Frequency Reuse Scheme With Three Regions in Cooperative Relaying For Multi-cell OFDMA Systems

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***Abstract*—Cooperative relaying has shown as promissing approach to improve transmission reliability in cellular network. In this paper cooperative relaying and frequency reuse partitioning are exploited to avoid the co-channel cell interference (CCI) in the downlink multi-cell OFDMA systems. In our system layout, each cell is divided into three regions: the central region, the middle region and the edge region. The frequency reuse factor (FRF) is set to 1 in the central region. Depending on the number of sectors in the middle and the edge region, the FRFs of 3, 7/3, 7/4, 4 and 6 have been applied. A fixed relay station (RS) by sector, which amplifies and forwards the received signal to the mobile, is placed at the limit of the middle region and the edge region. Numerical results are presented to demonstrate the effectiveness of the proposed cooperative scheme for CCI mitigation in the edge of the cell.**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is one of the promising modulation techniques for the next generation of mobile communication systems due to its ability to fight 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. [2] proposes a frequency reuse scheme for fixed two-hop OFDMA relaying network where CCI minimum is achieved by adjusting relay station and base station transmission power radio. In [3] and [4], the FRF=3 can enhance the average signal to interference plus noise ratio (SINR) and reduce the amount of the CCI in the boundary of the cell. While the traditional FRFs are fixed at 1, 3 or 7, some of fractional number like 7/3 and 7/4 are used in [5] and [6]. [7] presents two cyclic delay optimization schemes based on linear approximation of the channel phase and the strongest path for multi-cell OFDM system with cooperative relay.

In this paper, we propose a frequency reuse scheme for multi-cell OFDMA system with cooperative relaying with fixed relay and multiple mobile station. In our system layout, each cell is divided into three regions: the central region, the middle region and the edge region. The FRF is set to 1 in the central region. By dividing the middle region into three or four sectors, the FRFs of 3 or 4 have been adopted. In the edge region, the FRFs of 7/3, 7/4 and 6 have been respectively applied with three, four and six sectors. We place a single fixed RS by sector at the limit of the middle region and the edge region. Downlink cooperation is triggered with the Non Orthogonal Amplify and Forward (NAF) cooperation protocol with one relay and two times slots [8]. The proposed scheme has been compared with schemes without cooperation given in [4], [5] and [6]. Simulation results show that our cooperative scheme appreciably outperforms traditional frequency reuse scheme without cooperation.

The remainder of this paper is organized as follows. The system model is introduced in section II, the mathematical model for first and second time slot is described in section III, the proportional fair scheduling algorithm is given in section IV, simulation results are shown in section V and we conclude by section VI.

II. System Model

We consider a downlink multi-cell OFDMA system with 19-cells structure where each cell is divided into three regions as shown in Fig.2. The cell of our interest is the cell 0 (the central cell in the system layout) when the considered user moves away from the base station. We place a single RS by sector at the limit of the middle region and the edge region in each cell as shown in Fig.1. We assume that the relays operate in a duplex mode i.e the communication is done in two steps. In the first step (first time slot), the base station (BS) transmits whereas all RS remain silent and the signal is received both at RS and mobile. In the second step (during the second time slot) all BS remain silent and each relay forwards the previously received signal to the mobile.

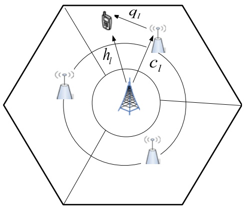

Fig. 1. Cooperative relaying communication within one 3-sectored cell

A. Difference Set

The notion of difference set [Appendix] has been studied in information theory. It gives a specific distribution of the available channels between neighboring cells. As shown in [9], the difference set can allocate the same number of channels to each cell while fixing the number of shared channels between any two neighboring cells.

B. Scheme with FRFs of 1, 3 and 7/3

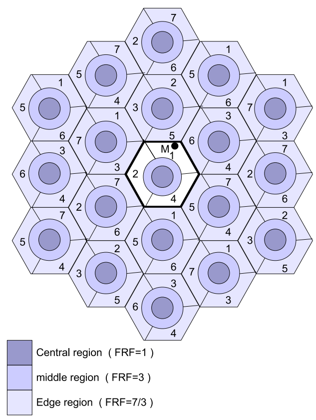

Fig. 2. system layout of cooperative relaying communication, $FRF = 7/3$ by $(7, 3, 1)$ difference set

In this scheme, the total bandwidth is divided into three parts corresponding to three regions as shown in Fig.3. In the central region the FRF is set to 1 and the mobile n is subjected to the interference of 18 cells. In the middle region, the equivalent bandwidth is partitioned into three parts and the FRF of 3 has been applied. In the edge region, by dividing the matching bandwidth into seven breakdowns and using the $(7, 3, 1)$ difference set, the FRF of $7/3$ can be achieved. This reuse with 3-sectored cell provides a significant reduction into number of interfering sectors (cells with channels $(1, 5, 6)$ and $(1, 7, 3)$).

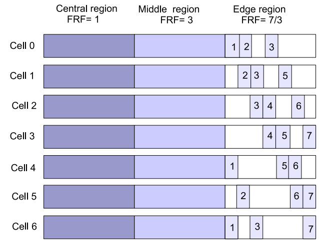

Fig. 3. Frequency band partitioned with reuses 1, 3 and $7/3$

C. Scheme with FRFs of 1, 4 and 7/4

In this scheme, the FRF is equal to 1 in the central region. In the middle region, the FRF is set to 4 with four sectors. Also, the edge region is divided into four sectors and using the $(7, 4, 2)$ difference set, the FRF of $7/4$ can be applied. Practically this reuse can eliminate all the interfering sectors.

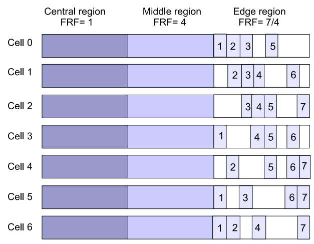

Fig. 4. Frequency band partitioned with FRFs of 1, 4 and $7/4$

D. Scheme with FRFs of 1, 3 and 6

Similarly, the FRF is set to 1 in the central region. As shown in Fig.5, by dividing the middle and the edge region respectively into three and six sectors, the FRFs of 3 and 6 have been adopted.

III. Mathematical Model

A. First time slot

Considering the cell 0, the received signal at the mobile n directly from the different base stations during the first time slot can be given by

$$r_{1,n}(t) = \sum_{i=0}^{I} \sum_{l=0}^{L-1} h_l^{(i)} s_{i,n}(t - v_l^{(i)}) + Z_1(t) \tag{1}$$

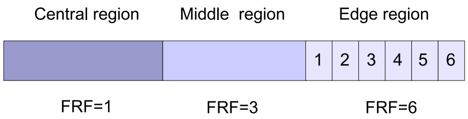

Fig. 5. Frequency band partitioned with FRFs of 1, 3 and 6

where I is the number of co-channel cells. $h_l^{(i)}$ is the channel impulse of the l^{th} path within the cell i and v_l is the corresponding time delay. $Z_1(t)$ is the thermal noise. The demodulated output of the k^{th} OFDM symbol at subcarrier m for user n can be written as

$$R_{1,n}(k,m) = \sum_{i=0}^{I} H_{1,n}^{(i)}(k,m) s_{i,n,m} + z_{1,m} \quad (2)$$

where $z_{1,m}$ is the additive thermal noise which is modeled as zero mean complex Gaussian process with a power spectral density of N_0 and $H_{1,n}^{(i)}(k,m)$ is the channel transfer function of the k^{th} OFDM symbol for mobile n at subcarrier m which can be formulated as

$$H_{1,n}^{(i)}(k,m) = \sum_{l=0}^{L-1} h_l^{(i)}(kT_s) \exp(-2\pi j m \Delta f v_l^{(i)}) \quad (3)$$

where T_s and $\Delta f = T_s^{-1}$ are respectively the OFDM symbol duration and subcarrier spacing. In the following and without loss of generality, we denote $H_{1,n}^{(i)}(k,m)$ as $H_{1,n,m}^{(i)}$. The received signal at the relay within cell 0 from different base stations can be written by

$$y_1(t) = \sum_{i=0}^{I} \sum_{l=0}^{L-1} h_l^{(i)} s_{i,n}(t - \tau_l^{(i)}) + z_r(t) \quad (4)$$

The decibel path-loss and shadow attenuation of mobile n at the distance d_n from the serving base station are given by[10]

$$PL_{dB}(d_n) = 46.3 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_t) \quad (5)$$
$$-a(h_m) + (44.9 - 6.55 \log_{10}(h_t) log_{10}(d_n)) + SH_\sigma(dB)$$

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

$$a(h_m) = [1.1 \log_{10}(f_c) - 0.7]h_m - 1.56 \log_{10}(f_c) - 0.8 \quad (6)$$

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 mobile n on subcarrier m can be written as

$$g_{1,n,m}^{(0)} = 10^{-PL_{dB}(d_n)/10} |H_{1,n,m}^{(0)}|^2 \quad (7)$$

The received (SINR) for mobile n on subcarrier m during the first time slot can be expressed as

$$\Gamma_{1,n,m} = \frac{g_{1,n,m}^{(0)} p_{n,m}^{(0)}}{N_0 \Delta_f + \sum_{i=1}^{I} g_{1,n,m}^{(i)} p_{n,m}^{(i)}} \quad (8)$$

where $p_{n,m}^{(0)}$ and $p_{n,m}^{(i)}$ are respectively, the transmit power of useful signal on subcarrier m for mobile n allocated by its serving cell and the i^{th} co-channel cell, $g_{1,n,m}^{(i)}$ is the channel gain between mobile n and co-channel cell i on subcarrier m.

B. Second time slot

Each relay amplifies and forwards its received signal while the base stations are silent. Therefore the received signal at the mobile n from the different relays during the second time slot can be developed as

$$r_{2,n}(t) = \sum_{i=0}^{I} \beta_i \sum_{l=0}^{L-1} q_l^{(i)} y_1(t - \tau_l^{(i)}) + Z_2(t) \quad (9)$$

where β_i is the amplification factor used at the relay within cell i and given by the following expression

$$\beta_i = \sqrt{\frac{E_s^{(i)}}{E_s^{(i)} \sum_{l=0}^{L-1} |c_l^{(i)}|^2 + N_0 \Delta f}} \quad (10)$$

$E_s^{(i)} = p_{n,m}^{(i)} T_s$ denotes the average energy per transmitted symbol of cell i. The demodulated signal sample of the k^{th} OFDM symbol at subcarrier m for mobile n can written as

$$R_{2,n}(k,m) = H_{2,n,m}^{(0)} s_{0,n,m} + \sum_{i=1}^{I} H_{2,n,m}^{(i)} s_{i,n,m} + z_{2,m} \quad (11)$$

where

$$H_{2,n,m}^{(0)} = \beta_0 Q_{n,m}^{(0)} C_{n,m}^{(0)} \quad (12)$$

$$H_{2,n,m}^{(i)} = \beta_0 Q_{n,m}^{(0)} C_{n,m}^{(i)} + \beta_i Q_{n,m}^{(i)} C_{n,m}^{(i)} \quad (13)$$

For $i = 0, 1, 2, ..., I$, $C_{n,m}^{(i)}$ denotes the channel transfer function between base station i and its RS at the mobile n on subcarrier m. $Q_{n,m}^{(i)}$ is the channel transfer function between the relay of base station i and mobile n on subcarrier m. The channel gain between the serving base station and mobile n on subcarrier m can be expressed by

$$g_{2,n,m}^{(0)} = 10^{-PL_{dB}(d_n)/10} |H_{2,n,m}^{(0)}|^2 \quad (14)$$

During the second time slot, the SINR for mobile n on subcarrier m is given by the following formula

$$\Gamma_{2,n,m} = \frac{g_{2,n,m}^{(0)} p_{n,m}^{(0)}}{N_0 \Delta_f + \sum_{i=1}^{I} g_{2,n,m}^{(i)} p_{n,m}^{(i)}} \quad (15)$$

where $g_{2,n,m}^{(i)}$ is the channel gain between mobile n and co-channel cell i on subcarrier m. The received SINR at the mobile n on subcarrier m in time slot 1 and 2 are maximum ratio combined (MRC) as follows

$$\Gamma_{n,m} = \Gamma_{1,n,m} + \Gamma_{2,n,m} \quad (16)$$

IV. Proportional Fair Scheduling Algorithm

In this paper, we propose a proportional fair scheduling algorithm to allocate the available subcarriers for users [11]. In mathematical terms, the index of the picked user satisfies

$$j_m = argmax_n \frac{\mu_{n,m}}{T_n} \quad (17)$$

where $\mu_{n,m}$ is the instantaneous transmittable rate of the subcarrier m when transmitted for user n at the current slot. T_n is the average rate of user n at the previous slot. $\mu_{n,m}$ can be expressed as

$$\mu_{n,m} = log_2(1 + \frac{\Gamma_{n,m}}{\gamma}) \quad (18)$$

where γ is the SINR gap related to the target BER given by the following expression [12]

$$\gamma = \frac{-1.5}{Log(5BER)}. \quad (19)$$

The algorithm works as follow
1. Scheduling the user n with the highest ratio of $\frac{\mu_{n,m}}{T_n}$ out of all users will receive transmission at decision time.
2. Update the average rate for each user as follow

$$T_n(t+1) = (1 - \frac{1}{t_c})T_n(t) + \frac{\mu_{n,m}}{t_c} \quad (20)$$

if user n is scheduled, else

$$T_n(t+1) = (1 - \frac{1}{t_c})T_n(t) \quad (21)$$

We assume that the information on the instantaneous transmittable rate of each downlink subcarrier is reported by the mobile. The update of the average rate as specified here is done using a low pass filter with a time constant of t_c slots.

V. Simulation Results

From Fig.6 to Fig.8, we consider a single frequency multi-cell OFDMA system and we assume that all available subcarriers are transmitted with equal power allocation. As example, we set a distance of $800m$ between the BS and the RS. The proposed cooperative scheme is compared with three other schemes: the first scheme refers to [5] uses the FRFs of $7/3$ and $7/4$ with the difference set but without cooperation, nor sectorization technique. The second scheme given in [6] uses the FRFs of $7/3$ and $7/4$ in the edge of the cell but without cooperation. The third one is our previous study given in [4] which exploits the reuses $(1, 3)$ and provides an optimal dimension of the central region that can enhance the received SINR and reduce its variance in the edge of the cell. A summary of simulation parameters is given in Table I

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Cellular layout	Hexagonal grid,19 cells
channel bandwidth	10 MHz
Carrier frequency	2.5 GHz
FFT size	512
Number of subcarriers	350
Subcarrier spacing	15 KHz
White noise power density	-174 dBm/Hz
Fast fading model	Cost 231-Hata model
Lognormal shadowing	σ=8dB
BS transmit power	43dBm
Relay transmit power	33dBm
Minimum mobile to BS distance	100m
BER	10^{-6}
The cell radius	1.5Km
Inter-cell distance	2.8Km
BS height	32m
Mobile terminal height	1.5m

Fig.6 illustrates the received SINR of the proposed scheme, scheme given in [4], [5] and [6] versus the distance between the serving base station and the considered mobile n. The switching between the central region and the middle region is based on the distance threshold which equals to $600m$ in our simulations. We can see that the received SINR values gradually descend as user moves away from the base station due to the path-loss and CCI of adjacent cells. In the central region, all schemes provide similar performance by using the same reuse pattern.ie FRF=1. In this region, the received SINR is decreasing according to equation (8) with $I = 18$. The distance values are continually inspected by the serving base station. When the distance between the serving BS and the considered mobile exceeds the distance threshold, he is treated as the middle region region and is subjected to CCI of seven and six sectors respectively with FRFs of 3 and 4. In the edgeof the cell, the considered user receives interference from four, two and one cell respectively with the FRFs of 6, $7/3$ and $7/4$. We can easily deduce from this figure that the proposed cooperative scheme gives a better performance than the three other schemes. It can bring near $4dB$, $8dB$ and $10dB$ in comparison respectively with scheme given in [6], [4] and [5].

We can also presume from the cumulative distribution function (CDF) given in Fig.7 that the cooperative scheme with the FRFs of 1 and $7/3$, $7/4$ and 6 is very efficient to reduce the amount of the CCI in the cell edge.

Fig.8 depicts the outage probability vs the threshold of acceptable performance γ_c for different schemes. For the proposed scheme, the probability that the received SINR values are below γ_c is smaller than the three other schemes.

In Fig.9, we evaluate the performance of the proposed cooperative scheme in terms of average spectral efficiency (averaged over all simulation times) for the edge of the cell 0. In our scheme, the available 350 subcarriers are divided into seven groups. We evaluate the performance of our scheme with the FRF of $7/3$ i.e 3 groups in each cell. The proportional fair scheduling algorithm is adopted for all schemes. As it is seen from this figure, the proposed scheme with fixed relaying performs much better than the others schemes. It provides about 1 bit/sec/hz, 1.5 bit/sec/hz and 1.75 bit/sec/hz in comparison respectively with schemes presented in [6], [4] and [5]

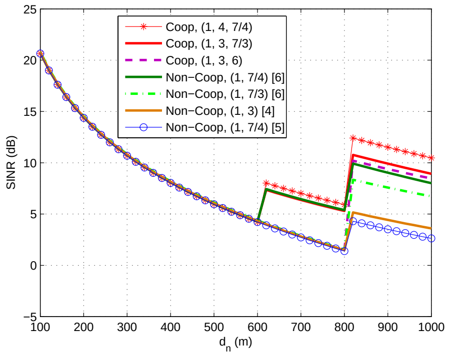

Fig. 6. The received SINR for the proposed cooperative relaying scheme, schemes without cooperation given in [4], [5] and [6]

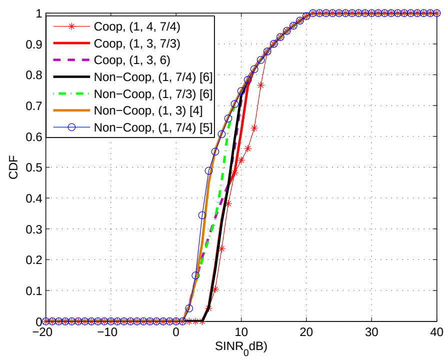

Fig. 7. Cumulative distribution function of the received SINR

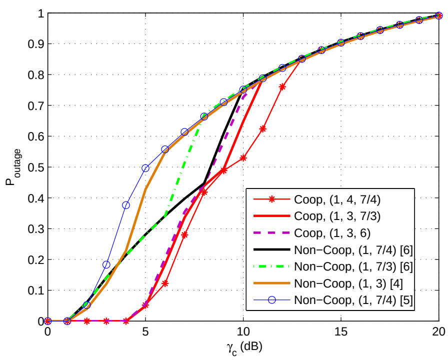

Fig. 8. Outage probability of the received SINR varying with the threshold γ_c(dB)

VI. Conclusion

The aim of this paper is to investigate the frequency reuse partitioning with cooperative relaying in multi-cell OFDMA

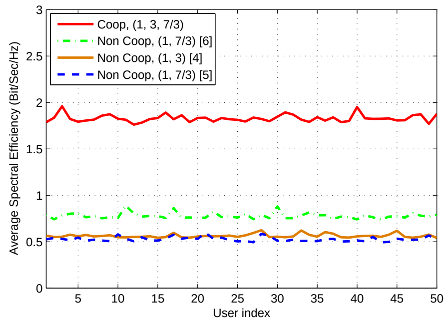

Fig. 9. Average spectral efficiency for the cooperative scheme, non-cooperative schemes given in [4], [5] and [6] in the edge of cell 0 with $t_c = 100$ slots, 150 subcarriers (3 groups) and 50 users

systems.Verified by simulation results, the proposed cooperative scheme effectively reduces the amount of the CCI in the edge of the cell and can compensate the waste of the available bandwidth caused by the use of $FRFs < 1$.

Appendix

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

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.

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.

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.

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 [5], 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 any two neighboring cells equals to 2.

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