Joint Frequency-domain Equalization and Multiple Transmit/Receive Antenna Diversity for DS-CDMA

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Abstract

Frequency-domain equalization used in MC-CDMA can be applied to the reception of DS-CDMA signals. Further performance improvement can be attained by the additional use of multiple transmit/receive antenna diversity. The BER performance improvement attainable by the joint use of frequency-domain equalization and multiple transmit/receive antenna diversity in a frequency-selective fading channel is evaluated by computer simulation. In this paper, delay transmit diversity (DTD) is used as transmit diversity. It is found that DTD is effective to improve the BER performance in a fading channel with weak frequency-selectivity.

1. Introduction

Recently, direct sequence code division multiple access (DS-CDMA) has been used for improving the BER performance of around a few Mbps transmissions by employing rake combining [1] to fully exploit the frequency-selectivity of the fading channel [2]. However, the rake combiner requires as many fingers (correlators) as the number of propagation paths to collect most of the transmitted power, otherwise a significant performance degradation occurs [3]. Furthermore, the large inter-path interference (IPI) degrades the BER performance even with ideal rake combining.

Recent studies have been shifted from DS-CDMA to multicarrier (MC) transmission techniques to overcome the frequency-selectivity of the fading channel by applying parallel transmission using many orthogonal subcarriers [4]. Much attention has been paid to orthogonal frequency division multiplexing (OFDM) and MC-CDMA. MC-CDMA has been considered a promising candidate for broadband wireless multiple access [5]. Using one-tap minimum mean square error (MMSE) frequency-domain equalization, much better BER performance can be attained with MC-CDMA than with DS-CDMA [6]. However, there is a drawback in MC transmission, i.e., linear transmit power amplifiers with large peak-to-average power ratio (PAPR) are necessary. More recently, application of frequency-domain equalization to orthogonal multicode DS-CDMA transmission (used in the forward link of cellular DS-CDMA communications systems) has been proposed [7] in order to reduce the multi-access interference (MAI) resulting from IPI, and hence improve its BER performance in a frequency-selective fading channel.

Transmit antenna diversity as well as receive antenna diversity are well-known effective techniques to improve the transmission performance [8]. In this paper, the joint use of frequency-domain equalization and multiple transmit/receive antenna diversity is considered for DS-CDMA. As the transmit antenna diversity, delay transmit diversity (DTD) is considered. Remainder of this paper is organized as follows. Section 2 presents the joint use of frequency-domain equalization and DTD/receive antenna diversity combining. In Sect. 3, the BER performance improvement achievable with DTD in a frequency-selective Rayleigh fading channel is evaluated by computer simulation. Section 4 offers some conclusions and future work.

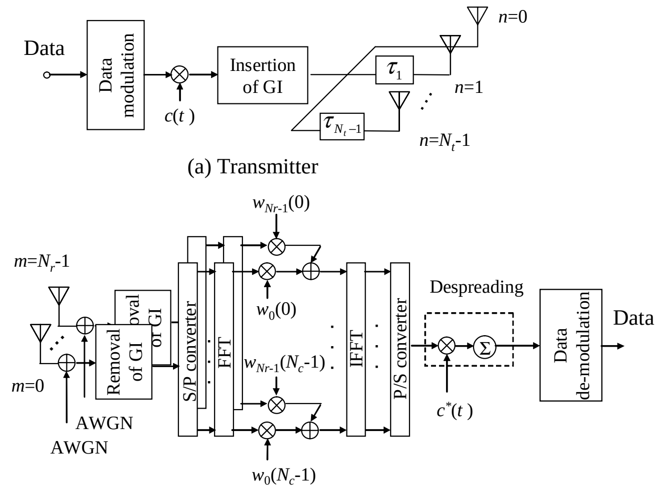
2. Joint Use of Frequency-domain Equalization and DTD/Receive Antenna Diversity

2.1 Transmitted and received signals representation with DTD

Transmission system model for DS-CDMA using frequency-domain equalization and DTD/receive antenna diversity is illustrated in Fig.1. Throughout this paper, the chip-spaced time representation of transmitted signals is used. Without loss of generality, the data symbol sequence $\{d(n);n=0\sim N_c/SF-1\}$ and the spreading chip sequence $\{c(t);t=0\sim SF-1\}$ of one frame are considered, where $|d(n)|=|c(t)|=1$ and N_c and SF are chosen so that the value of N_c/SF becomes an integer. The GI-inserted chip sequence $\{s(t);t=-N_g\sim N_c-1\}$ can be expressed using the equivalent lowpass representation as

$$s(t)=\sqrt{2E_c/T_c}\,d(\lfloor t/SF\rfloor)c(t \bmod SF)\,,\ t=-N_g\sim N_c\text{-}1 \quad (1)$$

where E_c and T_c denote the chip energy and the chip duration, respectively, and $\lfloor x\rfloor$ represents the largest integer smaller than or equal to x. With DTD, the GI-inserted chip sequence is inflicted different time delays $\{\tau_n\,;\,n=0\sim N_t-1\}$ and transmitted from N_t transmit antennas simultaneously.



(b) Receiver

Fig.1 DS-CDMA transmission system model.

The chip sequence transmitted over a frequency-selective fading channel having an L-path exponentially decaying power delay profile with a decay factor of α is received by each of the N_r antennas at the receiver. The received signal sample $r_m(t)$ at time t on the m-th antenna, m=0 ~ N_r-1, can be expressed using the equivalent lowpass representation as

$$r_m(t)=\sqrt{\frac{1}{N_t}}\sum_{n=0}^{N_t-1}\sum_{l=0}^{L-1}\xi_{n,m,l}s(t-\tau_n-l)+\eta_m(t) \quad , (2)$$

where $\xi_{n,m,l}$ is the l-th path gain between the n-th transmit antenna and the m-th receive antenna and $\eta_m(t)$ is the zero-mean complex noise process having a variance of $2N_0/T_c$ with N_0 being the single-sided power spectrum density of the additive white Gaussian noise (AWGN) process. Since the transmit power from each antenna is $1/N_t$ times that of the single transmit antenna case, the total transmit power is kept the same. For the case of the equal time delay difference (i.e., $\tau_n=n\Delta\tau$), the equivalent power delay profile observed at the receiver is illustrated in Fig. 2 for N_t=2 and $\Delta\tau$=16 symbols when L=16 and α=4 dB. It can be clearly understood from Fig. 2 that DTD increases the frequency-selectivity of the channel, thereby improving the BER performance with frequency-domain equalization.

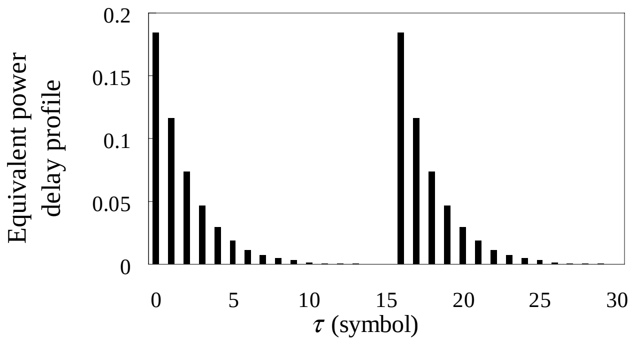


Fig. 2 Equivalent power delay profile observed at the receiver for N_t=2 and $\Delta\tau$=16 symbols when L=16 and α=4 dB.

2.2 Joint use of Frequency-domain equalization and antenna diversity combining

After the removal of GI, the received chip sequence on each antenna is decomposed by N_c-point fast Fourier transform (FFT) into N_c subcarrier components $\{R_m(k); k=0\sim N_c-1\}$ (although DS-CDMA does not apply subcarrier modulation as in MC-CDMA and OFDM, we use the terminology “subcarrier”). The kth subcarrier component $R_m(k)$ can be written as

$$R_m(k)=\sqrt{1/N_t}H_m(k)S(k)+N_m(k) \quad , (3)$$

where $S(k)$, $H_m(k)$ and $N_m(k)$ are the kth subcarrier component of transmitted N_c-chip sequence $\{s(t); t=0\sim N_c-1\}$, the channel gain and the noise component due to the AWGN, respectively. They are given by

$$\begin{cases} S(k)=\sum_{t=0}^{N_c-1}s(t)\exp\left(-j2\pi k\frac{t}{N_c}\right) \\ H_m(k)=\sum_{l=0}^{L-1}\xi_{l,m}\exp\left(-j2\pi k\frac{l}{N_c}\right) \\ N_m(k)=\sum_{t=0}^{N_c-1}\eta_m(t)\exp\left(-2\pi k\frac{t}{N_c}\right) \end{cases} . (4)$$

Then, joint one-tap FDE and antenna diversity combining is carried out to obtain

$$\tilde{R}(k)=\sum_{m=0}^{N_r-1}R_m(k)w_m(k) \, , (5)$$

where $w_m(k)$ is the equalization weight based on minimum mean square error (MMSE) criterion. MMSE weight is given by [7]

$$w_m(k)=\frac{H_m^{\,*}(k)}{\sum_{m=0}^{N_r-1}|H_m(k)|^2+\left(\frac{1}{N_t}\frac{E_c}{N_0}\right)^{-1}} \, , (6)$$

where E_c/N_0 represents the average chip energy-to-AWGN power spectrum density ratio and * denotes the complex conjugate operation. Inverse FFT (IFFT) is applied to obtain the equalized and diversity combined time-domain chip sequence for succeeding despreading and data demodulation.

3. Computer Simulation

We assume binary phase shift keying (BPSK) data and spreading modulation, an FFT window size of N_c=256 chips and a GI of N_g=32 chips. The fading channel is assumed to be an L=16-path frequency-selective Rayleigh fading channel. Perfect chip timing and ideal channel estimation are assumed.

In Sect. 2, we have assumed block fading, where the path gains stay constant over one data frame (the frame length in time equals $(N_c+N_g)T_c$, with T_c denoting the chip duration). However, in practice, path gains may vary during one frame if the mobile station travels fast. It is interesting to see the impact of the fading maximum Doppler frequency f_D on the achievable BER performance, where f_D is given by the traveling speed/carrier wavelength [1]. The BER dependency on f_DT_c at the average bit energy-to-AWGN noise power spectrum density ratio E_b/N_0=15 dB is plotted in Fig. 3 for the single receive antenna case. It can be seen that the achievable BER is almost insensitive to f_DT_c if f_DT_c<0.0001 when N_c=256 (this corresponds to the traveling speed of 200 km/h for the chip rate ($1/T_c$) of 10Mbps and 5GHz carrier frequency). Hence, block fading is assumed in the following simulations.

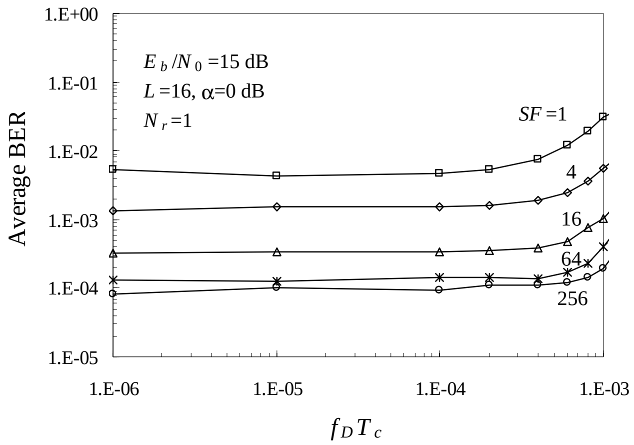


Fig. 3 Dependency of the BER on the maximum Doppler frequency f_DT_c at the average E_b/N_0=15 dB.

Figure 4 plots the dependency of the BER on the time delay insertion $\Delta\tau$ at the average received E_b/N_0=15 dB when N_t=2. As $\Delta\tau$ increases, the BER reduces and stays constant, but starts to increase when the maximum time delay difference resulting from the delay insertion and the propagation delay becomes larger than GI. Therefore, in the following simulation, $\Delta\tau$ is set as

$$\Delta\tau = \left\lfloor \frac{N_g - L}{N_t - 1} \right\rfloor \text{ chips,} \quad (7)$$

so that the maximum time delay difference is within the GI.

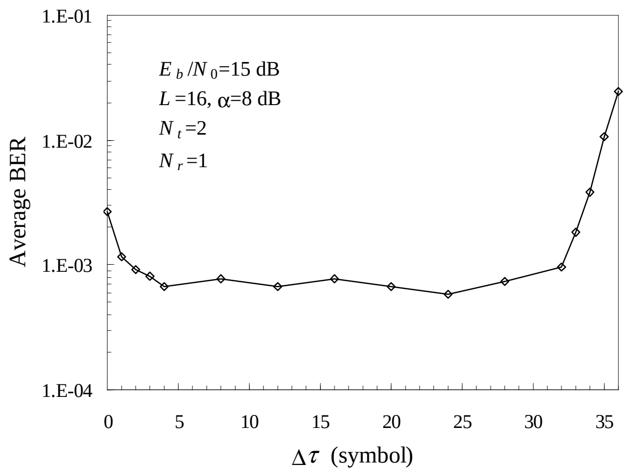
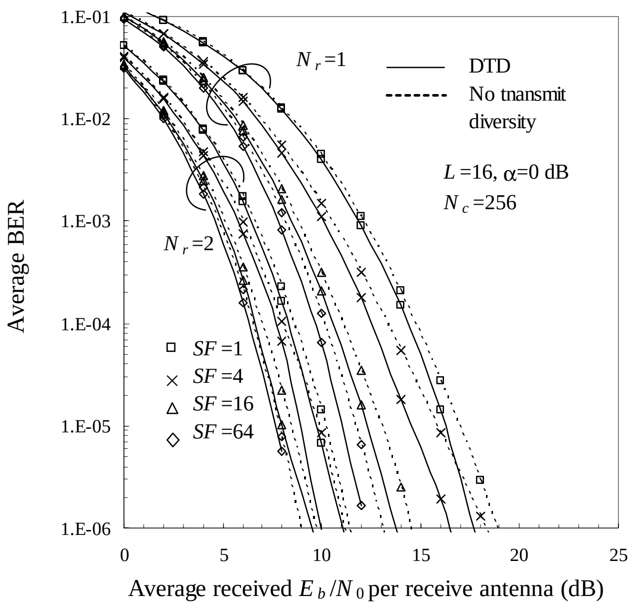
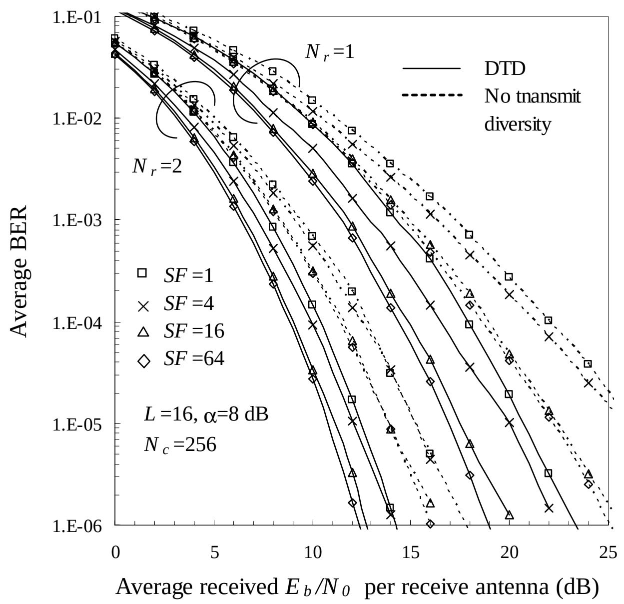


Fig. 4 BER dependency on $\Delta\tau$ at the average E_b/N_0=15 dB.

The simulated BER performances of DS-CDMA with joint frequency-domain equalization and N_t=2-antenna DTD are plotted in Fig. 5 with *SF* as a parameter as a function of the average E_b/N_0. Receive antenna diversity is considered (N_r=1, 2). For comparison, the BER performance for N_t=1 is also plotted. The case of α=0 dB represents a strong frequency-selective channel (see Fig. 5(a)) and that of 8 dB represents a weak frequency-selective channel (see Fig. 5(b)). An improved BER performance achieved when α=0 dB compared to the case of α=8 dB is due to the effect of increased frequency diversity. For the case of α=0 dB, performance improvement obtainable by DTD is less irrespective of *SF* because the channel frequency-selectivity is already strong enough and additional frequency diversity effect is very small. On the other hand, for the case of α=8 dB, with DTD, the frequency-selectivity of the equivalent channel becomes stronger and hence, the BER performance improves for all *SF*; a DTD gain of 4.2 dB is attained for BER=10^{-4} when *SF* = 64 and N_r=1. It can be clearly seen that the use of antenna diversity combining is always beneficial irrespective of *SF* and α. Since larger frequency diversity effect is obtained when α=0 dB, the additional performance improvement due to antenna diversity combining is smaller than when α=8 dB.



(a) α=0 dB



(b) α=8 dB

Fig.2 Simulated BER performance with joint frequency-domain equalization and DTD.

4. Conclusion

In this paper, the joint frequency-domain equalization and DTD/receive antenna diversity was applied to the reception of DS-CDMA signals and the BER performance improvement in a frequency-selective Rayleigh fading environment was evaluated by computer simulation. When the channel frequency-selectivity is weak, joint use of frequency-domain equalization and DTD is useful since DTD can increase the degree of channel frequency-selectivity. The additional use of receive antenna diversity is always beneficial irrespective of the degree of channel frequency-selectivity.

5. References

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