Performance Improvement of Downlink MC-CDMA Cellular System with an Intermittent Transmission

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***Abstract*— Throughput performance of MC-CDMA systems depends on the success in managing interference arising from intercell transmission. In this paper, we propose a new intercell interference mitigation scheme for downlink MC-CDMA scheme. In the proposed scheme, a base station transmits downlink signals intermittently to mobile terminals at the edge of cell. The intercell interference can be seen as a partial interference depend upon the on and off period of the adjacent downlink signals. So it is possible for the channel equalizer to suppress this partial intercell interference by setting the weight changes in accordance with the intercell interference. As results, the frame error rate of the proposed scheme is always better than that of the conventional scheme and good throughput performance is achieved especially when the traffic is high.**

***Index Terms*— MC-CDMA, Intercell-Interference, downlink, asynchronous cellular system**

I. INTRODUCTION

The demand for wireless wideband access is increasing and the next generation cellular systems are expected to support variety of media transmitted in IP-based packets. Multicarrier code division multiple access (MC-CDMA) has been considered as a promising candidate for downlink physical layer of next generation cellular systems [1]. The maximizing the downlink throughput in the limited amount of spectrum has been a main focus of researches. At the moment, 5Gbps downlink transmission using 12x12 MIMO technique is the maximum rate for an isolated cell [2].

In practical cellular systems, such high throughput may not be possible due to the interference arising from neighboring cells, especially for terminals at the edge of cell. To combat with intercell interference, the following two approaches are considered in literatures: mitigation of intercell interference by coordination between base stations and intercell interference cancellation.

The schemes that rely on coordination between base stations are very effective for mitigation of intercell interference. A well-known example of the scheme is the site-diversity reception [3]. If the tight synchronization between base stations is guaranteed, a mobile terminal at the edge of cells enjoys reception of signals from multiple base stations. In other words, there is no intercell interference to the mobile terminal. Such an intercell interference free environment is also possible by an appropriate scheduling of downlink transmissions. Indeed, it has been shown that the maximum throughput is obtained when each base station transmits one at a time, having on and off periods [4]. A drawback of these schemes is quick adaptation of traffic and channel conditions by a base station and it must communicate with adjacent base stations for an appropriate scheduling of downlink transmission to minimize intercell interference.

The latter case is also well studied in literatures. Intercell as well as intracell interference cancellation is an effective technique for enhancing the capacity [5]. However, the interference cancellation scheme is rather complex and requires much processing power. Thus for mobile terminals, small size and longer battery life are demand, such interference cancellation scheme having a complex processing are inadequate. A solution is to equalize downlink signals at a base station, known as pre-equalizing technique adopted with TDD mode [6]. Adaptive array antenna techniques are also effective for minimizing intercell interference [7]. A drawback is that these schemes require the completely estimation of channel conditions and the channel parameters. Usually the channel information are gathered from mobile terminals with a high feedback overhead.

In this paper, we propose a new intercell interference mitigation scheme for downlink MC-CDMA scheme. We consider an asynchronous base station that no coordination between base stations is assumed and the transmission is independently performed in a cell wise manner. We consider no intercell cancellation at a terminal or pre-equalization at a base station. Even in such tough situation, high throughput downlink transmission is possible by a simple examination of the following properties of our scheme. In the proposed scheme, a base station transmits downlink signals intermittently to mobile terminals at the edge of cell. Therefore, the intercell interference can be seen as a partial interference depend upon the on and off period of the adjacent base station. This partial intercell interference can be modeled as Gaussian random variable, whose variance varies according to on and off period. So

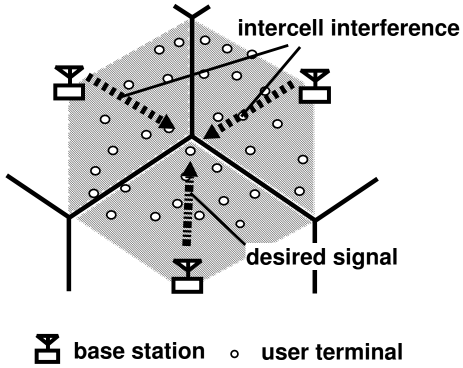

Fig. 1. Three base stations model.

it is possible for the channel equalizer to suppress this partial intercell interference by setting the weight, that changes in accordance with the intercell interference of off period. Moreover, thanks to the bit interleaved coded modulation, a bit with highly affected intercell interference can be recovered by a bit with no intercell interference. So further suppression of intercell interference is possible. As we show shortly, the intermittent downlink transmission is simple and effective for suppress the intercell interference.

II. PROPOSED SCHEME

A. System model

We consider three cells MC-CDMA downlink cellular system as shown in Fig. 1. Each cell is the hexagonal form and has one base station in the center. Each cell is divided in three sectors. We assume that there are no interference from other sectors in a cell. We assume asynchronous base stations, i.e., each base station transmits its downlink signals in an arbitrary timing. As shown in Fig. 1, the terminal at the edge of cell is interfered by two downlink signals from the adjacent two cells.

B. Base station transmitter structure

Fig. 2 shows the base station transmitter. It is assumed that there are K terminals in a cell. Each terminal's data is coded with coding rate R, and interleaved by bit-interleaver. The interleaved bits are modulated and i-th cell k-th user's complex symbols $d_k^{(i)}(m)$ are obtained. The symbol $d_k^{(i)}(m)$ are spread using the spreading code $c_{sp,k}(n)$ with spreading factor SF. Spread streams are added and multiplied by a scrambling code $c_{sc}^{(i)}(n)$. When the number of subcarriers is N, the n-th subcarrier components of i-th cell signal in frequency domain $S^{(i)}(n)$ are described as

$$S^{(i)}(n) = \sqrt{\frac{2P}{N \cdot SF}} \sum_{k=0}^{K-1} d_k^{(i)}\left(\left\lfloor \frac{n}{SF} \right\rfloor\right) \cdot c_{sp,k}(n \bmod SF)\, c_{sc}^{(i)}(n), \tag{1}$$

where P is a transmission power. They are converted in time domain by N-points IFFT (Inverse Fast Fourier Transform) processing. The i-th cell transmitting signal $s^{(i)}(t)$ is described as

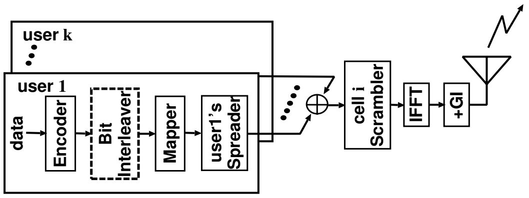

Fig. 2. Base Station Transmitter.

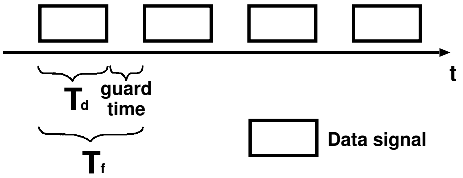

Fig. 3. Base station intermittent transmission.

$$s^{(i)}(t) = \sum_{n=0}^{N-1} S^{(i)}(n) \exp\left(j2\pi n \frac{t}{N}\right). \tag{2}$$

C. Intermittent Transmission

To reduce the inter-cell interference and by that, improve the performance of the terminals at the edge of cell, we propose the intermittent transmission. When each base station transmits the signal to the terminals at the edge of cell, the signal is divided in a certain section and transmitted intermittently. Fig. 3 shows the intermittent transmission at a base station. We define $\mathrm{T_d}$ as the time of divided signal is transmitted and $\mathrm{T_f}$ is $\mathrm{T_d}$ plus the time that the signal is not transmitted, *guard time*. Thus, base station transmits the signal at the edge of cell only during $\mathrm{T_d}$ and does not transmit the signal during guard time.

D. Channel model

Transmitted signal goes through L-paths frequency selective Rayleigh fading channel. The i-th cell impulse response $h^{(i)}(t)$ is that $h^{(i)}(t) = \sum_{l=0}^{L-1} h_l^{(i)} \delta(t - \tau_l^{(i)})$, where $h_l^{(i)}$ denotes l-th path gain of i-th cell signal and is independent zero-mean complex Gaussian. $\tau_l^{(i)}$ is the delay of l-th path of i-th cell signal and $\delta(\cdot)$ denotes the delta function. In asynchronous three cells cellular system in Fig. 1, the received signal $r(t)$ is

$$r(t) = \sum_{i=0}^{i=2} \sum_{l=0}^{L} \alpha^{(i)}\, h_l^{(i)}\, s^{(i)}(t - \tau_l^{(i)} - \lambda^{(i)}) \,+\, z(t), \tag{3}$$

where $z(t)$ denotes thermal noise and $\alpha^{(i)}$ the distance attenuation of the i-th cell signal. The parameter $\lambda^{(i)}$ means the differences of arrival time for $s^{(i)}(t)$. It is assumed that own cell signal is $s^{(0)}(t)$ so $\lambda^{(0)} = 0$. Fig. 4 shows the relationship that $s^{(1)}(t)$ and $s^{(2)}(t)$ are received with the time difference $\lambda^{(1)}$ and $\lambda^{(2)}$, respectively. While $s^{(1)}(t)$ and $s^{(2)}(t)$ with the time difference $\lambda^{(1)}$ and $\lambda^{(2)}$ overlap and those become interference to $s^{(0)}(t)$.

E. The amount of adjacent cell interference

We assume that all terminal knows the duration of guard time and the timing $\lambda^{(i)}$. Estimation of $\lambda^{(i)}$ can be taken easily by the power of received signal. It is assumed that

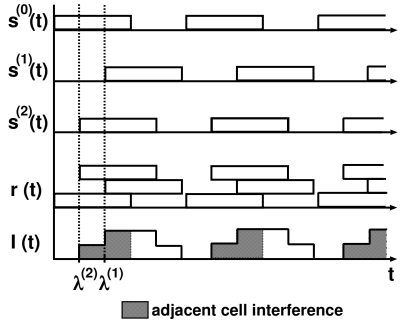

Fig. 4. The relationship between the received signal and base station signals in case of the intermittent transmission.

$\mathrm{T_d}$ and $\mathrm{T_f}$ are same in all base station. In the intermittent transmission, there are three cases for adjacent cell signal overlapping. The amount of interference from i-th cell signal to own cell signal $I^{(i)}$ ($i \neq 0$, $\mathrm{T_f} < 2\mathrm{T_d}$) in the duration $\mathrm{T_d}$ can be written as

$$I^{(i)} = \begin{cases} P\alpha^{(i)}(\mathrm{T_d} - \lambda^{(i)}) & (0 \le \lambda^{(i)} < \mathrm{T_f} - \mathrm{T_d}) \\ P\alpha^{(i)}(2\mathrm{T_d} - \mathrm{T_f}) & (\mathrm{T_f} - \mathrm{T_d} \le \lambda^{(i)} < \mathrm{T_d}) \\ P\alpha^{(i)}(\lambda^{(i)} + \mathrm{T_d} - \mathrm{T_f}) & (\mathrm{T_d} \le \lambda^{(i)} < \mathrm{T_f}) \end{cases}$$

In asynchronous cellular system, It is assumed that $\lambda^{(i)}$ is randomly distributed. In this assumption, the average amount of interference from i-th cell signal to own cell signal is $P\alpha^{(i)}\mathrm{T_d}\frac{\mathrm{T_d}}{\mathrm{T_f}}$. In the intermittent transmission, the average amount of the interference is $\frac{\mathrm{T_d}}{\mathrm{T_f}}$ times lower than that in the continuous transmission ($\mathrm{T_d} = \mathrm{T_f}$). We will normalize $\mathrm{T_d} = 1.0$ in the following.

F. Terminal receiver structure

Fig. 5 shows the structure of receiver. The FFT processing is applied and the stream is equalized in frequency domain. Own cell scrambling code is multiplied to the stream and despread using own spreading code. Next, the despread symbols are demodulated and inputted to the deinterleaver. Finally, deinterleaved symbols are decoded.

III. PERFORMANCE IMPROVEMENT BY CONSIDERING ADJACENT CELL INTERFERENCE AS PARTIAL INTERFERENCE

In the intermittent transmission, adjacent cell interference is also the intermittent interference. Each base station transmits the signal in an arbitrary timing, the whole adjacent cell signals do not overlap when the terminals receive signal. Adjacent cell signals overlap partly, as shown in Fig. 4. So we can take adjacent cell interference as partial interference. In other words, the scale of adjacent cell interference varies in the duration that terminals are receiving own cell signal. In our proposed scheme, we focus on this point that the scale of adjacent cell interference varies by every OFDM symbols.

It is considered that the burst error occurred in some received OFDM symbols. In the intermittent transmission, the length of burst errors are long. Adjacent cell signals arrive to the terminal and the interference continues $\mathrm{T_d}$. In order to get the effect of channel coding in this case, we should make the coded bits that are interfered statistically independent and compensate the interfered coded bits by the coded bits that are not interfered. Since the interference lasts some time, the coded bits that are not interfered are apart from the interfered coded bits. In proposed scheme, we use the bit-interleaver. The performance can be improved by the effect of channel coding using this interleaver.

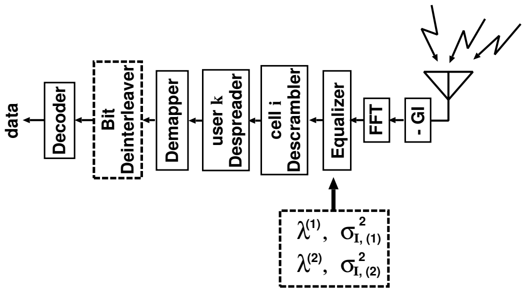

Fig. 5. Terminal Receiver structure.

IV. ADAPTIVE EQUALIZATION FOR PARTIAL INTERFERENCE

Each terminal has the equalizer to compensate the effect of fading. In this paper, MMSE (Minimum Mean Square Error) equalizer is applied [8]. In [8], the weight of the equalizer with MMSE criterion has the term of the noise variance. Adjacent cell interference can be taken as noise. We already described that adjacent cell signal interference is the partial interference, so the variance of adjacent cell interference varies with adjacent cell signals overlapping. The n-th subcarrier equalizer weights $w_{MMSE}(n)$ are described as

$$w_{MMSE}(n) = \frac{H^{*(0)}(n)}{\frac{K}{SF} \mid H^{(0)}(n)|^2 + \frac{\sigma_n^2 + \sigma_I^2}{\frac{P\alpha^{(0)}}{K}}} \tag{4}$$

where $H^{(0)}(n)$ denotes n-th subcarrier channel gain of own cell signal and $[\cdot]^*$ is the complex conjugate. σ_n^2 and σ_I^2 are respectively the noise variance and adjacent cell interference variance. For example, in Fig. 4, where $\lambda^{(2)} \le \lambda^{(1)}$, σ_I^2 is

$$\sigma_I^2 = \begin{cases} 0 & (0 \le t < \lambda^{(2)}) \\ \sigma_{I,(2)}^2 & (\lambda^{(2)} \le t < \lambda^{(1)}) \\ \sigma_{I,(1)}^2 + \sigma_{I,(2)}^2 & (\lambda^{(1)} \le t < \mathrm{T_d}), \end{cases} \tag{5}$$

where $\sigma_{I,(i)}^2$ denotes i-th cell interference variance. We assume that each terminal knows $\lambda^{(i)}$, so the tap weights can be adjusted to σ_I^2. In proposed receiver, w_{MMSE} in Eq. (4) changes based on Eq. (5) by every OFDM symbol.

V. NUMERICAL RESULTS

The simulation parameters are shown in Table 1. We define $\mathrm{T_f}$ as the duration of one frame and 1024 bits are transmitted in the duration $\mathrm{T_d}$. All terminal uses turbo code with R = 1/2, and QPSK modulation. SNR_0 denotes the

TABLE I
SIMULATION PARAMETERS

data size	1024
channel coding decoding	turbo code, R = 1/2 Max-Log-Map, 5-iterations
interleaver size	2048
data modulation	QPSK
spreading factor	16
spreading code scrambling code	Walsh-Hadamard code random code
number of subcarriers	256
SNR$_0$	120 dB
distance between base station	500 m
distance attenuation	3.76
channel model	16-paths Rayleigh fading + neighboring cell signal + AWGN
channel estimation	ideal

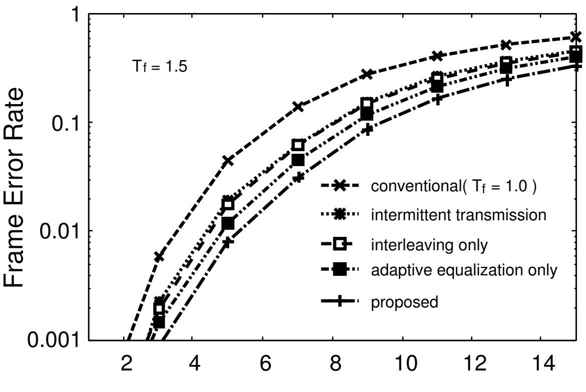

Fig. 6. Frame error rate with the number of terminals in a cell.

transmitter signal power to received noise power ratio. It is assumed that channel characteristic is constant during T_d and channel estimation is ideal. All terminal knows $\lambda^{(i)}$ and $\sigma^2_{I,(i)}$. $\lambda^{(i)}$ is randomly distributed. To evaluate the performance of terminals at the edge of cell we assume that all terminal is at the edge of a cell, that is to say, the outside of the place that the normalized distance between the terminal and base station is 0.75.

Fig. 6 shows the average frame error rate of the terminal at the edge of a cell. T_f = 1.5 is used so the duration of guard time is 0.5 times of T_d. The performance improves with the intermittent transmission and adaptive equalization. The effect of interleaver is small without adaptive equalization. This is also true for the adaptive equalization without interleaving. As we utilize adaptive equalization with bit-interleaver, the proposed scheme gives a good performance compared to conventional scheme.

Fig. 7 shows the throughputs performance of the terminal at the edge of cell. T_f = 1.5 is used. When the number of transmitting terminals is small, conventional scheme shows a good performance. However, when the number of transmitting terminals is large, the proposed scheme overstrides conventional scheme since the effect of adjacent cell interference is large. When the effect of adjacent cell interference is large, the intermittent transmission is effective. The throughput performance is the tradeoff between the effect of adjacent cell interference and guard time.

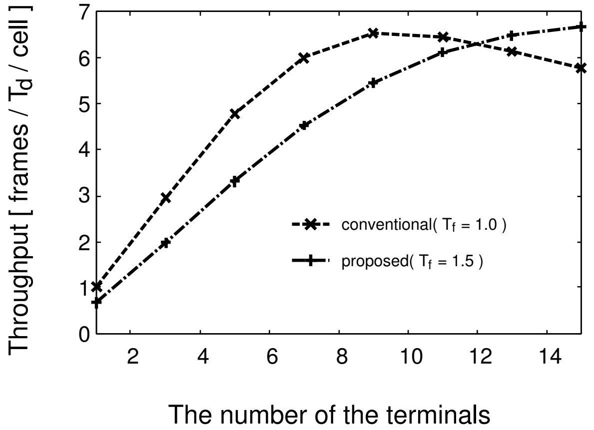

Fig. 7. Throughputs vs the number of terminals in a cell.

VI. CONCLUSION

In this paper, we proposed the new intercell interference mitigation scheme for downlink MC-CDMA asynchronous cellular system. In the proposed scheme, a base station transmits the signal to mobile terminal intermittently. With intermittent transmission, we can see intercell interference as a partial interference. So it is possible for the channel equalizer and bit-interleaver to suppress this partial intercell interference. As we have shown, the intermittent transmission is effective for the mitigation of intercell interference.

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