LETTER

Frequency-Domain Pre-Rake Transmission for DSSS/TDD Mobile Communications Systems

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SUMMARY In this Letter, a frequency-domain pre-rake transmission is presented for a direct sequence spread spectrum with time division duplex (DSSS/TDD) system under a frequency-selective fading channel. The mathematical relationship between frequency-domain and time-domain pre-rake transmissions is discussed. It is confirmed by the computer simulation that, similar to the time-domain pre-rake transmission, frequency-domain pre-rake transmission can improve the bit error rate (BER) performance. The frequency-domain pre-rake transmission shows only slight performance degradation compared to the frequency-domain rake reception for large *SF*.

key words: *frequency-domain equalization, pre-rake, spread spectrum, mobile radio*

1. Introduction

Recently, there have been strong demands for high-speed data transmissions in mobile communications. Radio channels for such high-speed data transmissions are characterized by frequency-selective multipath fading, and severely degrade the bit error rate (BER) performance [1]. Direct sequence spread spectrum (DSSS), which uses time-domain spreading and despreading, can exploit the frequency-selectivity of the channel by the well-known time-domain rake reception, to improve the BER performance [2]. In DSSS communications, increasing the chip rate can increase the data rate. However, as the chip rate becomes higher, the number of resolvable propagation paths increases. A large number of rake fingers are necessary for collecting enough signal power and this increases the complexity of the time-domain rake receiver. Recently, much attention has been paid to multicarrier (MC) technique, known as MC-CDMA [3], which uses frequency-domain spreading and despreading to exploit the frequency-selectivity of the channel by one-tap frequency-domain equalization (FDE).

Recently, it has been shown [4] that time-domain rake reception can be implemented in the frequency-domain as the frequency-domain rake reception. It is known [5] that time-domain rake reception can be moved to the transmitter side as pre-rake transmission. In this Letter, we show that, similar to time-domain pre-rake transmission, frequency-domain rake reception can be moved to the transmitter side as the frequency-domain pre-rake transmission. For pre-rake transmission, transmit channel estimation is necessary. For a DSSS/time division duplex (TDD) system, the receive channel estimate can be used as the transmit channel estimate since the same carrier frequency is utilized for transmit and receive channels. Pre-rake transmission and rake reception both in the frequency-domain can be implemented at one transmit/receive side, while the other receive/transmit side has simple despreading and spreading functions. In this Letter, the achievable BER performance with the frequency-domain pre-rake transmission is evaluated by computer simulation and compared with that of frequency-domain rake reception.

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2. Frequency-Domain Pre-Rake Transmission

Transmitter and receiver structures for frequency-domain pre-rake transmission for a DSSS/TDD system are illustrated in Fig. 1. Frequency-domain pre-rake transmission requires fast Fourier transform (FFT) and inverse FFT (IFFT) operations. The spread chip sequence is divided into a sequence of chip blocks of N_c chips each, for each chip-block the FFT is applied for pre-equalization.

Without loss of generality, we consider the transmission of N_c/SF data-modulated symbols $\{d(i);\ i = 0 \sim N_c/SF - 1\}$ with $|d(i)| = 1$ in a chip block, where SF is the spreading factor. The discrete-time representation is used throughout the Letter. The DSSS signal at the t-th chip time instance can be expressed, using the equivalent lowpass representation, as

$$s(t) = c(t)d\left(\left\lfloor \frac{t}{SF} \right\rfloor\right), \quad 0 \le t < N_c - 1, \tag{1}$$

where E_c denotes the transmit chip energy, T_c the spreading chip period, and $c(t)$ the t-th spreading chip with $|c(t)| = 1$. N_c-point FFT is applied to decompose the spread signal $s(t)$

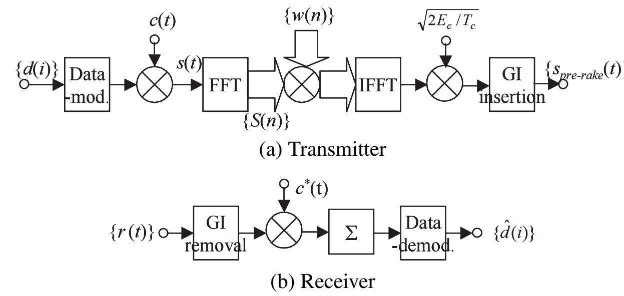


Fig. 1 Transmitter and receiver structures for frequency-domain pre-rake transmission.

into N_c frequency components $\{S(n); n = 0 \sim N_c - 1\}$. After multiplying the complex-valued weights $\{w(n); n = 0 \sim N_c - 1\}$, N_c-point IFFT is applied to obtain the frequency-domain spread signal $s_{pre-rake}(t)$, which can be expressed as

$$s_{pre-rake}(t) = \sqrt{\frac{2E_c}{T_c}} \sum_{n=0}^{N_c-1} \left\{ \frac{1}{N_c} w(n) S(n) \right\} \exp\left(j2\pi n \frac{t}{N_c} \right) \tag{2}$$

for $0 \le t < N_c - 1$, where $S(n)$ is given by

$$S(n) = \sum_{t=0}^{N_c-1} s(t) \exp\left(-j2\pi n \frac{t}{N_c} \right). \tag{3}$$

We use the transmission weight that maximizes the received signal-to-noise power ratio (SNR) at the receiver:

$$w(n) = \frac{H^*(n)}{\sqrt{\frac{1}{N_c^2} \sum_{n=0}^{N_c-1} |S(n)|^2 |H(n)|^2}}, \tag{4}$$

where $H(n)$ is the transmit channel gain at the n-th frequency. Assuming a chip-spaced L path fading channel and denoting the complex-valued path gain and time delay of the l-th propagation path by ξ_l and τ_l, respectively, $H(n)$ is given by

$$H(n) = \sum_{l=0}^{L-1} \xi_l \exp\left(-j2\pi n \frac{\tau_l}{N_c} \right). \tag{5}$$

For simplicity, we have assumed block fading, where the path gains remain constant over a N_c-chip block. The denominator of Eq. (4) is introduced to keep the transmit power, averaged over an N_c-chip block the same as before frequency-domain pre-rake and

$$\begin{cases} \frac{1}{N_c^2} \sum_{n=0}^{N_c-1} |S(n)|^2 = 1 \\ \frac{1}{N_c^2} \sum_{n=0}^{N_c-1} |S(n)|^2 |H(n)|^2 = \frac{1}{N_c} \sum_{t=0}^{N_c-1} \left| \sum_{l=0}^{L-1} \xi_l^* s(t+\tau_l) \right|^2 \end{cases}. \tag{6}$$

When frequency-domain pre-rake transmission is applied, a cyclic prefix of N_g chips needs to be inserted into the guard interval (GI), as shown in Fig. 2 [4].

The GI-inserted DSSS signal $\{s_{pre-rake}(t); t = -N_g \sim N_c - 1\}$ is transmitted over a frequency-selective block fading channel. The received signal can be represented as

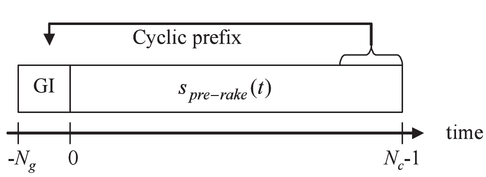


Fig. 2 Frame structure.

$$r(t) = \sum_{l=0}^{L-1} \xi_l s_{pre-rake}(t - \tau_l) + \eta(t), \tag{7}$$

where $\eta(t)$ is the zero-mean noise process due to the additive white Gaussian noise (AWGN) having a variance of $2(N_0/T_c)$ with N_0 being the one-sided power spectrum density. After some manipulation, we can show

$$\begin{aligned} r(t) &= \sqrt{\frac{2E_c/T_c}{\frac{1}{N_c^2} \sum_{n=0}^{N_c-1} |S(n)|^2 |H(n)|^2}} \\ &\times \left[\left(\sum_{l=0}^{L-1} |\xi_l|^2 \right) s(t) + \sum_{l=0}^{L-1} \sum_{\substack{l'=0 \\ \neq l}}^{L-1} \xi_l \xi_{l'}^* s(t - \tau_l + \tau_{l'}) \right] \\ &+ \eta(t), \end{aligned} \tag{8}$$

where the first term in the square bracket is the desired signal component and the second the inter-path interference (IPI). It can be readily understood from Eq. (8) that the desired signal component is equal to that of the time-domain rake reception. Therefore, simple despreading (implemented by a single correlator) can be applied at the receiver to obtain the i-th received symbol $\hat{d}(i)$ as

$$\hat{d}(i) = \sum_{t=iSF}^{(i+1)SF-1} r(t) c^*(t) \tag{9}$$

for data demodulation.

Below, we discuss the mathematical relationship between frequency-domain and time-domain pre-rake transmissions. Time-domain pre-rake transmission [5] transmits L copies of the same chip sequence after multiplication of complex conjugation of path gains and time delay adjustment so that all L transmitted copies arrive at the receive antenna at the same time and in phase. Therefore, all L transmitted copies are constructively combined and received at the receive antenna. Substituting Eq. (3) into Eq. (2) and using Eq. (5), time-domain expression for the transmit signal using frequency-domain pre-rake transmission can be is given by

$$\begin{aligned} & s_{pre-rake}(t) \\ &= \sqrt{\frac{2E_c/T_c}{\frac{1}{N_c^2} \sum_{n=0}^{N_c-1} |S(n)|^2 |H(n)|^2}} \sum_{t'=0}^{N_c-1} s(t') h^*(t' - t) \\ &= \sqrt{\frac{2E_c/T_c}{\frac{1}{N_c^2} \sum_{n=0}^{N_c-1} |S(n)|^2 |H(n)|^2}} \sum_{l=0}^{L-1} \xi_l^* s(t + \tau_l), \end{aligned} \tag{10}$$

which clearly shows that frequency-domain pre-rake transmission is equivalent to the time-domain pre-rake transmission. It has also been shown in [4] that frequency-domain and time-domain rake combining are equivalent. This confirms that either frequency-domain processing or

Table 1 Simulation condition.

Data modulation		QPSK
Transmitter	No. of FFT points	N_c=256 (chips)
	GI	N_g=32 (chips)
	Spreading sequence	M-sequence
	Spreading factor	*SF*=16, 64, and 256
Channel model	Fading type	Frequency-selective block Rayleigh
	Power delay profile	*L*-path uniform power delay profile
Receiver	Despreader	Single-finger correlator
	Channel estimation	Ideal

time-domain processing can be implemented at the transmitter side or the receiver side, but with only slight performance loss of $10\log_{10}(1+N_g/N_c)$ dB in the frequency-domain processing due to the insertion of GI.

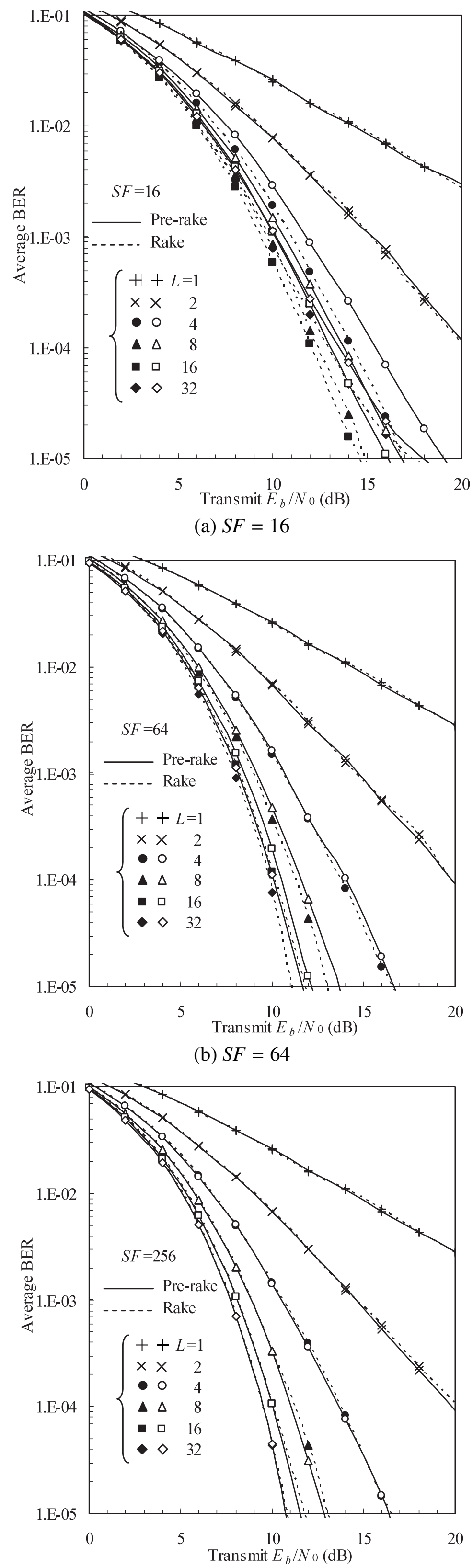
3. Computer Simulation

Table 1 summarizes the numerical and simulation conditions. The spreading chip sequence is the M-sequence of 4095 chips. N_c=256, N_g=32, and coherent quadrature phase shift keying (QPSK) data-modulation are assumed. The fading channel is a chip-spaced L-path frequency-selective block Rayleigh fading channel with uniform power delay profile (i.e., $E[|\xi_l|^2] = 1/L$). Transmit channel estimation is assumed to be ideal.

The simulated average BER performance with frequency-domain pre-rake transmission is plotted for various numbers L of propagation paths in Fig. 3 as a function of the average transmit signal energy per bit-to-AWGN power spectrum density ratio E_b/N_0 (=$0.5SF(E_c/N_0)(1+N_g/N_c)$ for QPSK). As L increases (the channel frequency-selectivity becomes stronger), the BER performance improves owing to increasing frequency diversity effect achieved by the pre-equalization at the transmitter. For performance comparison, we also carried out the computer simulation for the frequency-domain rake reception [4] and the results are plotted in Fig. 3. It is seen that for large L (e.g., L=32), the frequency-domain pre-rake transmission exhibits slight performance degradation compared to the frequency-domain rake reception. However, this performance degradation in the pre-rake transmission reduces as SF increases; almost no performance degradation is seen when SF=256.

4. Conclusion

In this Letter, frequency-domain pre-rake transmission was presented for a DSSS/TDD system. The achievable BER performance in a frequency-selective block Rayleigh fading channel was evaluated by computer simulation to show



(a) SF = 16

(b) SF = 64

(c) SF = 256

Fig. 3 BER performance.

that frequency-domain pre-rake transmission can achieve the BER performance close to the frequency-domain rake reception. Similar to the time-domain pre-rake transmission, the frequency-domain pre-rake transmission allows all the necessary transmit/receive signal processing to be implemented at one transmit/receive side; the other receive/transmit side requires simple spreading and despreading fucntions. It was mathematically shown that the frequency-domain and time-domain pre-rake transmissions are equivalent.

Pre-rake transmission in both frequency-domain and time-domain requires transmit channel estimation. We have assumed a DSSS/TDD system, in which the receive channel estimate can be used as the transmit channel estimate. However, there exists the time lag between receive slot and transmit slot. This may affect the pre-rake transmission performance in a fast fading channel. This is an important issue to be addressed.

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