Comparison of Chip Interleaved MC-CDMA and DS-CDMA with Frequency-domain Equalization

Deepshikha Garg and Fumiyuki Adachi
Department of Electrical and Communications Engineering
Graduate School of Engineering, Tohoku University, Sendai, Japan
deep@mobile.ecei.tohoku.ac.jp, acachi@ecei.tohoku.ac.jp

Abstract *DS-CDMA with minimum mean square error frequency-domain equalization (MMSE-FDE) can provide much better performance than that with rake combining in a frequency-selective fading channel and is comparable to that of MC-CDMA with MMSE-FDE. Chip interleaving is a form of channel interleaving that improves the DS-CDMA performance by converting the channel into a highly time-selective channel; the time-selectivity can be benefited with chip interleaving. When FDE is used, the frequency-selectivity of the channel is thoroughly exploited. In this paper, we apply chip interleaving to DS-CDMA with MMSE-FDE and compare its performance with chip interleaved MC-CDMA. It is found that chip interleaving improves the performance for both DS-CDMA and MC-CDMA; however the performance of DS-CDMA is better than that of MC-CDMA even with chip interleaving.*

1 INTRODUCTION

Recently, multicarrier code division multiple access (MC-CDMA) [1] based on orthogonal frequency division multiplexing (OFDM) has been attracting much attention and is under extensive study. In MC-CDMA, the data-modulated symbol to be transmitted is spread over a number of subcarriers using an orthogonal spreading sequence defined in the frequency-domain to obtain the frequency diversity effect. Simple one-tap minimum mean square error frequency-domain equalization (MMSE-FDE) is used at the receiver as it provides the best tradeoff between orthogonality restoration and noise enhancement. On the other hand, in direct sequence CDMA (DS-CDMA), time-domain spreading is used; however it is shown in [2] that DS-CDMA with MMSE-FDE gives much better bit error rate (BER) performance than with rake combining and is comparable to that of MC-CDMA with MMSE-FDE in a frequency selective fading channel [3].

Chip interleaving that exploits the spreading process in DS-CDMA was proposed to improve the BER performance in the frequency-nonselective fading channel [4]. The use of chip interleaving increases the fading rate, thereby transforming the channel into a highly time-selective fading channel; the equivalent propagation channel gain seen after chip de-interleaving varies over one symbol interval. As a result, time-diversity effect is obtained and the received symbol energy varies less. When FDE and chip interleaving are jointly used, the frequency-selectivity and time-selectivity of the channel are both expected to be thoroughly exploited.

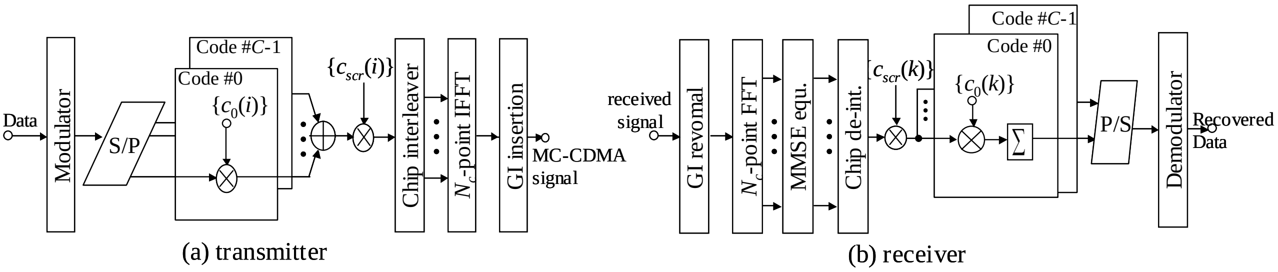
For high-speed data transmissions, orthogonal code multiplexing is applied. However, orthogonal multicode transmission relies on the condition that the channel gain remains constant over one symbol interval. Hence, using chip interleaving degrades the orthogonal multicode transmission performance because of partial destruction of orthogonality property. However, when subcarrier-by subcarrier or chip-by-chip MMSE-FDE is applied, the orthogonality is partially restored in addition to achieving frequency diversity. In this paper, the diversity-orthogonality trade-off is evaluated for chip interleaved DS-CDMA and MC-CDMA.

The remainder of this paper is organized as follows. The transmission system model for DS-CDMA and MC-CDMA are presented in Section 2. Some of the simulation results are presented in Section 3. Section 4 concludes the paper.

2 TRANSMISSION SYSTEM MODEL WITH CHIP INTERLEAVING

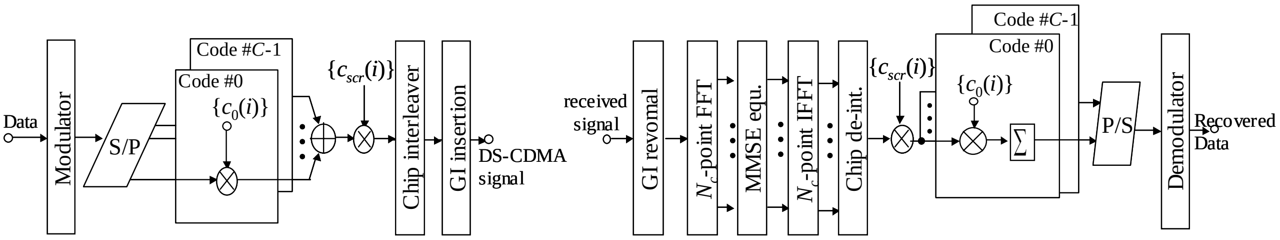
2.1 MC-CDMA

The MC-CDMA transmission system model with chip interleaving is shown in Fig. 1. The binary information sequence is transformed into a data-modulated symbol sequence. The symbol sequence is



(a) transmitter (b) receiver

Figure 1. Transmission system model for MC-CDMA.



(a) transmitter (b) receiver

Figure 2. Transmission system model for DS-CDMA.

serial-to-parallel (S/P) converted to *C* streams and after each stream is spread in frequency using different orthogonal codes they are code-multiplexed (*C* is called the code multiplexing order). The code-multiplexed signal is then further multipled by a common scrambling sequence and interleaved with a random chip interleaver. In order to attain maximum interleaving effect, two-dimensional random interleaving is used. The interleaving is performed in two steps - inter-subcarrier interleaving is performed first and then, intra-subcarrier interleaving is done. After chip interleaving, IFFT is performed and the signal transmitted after the guard interval (GI) insertion. At the receiver, de-interleaving is carried out after FFT and MMSE-FDE and is followed by frequency-domain despreading i.e., code demultiplexing and after parallel-to-serial (P/S) conversion, data-demodulation is performed.

2.2 DS-CDMA

The system model is similar to that of MC-CDMA except that the spreading is done in time-domain in contrast to MC-CDMA wherein the spreading is done in frequency-domain. The DS-CDMA system is shown in Fig. 2. The code-multiplexing order for DS-CDMA is also taken to be *C*. Chip interleaving is performed after the symbols are spread. A random chip interleaver is employed. GI required in DS-CDMA with MMSE-FDE [2] is inserted after chip interleaving. At the receiver, GI is removed, FFT, MMSE-FDE and IFFT operations are performed. Then, after the entire chip sequence is recovered, chip de-interleaving is performed. The chip de-interleaved sequence is despread and data-demodulated.

3 SIMULATION RESULTS AND DISCUSSIONS

For the simulation purposes, we assume a frequency-selective Rayleigh fading channel having a 16-path exponential power delay profile with a time-delay spacing of 1 T_c and the power difference of αdB between adjacent paths and a normalized maximum Doppler frequency $f_DT_cN_c$ of 0.01, where T_c is the FFT sampling interval (equal to the chip duration) and N_c is the number of subcarriers (equal to the number of FFT points) for MC-CDMA (DS-CDMA). In the simulation, N_c = 256 is assumed. Data-modulation and spreading-modulation are taken to be QPSK and BPSK, respectively. A 256x256 chip interleaver is assumed.

3.1 Chip interleaving gain for MC-CDMA and DS-CDMA

Figures 3 and 4 plots the average BERs of DS-CDMA and MC-CDMA as a function of the average received signal energy per bit-to-the AWGN power spectrum density ratio E_b/N_0 with *SF* as a parameter for the code multiplex order *C*=1 and α=0dB (strong frequency-selective channel). For reference, the BER curves for *SF*-branch antenna diversity combing using maximum ratio combing (MRC) [5] with independent fading on each branch are also plotted. It is seen that for both DS-CDMA and MC-CDMA, the BER performance improves with the increase in *SF* because of the increase in the frequency-diversity effect. However the two systems have different diversity orders even for the same *SF*.

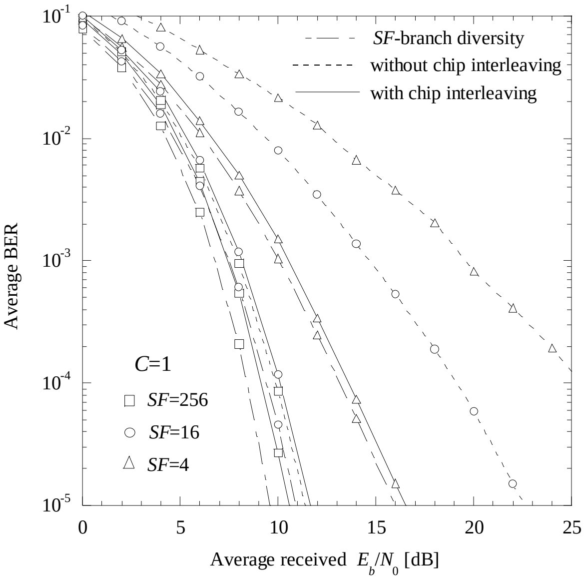


Fig. 3 Chip interleaving gain for MC-CDMA. Single-code case (*C*=1).

Frequency-domain despreading in MC-CDMA is similar to *SF*-branch antenna diversity with correlated fading. Chip interleaving distributes the subcarriers, bearing the information of the same symbol in time and frequency, and reduces the correlation among those subcarriers. The chip interleaved BER performance is seen to be better than that without chip interleaving for all *SF*. It is seen that for MC-CDMA when *SF*=4, the chip interleaved performance is exactly 0.5 dB inferior to the 4-branch diversity. The 0.5 dB penalty is due to the guard interval insertion loss. With chip interleaving, the channel gains on the 4 subcarriers with the same information symbol are almost independent for a fast fading channel with many independent strong paths. Even for *SF*=16 and *SF*=256, the chip interleaved curves are very similar to the 16- and 256-branch diversity curves. However as *SF* increases, there remains some correlation among the channel gains of the subcarriers bearing the information of the same symbol.

The scenario is completely different for DS-CDMA. In DS-CDMA, each symbol is spread over the entire bandwidth and hence, the frequency-diversity is not sensitive to the value of *SF*, but N_c and the number L of propagation paths [6]. For all *SF*, chip interleaved performance is better than that without chip interleaving. It is seen that the chip interleaved curve for *SF*=4 is not similar to the 4-branch diversity curve. The slope of the chip interleaved *SF*=4 curve is steeper than that of 4-branch diversity and is similar to that of 16-branch diversity. This is because it is assumed that there are 16 independent paths in the channel. Even for higher *SF*, i.e., *SF*=16 and 256, the BER performance improves but the slope of the curves is similar to the 16-branch diversity curve.

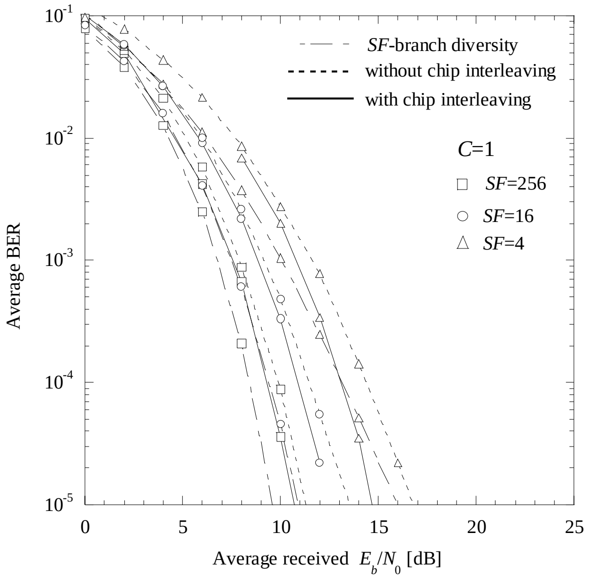


Fig. 4 Chip interleaving gain for DS-CDMA. Single-code case (*C*=1).

The chip interleaving gain for the two systems is compared in Fig. 5 which plots the chip interleaved performance and the *SF*-branch diversity curve. It is seen that when *SF* is small, the DS-CDMA performance is better. As said earlier, in MC-CDMA, the maximum diversity order attainable is a function of *SF*; with smaller *SF*, the diversity order is smaller. However, with DS-CDMA, the diversity order is not a function of *SF* but N_c and L. Hence, due to higher frequency-diversity effect, the DS-CDMA performance is better than that of MC-CDMA. However for larger *SF* the chip interleaved performance of MC-CDMA is better than that of DS-CDMA as some residual inter-symbol interference (ISI) is always present in DS-CDMA even for *C*=1 [6].

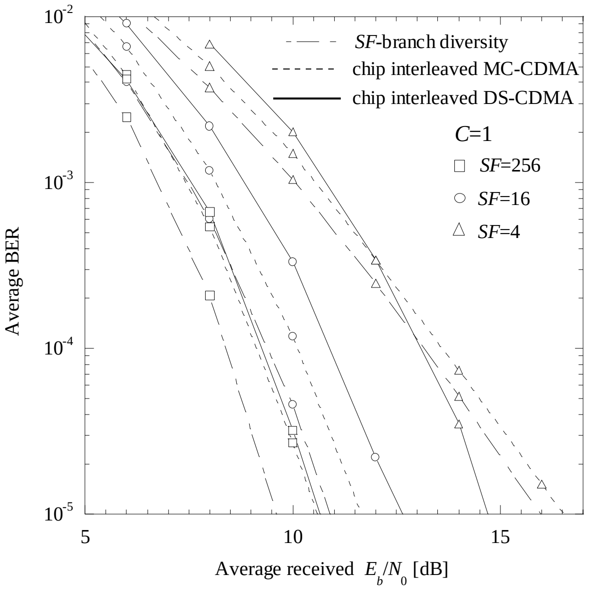


Fig. 5 Comparison of chip interleaved BER performance for DS-CDMA and MC-CDMA. Single-code case (*C*=1).

3.2 Comparison of MC-CDMA and DS-CDMA for full load condition

Figures 6 and 7 plot the average BER as a function of the average received E_b/N_0 with *SF* as a parameter for DS-CDMA and MC-CDMA when α=4dB. Full load condition with the number of multiplexed codes *C*=*SF* is assumed. With *C*=*SF*, the inter-code interference is higher for higher *SF*, but at the same time, the diversity order is also higher. It is seen that for MC-CDMA, the BER performance improves with the increase in *SF* because the increase in the frequency-diversity effect is larger than the increase in inter-code interference. Even for *C*=*SF*, the chip interleaved BER performance is seen to be better than that without chip interleaving for all values of *SF*. This is because the chips are spread apart both in time and frequency and hence there is less correlation among the channel gains experienced by the chips belonging to the same symbol. The orthogonality destruction is severer with chip interleaving, but it is seen that when subcarrier-by-subcarrier MMSE-FDE is used, the diversity effect can offset the orthogonality destruction.

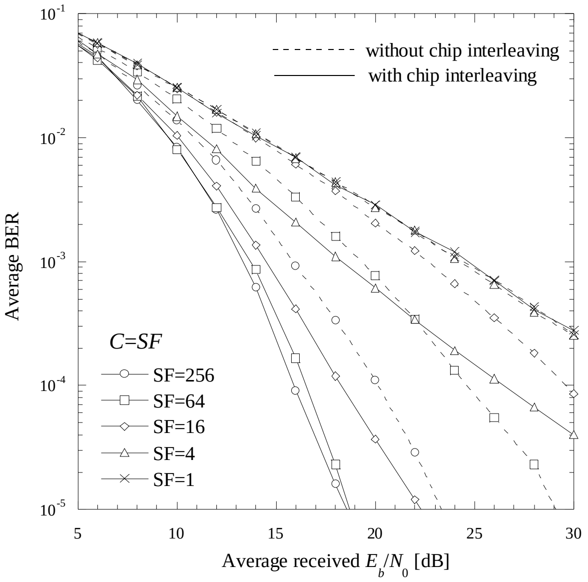


Fig. 6 BER performance with and without chip interleaving for MC-CDMA. Full load case (C=SF).

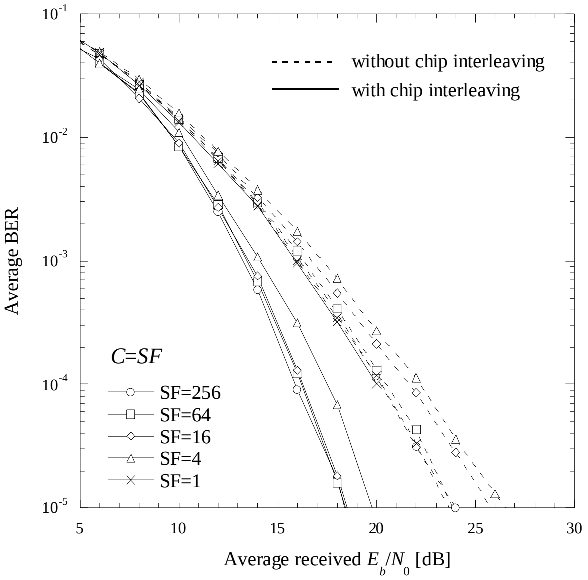


Fig. 7 BER performance with and without chip interleaving for DS-CDMA. Full load case (C=SF).

From Fig. 7, we see that the BER performance of DS-CDMA is almost insensitive to the value of *SF*. With higher *SF*, the ISI decreases but the inter-code interference increases. Even for DS-CDMA, chip interleaving improves the BER performance for all values of *SF*. In addition to the frequency-diversity effect, chip interleaving achieves a time-diversity gain as the chips in a symbol are distributed in time. When *SF*=256, about 4dB improvement is seen in the average received E_b/N_0 required for a BER=10^{-4}.

Figure 8 compares the chip interleaved BER performances of DS-CDMA and MC-CDMA. It is seen that for larger *SF* (>64), BER performance is almost the same for DS-CDMA and MC-CDMA since they benefit from large frequency and also time-diversity effects. However, for smaller *SF*, the DS-CDMA performance is better than that of MC-CDMA.

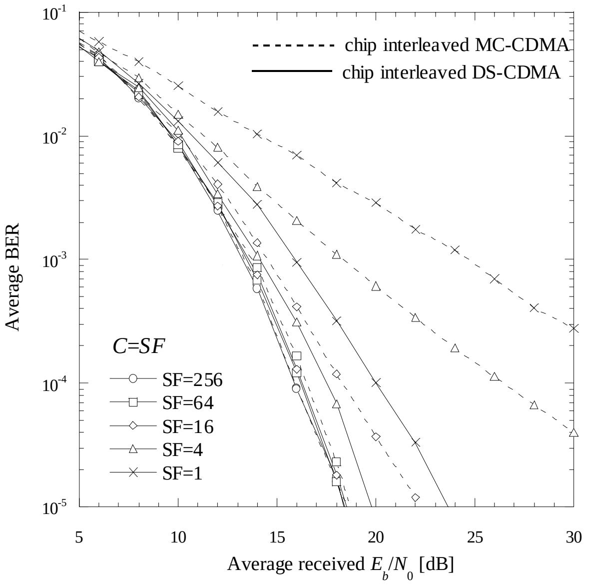


Fig. 8 Comparison of chip interleaved BER performance for DS-CDMA and MC-CDMA. Full load case (C=SF).

4 CONCLUSION

The effect of chip interleaving was evaluated for DS-CDMA and MC-CDMA both with MMSE-FDE. It was found that chip interleaving improves the performance for both DS-CDMA and MC-CDMA. The chip interleaving gain is larger for MC-CDMA than DS-CDMA. However, even with chip interleaving, which introduces a fair amount of time-diversity effect, it is found that the DS-CDMA performance is better than that of MC-CDMA in a frequency-selective fading channel.

REFERENCES

[1] S. Hara and R. Prasad, "Overview of multicarrier CDMA," IEEE Commun. Mag., pp.126-133, Dec. 1997.

[2] F. Adachi, T. Sao, and T. Itagaki, "Performance of multicode DS-CDMA using frequency domain equalization in a frequency selective fading channel," Electronics Letters, vol. 39, No.2, pp. 239-241, Jan. 2003.

[3] W. C., Jakes Jr., Ed., *Microwave mobile communications*, Wiley, New York, 1974.

[4] D. Garg and F. Adachi, "Chip interleaved turbo codes for DS-CDMA mobile radio in a fading channel," Electronics Letters, vol. 38, No. 13, pp. 642-644, June 2002.

[5] J. G. Proakis, *Digital Communications*, 3rd edition, McGraw Hill, 1995.

[6] K Takeda and F. Adachi, "Bit error rate analysis of DS-CDMA with joint frequency-domain equalization and antenna diversity combining," (in Japanese) Technical Report of IEICE, RCS2004, Jan. 2004.