A New Subblock Partitioning Scheme Using Subblock Partition Matrix for PTS

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***Abstract*—In this paper, we propose a new subblock partitioning scheme using the subblock partition matrix for the partial transmit sequence. Based on the convolution property of the inverse fast Fourier transform (IFFT), the subblock partition matrix can be derived. The signal subsequences for the PTS scheme are generated from the circular convolution of the signal sequence and the subblock partition matrix. Since several IFFT operations of the signal subsequences are replaced by the convolution of the signal sequence with the proposed subblock partition matrix, only one IFFT operation is required. The interleaved subblock partitioning scheme is suitable for the proposed subblock partition matrix in terms of complexity.**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is an attractive technique for high speed data transmission in the multipath fading channel. It has already been adopted in several wireless communication systems such as the wireless local area network (WLAN, IEEE 802.11). However, an OFDM signal of the transmitter occasionally shows the high peak-to-average power ratio (PAPR) in the time domain. An OFDM signal with high PAPR may suffer from significant intermodulation and out-of-band radiation due to the distortion of the signal through the nonlinear high power amplifier (HPA).

An input symbol sequence $\mathbf{X} = [X_0\ X_1 \cdots X_{N-1}]$ is given as a vector of complex-valued symbols modulated by M-PSK or by M-QAM. The discrete time OFDM signal sequence $\mathbf{x} = [x_0\ x_1 \cdots x_{N-1}]$ after inverse fast Fourier transform (IFFT) can be represented as

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j\frac{2\pi nk}{N}}, \qquad 0 \le n \le N-1 \tag{1}$$

where X_k is an input data symbol loaded on the kth subcarrier and N is the number of the subcarriers. The PAPR of the OFDM signal sequence $\mathbf{x}$ is defined as

$$\text{PAPR}(\mathbf{x}) = \frac{\max\limits_{0\le n\le N-1} |x_n|^2}{E[|x_n|^2]} \tag{2}$$

where $E[\cdot]$ denotes the expectation.

Many PAPR reduction schemes have been proposed for OFDM systems. Partial transmit sequence (PTS), one of symbol scrambling methods, can reduce the PAPR of OFDM signals with no signal distortion [1]. An input symbol sequence $\mathbf{X}$ in the PTS scheme is partitioned into V disjoint symbol subsequences $\mathbf{X}_v = [X_{v,0}\ X_{v,1} \cdots X_{v,N-1}]$, $v = 0, 1, \cdots, V-1$, which are called a subblock. Each data symbol on the subcarrier should belong to only one subsequence $\mathbf{X}_v$. Except for subcarriers to allocate the data in the vth subblock, $X_{v,k} = 0$, $0 \le k \le N-1$. Each signal subsequence $\mathbf{x}_v$, the IFFTed version of $\mathbf{X}_v$, is then multiplied by an rotating factor b_v^u chosen from a given alphabet $\mathbb{B}$, which is usually $\{\pm 1\}$ or $\{\pm 1, \pm j\}$. Then, they are summed to result in the uth alternative signal sequence $\mathbf{x}^u$ given by

$$\mathbf{x}^u = \sum_{v=1}^{V} b_v^u \mathbf{x}_v \tag{3}$$

where $1 \le u \le U$ and U is the number of alternative signal sequences. The PAPR of each alternative signal sequence is computed and then the signal sequence with the minimum PAPR is transmitted.

In this paper, we propose a new subblock partitioning scheme using the subblock partition matrix for the PTS. Based on the convolution property of the IFFT, the subblock partition matrix is derived. The signal subsequences are obtained by the circular convolution of the signal sequence and the subblock partition matrix. As IFFT operations to generate V signal subsequences are replaced by the computation of the proposed subblock partition matrix, only one IFFT operation is performed without the need of additional IFFT. The interleaved subblock partitioning scheme is suitable for the use of the subblock partition matrix because the elements of the subblock partition matrix are almost zero.

II. A New Subblock Partitioning Scheme

In this section, we propose a new subblock partitioning scheme using the subblock partition matrix for the PTS scheme. While V IFFT operations to generate V signal subsequences in the PTS scheme are inevitable, the proposed method requires only one IFFT operation for $\mathbf{x}$ and uses the subblock partition matrix $\mathbf{T}_v$ in the time domain in order to obtain V signal subsequences. Let $\mathbf{P}_v = [P_{v,0}\ P_{v,1} \cdots P_{v,N-1}]$ be a subblock partition vector, where $P_n \in \{0, 1\}$, $0 \le n \le N-1$. Then, the vth subblock $\mathbf{X}_v$ in the frequency domain can be written as

$$\begin{aligned}\mathbf{X}_v &= [P_{v,0}X_0\ P_{v,1}X_1\ \cdots\ P_{v,N-1}X_{N-1}] \\ &= \mathbf{R}_v\mathbf{X}\end{aligned} \tag{4}$$

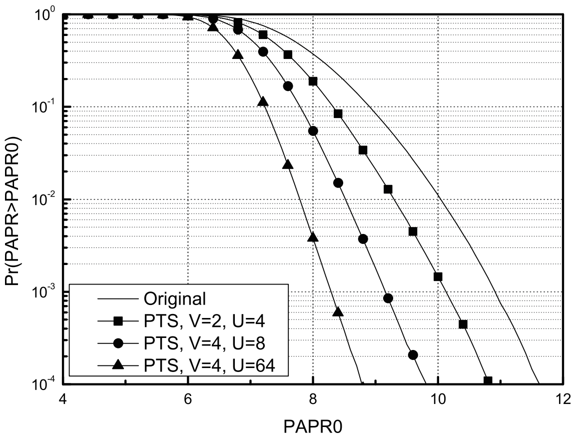

Fig. 1. PAPR reduction performance of the PTS scheme using the interleaved subblock partition matrix for 16QAM and $N = 256$.

where $\mathbf{R}_v$ is the matrix form corresponding to the subblock partition vector.

Similar to the conversion matrix for the selected mapping (SLM) scheme in [2], the proposed scheme uses a signal sequence $\mathbf{x}$ after IFFT to generate $\mathbf{x}_v$, $0 \le v \le V-1$. From (4), the signal subsequence $\mathbf{x}_v$ is given as

$$\begin{aligned}\mathbf{x}_v &= \mathrm{IFFT}\{\mathbf{X}_v\} \\ &= \mathbf{Q}\mathbf{R}_v\mathbf{X} \\ &= \mathbf{Q}\mathbf{R}_v\mathbf{Q}^{-1}\mathbf{x}\end{aligned} \tag{5}$$

where $\mathbf{Q}$ is the IFFT matrix and $\mathbf{X} = \mathbf{Q}^{-1}\mathbf{x}$. Therefore, the subblock partition matrix can be defined as $\mathbf{T}_v = \mathbf{Q}\mathbf{R}_v\mathbf{Q}^{-1}$.

Based on the convolution property of the IFFT, the subblock partition matrix $\mathbf{T}_v$ can be expressed by the subblock partition vector $\mathbf{P}_v$. It means that the signal subsequence $\mathbf{x}_v$ can be acquired by a circular convolution of the signal sequence $\mathbf{x}$ and the IFFT output of the subblock partition vector $\mathbf{P}_v$. Let $\mathbf{t}_v = [t_{v,0}\ t_{v,1} \cdots t_{v,N-1}]^T = \mathrm{IFFT}\{\mathbf{P}_v\}$, where $(\cdot)^T$ is the transpose of a vector. The subblock partition matrix $\mathbf{T}_v$ can be rewritten as

$$\mathbf{T}_v = [\mathbf{t}_v\ \mathbf{t}_v^{<1>}\ \mathbf{t}_v^{<2>} \cdots \mathbf{t}_v^{<N-1>}] \tag{6}$$

where $\mathbf{t}_v^{<\tau>}$ is a circularly down-shifted version of $\mathbf{t}_v$ by τ elements.

In general, adjacent, interleaved, and random subblock partitioning schemes as the subblock partitioning method for the PTS scheme exist [1]. And they can be expressed as the subblock partition matrix $\mathbf{T}_v$. However, adjacent and random partitioning schemes are not implementable by $\mathbf{T}_v$ because the complexity of the circular convolution between $\mathbf{t}_v$ and $\mathbf{x}$ is larger than that of IFFT. On the other hand, the interleaved subblock partitioning scheme is suitable for the use of $\mathbf{T}_v$. Almost all of the elements in $\mathbf{t}_v$ of the interleaved subblock partitioning scheme are zero except for V nonzero elements of which each belongs to the set $\{e^{j\frac{2\pi}{V}\cdot 0}, e^{j\frac{2\pi}{V}\cdot 1}, \cdots, e^{j\frac{2\pi}{V}\cdot (V-1)}\}$. The element of the subblock partition vector $\mathbf{P}_v$ for the interleaved subblock partition is defined by

$$P_{v,k} = \begin{cases} 1, & k = Vq + v \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

TABLE I

COMPUTATIONAL COMPLEXITY COMPARISON OF THE RANDOM AND THE PROPOSED SUBBLOCK PARTITIONING SCHEMES TO GENERATE V SIGNAL SUBSEQUENCES WITH $V = 2, 4$.

	Total number of complex additions	Total number of complex multiplications
Random subblock partitioning scheme	$VN \log_2 N$	$\frac{VN}{2} \log_2 N$
Proposed subblock partitioning scheme	$N \log_2 N + V(V-1)N$	$\frac{N}{2} \log_2 N$

where $0 \le q \le N/V - 1$, $0 \le k \le N-1$, and $0 \le v \le V-1$. From (9), the elements of $\mathbf{t}_v$ for the interleaved subblock partitioning scheme can be expressed by

$$t_{v,n} = \begin{cases} e^{j\frac{2\pi v}{V}l}, & n = \frac{N}{V}l \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

where $0 \le l, v \le V-1$ and $0 \le n \le N-1$. When $V = 2, 4$, it is easy to check that the V nonzero elements of $\mathbf{t}_v$ belong to the set $\{\pm 1\}$ and $\{\pm 1, \pm j\}$, respectively. In this case, if the subblock partition matrix $\mathbf{T}_v$ is used to generate V signal subsequences without additional IFFT operations, $(V-1)N$ complex additions from the computation of $\mathbf{T}_v$ and $\mathbf{x}$ are only required in order to obtain one signal subsequence.

Fig. 1 shows the PAPR performance of the PTS scheme using the interleaved subblock partition matrix for 16QAM with $N = 256$, and $V = 2, 4$. Table I compares the computational complexity of the random subblock partitioning scheme and the proposed scheme using the subblock partition matrix with $V = 2, 4$. It is known that a N-point IFFT operation requires $N/2\log_2 N$ complex multiplications and $N\log_2 N$ complex additions. For $V > 4$, it is investigated that additional complex multiplications are required. Hence, further works will focus on the reduction of the computational complexity to obtain $\mathbf{x}_v$.

III. CONCLUSION

In this paper, we proposed a new subblock partitioning scheme using the subblock partition matrix for the PTS scheme. Based on the convolution property of the IFFT, the subblock partition vector for the interleaved subblock partition consists of $N - V$ zero elements and V nonzero elements. The complexity of the proposed subblock partitioning scheme is lower than that of the adjacent and the random subblock partitioning scheme. Especially, additional $(V-1)N$ complex additions to generate a signal subsequence are required for the PTS scheme with $V = 2,\ 4$.

ACKNOWLEDGMENT

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. 2011-0000328).

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