Orthogonal Frequency and Code Division Multiplexing Using Modified Pseudo-Ternary M-Sequences Pair

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Abstract: In recent years, Orthogonal Frequency and Code Division Multiplexing(OFCDM) systems have been studied. OFCDM achieves hign spectral efficiency and data transmission rate. However, OFCDM has the problem that peak-to-average ratio(PAPR) is hign. Thus, a serious problem encountered with OFCDM is to suppress PAPR. In this paper, OFCDM system using Modified Pseudo-Ternary M-sequences(MPTM) pair as the spreading codes is proposed. MPTM is made by mixing {0,1}-valued M-sequences and bi-orthogonal codes. The complementary cumulative distribution function(CCDF) of PAPR and BER performance of the proposed system are evaluated by computer simulation. Consequently, the proposed system achieves the PAPR reduction more than the conventional system without the deterioration of bit error rate(BER) performance. BER of the proposed system is identical to that of the conventional system with the {+1,-1}-valued orthogonal M-sequences.

Keywords—**OFCDM, Code Shift Keying, M-sequence, bi-orthogonal code, peak-to-average power ratio**

1. Introduction

In recent years, Orthogonal Frequency and Code Division Multiplexing(OFCDM) systems have been studied[1]-[5]. OFCDM, which is made by mixing Orthogonal Frequency Division Multiplexing(OFDM) and Code Division Multiple Access(CDMA), achieves high spectral efficiency and data transmission rate. As in the case of OFDM, OFCDM has the PAPR(Peak-to-Average Power Ratio) problem. Thus, a serious problem encountered with OFCDM is to suppress PAPR.

Considerable researches have been carried out on the PAPR reduction methods for OFCDM and OFDM[4]-[15]. In [4][6], the method using Peak Reduction Signal Addition(PRSA) was proposed. Although this method achieves the PAPR reduction, bit error rate(BER) deteriorates because inter-signal interference occurs by peak reduction. As a method without the deterioration of BER, Selected Mapping(SLM) and Partial Transmit Sequences(PTS) were investigated[7]-[13]. The SLM generates a number of statistically independent sequences, and the SLM sequence with the smallest PAPR is selected and transmitted. Nevertheless, the effect of PAPR reduction of SLM becomes small. In PTS, the data is divided into a set of disjoint subblocks, then an inverse fast Fourier transform(IFFT) is applied followed by an optimal combination of phase factors. The subblocks are then combined to form the OFDM symbol for transmission. PTS can improve PAPR more than SLM. When we considerably increase the PAPR reduction, computational complexity increases. In SLM and PTS, the data transmission rate deteriorates and the system complexity becomes higher because the receivers require the side information. Although Clipping & Filtering(C&F) method is one of the simple PAPR reduction methods, computational complexity increases with increase of the number of repeated operations. In OFCDM, the pseudo-noise(PN) code is also a key to realize the PAPR reduction method. We consider a PN code design for OFCDM.

We designed the modified pseudo-ternary M-sequences, denoted MPTM, for performing the code synchronization[16]. It is expected that MPTM reduces PAPR because the number of mark signals of MPTM is smaller than that of M-sequence code or Gold code. Thus, in this paper, we propose the OFCDM system using MPTM. MPTM is made by mixing {0,1}-valued M-sequences and the bi-orthogonal codes. MPTM pair consists of MPTM and {-1,1}-valued M-sequences. We evaluate the complementary cumulative distribution function(CCDF) of PAPR and BER performance of the proposed system.

2. System Overview

2.1 System Concept

Figure 1 shows the concept of the proposed system. The modified pseudo-ternary M-sequence(MPTM) is obtained by the {0,1}-valued orthogonal M-sequences and the bi-orthogonal code. The {0,1}-valued orthogonal M-sequence is the primitive M-sequence with an additional chip. The bi-orthogonal code, which is generated by the $M/2 \times M/2$ Hadamard matrix, is {+1,-1}-valued orthogonal code. Since $M/2$ is equal to the number of +1's chips in {0,1}-valued M-sequence, $M/2 = (L+1)/2$. The modified pseudo-ternary M-sequences are obtained by determining the polarity of +1 chips by a bi-orthogonal code. The data transmission is performed by Code-Shift-Keying(CSK) that is one of the multi-level transmissions. CSK selects a code from M assigned codes by source data. In Fig.1, the MPTM signals on the adjacent sub-channel does not overlap. Because the proposed system assigns MPTM and $\overline{\mathrm{MPTM}}$ alternately to the subcarriers, it is expected that the proposed system can realize PAPR reduction.

2.2 System Structure

Figure 2 illustrates the system model of the transmitter of the proposed system. In the subcarriers #1(f_1), #3(f_3), $\cdots$, #$n-1(f_{n-1})$, M MPTM codes are used for CSK. And in the subcarriers #2(f_2), #4(f_4), $\cdots$, #$n(f_n)$, M $\overline{\mathrm{MPTM}}$ codes are used. We consider the data transmission using the subcarrier #1(f_1). Since the length of MPTM code is M[chips], source data are divided every $\log_2 M$ bits. One of M MPTM codes is

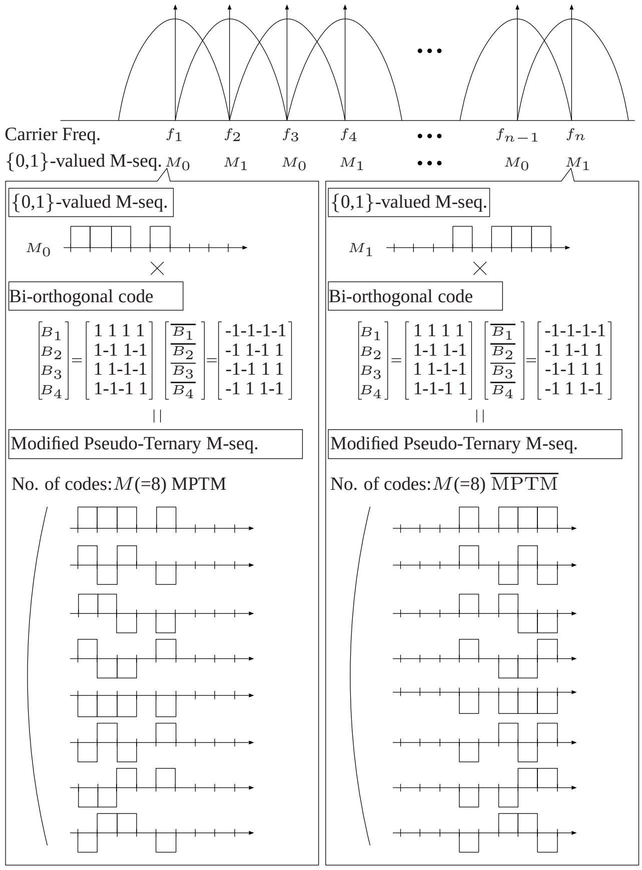

Figure 1. Concept of the proposed system

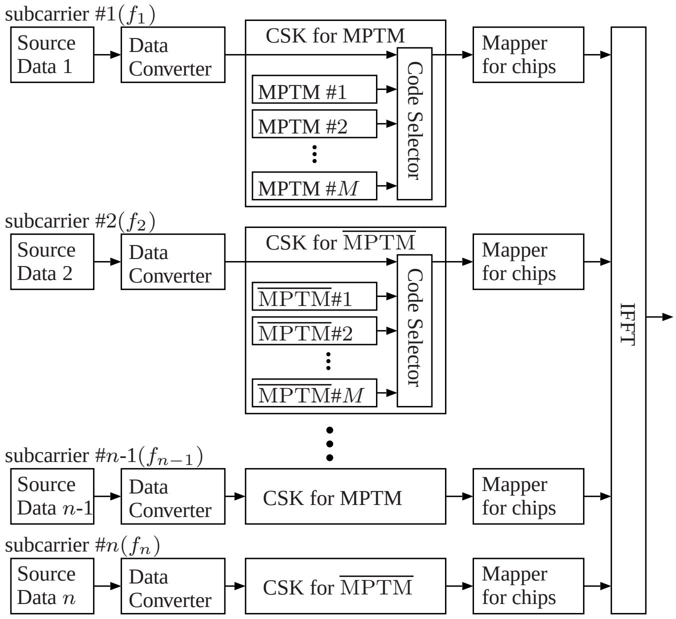

Figure 2. System model of transmitter

selected by the divided source data. The selected MPTM code is mapped for chips to the frequency domain data. Thus, the transmission signal is represented by selected MPTM code. The transmission signal of the subcarrier #2(f_2) is performed by using $\overline{\mathrm{MPTM}}$. Therefore, n data mapped to the frequency domain are got into IFFT one chip by one chip parallelly, so IFFT system runs M times. The time domain signal which has M chips is made and transmitted.

Figure 3 illustrates the system model of the receiver of the proposed system. The received signal is sampled and divided to M blocks, and converted parallel from serial. M blocks are got into M FFT systems. In the receiver, subcarrier demapping is performed to extract data mapped to the assigned subcarriers. Thus, data for the subcarrier #i is estimated by the CSK demodulator with MPTM set when i is an odd number. If i is an even number, the transmitted data is demodulated by using $\overline{\mathrm{MPTM}}$ set. The CSK demodulator for subcarrier #i(odd number) contains $M/2$ correlators, each one corresponds to one of $M/2$ MPTM codes. Each correlator consists of a multiplier that multiplies one of $M/2$ MPTM codes by the received signals and an integrator that integrates the product over the sequence period. The outputs of the $M/2$ correlators are all sampled at time T_s(the period of the sequence code). The magnitudes of the correlator outputs and this negative versions are examined and the largest one is selected. The transmitted data is extracted by the estimated MPTM code.

3. Performance Evaluation

In this section, we evaluate the CCDF of PAPR and BER performance of the proposed system by computer simulation. We compare the proposed system with the conventional system using {+1,-1}-valued orthogonal M-sequences. In simulation, the code length of the proposed system and the conventional system is 8[chip], and the number of subcarriers is 32. It is assumed to be the additive white Gaussian noise channel.

3.1 CCDF of PAPR Performance

Figure 4 shows CCDF of PAPR performance. The PAPR performance of the proposed system using MPTM pair is better than that of the conventional system using {+1,-1}-valued orthogonal M-sequences. When CCDF is 10^{-5}, the proposed system is superior to the conventional system about 0.4[dB]. This result suggests that the performance improvement becomes larger when the code length and the number of sabcarriers increase.

3.2 BER Performance

Figure 5 shows BER versus E_b/N_0. The proposed system, which is one of the Code-Shift-Keying, is superior to the conventional system using the binary modulation. The BER performance of the proposed system is identical to that of the conventional system using CSK. Besides, theoretical formula of BER of the proposed and conventional systems is written

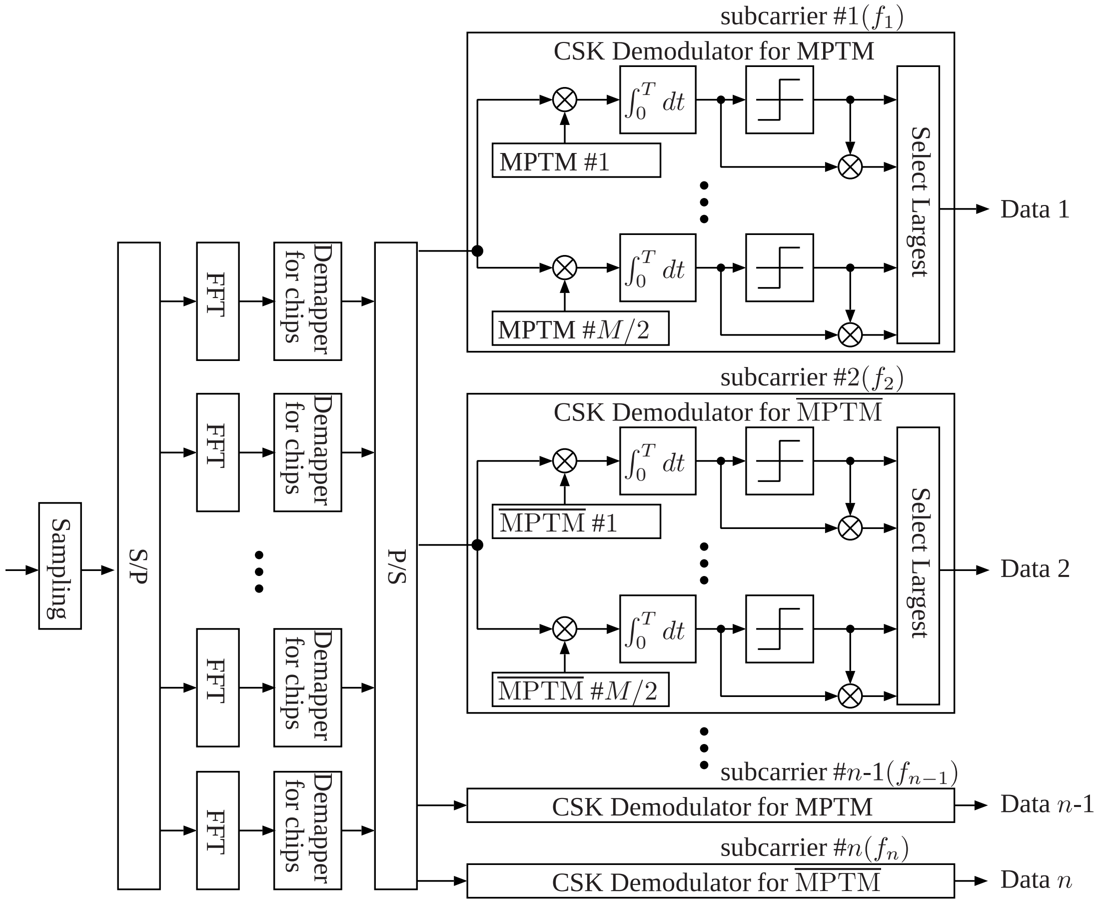

Figure 3. System model of receiver

as follows:

$$BER = \frac{1}{2} + \frac{1}{2}\left\{\int_{-\infty}^{-\sqrt{\log_2 M \frac{E_b}{N_0}}} \frac{1}{\sqrt{\pi}} e^{-x^2} \times \left\{-1 + \operatorname{erfc}\left(x + \sqrt{\log_2 M \frac{E_b}{N_0}}\right)\right\}^{\frac{M}{2}-1} dx - \int_{-\sqrt{\log_2 M \frac{E_b}{N_0}}}^{\infty} \frac{1}{\sqrt{\pi}} e^{-x^2} \times \left\{1 - \operatorname{erfc}\left(x + \sqrt{\log_2 M \frac{E_b}{N_0}}\right)\right\}^{\frac{M}{2}-1} dx\right\}. \tag{1}$$

Eq.(1) is identical to BER of the bi-orthogonal code. Simulation results of the proposed and conventional systems approach to theoretical values.

4. Conclusion

In this paper, we proposed the OFCDM system using MPTM pair. In our computer simulation, when code length is 8 and the number of subcarriers is 32, the BER performance of the proposed system is much the same as that of the conventional system. On the other hand, CCDF of PAPR performance of the proposed system is better than that of the conventional system.

In future work, we plan to derive the theoretical formula for BER and PAPR characteristics. Furthermore, we cogitate about how to set MPTM pair to subcarriers.

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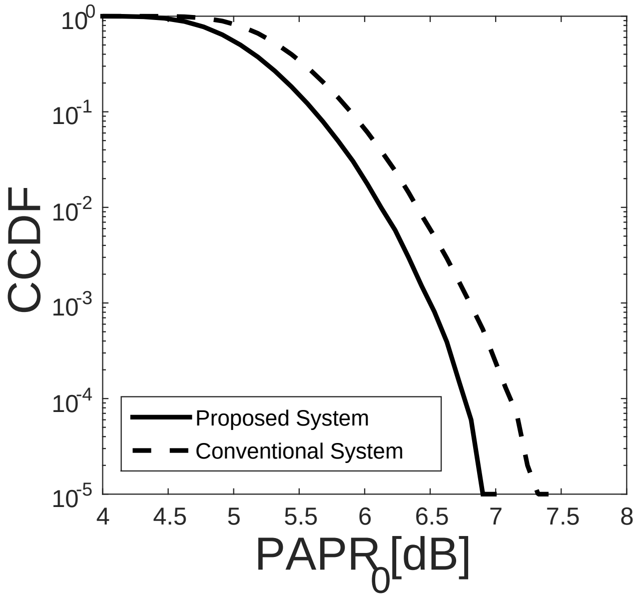

Figure 4. CCDF versus PAPR_0 when code length is 8, the number of subcarriers is 32

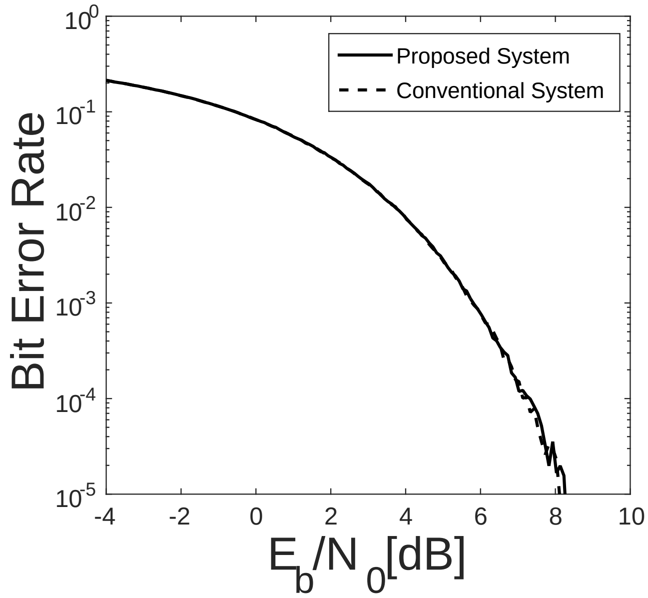

Figure 5. BER versus E_b/N_0 when code length is 8, the number of subcarriers is 32

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