System performance comparison of Fast-OFDM system and overlapping Multi-carrier DS-CDMA scheme

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Abstract: In this paper, an overlapped Orthogonal Frequency Division Multiplexing (OFDM) named as Fast-OFDM system and an overlapping multi-carrier direct-sequence code division multiple access (MC-DS-CDMA) scheme are introduced. The effect of the overlapping between sub-carriers, of Fast-OFDM and MC-CDMA with binary phase shift keying (BPSK), on the performance in an additive white Gaussian noise (AWGN) channel is investigated. The performance of MC-DS-CDMA system is compared to the Fast-OFDM system with conventional matched filter receiver.

1. Introduction

Due to the need for high data rate applications with reduced effect of Intersymbol Interference (ISI) and good performance in a multipath channel, OFDM has been proposed as one of the solutions, whereby the basic principle is to transmit the same data symbol over a number of narrow band orthogonal carriers. Reducing the spacing between subcarriers in OFDM system results in improved bandwidth efficiency. However, the orthogonality between subcarriers needs to be maintained for signal recovery at the receiver. A variation of OFDM named as Fast-OFDM [1] applies this idea, which reduces the frequency separation between subcarriers by a half when compared to standard OFDM system. Hence, it achieves twice the bandwidth efficiency. The Main limitation of this scheme is that it applies only for single dimensional modulation schemes like BPSK and M-ASK, which would limit the data rate as it is not compatible with complex modulation schemes such as QPSK and 16QAM.

The combination of OFDM and CDMA schemes has also drawn more attentions in the field of wireless communications, providing high data rate and robustness to multipath effects. This combination is referred as multi-carrier CDMA or OFDM/CDMA. There are mainly three categories of multi-carrier CDMA schemes: Multi-Carrier CDMA (MC-CDMA)[2-4], Multi-carrier Direct-Sequence CDMA (MC-DS-CDMA)[5;6], and Multi-tone CDMA (MT-CDMA)[7]. A number of authors also proposed several variants of these schemes [8-11].

The objective of this paper is to compare the performance of a Fast-OFDM system with a similar overlapping MC-DS-CDMA system under the same conditions and investigate the system structure of MC-DS-CDMA system.

2. Fast-OFDM

OFDM is a multi-carrier transmission technique, which divides the available spectrum into many orthogonal sub-carriers, each one being modulated by a low data rate stream. The simultaneous transmission of these sub-carriers increases the symbol duration, which combats multi-path delay spread over a wireless channel. By making the carriers orthogonal to one another, the channels can be placed closer together to achieve a more efficient use of the allocated bandwidth. Fast-OFDM is an adapted version of OFDM developed by Izzat Darwazeh and M.R.D. Rodrigues at University College

London in 2002 [1] with a similar system reported by Xiong in [12]. It is based on the OFDM principle with the advantage of having twice the bandwidth efficiency of OFDM, where the frequency separation of the sub-carriers is *1/(2T)* Hz, and *T* is the duration of the signaling interval. In other words, a FOFDM system will achieve the same data rate as an OFDM one, while using only half of the bandwidth. The complex envelope of a FOFDM signal can be written as:

$$S_{tx,FOFDM}(t) = \sum_{k=-\infty}^{\infty}\sum_{n=0}^{N-1} a_{n,k}\, g_n(t-kT); \qquad \text{Where} \quad g_n(t) = \frac{1}{\sqrt{T}} e^{j\frac{2\pi \cdot nt}{2\cdot T}}, t \in [0,T], \tag{2.1}$$

T is duration of the symbol, $a_{n,k}$, is the complex symbol transmitted on the *nth* subcarrier at the *kth* signaling interval, *N* is the number of OFDM subcarriers, $g_n(t - kT)$ is the complex subcarrier. The block diagram of a Fast-OFDM system is shown in Figure 1.

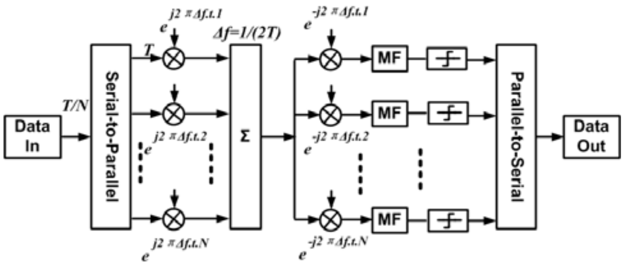

Figure 1. Oscillator Based Fast OFDM System

It was stated above that the major disadvantage of FOFDM is that it can only handle single-dimensional modulation schemes, such as BPSK and M-ASK. Orthogonality between subcarriers is only for the real part of a FOFDM signal, whereas the imaginary part of the signal loses orthogonality when the frequency separation becomes less than 1/T. Hence, for a received signal *r(t)* over a lossless channel, assuming time interval *k* starts from 0,

$$r(t) = S'_{tx,OFDM\,tx}(t) = \sum_{k'=-\infty}^{\infty}\sum_{n'=0}^{N-1} a'_{n,k}\, g'_{n',FOFDM}(t-k'T) \tag{2.2}$$

The recovered symbol, $y_{n,k}$, is [1]

$$y_{n,k} = \int_{kT}^{(k+1)T} r(t)\cdot g^*_{n,FOFDM}(t-kT)dt = \int_{kT}^{(k+1)T} \sum_{k'=-\infty}^{\infty}\sum_{n'=0}^{N-1} a'_{n,k}\, g'_{n',FOFDM}(t-k'T)\cdot g^*_{n,FOFDM}(t-kT)dt$$

$$y_{n,k} = \frac{1}{T}\int_0^T \sum_{n'=0}^{N-1} a_{n',k} e^{j\frac{\pi\cdot n'\cdot t}{T}} \cdot e^{-j\frac{\pi\cdot n\cdot t}{T}} dt = \frac{1}{T}\int_0^T \sum_{n'=0}^{N-1} a_{n',k} e^{j\frac{\pi\cdot(n'-n)\cdot t}{T}} dt = \sum_{n'=0}^{N-1} a_{n',k} \operatorname{sinc}[\pi(\frac{n'-n}{2})] e^{j\frac{\pi\cdot(n'-n)}{2}}$$

For real received signals (with BPSK or MASK), which are multiplied by the complex term, $sinc[\pi(n'- n)/2]e^{j\pi(n'- n)/2}$, only the imaginary part of the recovered symbol will be distorted. The symbol can be recovered with no ICI by taking its real part, as information is carried only in real part of the symbol. However, for complex modulation scheme, like QPSK or 16QAM, multiplication with the complex term $sinc[\pi(n'- n)/2]j^{(n'- n)}$ will distort both parts of the symbol, and hence makes the recovery of the symbol by traditional means, impossible.

3. Overlapping MC-DS-CDMA

The basic principle of a multi-carrier CDMA system is that each user data is first spread using a user specific spreading code and then modulated onto a set of subcarriers using OFDM. One major advantage of this system is that by transmitting a data stream in parallel, it lowers the symbol rate in each subcarrier, in other words, it extends the symbol duration and makes it easier to quasisynchronize the transmission.

MC-DS-CDMA is one type of multicarrier CDMA schemes which performs the spreading process in time domain. It spreads a set of Serial-to-Parallel (S/P) converted data streams using a given spreading code and then modulates a different sub-carrier with each of the spread data stream. Figure 2 shows a block diagram of a single-user MC-DS-CDMA system. The transmitter first converts the original data stream into N_{sc} parallel substreams, which are then multiplied with a spreading code of processing gain, G_{MD}. The spread substreams are then modulated with N_{sc} subcarriers frequency spaced at $\Delta f = 1/T_c = G_{MD}/N_{sc}T_b$, where T_b is the initial bit duration and T_c is the spreading code chip duration. Finally the MC-DS-CDMA signal is generated by adding up all the modulated substreams.

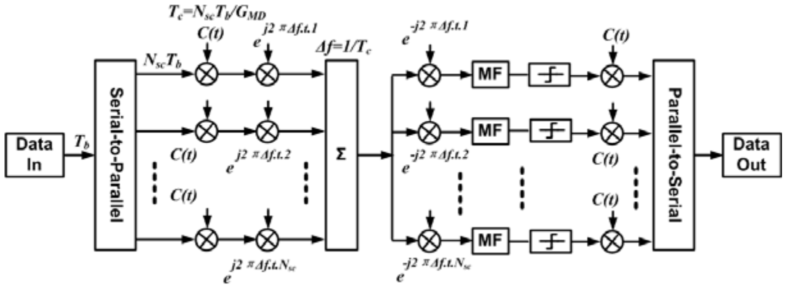

Figure 2. Single-user MC-DS-CDMA System

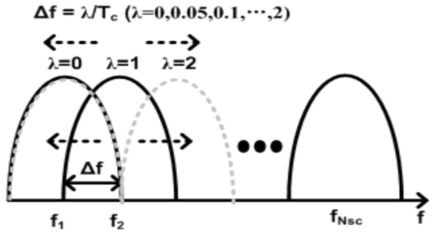

Figure 3 Power Spectrum of the overlapping MC-DS-CDMA system

The MC-DS-CDMA system analyzed in this paper is based on the one proposed in [6] except that the frequency separation between sub-carriers is λ/T_c, where T_c is code duration. λ is the overlapping coefficient varied from 0 to 2, which results in overlapping percentage of 100% to 0%. For the case of OFDM, $\lambda = 1$ (corresponds to 50% overlapping) while $\lambda = 0.5$ (corresponds to 25% overlapping) is the case of Fast-OFDM. The power spectrum of the overlapping MC-DS-CDMA system is shown in Figure 3.

4. Results and discussion

Both of the systems are simulated using Advanced Design System (ADS) under the same conditions with the initial bit rate 1 Mbps (or T_b = 1 usec). The total number of subcarriers N_{sc} is 4. Figure 4a and 4b shows the BER performance of the Fast-OFDM system and overlapping MC-DS-CDMA with code length set to 4, 8 and 16 at EbNo is 0dB and 4dB, respectively. The overlapping coefficients are varied from 0 to 2. The spreading code used is Walsh Hadamard (WH) codes with a pattern of (1,-1,-1,1,1,-1,-1,1…). The results show that the BER performance of MC-DS-CDMA schemes is comparable to the Fast-FODM system. Different code lengths produce similar results. The BER performance at λ is 1, 2 and 0.5 are close to ideal BPSK BER result as the orthogonality remains between subcarriers for data recovery. However, when λ takes other values, the orthogonality lost between subcarriers, resulting in Intercarrier Interference (ICI). Especially when λ is smaller than 0.5, subcarriers are spaced more closely. This results in more ICI and degradation in BER performance. In the case when λ is 0, subcarriers are fully overlapped and the modulated substreams are at worst case ICI. Figure 5 shows the BER performance of both system when λ is 0.25(87.5% overlapping), 0.5(75% overlapping), 1(50% overlapping) and 2(0% overlapping). For λ=0.25, the orthogonality between subcarriers is lost. The BER performance for both systems is much worse than the ideal case. For λ=0.5, λ=1 and λ=2, the orthogonality remains for signal recovery. The BER performances are close to the ideal.

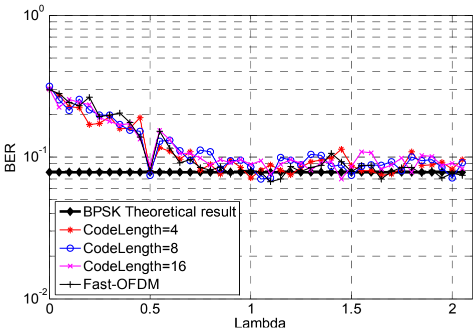

Figure 4a BER results at EbNo=0dB

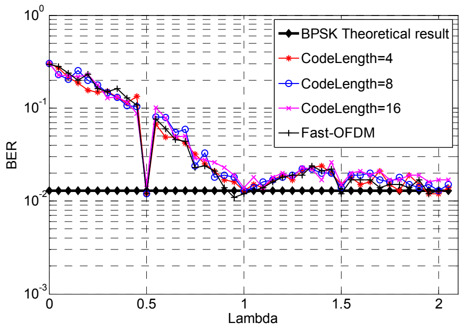

Figure 4b BER results at EbNo=4dB

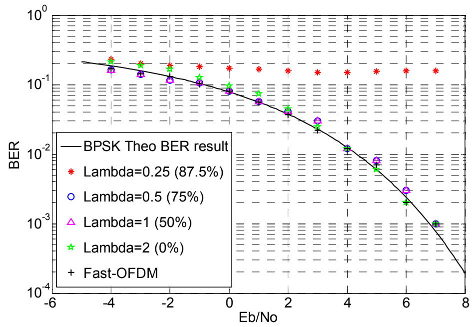

Figure 5 BER results with varying Eb/No

5. Conclusions

The BER performance of a Fast-OFDM system and overlapping MC-DS-CDMA system in an AWGN channel under the same conditions is investigated. It is shown that the MC-DS-CDMA systems with different code lengths are comparable to the Fast-OFDM system at the overlapping coefficient λ is 0.5, 1 and 2. The BER performance decreases heavily when the orthogonality between subcarriers is lost for both systems.

Reference

[1] M. R. D. Rodrigues and I. Darwazeh, "Fast OFDM: A Proposal For Doubling the Data Rate of OFDM Schemes,", 3 ed Beijing, China: 2002, pp. 484-487.

[2] K. Fazel and L. Papke, "On the performance of convolutionally-coded CDMA/OFDM for mobile communications system," 1993, pp. 468-472.

[3] N. Yee, Linnartz J.P., and G. Fettweis, "Multi-carrier CDMA in indoor wireless radio network," 1993, pp. 109-113.

[4] A. Chouly, A. Brajal, and S. Jourdan, "Orthogonal multicarrier techniques applied to direct sequence spread spectrum CDMA systems," 1993, pp. 1723-1728.

[5] V. M. DaSilva and E. S. Sousa, "Performance of orthogonal CDMA codes for quasi-synchronous communication systems," Ottawa, Canada: 1993, pp. 995-999.

[6] S. Hara and R. Prasad, "Overview of multicarrier CDMA," *Communications Magazine, IEEE*, vol. 35, no. 12, pp. 126-133, 1997.

[7] L. Vandendorpe, "Multitone direct sequence CDMA system in an indoor wireless environment," Delft, The Netherlands: 1993, p. 4.1.1-4.1.8.

[8] L. Hanzo, L.-L. Yang, E.-L. Kuan, and K. Yen, in *Single- and Multi-Carrier DS-CDMA Multi-user Detection Space-Time Spreading, Synchronisation and Standards* John Wiley & Sonsl, 2003.

[9] L. L. Yang and L. Hanzo, "Slow frequency-hopping multicarrier DS-CDMA," Amsterdam, The Netherlands: 1999, pp. 224-229.

[10] S. Kondo and B. Milstein, "Performance of multicarrier DS CDMA systems," *Communications, IEEE Transactions on*, vol. 44, no. 2, pp. 238-246, 1996.

[11] E. A. Sourour and M. Nakagawa, "Performance of orthogonal multicarrier CDMA in a multipath fading channel," *Communications, IEEE Transactions on*, vol. 44, no. 3, pp. 356-367, 1996.

[12] X. Fuqin, "M-ary amplitude shift keying OFDM system," *Communications, IEEE Transactions on*, vol. 51, no. 10, pp. 1638-1642, 2003.