Analysis and Suppression of MAI in WiMAX Uplink Communication System with Multiple CFOs

Xiupei Zhang and Heung-Gyoon Ryu

Department of Electronic Engineering, Chungbuk National University,
Cheongju, Chungbuk, Korea 361-763
ZhangXP.CN@gmail.com, ecomm@cbu.ac.kr

Abstract. Nowadays, OFDMA (Orthogonal Frequency Division Multiple Access) technique has been used in WiMAX communication system to achieve very high data rate as well as multi-user service. However, similar with other OFDM-based systems, OFDMA system is very sensitive to frequency synchronization errors, especially in the uplink communications where different users always have different CFOs (Carrier Frequency Offset). When multiple CFOs exist, the orthogonality which separates different subcarriers will be lost, and ICI (Inter Carrier Interference) as well as MAI (Multi-Access Interference) will be generated to disturb the received signals. Then, the system performance will be highly degraded. To overcome this problem, it is of great importance to do research on the suppression to the interferences caused by multiple CFOs. In this paper, we first analyze the interferences, including ICI and MAI, caused by multiple CFOs in the uplink communications of OFDMA system. Next, the suppression method based on block type pilots is proposed to overcome the interferences simultaneously. Compared with other interference suppression methods, the proposed method could directly get the interference components from inverse matrix, thus it doesn't need to do the CFO estimation. From the simulation results, it can be seen that the multiple CFOs will make serious degradation to the system performance. But through the proposed suppression algorithm, the system performance can be significantly improved.

Keywords: WiMAX; OFDMA; CFO; MAI; ICI; Interference Suppression.

1 Introduction

OFDM (Orthogonal Frequency division multiplexing) has been widely used in digital communication system to achieve very high data rate. In OFDM system, wide transmission bandwidth is divided into several narrow bands and data are paralleled transmitted on these narrow bands by exploiting orthogonal subcarriers. Thus, decreasing the effect of ISI (Inter Symbol Interference), good spectrum efficiency, anti frequency selective fading and many other advantages can be achieved. Combined with frequency division multiple access technique, OFDMA system is proposed to support

X. Jun Hei and L. Cheung (Eds.): AccessNets 2009, LNICST 37, pp. 204–218, 2010.

multi-user service. In OFDMA system, available subcarriers are divided into several groups and these groups are assigned to different users to transmit data simultaneously. The OFDMA system inherits the advantages of OFDM and has been widely used in wireless communication system. For example, IEEE 802.16 standardization group has considered OFDMA as the broadband wireless access standard for WAN (Wide Area Network) and UMTS (Universal Mobile Telecommunications System), the European standard for the 3G cellular mobile communications, also exploits OFDMA technique [1].

However, similar with other OFDM based systems, OFDMA system is sensitive to CFO (Carrier Frequency Offset), which is unavoidable in wireless communication system. In OFDMA uplink communications, the received signals are the combination of multiple signals coming from different users, each of which experiences a different CFO mainly due to oscillator instability and Doppler shift [2]. The multiple CFOs destroy the orthogonality among subcarriers, thus, not only ICI (Inter Carrier Interference) but also MAI (Multi-Access Interference) will be generated to disturb the received signal. Then the system performance will be seriously degraded.

Synchronization between users is difficult in OFDMA uplink communications. Conventional CFO correction methods, such as [3], which are used in the downlink communications, are designed for signal user system, and they are unable to correct the multiple CFOs in the uplink communications because one user's CFO correction will aggravate the MAI from other users. To overcome this problem, many previous works has been proposed to estimate [2, 4, 5, and 6] or suppress the multiple CFOs effects [7-13]. These synchronization methods can be classified as two groups. The first is called feedback method, which exploits a downlink control channel to transmit the estimated CFO information obtained by the base station to each user, and each user can then correct the CFO by adjusting the carrier frequency. However, this method will increase the transmission overhead and possibly cause outdated estimation in time-varying scenario. An alternative is to achieve synchronization via signal processing at the uplink receiver without the help of a control channel [7], such as [7-13]. In [8-10], SIC (Successive Interference Cancellation) as well as PIC (Parallel Interference Cancellation) methods were raised. In these methods, the received signals are classified as reliable group and unreliable group. The reliable signals are directly detected and cancelled from the received signal while the unreliable signals are detected after cancellation of the MAI effects due to reliable signals. Another kind of interference suppression methods which exploit inverse matrix, were discussed in [11-13]. However, the methods in [8-12] need perfect multiple CFOs estimation, which is impossible in practical system, and the residual CFO will also degrade system performance.

In this paper, firstly, we analyze the interferences caused by multiple CFOs in OFDMA uplink communications. From the analysis, we can see that the received signals are seriously disturbed by multiple CFOs. Also, we express the received signal in matrix form. Then, a joint suppression method based on block type pilots is proposed.

Here we suppose different users start to communicate with the base station at different time slots. Different with other interference suppression methods, the proposed method could directly get the interference components by exploiting block type pilot, thus it don't need to do the multiple CFOs estimation. After that, the interference matrix can be reconstructed and the influence of multiple CFOs can be easily cancelled by using the inverse matrix method. Then, making suppression to the interferences caused by multiple CFOs is feasible.

This paper is organized as follows. In Section 2, we describe the system model of OFDMA uplink communications. Next, in Section 3, we analyze the effect ofmultiple CFOs, and according to the analysis, the interference suppression method is stated. Finally, the suppression method is simulated and the results are shown in Section 4. Comparing the simulation results, we can draw the following conclusion, that multiple CFOs will make great degradation to the system performance, but through the propose algorithm, the system performance can be significantly improved.

2 OFDMA Uplink System Model

Fig.1 shows the block diagram of OFDMA uplink communications.

In OFDMA uplink communications, all subcarriers are divided into several groups. Instead of being modulated on all available subcarriers, data symbols from one user are transmitted on one group of subcarriers.

Now we consider an OFDMA uplink system in which the number of total available subcarriers is N and the number of users communicating with the base station is K. According to the data transmission demand, different groups with different numbers of subcarriers are assigned to each user. Without loss of generality, we suppose each user only occupies one subcarrier group, the subcarrier group assigned to the *kth* user is denoted as S^k, the subcarrier number of S^k is M_k and $\mathbf{D}_k=[d^k_0, d^k_1, d^k_2..., d^k_{Mk-1}]^T$ is the transmitted data of the *kth* user. Then, $\bigcup_{k=1}^{K-1} S^k = \{0,1,2,...,N-1\}$ and $S^i \bigcap S^j = \phi$, for $i \neq j$.

After subcarrier mapping, the modulation symbol vector of *kth* user can be shown as

$$\mathbf{X^k} = \mathbf{\Theta^k} \cdot \mathbf{D_k} = [X_0^k, X_1^k, ..., X_{N-1}^k]^T , \tag{1}$$

where $\mathbf{\Theta^k}$ is the subcarrier mapping matrix with the size of $N \times M_k$. And the components in $\mathbf{\Theta^k}$ satisfy the following demand, if the *jth* data in $\mathbf{D}_k$ transmitted on the *ith* subcarrier, $\Theta^k_{ij}=1$, otherwise $\Theta^k_{ij}=0$. Then after N-IFFT, the transmitted signal can be shown as

$$s^k(n) = \sum_{l=0}^{N-1} X_l^k \cdot e^{j2\pi nl/N} = \sum_{l=0}^{N-1} X_l^k \cdot p_{n,l} . \tag{2}$$

A cyclic prefix is inserted in front of the transmitted signal before being sent into the communication channel, to overcome the influence of ISI.

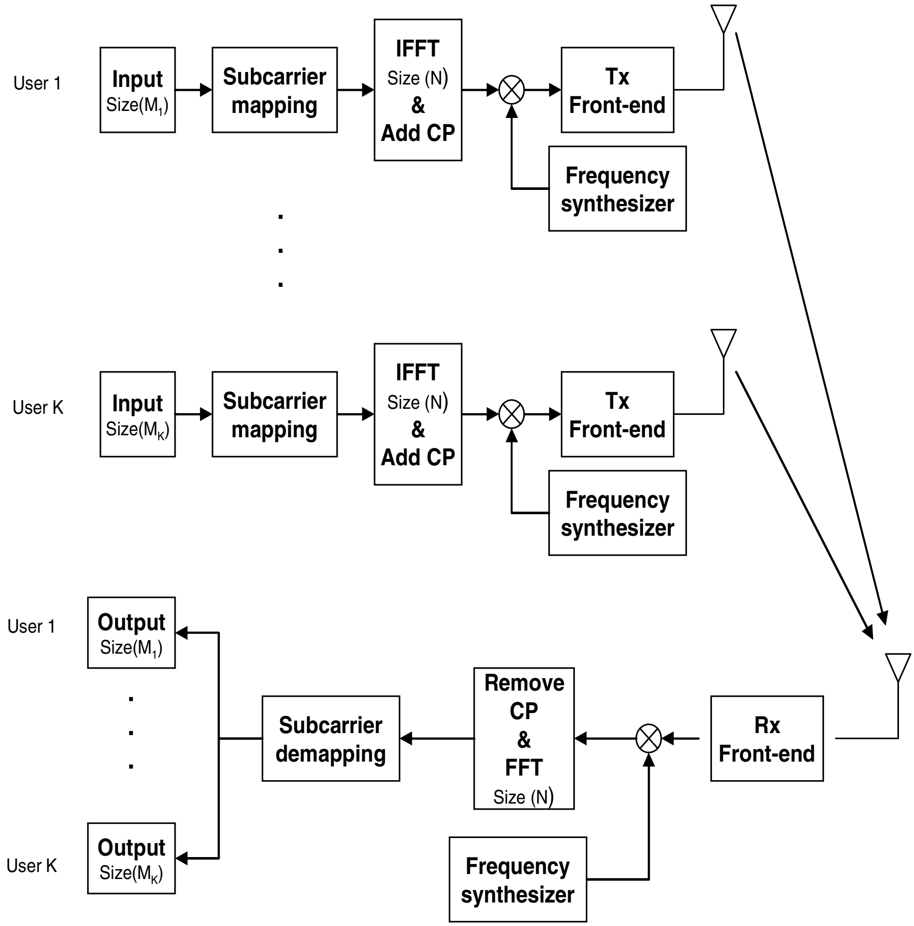

Fig. 1. This figure shows the OFDMA uplink system block diagram. The number of total available subcarriers is N and the number of users communicating with the base station is K.

Here we consider each user experiences a frequency selective channel with the impulse response $h^k(n)$, then the received signals at the base station can be written as

$$r(n) = \sum_{k=0}^{K-1} \left[s^k(n) \otimes h^k(n) + v^k(n) \right], \tag{3}$$

where $v^k(n)$ is the AWGN noise on the *kth* user.

All users are assumed to be synchronized in the time domain. Then after N-FFT, the output of the *ith* subcarrier can be written as

$$Y_i = \frac{1}{N} \sum_{n=0}^{N-1} r(n) \cdot e^{-j2\pi ni/N} . \tag{4}$$

After frequency domain equalizer and subcarrier demapping, the transmitted data of each user can be recovered.

3 Multiple CFO in OFDMA Uplink and Interference Cancellation

In this section, we will analyze ICI as well as MAI generated from the multiple CFOs in OFDMA uplink communications. Next, according to the analysis results, we describe the proposed interferences suppression algorithm.

3.1 Multiple CFO in the OFDMA Uplink

To analyze the ICI and MAI in OFDMA uplink communications, we introduce multiple CFOs into the transmitted signals. We assume the CFO of the *kth* user is Δf_k, then, at the receiver, after removing cyclic prefix, the received signal can be written as

$$r(n)=\sum_{k=0}^{K-1}\{[s^k(n)\otimes h^k(n)]\cdot e^{j2\pi\Delta f_k n}+v^k(n)\}\,. \tag{5}$$

After N-FFT, the obtained signal on the *ith* subcarrier can be written as

$$\begin{aligned} Y_i &= \frac{1}{N}\sum_{n=0}^{N-1} r(n)\cdot e^{-j2\pi ni/N} \\ &= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{K-1}\{[s^k(n)\otimes h^k(n)]e^{j2\pi\Delta f_k n}\}e^{-j2\pi ni/N}+V_i \\ &= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{K-1}\sum_{l=0}^{N-1} X_l^k H_l^k\cdot e^{j2\pi nl/N}e^{j2\pi\Delta f_k n}e^{-j2\pi ni/N}+V_i\,, \\ &= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{K-1} X_i^k H_i^k\cdot e^{j2\pi\Delta f_k n} \\ &\quad +\frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{K-1}\sum_{\substack{l=0,\\ l\neq i}}^{N-1} X_l^k H_l^k\cdot e^{j2\pi n(l-i)/N}\cdot e^{j2\pi\Delta f_k n}+V_i \end{aligned} \tag{6}$$

where H^k_l is the frequency domain channel response and V_i is the frequency domain AWGN noise.

According to the subcarrier mapping method, one subcarrier can only be assigned to one user. Thus, among the K individual X^k_i, only one X^k_i is the the transmitted data of the user who exploit the *ith* subcarrier, and the other X^k_i are zero. We suppose this X^k_i belongs to the *k'th* user. Then, Y_i can be written as

$$
\begin{aligned}
Y_i &= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{K-1} X_i^k H_i^k \cdot e^{j2\pi\Delta f_k n} \\
&\quad + \frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{K-1}\sum_{\substack{l=0,\\ l\neq i}}^{N-1} X_l^k H_l^k \cdot e^{j2\pi n(l-i)/N} \cdot e^{j2\pi\Delta f_k n} + V_i \\
&= \frac{1}{N}\sum_{n=0}^{N-1} X_i^{k'} H_i^{k'} e^{\frac{j2\pi n\varepsilon_{k'}}{N}} + \frac{1}{N}\sum_{n=0}^{N-1}\sum_{\substack{l=0\\ l\neq i}}^{N-1} X_l^{k'} H_l^{k'} e^{\frac{j2\pi n[(l-i)+\varepsilon_{k'}]}{N}} \\
&\quad + \frac{1}{N}\sum_{n=0}^{N-1}\sum_{\substack{k=0,\\ k\neq k'}}^{K-1}\sum_{\substack{l=0,\\ l\neq i}}^{N-1} X_l^k H_l^k e^{\frac{j2\pi n[(l-i)+\varepsilon_k]}{N}} + V_i \\
&= \underbrace{X_i^{k'} H_i^{k'} \cdot I_0^{k'}}_{I} + \underbrace{\sum_{\substack{l=0,\\ l\neq i}}^{N-1} X_l^{k'} H_l^{k'} \cdot I_{l-i}^{k'}}_{II} \\
&\quad + \underbrace{\sum_{\substack{k=0,\\ k\neq k'}}^{K-1}\sum_{\substack{l=0,\\ l\neq i}}^{N-1} X_l^k H_l^k \cdot I_{l-i}^k}_{III} + \underbrace{V_i}_{IV}
\end{aligned}
\tag{7}
$$

where ε_k is the normalized CFO and

$$
I_L^k = \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi n[L+\varepsilon_{k'}]/N} \tag{8}
$$

is the interference coefficient.

From (7), we can see that the received signal is comprised of 4 components. Component *I* corresponds to the original data of the *kth* user transmitted on the *ith* subcarrier, component *II* corresponds to ICI caused by the other data of the *kth* user transmitted on the other subcarrier, component *III* corresponds to the MAI caused by the data of the other users, and component *IV* corresponds to the AWGN noise.

3.2 Interference Cancellation Algorithm

From the above analysis, we can see that the multiple CFOs not only generate ICI but also MAI. Thus, the received signal will be seriously disturbed and the system performance will be seriously degraded. In order to improve system performance, we have to make suppression to these interferences. In this part, we propose a suppression method which is based on block type pilots.

As described above, when multiple CFOs exist in OFDMA uplink communications, the received signal at the base station can be expressed as formula (7). Then, according to formula (7), we express the received frequency domain signal vector in matrix form as follows

$$\mathbf{Y} = \mathbf{I} \cdot \mathbf{H} \cdot \mathbf{X} + \mathbf{V}\,, \tag{9}$$

where $\mathbf{X} = \sum_{k=1}^{K} \mathbf{X}^{\mathbf{k}} = [D_0, D_1, ..., D_{N-1}]^T$ is the modulation symbol vector transmitted on the communication band, $D_i = \sum_{k=1}^{K} d_i^k$ denotes the data transmitted on the *ith* subcarrier, $\mathbf{H} = diag(H_0^{(k)}, H_1^{(k)}, \ldots H_{N-1}^{(k)})$ is the frequency domain channel response, $\mathbf{V}$ is the AWGN noise vector and

$$\mathbf{I} = \begin{bmatrix} I_0^{(k)} & I_1^{(k)} & I_2^{(k)} & \ldots & I_{N-1}^{(k)} \\ I_{-1}^{(k)} & I_0^{(k)} & I_1^{(k)} & \ldots & I_{N-2}^{(k)} \\ I_{-2}^{(k)} & I_{-1}^{(k)} & I_0^{(k)} & \ldots & I_{N-3}^{(k)} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ I_1^{(k)} & I_2^{(k)} & I_3^{(k)} & \ldots & I_0^{(k)} \end{bmatrix} \tag{10}$$

is the interference matrix. The superscript of $I_L^{(k)}$ is related with the user's index. For example, if the *ith* subcarrier is assigned to the *k'th* user to transmit data, the superscripts of the components in the *ith* column of the interference matrix should be set as *k'*.

From (8), we can see that

$$\begin{aligned} I_{-L}^{k} &= \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi n[-L+\varepsilon_{k'}]/N} \\ &= \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi n[N-L+\varepsilon_{k'}]/N} \\ &= I_{N-L}^{k} \end{aligned}\;. \tag{11}$$

Thus the interference can be rewritten as

$$\mathbf{I} = \begin{bmatrix} I_0^{(k)} & I_1^{k()} & I_2^{(k)} & \ldots & I_{N-1}^{(k)} \\ I_{N-1}^{(k)} & I_0^{(k)} & I_1^{(k)} & \ldots & I_{N-2}^{(k)} \\ I_{N-2}^{(k)} & I_{N-1}^{(k)} & I_0^{(k)} & \ldots & I_{N-3}^{(k)} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ I_1^{(k)} & I_2^{(k)} & I_3^{(k)} & \ldots & I_0^{(k)} \end{bmatrix}. \tag{12}$$

From the above formula, we can see that the interference matrix is comprised of $K\times N$ different components. However, the rank of matrix in formula (9) is N, thus it is impossible to get these $K\times N$ components directly.

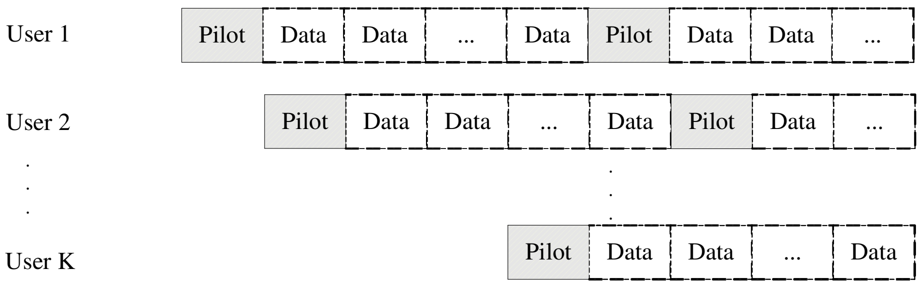

Fig. 2. In OFDMA uplink communications, different users always start to communicate with the base station at different time slots. Thus we suppose all users start to communicate with the base station at different time slots.

In OFDMA uplink communications, different users always start to communicate with the base station at different time slots. Thus we suppose all users start to communicate with the base station at different time slots, as shown in Fig 2. Then, in one OFDM symbol period, only one pilot block which belongs to one user will arrive at the base station. Therefore, estimating the components in the interference matrix is feasible. We also assume that the CFO of each user is quasi static during the pilot block and the following data blocks.

Firstly, making initialization by setting **X=0** and $I_L^{(k)} = 0$. To simplify the statement, we suppose all users start to communicate with the base station abide by the user's index order. Thus the first OFDM symbol arrived at the base station is the pilot block belonging to the user with index 0. Then we can set $\mathbf{X}=\mathbf{X}^{\mathbf{0}}$. Because the other users haven't started to communicate with the base station, we can obtain $I_L^{(k)} = 0, (k \neq 0)$. This is the same condition with single user.

Firstly, we set all components in the interference matrix to be 0. Then rewrite formula (9) as

$$\begin{aligned}
\mathbf{Y} &= \mathbf{I}\cdot\mathbf{X}+\mathbf{V} \\
&= \tilde{\mathbf{X}}\cdot\tilde{\mathbf{I}}+\mathbf{V} \\
&= \tilde{\mathbf{X}}^0\cdot\mathbf{I}^0+\mathbf{V} \\
&= \begin{bmatrix} X_0^0\cdot H_0^0 & X_1^0\cdot H_1^0 & \dots & X_{N-1}^0\cdot H_{N-1}^0 \\ X_1^0\cdot H_1^0 & X_2^0\cdot H_2^0 & \dots & X_0^0\cdot H_0^0 \\ \dots & \dots & \dots & \dots \\ X_{N-1}^0\cdot H_{N-1}^0 & X_0^0\cdot H_0^0 & \dots & X_{N-2}^0\cdot H_{N-2}^0 \end{bmatrix} \cdot \begin{bmatrix} I_0^0 \\ I_1^0 \\ \dots \\ I_{N-1}^0 \end{bmatrix} + \mathbf{V}
\end{aligned}, \qquad (13)$$

where $\mathbf{I}^{\mathbf{0}}=[I^0_{0}, I^0_{1}, \dots, I^0_{N-1}]^{\mathrm{T}}$ is the interference vector which is caused by the CFO from the first user in the interference matrix. We assume we already know the channel response by channel estimation. Since this OFDM symbol is the pilot block, the transmitted data on each subcarrier are already know to the receiver. Thus $\tilde{\mathbf{X}}^{\mathbf{0}}$ and its inverse matrix $\tilde{\mathbf{X}}^{\mathbf{0}^{-1}}$ can be easily obtained. Then the interference vector $\mathbf{I}^{\mathbf{0}}$ can be estimated by the inverse matrix $\tilde{\mathbf{X}}^{\mathbf{0}^{-1}}$ as follows

$$\mathbf{I}^0 = \tilde{\mathbf{X}}^{0^{-1}} \cdot \mathbf{Y} . \tag{14}$$

After that, we update the interference matrix with the interference vector $\mathbf{I}^{\mathbf{0}}$. In the following OFDM symbols, if the other users don't start to communicate with the base station, the interferences in the following received data blocks can be suppressed by

$$\begin{aligned} \mathrm{Y}_{\mathrm{suppressed}} &= \mathbf{H}^{-1} \cdot \mathrm{I}^{-1} \cdot \mathrm{Y} \\ &= \mathrm{X} + \mathbf{H}^{-1} \cdot \mathrm{I}^{-1} \cdot \mathrm{V} \end{aligned} . \tag{15}$$

We assume a new user start to communicate with the base station after several OFDM symbols.

To get the interference vector related with this new user's CFO, we can perform as follows.

a) Extract the received symbol vector, which belong to those users whose interference vectors already have been estimated. We ignore the MAI from the new arrived user and suppress the interference (ICI and MAI from those users) by using the formula (15).

b) The suppressed signal is detected and the transmitted data, which belong to those users whose interference vectors have already been estimated, can be obtained.

c) Reconstruct the detected symbol vector $\mathbf{X}^{\mathrm{detect}}$, and then calculate the interferences from the detected users by using

$$\mathbf{\Phi} = \mathbf{I} \cdot \mathbf{H} \cdot \mathbf{X}^{\det ect} . \tag{16}$$

d) Cancel the interferences caused by the detected users by

$$\mathbf{Y}^{New} = \mathbf{Y} - \mathbf{\Phi} . \tag{17}$$

e) Then, the interference vector of the new arrived user can be estimated by performing the same process to estimate the interference vector of the first user.

f) To obtain more accurate estimation results, we can calculate the MAI caused by the new arrived user and remove it from the received signal vector. Then perform the above process a)~f) with several iteration loops.

After obtain the new arrived user's interference vector, we can update the interference matrix with this interference vector and suppress the interference as (15).

When another user starts to communicate with the base station, the interference vector estimation process is same as described above.

When some user stops to communicate with the base station, update the interference matrix by setting the corresponding interference components to be 0.

The algorithm to estimate the interference matrix is list as follows.

- When first user start to communicate with the base station, estimate the interference vector of the first by using formula (13). Then make suppression to the received signal and update the interference matrix with $\mathbf{I}^{\mathbf{0}}$.

- When a new user start to communicate with the base station, estimate the interference vector as a)~f). Then make suppression to the received signal and update the interference matrix with the newly estimated interference vector.
- When some user stops to communicate with the base station, update the interference by the corresponding interference components to be 0.

4 Simulation Results and Discussion

Table 1 shows the simulation parameters. We assume that the normalized frequency offset of each user is a random value uniformly distributed in [-0.1, 0.1], and the multiple CFOs are quasi static during the pilot block and the following 5 data blocks.

Table 1. Simulation Parameters

OFDMA Uplink System	
Modulation scheme	16 QAM
Number of subcarriers/symbol (N)	128
Number of users (K)	2
Subcarrier mapping method	Localized method
CP length	32
Frame size	6
Channel model	AWGN & 802.16 SUI channel model [14]

The pilot sequence used in these simulations is CAZAC (constant amplitude zero autocorrelation) sequence, which is one type of polyphase codes and has many applications in channel estimation because of its good periodic correlation property [15]. Let L to be any positive integer larger than one and k be any number which is relatively to L. Then an example of CAZAC sequence is given as

$$\begin{cases} c_k(n) = e^{j\frac{2\pi k}{L}(n+n\frac{n+1}{2})}, n = 0, 1, ..., L-1, if\ L\, is\ odd \\ c_k(n) = e^{j\frac{2\pi k}{L}(n+\frac{n^2}{2})}, n = 0, 1, ..., L-1, if\ L\, is\ even \end{cases}. \tag{18}$$

Then we can get the following simulation results.

Fig. 3 shows the interference components caused by single subcarrier. From this figure, we can see that the interference components caused by single subcarrier on other subcarriers decreases as the distance between the two subcarriers increase. Thus the interference mainly attacks the neighbor subcarriers and localized mapping method is much more robust to MAI than interleaved method.

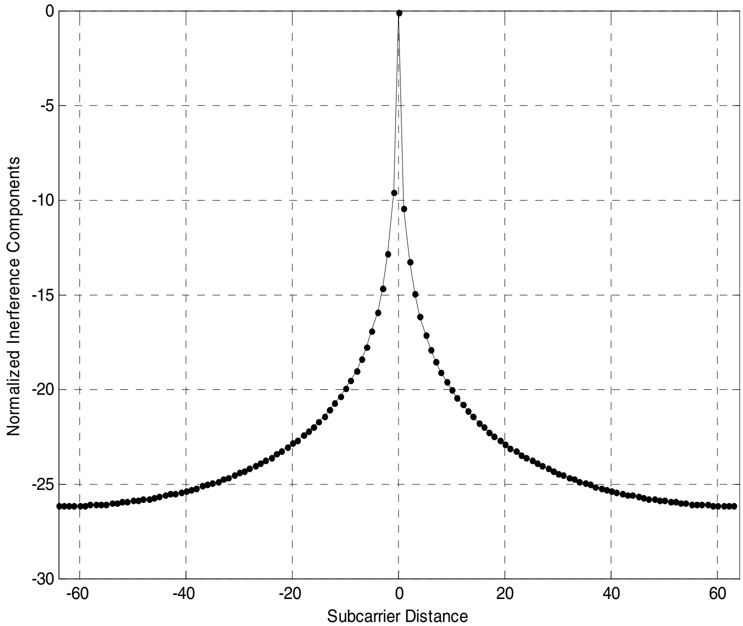

Fig. 3. Interference components caused by single subcarrier

First, let's check the BER performance of proposed method. Fig. 4 shows the BER performance in AWGN channel and Fig. 5 shows the 1 BER performance in frequency selective fading channel. The channel model used here is the 802.16 SUI-5A model, which is modeled as a tapped-delay ling with 3 non-uniform delay traps. The channel gain of each tap is [0, -5, -10]dB and the delay of each tap is [0, 4, 10]μs respectively. From the simulation results, we can see that with the increase of iteration, the performance of proposed method becomes better.

Then we can compare the BER performance with the method proposed in reference [11] for both the proposed method and the referenced method exploit the inverse matrix. Since the method proposed in reference [11] needs perfect multiple CFOs estimation, we simulate this method in two conditions. One condition is that the multiple CFOs are perfectly estimated and the other condition is that there is a MSE of multiple CFOs estimation about 10^{-4} [16]. Fig. 6 shows the BER performance of the two suppression methods in AWGN channel and Fig. 7 shows the BER performance in frequency selective fading channel. From the simulation results, we can see that when multiple CFOs are perfectly estimated, the referenced method can achieve the best performance. However, perfect estimation is impossible in practical system. When estimation error exists, the performance of referenced method will be highly degraded. Comparing these results, we can see that the proposed method with 5 iterations can achieve better performance than the referenced method with imperfect multiple CFOs estimation.

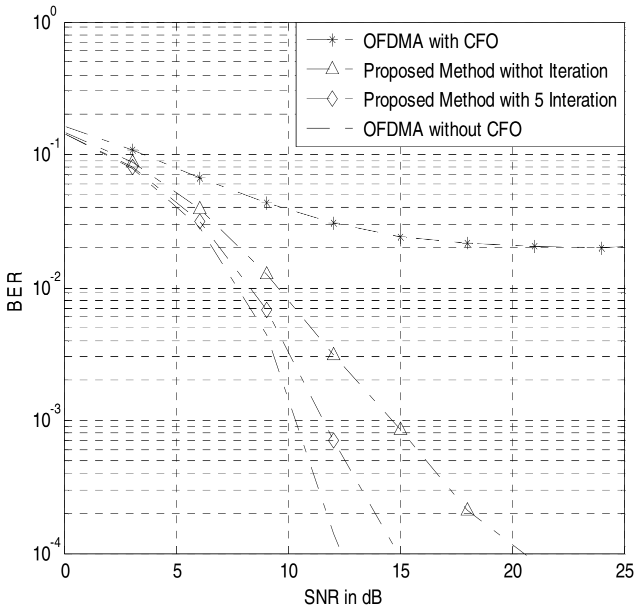

Fig. 4. BER performance of proposed method in AWGN channel

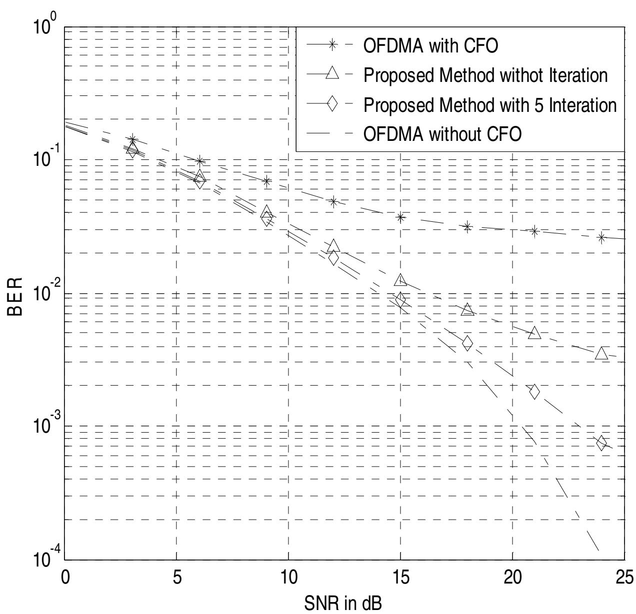

Fig. 5. BER performance of proposed method in frequency selective fading channel

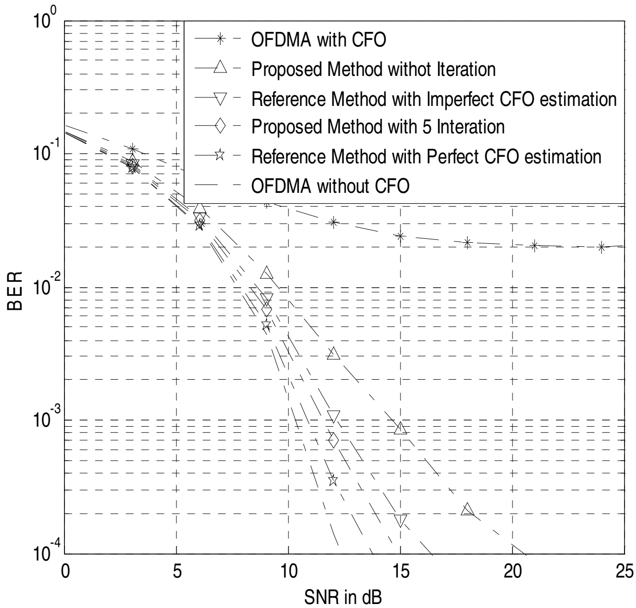

Fig. 6. Comparison of BER performance in AWGN channel

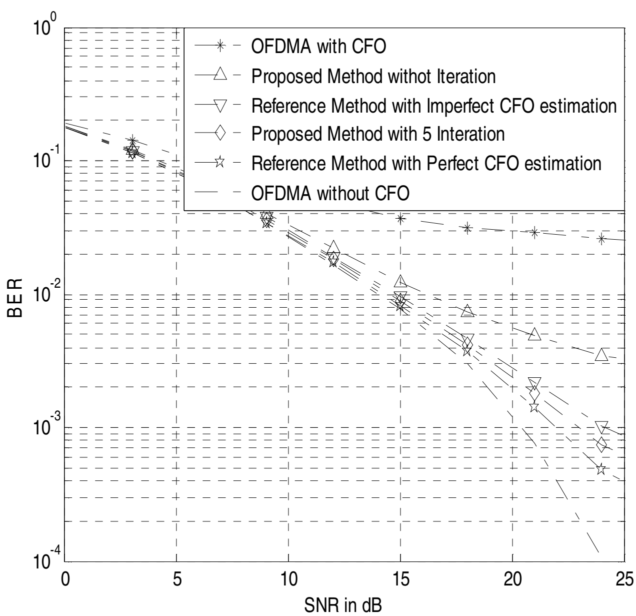

Fig. 7. Comparison of BER performance in frequency selective fading channel

5 Conclusion

In this paper, we have analyzed the interferences generated from multiple CFOs in OFDMA uplink communication system. According to the analysis results, we can see that the received signal will be seriously disturbed and the system performance will be seriously degraded. Also, we can see that the interference matrix is comprised of $K \times N$ different components. However, the rank of the received signal function is N, so it is impossible to get these $K \times N$ components directly. Thus we suppose all users start to communicate with the base station at different time and propose a novel suppression method which is based on block type pilots. Through the received pilot block, we can estimate all components in the interference matrix. Then by reconstructing the interference matrix from the estimation result, we can make suppression to the interferences and finally improve system performance. Simulation results show that the joint suppression algorithm works well in both AWGN and frequency selective fading channel. Compared with other algorithm, the proposed algorithm can achieve better performance when multiple CFOs estimation is imperfect. More accurate algorithm with less complexity should be studied in the future.

Reference

1. IEEE Standard for Local and metropolitan area networks, Part16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands. IEEE Std. 802.16e (2005)
2. Morelli, M.: Timing and frequency synchronization for the uplink of an OFDMA system. IEEE Transactions on Communications 52(2), 296–306 (2004)
3. van de Beek, J.J., Borjesson, P.O., Boucheret, M.L., Landstrom, D., Arenas, J.M., Odling, P., Ostberg, C., Wahlqvist, M., Wilson, S.K.: A time and frequency synchronization scheme for multiuser OFDM. IEEE Journal on Selected Areas in Communications 17(11), 1900–1914 (1999)
4. Yanxin, N., Hlaing, M.: Line Search Based Iterative Joint Estimation of Channels and Frequency Offsets for Uplink OFDMA Systems. In: IEEE GLOBECOM 2006, November 2006, pp. 1–5 (2006)
5. Movahedian, M., Ma, Y., Tafazolli, R.: An MUI resilient approach for blind CFO estimation in OFDMA uplink. In: IEEE 19th International Symposium on PIMRC 2008, September 2008, pp. 1–5 (2008)
6. Zhongren, C., Tureli, U., Yu-Dong, Y.: Deterministic multiuser carrier-frequency offset estimation for interleaved OFDMA uplink. IEEE Transactions on Communications 52(9), 1585–1594 (2004)
7. Dai, X.: Carrier frequency offset estimation and correction for OFDMA uplink. IET Communications 1(2), 273–281 (2007)
8. Fantacci, R., Marabissi, D., Papini, S.: Multiuser interference cancellation receivers for OFDMA uplink communications with carrier frequency offset. In: IEEE GLOBECOM 2004, November 2004, vol. 5, pp. 2808–2812 (2004)
9. Manohar, S., Sreedhar, D., Tikiya, V., Chockalingam, A.: Cancellation of Multiuser Interference Due to Carrier Frequency Offsets in Uplink OFDMA. IEEE Transactions on Wireless Communications 6(7), 2560–2571 (2007)

10. Nguyen, H.C., De Carvalho, E., Prasad, R.: Multi-User Interference Cancellation Scheme(s) for Muliple Carrier Frequency Offset Compensation in Uplink OFDMA. In: 2006 IEEE 17th International Symposium on PIMRC 2006, Sept. 2006, pp. 1–5 (2006)
11. Zhongren Cao, U.: Frequency synchronization for generalized OFDMA uplink. In: IEEE GLOBECOM 2004, November 29– December 3, vol. 2, pp. 1071–1075 (2004)
12. Yucek, T., Arslan, H.: Carrier Frequency Offset Compensation with Successive Cancellation in Uplink OFDMA Systems. IEEE Transactions on Wireless Communications 6(10), 3546–3551 (2007)
13. Sun, P., Zhang, L.: A Novel Pilot Aided Joint Carrier Frequency Offset Estimation and Compensation for OFDMA Uplink Systems. In: IEEE VTC Spring 2008, May 2008, pp. 963–967 (2008)
14. Erceg, V., Hari, K.V.S., Smith, M.S., Baum, D.S., et al.: Channel Models for Fixed Wireless Applications. Contribution IEEE 802.16.3c-01/29r1 (Feburary 2001)
15. Wen, Y., Huang, W., Zhang, Z.: CAZAC sequence and its application in LTE random access. In: IEEE Information Theory Workshop 2006, ITW 2006 Chengdu, October 2006, pp. 544–547 (2006)
16. Yonghong, Z., Leyman, A.R.: Pilot-Based Simplified ML and Fast Algorithm for Frequency Offset Estimation in OFDMA Uplink. IEEE Transactions on Vehicular Technology 57(3), 1723–1732 (2008)
17. Goldsmith, A.: Wireless Communications. Stanford University, Stanford (2004)