Performance of multicode DS-CDMA using frequency domain equalisation in frequency selective fading channel

F. Adachi, T. Sao and T. Itagaki

For the reception of multicode direct sequence (DS)-CDMA signals, the MMSE frequency domain equalisation is applied instead of RAKE combining. The achievable BER performance in a frequency selective Rayleigh fading channel is evaluated by computer simulation. It is shown by computer simulation that the DS-CDMA with MMSE frequency domain equalisation outperforms the DS-CDMA with RAKE combining and shows only slight performance degradation compared to the MC-CDMA with minimum mean square error combining (MMSEC).

Introduction: In direct sequence code division multiple access (DS-CDMA), one way to achieve high-speed data transmission is to use orthogonal multicode multiplexing [1]. However, frequency selective multipath fading encountered in a broadband wireless communication system severely degrades the bit error rate (BER) performance of multicode DS-CDMA. An effective technique to improve the BER performance is a RAKE receiver. However, as the spreading chip rate becomes higher, the frequency selectivity of the multipath channel becomes more severe due to the increasing number of resolvable propagation paths. This causes a number of problems. The intercode interference (ICI) becomes stronger and the accurate channel estimation necessary for RAKE combining becomes more difficult. The RAKE receiver complexity increases due to the increasing number of RAKE fingers required.

Recently, much attention has been paid to multicarrier CDMA (MC-CDMA) [2], in which the frequency domain spreading is used. The frequency selective fading distorts the MC-CDMA signals and destroys the orthogonality property of the spreading codes. Before despreading of the received MC-CDMA signal, frequency domain equalisation is applied for partial restoration of code orthogonality. The most effective frequency equalisation and despreading is the minimum mean square error combining (MMSEC) [3]. The frequency domain equalisation has also been attracting much attention recently for the single carrier wireless transmission systems [4].

In this Letter, we apply the concept of frequency domain equalisation to multicode DS-CDMA signal reception. First, a signal transmission system model of DS-CDMA with frequency domain equalisation based on minimum mean square error (MMSE) is presented and then, the achievable BER performance in a frequency selective Rayleigh fading channel is evaluated by computer simulation. The performance comparison is presented for the DS-CDMA with MMSE frequency domain equalisation and with RAKE combining (i.e. time domain equalisation) and the MC-CDMA with MMSEC.

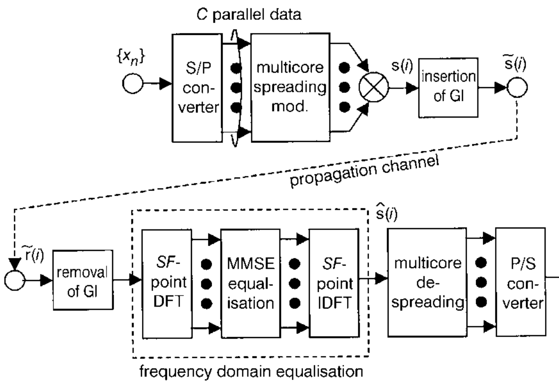

Fig. 1 *Multicode DS-CDMA transmission model*

MMSE frequency domain equalisation: The use of frequency domain equalisation avoids ICI, and the complexity and the channel estimation problems of RAKE combining. The frequency domain equalisation is implemented by first applying the discrete Fourier transform (DFT) to the received multicode DS-CDMA signal, then weighting the resulting frequency domain components based on MMSE criterion, and finally applying inverse DFT (IDFT) to transform the received signal back to a DS-CDMA signal in the time domain. The introduction of DFT and IDFT requires the insertion of a guard interval (GI) at the transmitter side as in MC-CDMA. The transmission system model of a multicode DS-CDMA system transmitting C data in parallel is shown in Fig. 1. Each data is spread using the time domain orthogonal spreading code with chip length T_c. Without loss of generality, we consider the time interval of one multicode DS-CDMA symbol, i.e. $0 \le t < T$ with $T = T_s + T_g$, where T_s and T_g are, respectively, the effective symbol length and GI, as introduced in MC-CDMA. Throughout this Letter, discrete-time representation of the multicode DS-CDMA signal is used.

Let x_n be the nth data-modulated symbol with $|x_n| = 1$. During $0 \le t \le T$, $\{x_n;\ n = 0 \sim C-1\}$ are transmitted in parallel using the orthogonal spreading codes $\{c_n(i);\ n = 0 \sim C-1,\ i = 0 \sim SF-1\}$ with $|c_n(i)| = 1$. After summing up (i.e. code multiplexing) the C parallel spread chip sequences, long scramble code $\{c_{scr}(i);\ i = \ldots, -1, 0, 1, \ldots\}$ with $|c_{scr}(i)| = 1$ is multiplied in order to transform the multicode DS-CDMA signal into noise-like signal. The resultant multicode DS-CDMA signal may be expressed using the equivalent lowpass representation as

$$s(i) = \sum_{n=0}^{C-1} \sqrt{2P}\, x_n c_n(i) c_{scr}(i) \tag{1}$$

for $i = 0 \sim SF-1$, where P represents the transmit power per data symbol. After insertion of the N_g-sample GI, where $N_g = T_g/T_c$, the resultant multicode DC-CDMA signal $\{\tilde{s}(i);\ i = -N_g \sim SF-1\}$ is transmitted over a multipath channel, where $\tilde{s}(i) = s(i \bmod SF)$.

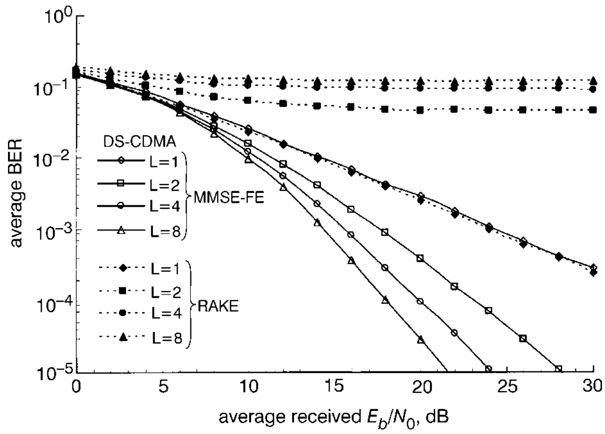

Fig. 2 *Comparison of DS-CDMA with MMSE-FE and with RAKE combining*

$E_b/N_0 = 0.5E_s/N_0$ for QPSK data modulation. $C/SF = 1$

The received multicode DS-CDMA signal, which is perturbed by the additive white Gaussian noise (AWGN), is sampled at the chip rate to obtain $\{\tilde{r}(i);\ i = -N_g \sim SF-1\}$. Ideal sampling timing is assumed. The N_g-sample GI is removed and SF-point DFT is applied to decompose the received DS-CDMA signal into the SF-carrier components:

$$r_k = \sum_{i=0}^{SF-1} \tilde{r}(i) \exp\left(\frac{-j2\pi ki}{SF}\right) \tag{2}$$

for $k = 0 \sim SF-1$. Let ξ_k denote the propagation channel gain at the kth carrier frequency. The MMSEC weight derived for MC-CDMA [3] can be applied to our case. The MMSE frequency domain equalisation weight for r_k is given by

$$w_k = \frac{\xi_k^*}{|\xi_k|^2 + [C/SF(1 + T_g/T_s)^{-1}(E_s/N_0)]^{-1}} \tag{3}$$

where E_s/N_0 represents the average received signal energy per data symbol-to-AWGN power spectrum density ratio and $(\cdot)^*$ denotes complex conjugate. The factor of $(1 + T_g/T_s)$ reflects the power penalty due to GI insertion. After MMSE frequency domain equalisation, IDFT is carried out to obtain the multicode DS-CDMA signal in the time domain:

$$\hat{s}(i) = SF^{-1} \sum_{k=0}^{SF-1} w_k r_k \exp\left(\frac{j2\pi ki}{SF}\right) \quad (4)$$

for $i = 0 \sim SF - 1$. Finally, multicode despreading is carried out to obtain

$$\hat{x}_n = \sum_{i=0}^{SF-1} \hat{s}(i)\{c_n(i)c_{scr}(i)\}^* \quad (5)$$

The soft values $\{\hat{x}_n;\ n = 0 \sim C - 1\}$ are parallel-to-serial converted for data demodulation.

Computer simulation: The spreading factor of $SF = 64$ and the guard interval of $\mathrm{GI} = 8T_c$ (i.e. $T_g/T_s = 1/8$) are assumed. Quadrature phase shift keying (QPSK) data modulation is used. The spreading codes and scramble code used are Walsh codes of 64 chips and *M*-sequence of 4095 chips. Channel is a very slow frequency selective Rayleigh fading channel with uniform power delay profile having L independent paths; the time delay of the lth path is assumed to be $\tau_l = lT_c$, $l = 0 \sim L - 1$. For performance comparison, DS-CDMA with RAKE combining and MC-CDMA with MMSEC, both using the same spreading factor, are considered. Channel estimation for frequency domain equalisation and RAKE combining is assumed to be ideal. It should be noted that for DS-CDMA with RAKE combining, no guard interval is necessary; hence, its transmission data rate is 9/8 times faster than that of DS-CDMA and MC-CDMA, both with frequency domain equalisation, for the same spreading bandwidth. Fig. 2 compares the simulated average BER performances of multicode DS-CDMA with MMSE frequency domain equalisation (MMSE-FE) and with RAKE combining for $C = 64$, i.e. $C/SF = 1$. RAKE combining exhibits large error floors when $L > 1$ due to strong ICI produced by asynchronism of propagation paths. Conversely, the use of frequency domain equalisation produces no error floor and significantly improves the average BER performance compared to the RAKE combining case. Fig. 3 compares the simulated average BER performances of DS-CDMA with MMSE-FE and MC-CDMA with MMSEC for $C = 64$. DS-CDMA with MMSE-FE shows only slight degradation in the BER performance compared to MC-CDMA.

Conclusion: We applied the MMSE frequency domain equalisation to the reception of multicode DS-CDMA signals. It was shown by computer simulation that the DS-CDMA with MMSE frequency domain equalisation outperforms DS-CDMA with RAKE combining and provides a BER performance only slightly degraded from MC-CDMA.

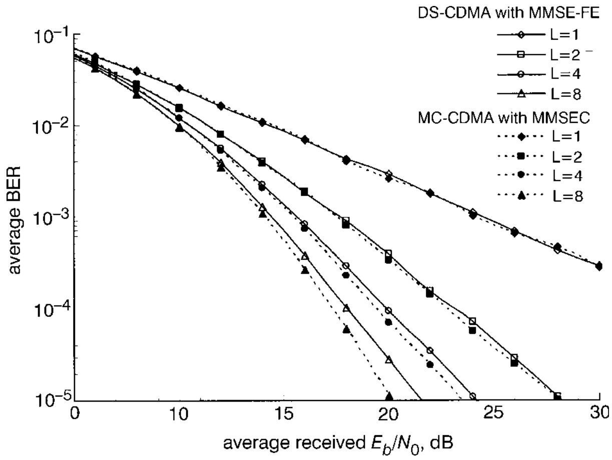

Fig. 3 *Comparison of DS-CDMA with MMSE-FE and MC-CDMA with MMSEC*

$C/SF = 1$

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F. Adachi, T. Sao and T. Itagaki (*Department of Electrical Engineering, Graduate School of Engineering, Tohoku University, 05 Aza-Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan*)

E-mail: adachi@ecei.tohoku.ac.jp

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