PERFORMANCE IMPROVEMENT TECHNIQUES
FOR CCK-OFDM WLAN MODEM

Wonjeong Jeong, Hyuncheol Park, Hyuckjae Lee and *Sunghyun Hwang

Information and Communications University (ICU), KOREA
*Samsung Electronics Co., KOREA

jwj0331@icu.ac.kr, hpark@icu.ac.kr, hjlee@icu.ac.kr, *hwangsh@samsung.com

Abstract

In this paper, we propose a new scheme using the 1st order Reed-Muller (RM) code with variables 4, RM(1, 4) which improves the performance of IEEE 802.11g wireless local area network (WLAN) modem in terms of peak-to-average power ratio (PAPR) and symbol error probability (SER). We show the equivalence between complementary code keying (CCK) codeword and coset of the 1st order Reed-Muller code with variables 3, RM(1, 3). This proposed system shows better performance than CCK in terms of PAPR and SER. When the numbers of IFFT point is 64, we reduce PAPR by 9dB and get a coding gain of 3dB at symbol error probability of 10^-4.

Introduction

The data rate and reliability required to support the new wireless multimedia services has increased the demand for high-speed wireless communication systems. Recently, both CCK and orthogonal frequency division multiplexing (OFDM) have been adopted as high-speed signaling schemes for IEEE 802.11g WLAN standard [1]. However OFDM carries a serious problem of having a large peak-to-average power ratio when added up coherently. A large PAPR in OFDM system brings disadvantages such as an increased complexity of the analog-to-digital and digital-to-analog converters, and a reduced efficiency of the RF power amplifier. A well-known approach to PAPR reduction is using the correlation properties of complementary sequences translating into a relatively small PAPR of 2 (3dB) when the codes are used to modulate an OFDM signal. In [2], Davis derived that these complementary sequences occur as cosets of the 1st order RM code within the 2nd order RM code and used these sequences to reduce PAPR in OFDM.

The paper is organized as follows. We show the equivalence between CCK and cosets of RM code, and PAPR reduction in the proposed system. Finally we give simulation results to confirm our derivation.

Equivalence Between CCK and Cosets of Reed-Muller Code

In IEEE 802.11g WLAN standard, for a block length of 8, 256 possible sequences \( c' \) can be constructed as follows:

\[
\begin{align*}
&\mathcal{c}' = \{c((n_1+n_2+n_3), (n_1+n_2+n_3), (n_1+n_2), (n_1), (n_2)) \mid (n_1+n_2+n_3) \}
\end{align*}
\]

(1)

where \( n_1, n_2, n_3 \in \{0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\} \).

Let \( G_m \) be the generator matrix of \( \text{RM}(1, m) \), and \( x_k, k = 1, 2, \ldots, m+1 \) be the row vectors of \( G_m \), where \( m \) is the number of variables. The set of codewords (mod \( Q \)) represented by (2) is Golay complementary sequences which have PAPR of 3dB at most [2):

\[
\mathcal{c} = \frac{Q}{2} \sum_{k=1}^{m+1} x_i(n) x_k(n) + u G_m
\]

(2)

where \( n \) is permutation of the symbols and \( u \in \{0, 1, \ldots, Q-1\} \) is information vectors. The first part of the right hand side is coset leader (3) and the second part is 1st order RM code.

\[
\frac{Q}{2} \sum_{k=1}^{m+1} x_i(n) x_k(n) + u G_m
\]

(3)

For \( m = 3, Q = 4 \), possible coset leaders based on (3) are \([0000,0020,0000,0020,00020,0002020,000202020] \). If coset leader \([0000,0020,0000,0020,00020,0002020,000202020]\) is chosen, (2) is equivalent to CCK codes (1) after some arrangements.

The generator matrix \( G_4 \) of \( \text{RM}(1, 4) \) code can be represented by using the generator matrix \( G_3 \) and all-zero and all-one vectors as shown below (4).

\[
G_4 = \begin{bmatrix} G_3 & G_3 & \mathbf{0} \end{bmatrix}
\]

Thus, the codeword for \( \text{RM}(1, 4) \) can be created by using the generator matrix \( G_3 \) of \( \text{RM}(1, 3) \). The proposed system is shown in Figure 1. The input vector of \( \text{RM}(1, 4) \) consists of five bits. Four bits of them is multiplied by the generator matrix \( G_3 \) and the remaining one bit is added to the above...
multiplication output after repeating to length 8 bits. After two outputs having length 8 bits is cascaded to have 16 bits, it is equivalent to the codeword of RM(1, 4) generated by \( G_4 \).

A coset leader is chosen among 12 possible coset leaders using (3) and added to the codeword to generate the coset of RM(1, 4). If the last bit of input vector is zero and the coset leader is selected as the vector of \([0002002000022202]\) or \([0002002002000222]\), the resulting codeword of length 8 is equal to CCK modulator.

Generally, RM codeword can be decoded with the fast Hadamard transform (FHT). Although to decode RM(1, 4) codeword, the FHT block of size \( 16 \times 256 \) is required, the proposed system uses \( 2 \) FHT blocks of size \( 8 \times 64 \). The upper FHT is used to decide four bits of input vector by searching the index of maximum value in the FHT output. To find the last bit, the phase difference between two FHT outputs is compared.

**PAPR REDUCTION OF OFDM**

Since CCK codeword is a Golay complementary sequence, its PAPR is at most 3dB [2]. When OFDM transmission is active, the data stream is encoded by CCK modulator before feeding into IFFT block as shown in Figure 1. We note that this is incompatible with IEEE 802.11g WLAN standard. Since the block length of RM (1, 3) code is 8, the 8 CCK codewords are grouped and fed into IFFT block of size 64. Each CCK codeword is a Golay complementary sequence with PAPR at most 2 (3dB). Therefore the PAPR of one OFDM symbol is upper bounded 16 (12dB). This is 6dB reduction in PAPR as comparing maximum possible PAPR of 64 (18dB) when uncoded. When we also use RM(1, 4), we can reduce PAPR at least 9dB.

**SIMULATION RESULTS AND CONCLUSIONS**

Golay sequences has a special property that its inverse Fourier transformed sequence has PAPR of at most 3dB. This makes the sequence desirable for OFDM systems. When this property is applied to the conventional IEEE 802.11g WLAN modem, we can construct same CCK modulator using the RM(1, 3) encoder and reduce 6dB of PAPR without additional blocks at the transmitter.

Also, when we use RM(1, 4), we can improve both error correction capability and PAPR reduction as compared with RM (1, 3). Although the code rate of RM(1, 4) is decreased as compared with RM(1, 3), we can get a coding gain of 3dB at SER of \( 10^{-4} \) as shown in Figure 2. If the value of the last bit in input vector is zero, this proposed system is the conventional CCK. Even though RM(1, 2) is equivalent to CCK with some modification, the performance of RM(1, 2) is no better than uncoded quaternary phase shift keying (QPSK). To adopt our proposed system, we remind that FHT or its compatible scheme should be used after fast Fourier transform (FFT) operation at the receiver.

**REFERENCES**

