Co-Channel Interference Cancellation in Cellular OFDM Networks

PART II: Co-Channel Interference Cancellation in Single Frequency OFDM Networks using Soft Decision MLE CCI Canceler

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요 약

본 논문에서는 OFDM 셀룰라 네트워크에서 셀 가장자리에 위치한 사용자를 위한 다운링크 동일채널간섭(CCI) 제거 기법을 소개한다. 기지국간의 협력적 심볼 전송은 동일 심볼을 다른 기지국에서 상이한 부반송파를 사용하여 전송함으로서 이루어진다. 단말기에서는 전송된 심볼을 추정하기 위하여 연판정 최대우도 동일채널간섭 제거기 (soft decision maximum likelihood CCI canceler)와 수정된 최대비 합성법 (modified maximum ratio combining (M-MRC))을 적용하며, 합성법에 사용된 가중치는 협력 기지국과 단말기 사이의 채널 상수에 의해서 유도된다. 시뮬레이션 결과로부터 제안된 기법이 주파수 선택적 페이딩 채널과 주파수 비선택적 페이딩 채널에서 각기 9 dB와 6 dB의 SIR 이득을 보임을 알 수 있다.

Key Words: Cellular OFDM, Virtual-MIMO, Maximum Likelihood CCI Cancellation, Coordinated Symbol Repetition.

ABSTRACT

In this paper, a new scheme of downlink co-channel interference (CCI) cancellation in OFDM cellular networks is introduced for users at the cell-edge. Coordinated symbol transmission between base stations (BS) is operated where the same symbol is transmitted from different BS on different sub-carriers. At the mobile station (MS) receiver, we introduce a soft decision maximum likelihood CCI canceler and a modified maximum ratio combining (M-MRC) to obtain an estimate of the transmitted symbols. Weights used in the combining method are derived from the channels coefficients between the cooperated BSs and the MS. Simulations show that the proposed scheme works well under frequency-selective channels and frequency non-selective channels. A gain of 9 dB and 6 dB in SIR is obtained under multipath fading and flat-fading channels, respectively.

I. Introduction

Orthogonal frequency division multiplexing (OFDM) has gained attention for radio transmission technology of next generation mobile systems, due to its advantages including its robustness in multipath fading environment. However, the performance of OFDM cellular network is affected by the interference more than by any other performance limiting factor[1]. Furthermore, users at the cell edges in a fully-loaded system experience a high co-channel interference (CCI) that degrades the performance. Techniques have been proposed to mitigate the CCI which can be categorized into two categories, namely: interference avoidance and interference

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논문번호 : KICS2007-03-116, 접수일자 : 2007년 3월 9일, 최종논문접수일자 : 2007년 7월 9일

averaging. When coordinated interference avoidance are available, interference avoidance techniques such as adaptive interference coordination based on cell load can be applied. Otherwise, interference averaging techniques such as low rate forward error correction (FEC) and interleave division multiple access (IDMA) can be applied[2]. These techniques of CCI mitigation are effective when the system is not fully loaded. However, the performance of these techniques is highly degraded when the system is fully loaded [3]. On the other hand, multiple antenna techniques have been investigated to reduce the interference by exploiting the spatial signatures of the desired and the CCI signals[4].

In this paper, a sub-carrier-based virtual MIMO (V-MIMO) coordinated symbol repetition (CSR) is proposed for OFDM-based cellular systems to reduce CCI at the mobile station receiver. The frequency reuse factor equals to 1; i.e. the neighbour base stations (BSs) use the same frequency band. Two different sub-carriers are used to transmit the same symbol from two cooperated BSs. Thus, the proposed scheme can be considered as a 2x2 MIMO system. we introduce a soft decision maximum-likelihood CCI canceler to extract the desired signal from the received signal. The outputs of the MLE CCI canceler are normalized using normalization factors calculated from the estimated channels between the mobile station (MS) and the cooperated BS to get channel diversity. The proposed CCI cancellation scheme can reduce effectively the CCI in frequency selective and non-selective fading channels without neither scarifying the full frequency reuse nor increasing the complexity of the receiver of the MS.

This paper is organized as follows. In section II, we introduce the effect of CCI on the BER performance degradation in OFDM cellular network and in section III we present the proposed CCI cancellation scheme with the modified MS receiver structure and the soft-decision CCI canceler. Section IV presents the simulation results and finally we draw conclusions in section V.

Ⅱ. Effect of CCI on the BER Performance Degradation in OFDM Cellular Networks

Herein, we present a general formula of the effect of CCI on the BER performance degradation in OFDM cellular networks. For detailed derivation refer to[5].

After a long derivation, the BER performance in OFDM cellular network with CCI for QAM modulation is given by

$$P_e = \frac{1}{\log\left(\sqrt{M}\right)}\left(1 - \frac{1}{\sqrt{M}}\right)\cdot \left[1 - \frac{1}{\sqrt{\frac{M-1}{3}\left[\sum_{j=2}^{K+1} \frac{1}{SIR_j} + \frac{2}{\log(M)\frac{E_b}{N_0}}\right] + 1}} \right] \tag{2-1}$$

where log2(M) is the QAM modulation order, K is the number of CCI interferer BSs, SIR is the signal-to-interferer ratio and E_b / N_0 is the average signal-to-noise (SNR) ratio per bit. As we see from equation (2-1), as SIR term decreases the overall BER performance is reduced to interference free system. Furthermore, as the SNR increases the CCI becomes dominant and as consequence the BER curve converges to a fixed threshold.

Ⅲ. System Model

In cellular OFDM system, the received signal at the MS is the sum of the desired signal and the CCI signals from other BSs, as shown in Fig. 1. The received baseband signal at the MS receiver is given by

$$y(l) = \sum_{i=1}^{N_{BS}} h_i(l)\, s_i(l) + n(l) \tag{3-1}$$

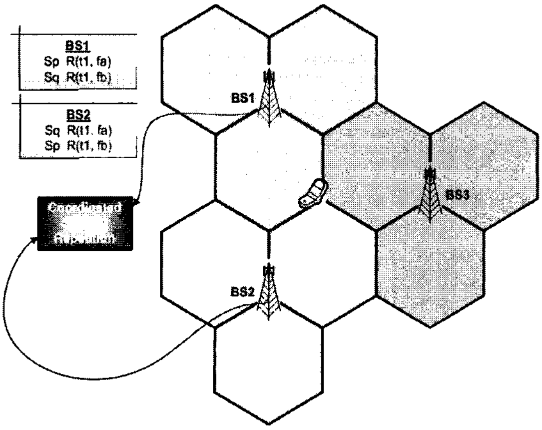

Fig 1. Cellular OFDM network with CCI and CSR.

where $s_i(l)$ and $h_i(l)$ are the transmitted signal and the channel coefficient between the *i-th* BS and the MS, at the *l-th* sub-carrier, respectively. Furthermore, *n(l)* is the double sided AWGN with zero mean and variance σ_n^2 and N_{BS} is the number of BSs. In a three-cell scenario, the data of the MS at the cell-edge is transmitted from two different BSs, the transmission matrix can be written as follows

$$\begin{array}{c} \\ f_a \\ f_b \end{array} \begin{array}{c} \begin{array}{cc} BS1 & BS2 \end{array} \\ \begin{bmatrix} s_p & s_q \\ s_q & s_p \end{bmatrix} \end{array} \tag{3-2}$$

where f_a and f_b are the *a-th* and *b-th* sub-carriers, respectively. To get better diversity performance, the separation between f_a and f_b should be greater than the coherence bandwidth of the channel. Also, s_p and s_q are the transmitted symbols while BS1 and BS2 are the cooperated BSs. In addition, BS3 transmits a CCI signal. Here, the overall *N* data sub-carriers are divided into G groups each composed of *M* sub-carriers. The cooperation between BS is applied over groups with fluctuating or bad reported SNR to improve the system performance without scarifying the spectral efficiency.

Fig. 2 shows the MS receiver structure; the received signal is firstly serial to parallel converted, the cyclic prefix (CP) is removed and then FFT is applied to get the frequency domain signal. At each sub-carrier, the soft decision MLE CCI canceler is applied to reduce the interference.

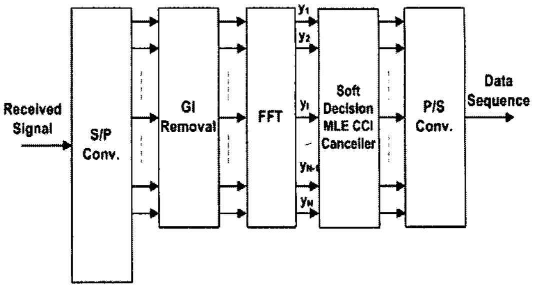

Fig. 2. MS receiver structure.

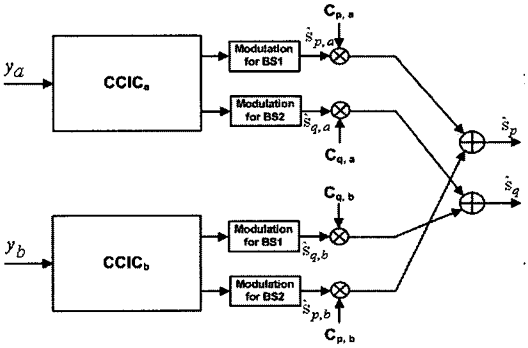

Fig. 3. Soft decision MLE CCI canceller.

Fig. 3 depicts the structure of the soft decision MLE CCI canceler. At first, the hard decisions are obtained by passing the received signals (y_a and y_b) on each sub-carrier into the MLE CCI canceler (CCIC). Only the estimated signals of the cooperated BSs are passed into the next step where the interference signals are not considered.

The CCIC generates replicas of the transmitted signals by computing all the weighted possible combinations as shown in Fig. 4. Herein, the weights represent the estimated channel coefficients at every data sub-carrier. The replica with the minimum Euclidean distance is chosen and the hard decisions are obtained[6]. The square Eucledian distance between received signal and generated replicas can be written as

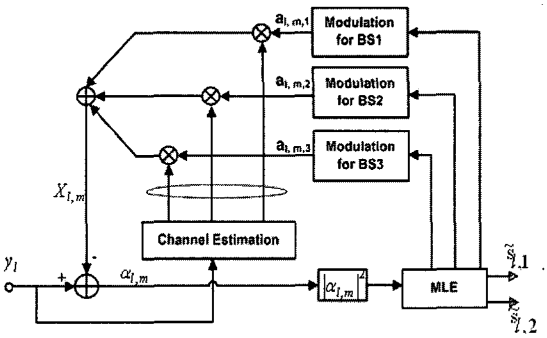

Fig. 4. Co-Channel Interference Canceller (CCCI).

$$|\alpha_{l,m}|^2 = \left| y(l) - \sum_{i=1}^{3} \hat{h}_i(l)\, a_i(l,m) \right|^2 \tag{3-3}$$

where y(l) and $\hat{h}_i(l)$ are the received signal and the estimated channel coefficient between the *i-th* BS and the MS at the *l-th* sub-carrier, respectively. Also, $a_i(l,m)$ are locally generated symbols to construct the replica $X_{l,m}$ where *m* is the replica index. Finally, the estimated symbols at the sub-carriers f_a and f_b (i.e. $\widehat{s_{p,a}}$, $\widehat{s_{p,b}}$, $\widehat{s_{q,a}}$ and $\widehat{s_{q,b}}$) are weighted according to the channel coefficients over which they are transmitted then combined.

The soft decisions at the output of the soft decision MLE CCI canceler are given by

$$\tilde{s}_p = \frac{|\hat{h}_1(a)|}{2\left(|\hat{h}_1(a)| + |h_2(a)|\right)} s_{p,a} + \frac{|h_2(b)|}{2\left(|\hat{h}_1(b)| + |h_2(b)|\right)} s_{p,b} \tag{3-4}$$

and

$$\tilde{s}_q = \frac{|\hat{h}_2(a)|}{2\left(|\hat{h}_1(a)| + |h_2(a)|\right)} s_{q,a} + \frac{|h_1(b)|}{2\left(|\hat{h}_1(b)| + |h_2(b)|\right)} s_{q,b} \tag{3-5}$$

where $\hat{h}_i(l)$ is the channel coefficient between the *i-th* BS and the MS at the *l-th* sub-carrier. This combining given by equations (3-4) and (3-5) can be considered as a modified maximum ratio combining (M-MRC) method[7] where received symbol with high respective power has a high weight in the combining scheme while received symbol with low respective power has a low weight.

Ⅳ. Simulation Results

Performance of the proposed soft decision MLE CCI canceler with CSR (i.e. V-MIMO) is evaluated for users at the cell edge. To detect the transmitted symbol at every sub-carrier, M^K replicas are calculated where M is the modulation alphabet size and K is the number of BSs. For example, for QPSK modulation (M = 4) and two CCI signals, the MS receiver should calculate $4^3 = 64$ replicas to detected the transmitted symbols. This indicates that the overall complexity of the proposed algorithm is acceptable compared to other CCI cancellation schemes. Table I shows the principal parameters used in the simulations. Three BSs are considered where CSR is applied between BS1 and BS2 and BS3 is considered as additional CCI. The total number of sub-carriers, the length of the CP, and modulation order used in the simulations are 64, 16 and 4 (QPSK), respectively. no forward error correction (FEC) is applied. Furthermore, when the BER performance is investigated for different average E_b/N_0 values, average signal to interference ratio between BS1

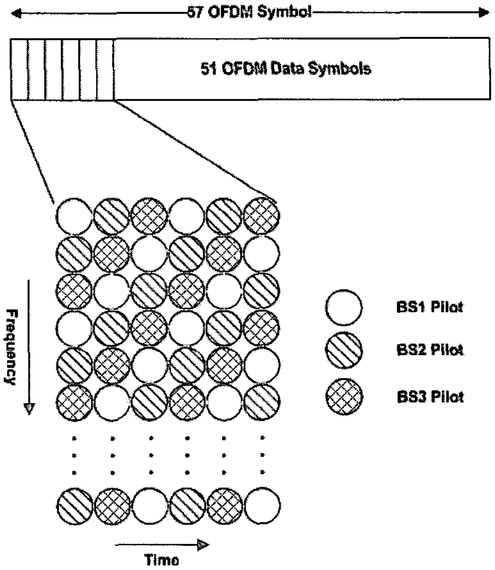

Fig. 5. Frame Structure.

Table 1. Simulation parameters.

Parameter	Value
Carrier Frequency	2 GHz
Number of Cells	3
Bandwidth	20 MHz
FFT size	64
Guard Interval	16
Modulation	QPSK
Speed	10 Km/h

and BS2 (SIR_{12}) and that between BS1 and BS3 (SIR_{13}) are set to 0 dB and 10 dB, respectively. Otherwise, average E_b/N_0 and SIR_{12} are fixed to 18 dB and 0 dB, respectively. Also, a frame is composed of 57 OFDM symbols; 51 data symbols and 6 pilot symbols used for channel estimation where pilot patterns of the three BS are mutually orthogonal. Fig. 5 shows the detailed frame structure indicating the different BSs pilots structures.

4.1 Simulation Under Frequency Non-Selective Fading Environment

In this subsection, single-path Rayleigh fading channel is considered. Unlike the conventional symbol repetition method[8] which does not work well in low frequency selectivity channels, the proposed algorithm works well under frequency non-selective channels.

When the same symbol is transmitted from two different BSs, the instantaneous channel power between the BSs and MS are not constant. Thus, one can get channel power diversity. Fig. 6 shows the improvement of the proposed scheme; at BER of 5×10^{-2}, we get a gain of 6 dB in SIR.

Fig. 7 shows the BER performance versus E_b/N_0 of the proposed scheme. the BER performance without any kind of CCI cancellation nor coordinated transmission between BS, presented in section II, is also shown. Furthermore, the dashed line shows the BER without coordination between BSs. At BER of 5×10^{-2}, we have a gain of 3 dB compared to the system performance without the proposed CCI cancellation scheme.

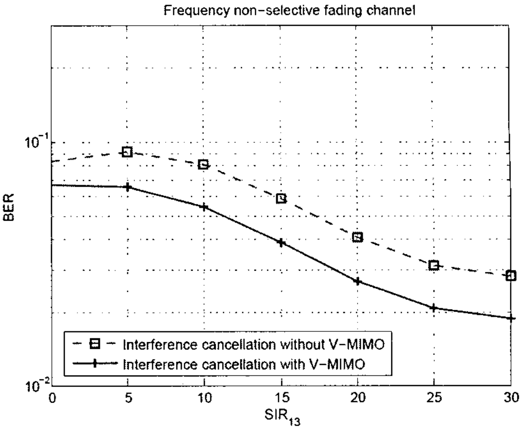

Fig. 6. SIR improvement of proposed scheme under frequency non-selective channel.

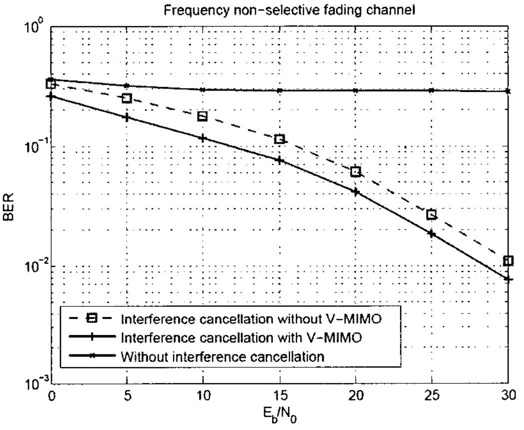

Fig. 7. E_b/N_0 improvement of proposed scheme under frequency non-selective channel.

4.2 Simulation Under Frequency Selective Fading Environment

For multi-path fading environment, we consider a 5-path Rayleigh distributed fading channel. The power delay profile is a general exponential decay model with path interval of three samples durations. Fig. 8 shows the BER performance versus SIR_{13}, at BER of 9×10^{-2}, we obtain a gain of 9 dB in the SIR. Fig. 9 shows the BER performance of the proposed scheme at fixed average SIR values. We obtain a gain of 3.3 dB in the average E_b/N_0 at BER of 6×10^{-2}. A slight additional improvement is obtained under multipath fading channel because of the frequency

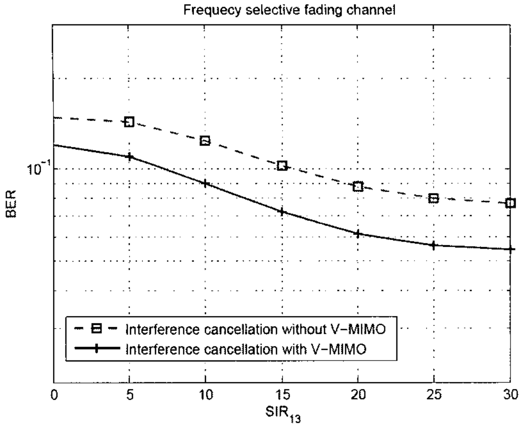

Fig. 8. SIR improvement of proposed scheme under frequency selective channel.

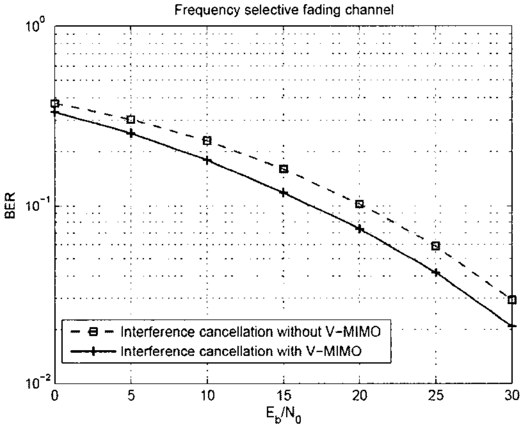

Fig. 9. E_b/N_0 improvement of proposed scheme under frequency selective channel.

diversity that is achieved by transmitting the same symbol on different sub-carriers from different BS.

V. Conclusions

In this paper, we introduced the concept of using V-MIMO (by applying CSR) in CCI cancellation in fully-loaded OFDM networks. we introduced the construction of soft decision MLE CCI canceler and a modified MRC scheme to combine the softly decided symbols transmitted from different BSs on different sub-carriers. The proposed scheme works well in frequency-selective environment by obtaining frequency diversity. Simulation results showed that the proposed scheme can efficiently reduce degradation caused by CCI and as consequence the system performance is improved.

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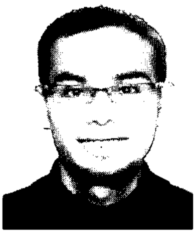

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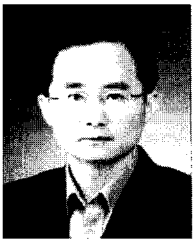

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