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A Joint Frequency-Domain Equalization (Fde) and Antenna Diversity Combining Method for the Multipath Fading in the Frequency-Selective Channel

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Abstract. In this study, a theoretical foundation is built to evaluate the downlink performance of an MC-CDMA cellular system with site diversity operation with and receive antenna diversity combining. An expression for the theoretical conditional bit error rate (BER) for the given set of channel gains is derived based on Gaussian approximation of the interference components in the composite receive signal. The local average BER is then obtained by averaging the conditional BER over the given set of channel gains using Monte-Carlo numerical method. The outage probability is measured from the numerically obtained cumulative distribution of the local average BER to determine the downlink capacity. Results from theoretical computation are compared to the results from computer simulation and discussed.

1 Introduction

The multicarrier-CDMA (MC-CDMA)[1,2] has been considered as a wireless access candidate for a wideband downlink transmission due to its robustness against the frequency-selectivity of the multipath channel and high frequency efficiency [3-5]. It is one of the new multiple access techniques proposed which based on the combination of the OFDM and CDMA. A basic MC-CDMA transmitter spreads the user's data symbol using an orthogonal spreading code in the frequency domain. Figure 1 shows the comparison between the three schemes: DS-CDMA, OFDM and MC-CDMA. The DS-CDMA spreads the user's data symbol using the spreading code in the domain whereas the OFDM transmit different user's data symbol on each subcarrier.

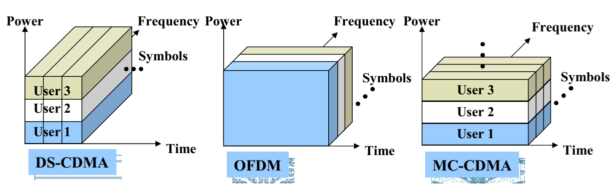

Figure 1. Comparison between DS-CDMA, OFDM and MC-CDMA.

The characteristics of MC-CDMA can be summarized as follows:

a) Transmits the same symbol in parallel through numbers of subcarriers in frequency domain.

b) Each data stream is serial-parallel converted before spreading to obtain almost frequency non-selective fading for each subcarrier (see Figure 2).

c) MC-CDMA lower the symbol rate in each subcarrier and the longer symbol duration makes it easier to quasi-synchronize the transmission.

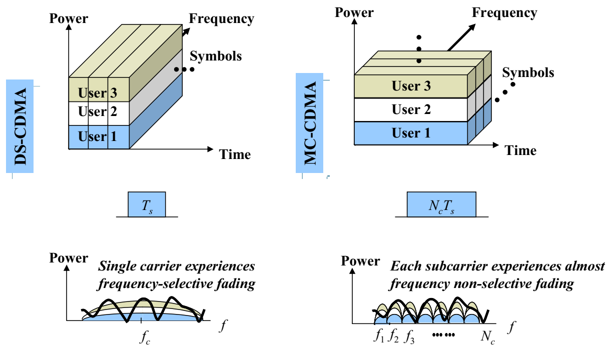

Figure2. Single-carrier CDMA (DS-CDMA) versus MC-CDMA.

OFDM should be used to mitigate the performance degradation due to frequency-selective fading while DS-CDMA is great to mitigate the interference in cellular deployment thought the use of scrambling codes [6,7]. Therefore, MC-CDMA inherits the benefits from the combination effort of CDMA and OFDM and makes it a great wireless access candidate for future cellular communications. A more detailed transmission system of a MC-CDMA cellular system is discussed in Chapter 4. In this study, joint frequency-domain equalization (FDE) and antenna diversity combining is applied to the reception of MC-CDMA cellular system, for combating ISI caused by the multipath fading in the frequency-

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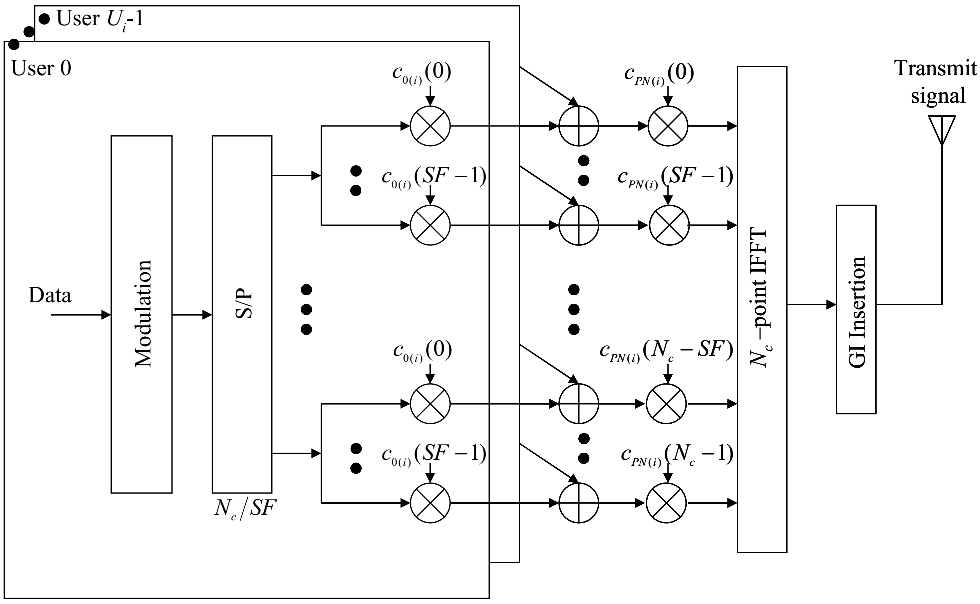
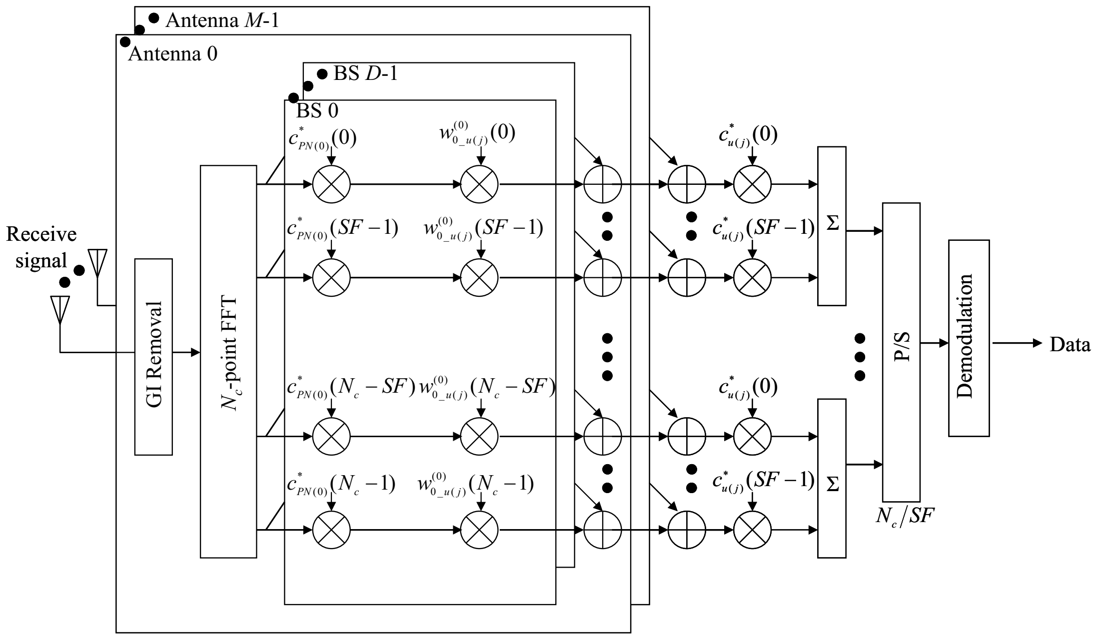


(a) Base station transmitter.



(b) Mobile station Receiver.

Figure 3. Downlink MC-CDMA transmitter/receiver with site diversity operation.

selective channel [8-11]. The FDE[12,13] and antenna diversity[14,15] are discussed in the next sections.

2 Downlink transmission model

The downlink MC-CDMA transmitter/receiver systems for site diversity operation with joint use of MMSE-FDE and receive antenna diversity is illustrated in Figure 3, where a system with Nc subcarriers and spreading factor SF is assumed.

3 Transmit signal representation

At BS i, the data modulated symbol sequence $\{d_{u(j)}(n); n=0\sim N_c/SF-1\}$ for user u of cell i is first serial-to-parallel (S/P) converted into Nc/SF parallel data sequences. Each of the S/P converter output is copied SF times and multiplied with the orthogonal spreading code $\{c_{u(j)}(k); k=0\sim SF-1\}$. All users' spread signal components at each subcarrier are combined and multiplied with the common scrambling code $\{c_{PN(i)}(k); k=0\sim N_c-1\}$ of BS i. Different scrambling codes are used in different cell sites for separating cell sites [1], besides making the resultant signal to be white-noise like. The composite transmit signal at subcarrier k is given as:

$$s_i(k)=\sqrt{\frac{2P_i}{SF}}\sum_{u(i)=0}^{U+\delta u_i-1} d_{u(i)}\left(\left\lfloor \frac{k}{SF}\right\rfloor\right)c_{u(i)}(k \bmod SF)c_{PN(i)}(k) \qquad (1)$$

with Pi and U+δui defined as the transmit power and the number of active channels (users) per BS i, respectively; where δu_i denotes the number of additional channels necessary for BS i in the site diversity operation; and $|d_{u(i)}(n)|=|c_{u(i)}(k)|=|c_{PN(i)}(k)|=1$. The orthogonal spreading and the scrambling codes have the following characteristics

$$\begin{cases} \dfrac{1}{SF}\displaystyle\sum_{k=0}^{SF-1} c_{u(i)}(k)c^{*}_{u'(i)}(k)=\delta(u-u') \\ E\left[c_{PN(i)}(k)c_{PN(i)}(k')\right]=\delta(k-k') \end{cases} \qquad (2)$$

However, perfect orthogonality between users cannot be achieved in a multipath fading channel, and this produces the multiple access interference (MAI). Furthermore, the inter-cellular interference (ICI) from other neighboring cells has to be considered since the scrambling codes between cells are not orthogonal.

After Nc-point IFFT, cyclic Ng-sample guard interval (GI) is inserted at the beginning of each symbol frame to mitigate the inter-symbol interference (ISI). The MC-CDMA transmit signal is then expressed as

$$s(t)=\sum_{k=0}^{N_c-1} s_i(k)\exp\left(j2\pi k\frac{t}{N_c}\right) \qquad (3)$$

for $t=-N_g \sim N_c-1$.

4 Numerical results and discussion

4.1 Monte-Carlo process

The evaluation of the downlink capacity is performed by the Monte-Carlo numerical method. An MC-CDMA system with Nc=256 subcarriers is assumed. The signal is assumed to propagate through a block Rayleigh fading channel with propagation path L=16 having the exponential power delay profile with decay factor γ dB. In an interference-limited environment with negligible AWGN effect, the interference coming from the second-tier cells is relatively weak and can be neglected. Therefore each user will receive the dominant interference from the six adjacent cells' BS's. The user of interest is located in cell 0 and there are 18 surrounding cells considered as co-channel cells. The maximum number of active BS, D varies from 1 to 7 where D=1 corresponds to the no site diversity operation and D=7 corresponds to the site diversity operation with six adjacent co-channel cells.

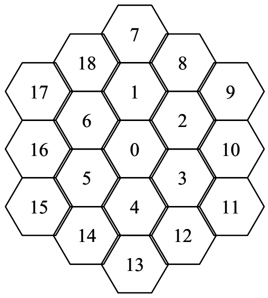
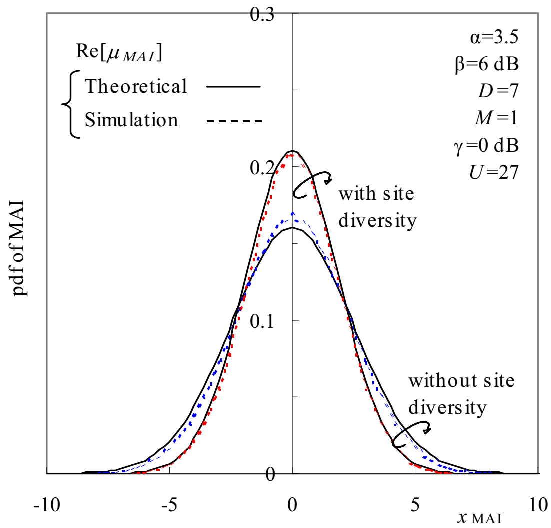


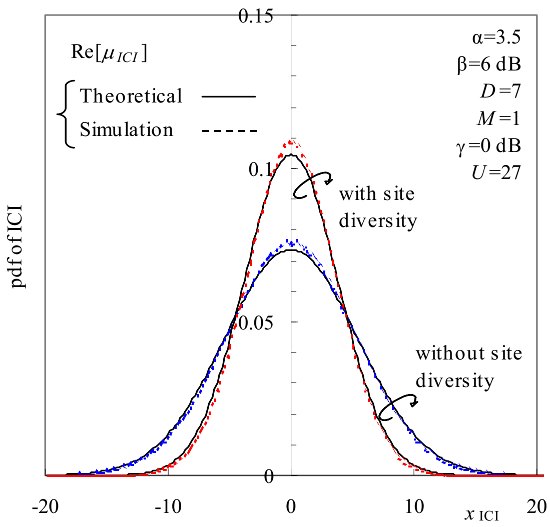
Figure 4. Cellular Structure.

4.2 Approximate analysis

The interference components have been approximated as the complex-valued Gaussian random variables for computing the conditional SINR and BER. To verify this approximation, the probability density functions (pdf's) of the MAI and ICI components obtained from the computer simulation are examined and plotted in Figure 5. A uniform power delay profile for the channel (γ =0 dB) and the number of users per cells, U=27 are assumed. Pth=4.5 dB is used for the case with site diversity operation. Only the real parts of μ MAI and μ ICI are plotted in Figure 5. The computer simulation plots show that the pdf's of the real part of μ MAI and μ ICI follow the Gaussian distribution with zero-mean. This therefore justifies the approximation used in the theoretical analysis.



(a) MAI component.



(b) ICI component.

Figure 5. Distributions of MAI and ICI components.

5 Conclusions

In this study, the theoretical treatment was developed for the downlink site diversity reception with joint use of MMSE-FDE and antenna diversity in a cellular MC-CDMA system. The expressions for the conditional SINR and BER were derived based on Gaussian approximation of the interference components; and the local average BER was numerically computed using Monte-Carlo computation method. The theoretical performance results were compared with computer simulation results to show a high degree of agreement. The pdf plots showed the real parts of MAI and ICI follow the Gaussian distribution and therefore, justifying the approximation used in the theoretical treatment.

Evidently, from both theoretical and simulation evaluations, the site diversity operation improves the MC-CDMA downlink performance. Both results showed that three (D=3) active BS's participating in site diversity operation are sufficient for achieving the maximum downlink capacity. Significant effect on the downlink capacity performance can be seen from different values of α, whereas the capacity performance is almost unaffected by different values of β. Increasing the number of receiving antenna increases the downlink capacity performance almost linearly. The larger the decay factor in the exponential power delay profile leads to a weaker frequency-selectivity of the fading channel, thus reducing the frequency-diversity effect exploited by MC-CDMA system and degrading the system overall performance.

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