System performance comparison of Fast-OFDM system with overlapping MC-DS-CDMA and MT-CDMA systems

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Abstract: In this paper, the adapted orthogonal frequency division multiplexing (OFDM) termed as Fast-OFDM system and overlapping multi-carrier code division multiple access systems (overlapping multi-carrier direct-sequence CDMA and overlapping multi-tone CDMA) are compared. The effect of the overlapping between sub-carriers, with binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK), on the performance in an additive white Gaussian noise (AWGN) channel is investigated. The results show that the system performance of an overlapping multicarrier-CDMA system is comparable to the Fast-OFDM system in the prescience of AWGN and inter-carrier interference when a conventional matched filter receiver is used.

1. Introduction

OFDM is currently widely used one of the transmission techniques that provides high data rate and alleviated multi-path impairments in wireless communications. Multiple subcarriers with equal frequency interval are adopted to form parallel data transmission in OFDM. Every separate data branch is modulated with equally-spaced subcarrier. 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. Fast-OFDM [1], also refered to M-ary amplitude shift keying (MASK) [2] is an OFDM-adapted system which reduces the frequency separation between subcarriers by a half when compared to standard OFDM system, hence achieving twice the bandwidth efficiency. The limitation of this scheme is that it mainly applies for single dimensional modulation schemes such as BPSK and M-ASK, which would limit the data rate as it is not compatible with complex modulation schemes such as QPSK and QAM.

Over the past few years, the combination of OFDM and CDMA schemes has generated great interest in the field of wireless communications, providing high data rate and robustness to multipath effects. This combination is referred to multi-carrier CDMA or OFDM/CDMA. There are mainly three categories of multi-carrier CDMA schemes: Multi-Carrier CDMA (MC-CDMA) [3-5], Multi-carrier Direct-Sequence CDMA (MC-DS-CDMA) [6;7] and Multi-tone CDMA (MT-CDMA) [8;9]. A number of authors also proposed several variants of these schemes [10]. Among these multi-carrier CDMA systems, MC-DS-CDMA systems have the advantage of higher frequency diversity and improved overall system performance as compared to other multi-carrier schemes. On the other hand, MT-CDMA is appealing due to the usage of longer spreading code sequences and spectrum overlapping, as this allows improved user accommodation when compared to DS schemes and as it provides higher bandwidth efficiency. The concept of overlapping multi-carrier CDMA systems was introduced by Hanzo [11], in which the overlapping was modeled by varying the frequency spacing between subcarriers for MC-DS-CDMA and MT-CDMA systems.

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

2. Fast-OFDM

FOFDM 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 signalling interval. In other words an FOFDM system will achieve the same data rate as that of an OFDM one, whilst using only half of the bandwidth. The complex envelope of a FOFDM signal is shown as follows:

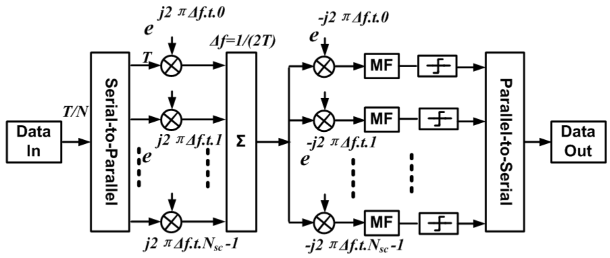

Figure 1: Oscillator Based Fast OFDM System.

$$S_{tx,FOFDM}(t) = \sum_{k=-\infty}^{\infty} \sum_{n=0}^{N-1} a_{n,k} g_n(t-kT) \quad (1)$$

where T is duration of the symbol. $a_{n,k}$ is the complex symbol transmitted on the *nth* subcarrier at the *kth* signalling interval, N is the number of OFDM subcarriers, $g_n(t-kT)$ is the complex subcarrier and is expressed as:

$$g_n(t) = \frac{1}{\sqrt{T}} e^{j\frac{2\pi \cdot nt}{2 \cdot T}}, t \in [0, T] \quad (2)$$

The block diagram of a conventional oscillator-based FOFDM system is shown in Figure 1.

2. Multi-carrier CDMA systems

In MC-DS-CDMA, the N_{sc} serial-to-parllel converted substreams are multiplied with a spreading code of codelength, G_{MD}, and then modulated with subcarriers spaced by $\Delta f = 1/T_c = G_{MD}/N_{sc}T_b$, where T_b is the initial bit period and T_c is the spreading code chip duration. To achieve orthogonality between subcarriers, the minimum spacing Δf between adjacent subcarriers should be inverse of the chip duration, i.e. $\Delta f = 1/T_c$. Whereas, in MT-CDMA, the spreading is effected after combining all the substreams modulated with a set of orthogonal subcarriers separated at the symbol rate. Therefore, strong spectral overlap among the different subcarriers after spreading exists in the MT-CDMA scheme. The main differences between these two systems are the position where data spreading is applied and the frequency spacing introduced between adjacent subcarriers. In MC-DS-CDMA systems, adjacent subcarriers are separated by $1/T_c$, where T_c is the chip duration after spreading, whereas, in the MT-CDMA systems, subcarriers are spaced at $1/T_s$ where T_s is the symbol duration

3. Overlapping multi-carrier CDMA systems

As MT-CDMA differs from MC-DS-CDMA only in its subcarrier spacing (Δf), various multi-carrier CDMA systems may be considered when the subcarrier spacing is varied from $1/T_s$ to $1/T_c$ [10]. An overlapping multi-carrier CDMA system can be constructed based on the MT-CDMA scheme, named as overlapping MT-CDMA, in which the frequency spacing between subcarriers is λ/T_s ($\lambda = 1, 2, \ldots, G_{DS}$), where λ is an overlapping coefficient. When $\lambda = 1$, we have an MT-CDMA system, while when $\lambda = G_{DS}$, we have an MC-DS-CDMA system. On the other hand, the overlapping multi-carrier CDMA system can also be generated based on a MC-DS-CDMA scheme with the frequency spacing of λ'/T_c, where T_c is the code duration. It varies from 0 to 2 which correspond to overlapping percentage of 100% to 0%. $\lambda' = 1$ corresponds to 50% overlapping which is the case similar to OFDM. $\lambda' = 0.5$ corresponding to 25% overlapping is the case similar to FOFDM. It should be noted that the λ' is related to λ as ratio of T_s/T_c, i.e. $\lambda = \lambda' \cdot T_s/T_c = \lambda' \cdot G_{DS}$.

Varying the overlapping coefficient, λ, results in different types of multi-carrer CDMA systems and different effects of multi-user and multi-carrier interference. For example, if λ is low, there is a strong overlapping between subcarriers. If the total bandwidth is given, then low value of λ leads to a high spreading gain, hence, reduction of multi-user interference. Conversely, if λ is high – for example $\lambda = 2G_{DS}$ – for a given total bandwidth, there is no overlap between subcarriers. Therefore, inter-carrier interference is reduced, but with an increase in multi-user interference due to the reduced processing gain on each subcarrier signal [10]. Hence, a trade-off exists between the overlapping bandwidth and the processing gain and there exists an optimised value of λ that provides good performance in the system in terms of minimised multi-user and multi-carrier interference, improved bandwidth efficiency and BER performance.

4. Results and discussion

The systems described above are simulated using Advanced Design System (ADS) under the same conditions with the initial bit rate 1 Mbps. To illustrate the effects, systems with 4 subcarriers are considered. Figure 2 shows the BER performance of the Fast-OFDM system and overlapping MC-DS-CDMA with code length set to 4, 8 and 16 at Eb/No of 4dB. The overlapping coefficients are varied from 0 to 2. 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 results when λ' is set to 1, 2 and 0.5, are close to ideal BPSK BER result as the orthogonality is preserved between subcarriers. However, when λ' takes other values, the orthogonality is lost, resulting in ICI. For the close spacing when λ' is less than 0.5, high ICI results in severe degradation in BER performance. In the case when λ' is 0, subcarriers are fully overlapped.

Figure 3 shows a comparison of the overlapping MT-CDMA system with code length = 8 and the variable frequency spacing OFDM systems with QPSK modulation scheme. The result is similar to BPSK case except that at the point 0.5, orthogonality between subcarriers is lost, ICI is remained for both systems.

Figure 4 and Figure 5 illustrate the BER performance of the FOFDM system and the overlapping MC-DS-CDMA systems when λ' is 0.25 (87.5% overlapping – the case similar to ½ of frequency spacing of FOFDM), 0.5 (75% overlapping – the case similar to FOFDM), 1 (50% overlapping – the case similar to OFDM) and 2 (0% overlapping – the case similar to FDM) in BPSK and QPSK system, respectively. In the BPSK system, the orthogonality is lost when $\lambda' = 0.25$, leading to degraded BER performance as compared to the theoretical BPSK BER result. For $\lambda' = 0.5$ and $\lambda' = 1$, the orthogonality remains for signal recovery. The BER results are close to ideal. As expected for the QPSK system, the overlapping MC-DS-CDMA system ($\lambda' = 0.5$) exhibits similar properties when compared to the FOFDM system showing BER degradation due to the loss of orthogonality.

For overlapping MT-CDMA system, similar comparison is performed when overlapping coefficient, λ, is varied for 0 to 16 (for different codelength considerations, 4, 8, 16). Similar to overlapping MC-DS-CDMA system, different code lengths do not affect the BER performance. Furthermore, the BER performance is close to the theoretical BPSK and QPSK systems when λ equals to $0.5\ i\ (i = 1,2,\ldots)$ and $i\ (i = 1,2,\ldots)$, respectively. This further explains the fact that the orthogonality among subcarriers continues in overlapping MT-CDMA system as the frequency spacing is varied from $1/T_s$ to $1/T_c$ for integer values of λ. For the range from 0 to 2, the results are viewed similar to overlapping MC-DS-CDMA when compared to FOFDM.

5. Conclusions

The performance of Fast-OFDM and overlapping MC-DS-CDMA and MT-CDMA systems, under the same conditions, are investigated by simulation. It is shown that the BER of overlapping MC-DS-CDMA systems with BPSK modulation and different code lengths is comparable to that of Fast-OFDM when the overlapping coefficient is set to 0.5, 1 and 2. As expected, the BER performance is severely degraded when the orthogonality between the subcarriers is lost for either system. In the case of BPSK, the MT-CDMA, MC-DS-CDMA and FOFDM exhibited similar properties under simple AWGN channel conditions. Future work will consider multi-path interferences and diversity receiver techniques for further comparison of these systems.

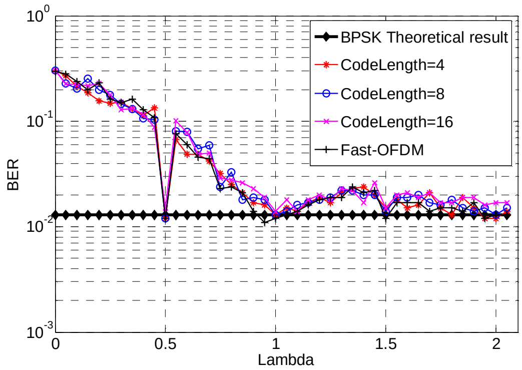

Figure 2: BPSK overlapping MC-DS-CDMA BER compare with variable OFDM with Eb/No=4dB.

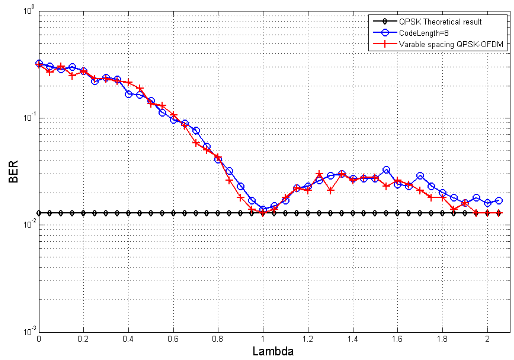

Figure 3: QPSK overlapping MC-DS-CDMA BER compare with variable OFDM with Eb/No=4dB.

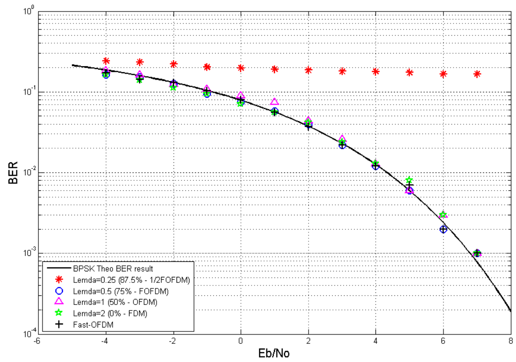

Figure 4: BPSK BER performance with varied overlapping coefficients.

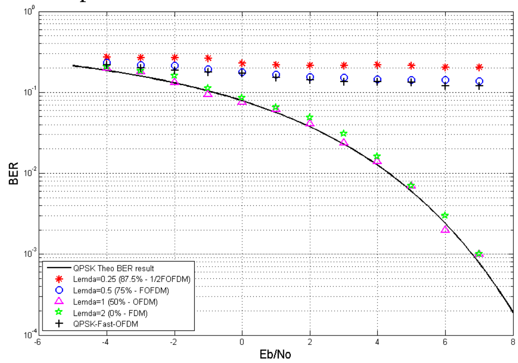

Figure 5: QPSK BER performance with varied overlapping coefficients.

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