

Improved DCM for PAPR Reduction in MB-OFDM Systems

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Abstract— The DCM scheme is exploited as the modulation scheme for high-data rate transmission in the MB-OFDM system. However, since the DCM modulated symbols are repeatedly fed into the IFFT block, the MB-OFDM system has a high PAPR problem. In this paper, improved DCM is proposed for PAPR reduction in the MB-OFDM systems. The proposed scheme uses a circular shifting operation of the gray coded 16-QAM constellation to reduce the PAPR. The simulation results show that the proposed scheme has a better PAPR performance than DCM.

Keywords— UWB, MB-OFDM, DCM, PAPR, circular shift

I. INTRODUCTION

Ultra Wide Band (UWB) systems were proposed to standardize wide bandwidth wireless communication systems, particularly for Wireless Personal Area Networks (WPAN). In 2002, the USA Federal Communications Commission (FCC) agreed to allocate 7500 MHz spectrum from 3,100MHz to 10,600MHz for UWB devices and limited the effective isotropic radiated power to -41.3dBm/MHz [1]. The WiMedia Alliance, working with the European Computer Manufacturers Association (ECMA), announced the Multi-Band Orthogonal Frequency Division Multiplexing (MB-OFDM) UWB radio platform which is called the ECMA-368 standard [2].

Dual Carrier Modulation (DCM) are exploited as the modulation schemes for MB-OFDM in the ECMA-368 standard. The DCM scheme transmits two 16-QAM symbols which are allocated to each subcarrier of the MB-OFDM with maximum distance. Therefore, at the receiver, even if one 16-QAM symbol is broken by a deep fading channel, the receiver can detect the transmitted signal by using the other 16-QAM symbol [3].

The High Power Amplifier (HPA) must be operated near the saturation region in order to achieve maximum output power efficiency because the nonlinear characteristic of the HPA is very sensitive to the variations in the signal amplitudes. The best solution is to reduce the Peak to Average Power Ratio (PAPR) before the MB-OFDM signal is transmitted [4]. Therefore, this paper proposes an improved DCM for PAPR reduction in the MB-OFDM systems.

Section II presents the MB-OFDM background and PAPR properties. Section III describes the DCM. Section IV

proposes the improved DCM. Section V presents the PAPR performance of the proposed scheme. Section VI draws the conclusions.

II. MB-OFDM SYSTEMS AND PAPR PROPERTIES

A. MB-OFDM Systems

In the ECMA-368 standard, the spectrum from 3,100MHz to 10,600MHz is divided into 14 sub-bands, each of which has a bandwidth of 528MHz [2]. Table 1 shows the physical layer specification of the MB-OFDM systems. A total of 100 sub-carriers are used per band. Frequency Domain Spreading (FDS), Time-Domain Spreading (TDS), and Forward Error Correction (FEC) coding are used to vary the data rates. The FEC is a convolutional code with coding rates of 1/3, 1/2, 5/8 and 3/4.

TABLE 1. PHYSICAL LAYER SPECIFICATION OF THE MB-OFDM SYSTEMS

Data Rate (Mb/s)	Modulation	Coding Rate (R)	FDS	TDS	Coded Bits / 6 OFDM Symbol	Info Bits / 6 OFDM symbol
53.3	QPSK	1/3	YES	YES	300	100
80	QPSK	1/2	YES	YES	300	150
106.7	QPSK	1/3	NO	YES	600	200
160	QPSK	1/2	NO	YES	600	300
200	QPSK	5/8	NO	YES	600	375
320	DCM	1/2	NO	NO	1200	600
400	DCM	5/8	NO	NO	1200	750
480	DCM	3/4	NO	NO	1200	900

The coded and interleaved binary data sequence is mapped onto the QPSK or DCM complex constellation. The resulting complex symbols are loaded to the data subcarriers of the MB-OFDM by using an Inverse Fast Fourier Transform (IFFT) to create baseband signal. The block diagram for the transmitter architecture that implemented the MB-OFDM system is shown in figure 1.

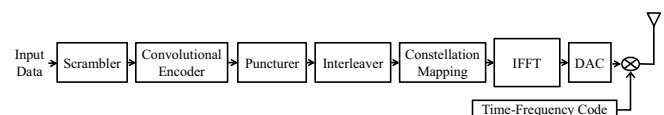


Figure 1. Block diagram of the MB-OFDM transmitter

B. PAPR Properties in the MB-OFDM Systems

The baseband MB-OFDM signal is represented as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi n \Delta f t}, \quad 0 \leq t \leq T \quad (1)$$

where X_n is the data symbol carried by the n_{th} subcarrier, Δf is the frequency difference between each subcarrier, N is the number of subcarriers, and T is the MB-OFDM symbol duration which must be $1/\Delta f$ to satisfy the orthogonal condition of each subcarrier [5]. The PAPR of the transmitted MB-OFDM signal can be defined as

$$\text{PAPR} = 10 \log_{10} \frac{P_{\text{peak}}}{P_{\text{av}}} [\text{dB}] \quad (2)$$

where $P_{\text{peak}} = \max |x(t)|^2$ is the peak power and $P_{\text{av}} = \frac{1}{T} \int_0^T |x(t)|^2 dt$ is the average power of the transmitted MB-OFDM signal.

III. DCM

DCM is used for high data rate transmission in the MB-OFDM system. The coded and interleaved binary data sequence is divided into the groups of 200bits, which are $\mathbf{b} = [b_0, b_1, \dots, b_{198}, b_{199}]$, and are grouped into 50 groups of 4bits. Each group is represented as $[b_{g(k)}, b_{g(k)+1}, b_{g(k)+50}, b_{g(k)+51}]$, where

$$g(k) = \begin{cases} 2k, & k \in [0, 24] \\ 2k + 50, & k \in [25, 49] \end{cases} \quad (3)$$

Each group of 4bits is then mapped onto the gray coded 16-QAM constellation and converted into two complex numbers which are $(d[k], d[k+50])$ depending on the order k . The resulting DCM symbols are allocated into two individual MB-OFDM data sub-carriers with 50 sub-carrier separation to achieve frequency diversity. Each OFDM sub-carriers occupies a bandwidth of about 4MHz for the 528Mhz sub-band. Therefore the bandwidth between the two individual MB-OFDM data sub-carriers related to the $(d[k], d[k+50])$ is at least 200MHz.

IV. IMPROVED DCM

The improved DCM uses the circular shifting operation of the gray coded 16-QAM constellation in the DCM mapping process for PAPR reduction.

The grouped information bits are represented as

$\mathbf{y}(k) = [b_{g(k)}, b_{g(k)+1}, b_{g(k)+50}, b_{g(k)+51}]$. For mapping $\mathbf{y}(k)$ onto the gray coded 16-QAM symbol, the symbol mapping vectors are defined as

$$\begin{aligned} \mathbf{I} &= [3, 1, -1, -3] \\ \mathbf{Q} &= [3, 1, -1, -3] \end{aligned} \quad (4)$$

The elements of the symbol mapping vector $\mathbf{I}$ and $\mathbf{Q}$ are represented as I_l and Q_l where l denotes the row of the vector for $l = 1, \dots, 4$.

$\mathbf{y}(k)$ is then mapped onto the gray coded 16-QAM symbol, which is represented as $d[k] = \alpha_k + j\beta_k$, depending on the order k , as illustrated in (5).

$$\begin{aligned} \alpha_k &= \begin{cases} I_1, & (b_{g(k)}, b_{g(k)+50}) = (0, 0) \\ I_2, & (b_{g(k)}, b_{g(k)+50}) = (0, 1) \\ I_3, & (b_{g(k)}, b_{g(k)+50}) = (1, 1) \\ I_4, & (b_{g(k)}, b_{g(k)+50}) = (1, 0) \end{cases} \\ \beta_k &= \begin{cases} Q_1, & (b_{g(k)+1}, b_{g(k)+51}) = (0, 0) \\ Q_2, & (b_{g(k)+1}, b_{g(k)+51}) = (0, 1) \\ Q_3, & (b_{g(k)+1}, b_{g(k)+51}) = (1, 1) \\ Q_4, & (b_{g(k)+1}, b_{g(k)+51}) = (1, 0) \end{cases} \end{aligned} \quad (5)$$

The resulting symbol for $d[k]$ is formed into the gray coded 16-QAM constellation as depicted in figure 2.

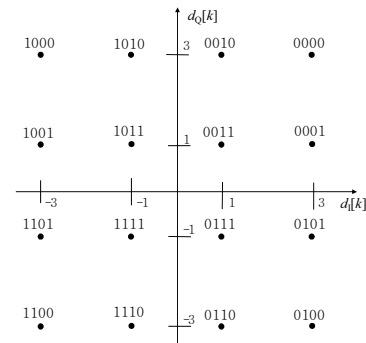


Figure 2. Gray coded 16-QAM constellation for $d[k]$

To apply the circular shifting operation to the gray coded 16-QAM constellation, let u and v be the shifting factors that shift the symbols of the gray coded 16-QAM constellation as much as u and v steps on the In-Phase and Quadrature axes respectively. Therefore, $d_{uv}[k+50] = \alpha_{k+50} + j\beta_{k+50}$ denotes the shifted 16-QAM

symbol separated 50 tones from $d[k]$. In addition, the shifting factors can be varied from 0 to 3, since the circular shifting is applied to the 16-QAM constellation. The shifted symbol mapping vectors for $d_{uv}[k+50]$ are defined as

$$\begin{aligned} \mathbf{I}_u &= S_u(\mathbf{I}) \\ \mathbf{Q}_v &= S_v(\mathbf{Q}) \end{aligned} \quad (6)$$

where the operation $S_i(\cdot)$ for $i=u, v$ is a clockwise circular shifting operation that shifts the vectors $\mathbf{I}$ and $\mathbf{Q}$ as much as i -step. The elements of the shifted symbol mapping vectors $\mathbf{I}_u$ and $\mathbf{Q}_v$ are represented as $I_{u,l}$ and $Q_{v,l}$, respectively.

Then, $y(k)$ is mapped onto the gray coded 16-QAM symbol $d_{uv}[k+50] = \alpha_{k+50} + j\beta_{k+50}$, which is shifted by u and v as illustrated in (7).

$$\begin{aligned} \alpha_{k+50} &= \begin{cases} I_{u,1}, & (b_{g(k)}, b_{g(k)+50}) = (0, 0) \\ I_{u,2}, & (b_{g(k)}, b_{g(k)+50}) = (0, 1) \\ I_{u,3}, & (b_{g(k)}, b_{g(k)+50}) = (1, 1) \\ I_{u,4}, & (b_{g(k)}, b_{g(k)+50}) = (1, 0) \end{cases} \\ \beta_{k+50} &= \begin{cases} Q_{v,1}, & (b_{g(k)+1}, b_{g(k)+51}) = (0, 0) \\ Q_{v,2}, & (b_{g(k)+1}, b_{g(k)+51}) = (0, 1) \\ Q_{v,3}, & (b_{g(k)+1}, b_{g(k)+51}) = (1, 1) \\ Q_{v,4}, & (b_{g(k)+1}, b_{g(k)+51}) = (1, 0) \end{cases} \end{aligned} \quad (7)$$

In order to illustrate the circular shifting operation of the gray coded 16-QAM constellation, one example is given in figure 3, where the shifting factors are $u = 3$ and $v = 3$.

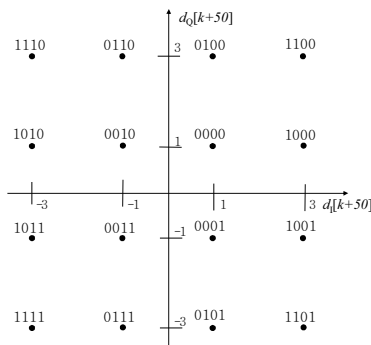


Figure 3. Gray coded 16-QAM constellation for $d_{33}[k+50]$

Finally, the two resulting 16-QAM symbols $(d[k], d_{uv}[k+50])$ are allocated into data subcarriers with 50 subcarriers separation to achieve frequency diversity.

Figure 4 depicts the block diagram of the improved DCM. The proposed scheme needs sub-blocks for all combination of allowed shifting factors. Among the sub-blocks, the one with the lowest PAPR is selected for transmission. Information about the shifting factors of the selected signal should be transmitted to the receiver as side information.

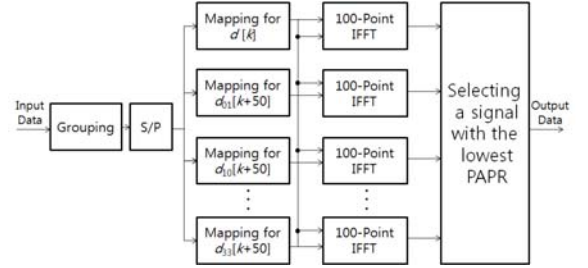


Figure 4. Block diagram of the improved DCM

V. SIMULATION RESULTS

In this section, the PAPR performance enhancement of the improved DCM is demonstrated in terms of the Complementary Cumulative Distribution Function (CCDF). The CCDF denotes the probability that the PAPR of a data block exceeds a given threshold which is PAPR_0 , and can be calculated as

$$\Pr(\text{PAPR} > \text{PAPR}_0) = 1 - (1 - e^{-\text{PAPR}_0})^N. \quad (8)$$

Figure 5 shows the PAPR performance of the DCM and the improved DCM.

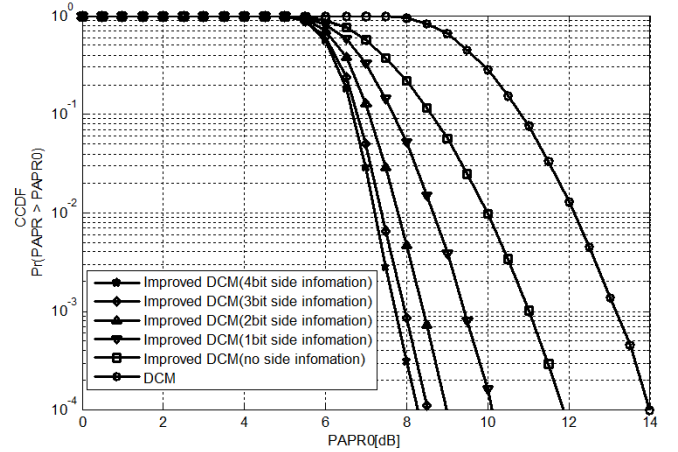


Figure 5. Comparison of PAPR performance for the DCM and the improved DCM ($N=100$)

As shown in figure 5, at $\text{CCDF} = 10^{-4}$, the improved DCM has 2dB better PAPR performance than DCM without side information and 4dB, 5dB, 5.5dB, 5.7dB better with 1, 2, 3, 4 side information bits respectively. For more than 4 side information bits, the PAPR performance of the improved DCM is almost the same.

VI. CONCLUSIONS

This paper has proposed the improved DCM for PAPR reduction in the MB-OFDM systems. The improved DCM uses the circular shifting operation of the gray coded 16-QAM constellation to reduce the PAPR. Simulation result shows that the proposed scheme has a better PAPR performance than DCM scheme.

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