Comparison of OFDM and multicode MC-CDMA in frequency selective fading channel

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An answer is provided to an interesting question: whether OFDM or multicode MC-CDM can achieve better BER performance for the same data rate and the same bandwidth in a frequency selective fading channel. It is suggested by computer simulation that multicode MC-CDMA using MMSEC provides a superior performance to OFDM.

Introduction: In next generation mobile communications systems, a very high-speed data transmission under severe frequency selective fading environments is required, particularly on the down link (base-to-mobile) [1]. Recently, orthogonal frequency division multiplexing (OFDM), that transmits many narrowband data-modulated orthogonal subcarriers in parallel, has gained much attention. Meanwhile, the combination of multicarrier (MC) and code division multiple access (CDMA), called MC-CDMA, has also been attracting increasing attention and is under extensive study [2]. Multicode MC-CDMA can be used for high data rate transmission, where multiple data-modulated symbols are code-multiplexed over a number of orthogonal subcarriers using orthogonal spreading sequences defined in the frequency domain. In multicode MC-CDMA, the same data rate as in OFDM can be achieved by transmitting as many as *SF* data symbols over *SF* subcarriers in parallel using the code-multiplexing method, where *SF* stands for the spreading factor. In a frequency selective fading channel, multicode MC-CDMA can achieve frequency diversity effect but orthogonal property among different spreading codes is partially lost. Orthogonality restoration combining (ORC) can perfectly restore orthogonality but produces noise enhancement. The most promising is the minimum mean square error combining (MMSEC) that can balance the orthogonality restoration and the noise enhancement [3]. An interesting question is: which can achieve a better bit error rate (BER) performance for the same data rate and the same bandwidth, OFDM or multicode MC-CDMA? In this Letter we provide an answer to this question.

Multicode MC-CDMA: The equivalent spreading factor SF_{eq} of multicode MC-CDMA is defined as the ratio of the number of code-multiplexed data symbols and the spreading factor *SF*. To make the data rate of multicode MC-CDMA equal to that of OFDM, we assume $SF_{eq}=1$, i.e. a total of *SF* data symbols are code-multiplexed. Assume a time interval of $0 \le t < T$, where $T = T_s + T_g$ is the multicode MC-CDMA symbol length with T_s and T_g representing the effective symbol length and the guard interval (GI), respectively. N_c subcarriers with carrier spacing of $1/T_s$ are used. Hence, N_c data modulated symbols $\{x(j);\ j=0 \sim N_c-1\}$ are spread using the orthogonal spreading codes $\{c_{n,m};\ n,\ m=0\sim SF-1\}$ and then transmitted, where $|c_{n,m}|=1$, and $|x(j)|=1$. Here, the *k*th subcarrier component s_k may be expressed using the equivalent baseband representation as

$$s_k = \sum_{n=0}^{SF-1} \sqrt{\frac{2P}{SF}} c_{scr,k} c_{n,k \bmod SF}\, x\left(n + \lfloor \frac{k}{SF} \rfloor\right) \qquad (1)$$

for $k=0\sim N_c-1$, where P represents the transmit power and $\{c_{scr,k};\ k=\ldots,-1,0,1,\ldots\}$ is the long scramble code to make the multicode MC-CDMA signal noise-like. N_c-point inverse fast Fourier transform (IFFT) is applied to the sequence $\{s_k;\ k=0\sim N_c-1\}$ to generate the multicode MC-CDMA signal $\{s(i);\ i=0\sim N_c-1\}$. After insertion of the N_g-sample GI, the resultant multicode MC-CDMA signal $\{\tilde{s}(i);\ i=-N_g\sim N_c-1\}$ is transmitted over a frequency selective fading channel, where $\tilde{s}(i)=s(i \bmod N_c)$. The faded multicode MC-CDMA signal perturbed by the additive white Gaussian noise (AWGN) is received and sampled at the rate of $\Delta T^{-1}=N_c/T_s$ to obtain $\{\tilde{r}(i);\ i=-N_g\sim N_c-1\}$. The N_g-sample GI is removed and N_c-point FFT is applied to decompose the received multicode MC-CDMA signal into the N_c-subcarrier components $\{r_k;\ k=0\sim N_c-1\}$. MMSEC is then applied to despread the multicode MC-CDMA signal. The decision variable for the data symbol $x(j)$ is obtained as

$$\tilde{x}(j) = \sum_{k=j-n}^{j-n+SF-1} w_k r_k c^*_{n,k \bmod SF} \qquad (2)$$

where w_k is the MMSEC weight for the *k*th subcarrier, $n = j \bmod SF$, and * denotes the complex conjugate operation. Assuming binary phase shift keying (BPSK) data modulation, w_k is given by [3]

$$w_k = \frac{H_k^*}{|H_k|^2 + (\Gamma/(1+T_g/T_s))^{-1}} \qquad (3)$$

where Γ is the average received signal energy per bit-to-AWGN power spectrum density ratio E_b/N_0 (the power penalty due to GI insertion is taken into account) and H_k is the propagation channel gain at the *k*th subcarrier frequency. It should be noted that the use of $SF=1$ and $c_{n,m}=1$ in (1) gives the OFDM signal generation and $w_k=H_k^*$ is used in (2) for coherent detection.

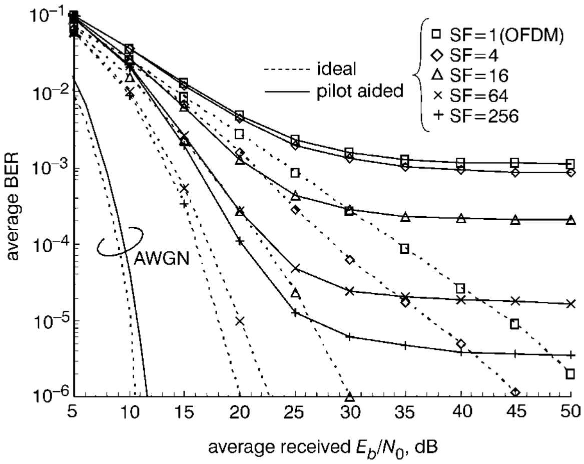

Fig. 1 *BER performance*

$SF_{eq}=1$; $\tau_{rms}/T_s=0.036$

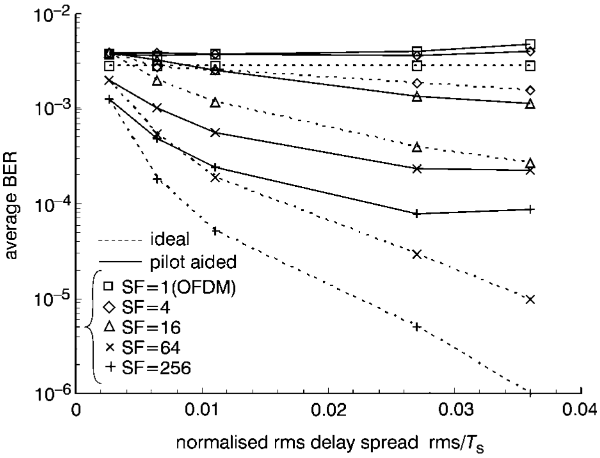

Fig. 2 *Impact of delay spread*

$SF_{eq}=1$; average $E_b/N_0=20$ dB

Computer simulation: $N_c=256$ subcarriers is assumed. Walsh codes are used as orthogonal spreading codes $\{c_{n,m}\}$. The scramble code $\{c_{scr,k}\}$ is the *m*-sequence having a repetition period of 4095 chips. The GI has a length of 32 FFT samples or one eighth of T_s. It is assumed that the propagation channel is characterised by a 16-path frequency selective Rayleigh fading process having a time delay separation of two FFT samples and an exponential power delay profile. The normalised maximum Doppler frequency of each path is $f_DT=0.001$. For channel estimation, two known pilot symbols are time-multiplexed every $18T$ for channel estimation on each subcarrier. Pilot aided channel estimation is first performed using simple averaging of the time-multiplexed two pilot symbols and then moving averaging operation over three subcarriers is applied. The pilot symbol energy is the same as the data symbol energy. Fig. 1 shows the simulated average BER performances of multicode MC-CDMA with $SF_{eq} = 1$ against average E_b/N_0 with the spreading factor as a parameter for the normalised rms delay spread $\tau_{rms}/T_s = 0.036$ of the channel. The BER performance curve in the AWGN channel (no fading) is also shown. For comparison, the results for ideal channel estimation are plotted as dotted lines. It is seen that the average BER performance continuously improves as the spreading factor increases. When ideal channel estimation is assumed, the use of $SF = 256$ reduces the required E_b/N_0 for $\text{BER} = 10^{-4}$ by as much as ~19 dB, compared to OFDM ($SF = 1$). When practical channel estimation is used, BER floors are produced due to channel estimation error. However, significant reductions in the BER floor value are seen in multicode MC-CDMA; the BER floor of multicode MC-CDMA with $SF = 256$ is $\sim 3.5 \times 10^{-6}$, while that of OFDM is $\sim 1.1 \times 10^{-3}$. Notice that since $SF_{eq} = 1$, the data rate of multicode MC-CDMA is always kept the same as in OFDM for all values of spreading factor. The use of the largest possible spreading factor, i.e. $SF = 256$, provides the best BER performance.

Fig. 2 shows how the delay spread affects the achievable BER of multicode MC-CDMA at the average $E_b/N_0 = 20$ dB. When ideal channel estimation is assumed, the BER continuously decreases as the delay spread increases (the frequency selectivity becomes stronger) while that of OFDM ($SF = 1$) is kept the same. It can be seen that the use of $SF = 256$ gives the lowest BER at all values of the rms delay spread. Even when practical channel estimation is used, as the delay spread becomes larger the BER of multicode MC-CDMA using $SF = 256$ decreases because of larger frequency diversity effect, but for too large delay spreads, the BER increases due to increased channel estimation error.

Conclusion: It was suggested by computer simulation that multicode MC-CDMA using MMSEC provides a superior performance to OFDM for the same data rate and the same bandwidth. The best performance is obtained using the largest possible spreading factor, which is equal to the number of subcarriers. The reason for this is that by spreading the same data symbol over all subcarriers, the frequency diversity effect can be maximised by using MMSEC.

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