Practically, this reuse can eliminate all the interfering sectors(except sector 1 of cell 12).

D. scheme II : Reuses 1, 2/3 and 3/7

In this scheme , the total bandwidth is divided into three parts corresponding to three regions. The fraction of the bandwidth designed for the middle region is divided into three breakdowns and using the 3-sectored cell, the FFR of $2/3$ is adopted. In this region the number of interfering sectors is set to 8 (sectors of cells 3,4,5,11,12,13,14 and 15). In the edge region, the FFR is set to $3/7$ and similarly with scheme I, the same distribution of the corresponding bandwidth is adopted.

III. SWITCHING BETWEEN DIFFERENT REGIONS

For scheduling between the central region and the edge region in scheme I or between the central region and the middle region in the scheme II, we use as the objective function the average to variance ratio of the instantaneous reported SINR for a given user.

A. Optimal dimension of the central region

In order to enhance the SINR level and reduce it's variance, we have to maximize the average to variance ratio of the received SINR for a given user. Thus, in our scheme, this parameter is used to achieve an optimal dimension of the central region and an efficient use of the available bandwidth. The objective function Γ can be written as

$$\Gamma(\gamma) = \frac{\bar{\gamma}(\gamma)}{V_\gamma(\gamma)} \tag{9}$$

where γ is the instantaneous reported SINR level for the considered user. The objective function is maximized by γ_{opt} which determined as

$$\gamma_{opt} = \max_{\gamma} \Gamma(\gamma) \tag{10}$$

B. Switching between the middle region and the edge region

The switching between the middle region and the edge region in the scheme II is based on the amount of CCI for the considered user. We can use an adaptive SINR level threshold for regions limit which can add flexibility and efficiency to our scheme for CCI avoidance in the cell-edge.

IV. SIMULATION RESULTS

In this section, some of simulation results are given to evaluate the performance of our scheme. Without loss of generality, we consider in the following a single frequency multi-cell OFDMA system and we assume that no power control i.e the total of the available subcarriers are transmitted with equal power allocation. The proposed scheme is compared to three other schemes: the first scheme refers to [3] which exploits the difference-set notion and uses the reuse 1, $3/7$ and $4/7$ but without sectorization technique, nor optimization regions. The second scheme refers to [4] which uses the FFR of 1, $2/3$ and $1/3$. The third scheme is the conventional reuse scheme which use the full sharing of the available bandwidth i.e $FFR = 1$ in each cell. Some of the simulation parameters are given in the following table.

Parameters	Values
Cellular layout	19 cell sites
Carrier frequency	2.5 GHz
Channel bandwidth	10 MHz
FFT size	512
Subcarrier spacing	15 KHz
BS power sensitivity	-174 dBm/Hz
BS transmission power	43dBm
Lognormal shadowing	0 mean and $\sigma = 8dB$
Channel model	Cost 231-Hata model
BER	10^{-6}
The cell radius	1.5 Km
Inter-cell distance	2.8 Km
Minimum Mobile to BS distance	100 meters
BS height	32 meters
Mobile terminal height	1.5 meters

Fig.3 depicts the objective function as function of the instantaneous SINR γ. It can be seen that the optimal size of the central region is achieved with $\gamma_{opt} = 8dB$.

Fig.4 shows the received SINR of the proposed scheme with reuses $(1, 3/7)$ and $(1, 4/7)$, schemes given in [3] and [6] versus the distance between the serving base station and the considered user. We can easly deduce that the received SINR level decreases as user moves away from the base station due to the increase of the number of CCI sources. In the central region, the received SINR is decreasing according to equation (6) with $I = 18$. The user SINR values are continually inspected by the serving base station. When the SINR level exceeds the SINR threshold $8dB$, the user is considered in the edge region and the number of interfering cells is decreasing to 2. It's clear that the performance of the proposed scheme is better than the scheme developed in [3]. Using the difference-set distribution with sectorization technique, the FFR of $4/7$ and $3/7$ can bring respectively near $5dB$ and $2dB$ for comparison with the scheme given in [3]. Also, the proposed scheme I provides more $2dB$ and $6dB$ gain in the cell edge than the scheme [6] and the conventional scheme. We can also deduce from the cumulative distribution function (CDF) given in Fig.5 that the proposed scheme provides better performance than the scheme given in [3], [4] and [6].

Fig.6 depicts the received SINR level as function of the distance between user and the serving base station for the proposed scheme II and scheme given in [3]. Our comparison is based on the number of interfering sectors with FFR of $3/7$ and $1/3$ in the cell edge. Indeed, using an efficient distribution of the valid bandwidth with difference-set in three sectored-cell, the FFR of $3/7$ can reduce effectively the CCI sources and bring more gain of the SINR level (near $2dB$) than the FFR of $1/3$. Consequently, as shown in Fig.7, the FFR of

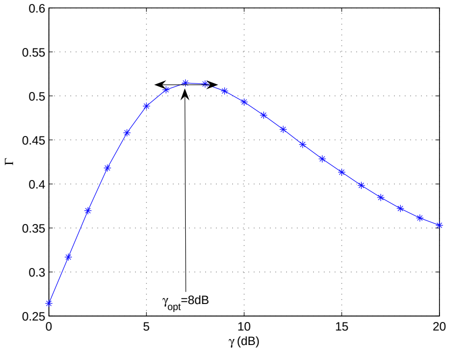

Fig. 3. The average to variance ratio of the received SINR

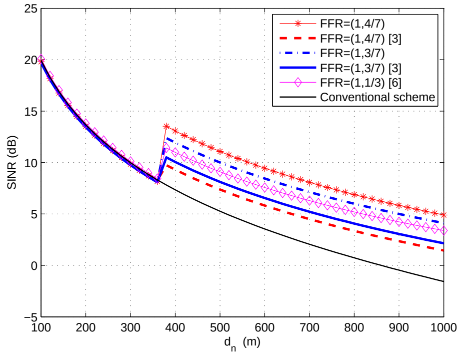

Fig. 4. Received SINR for scheme with reuses (1,3/7), (1,4/7), (1,1/3) and 1

$3/7$ in our scheme achieves better performance in terms of average spectral efficiency and it allows an efficient use of the available bandwidth since $3/7 > 1/3$.

V. CONCLUSION

In this paper, the FFR is introduced in multi-cell OFDMA system with a 19-cell structure. Our proposed scheme can be regarded as an extended study of the scheme referred as [3]. By using the notion of difference-set with sectorization technique, the FFR of $3/7$, $4/7$ and $2/3$ have been applied and considered as a powerful technique to enhance the channel quality in the cell edge.

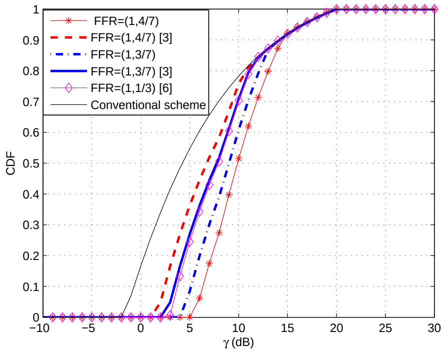

Fig. 5. Cumulative distribution function of the received SINR

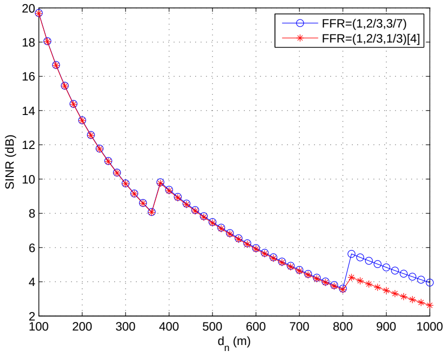

Fig. 6. Received SINR for the scheme with reuses $(1, 2/3, 3/7)$ and $(1, 2/3, 1/3)$

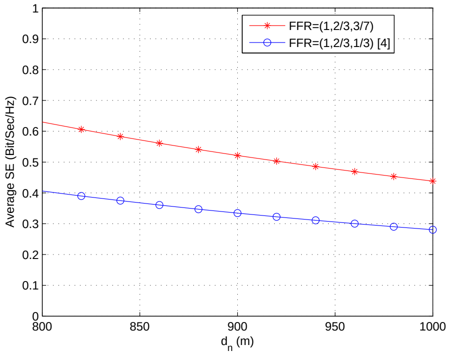

Fig. 7. Average spectral efficiency for the scheme with reuses $(1, 2/3, 3/7)$ and $(1, 2/3, 1/3)$

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