PAPR Reduction Method Based on Significant-Bit Scrambling for MIMO Vector-Coding Systems

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1. Introduction

In high speed wireless transmission, inter-symbol interference (ISI) caused in a frequency-selective channel severely degrades bit error rate (BER) performance. As a method to overcome frequency selectivity in wireless channel, vector coding (VC) transmission has been studied [1]. The VC is a kind of code-division multiplexing (CDM) where eigenvectors of channel autocorrelation matrix are used as spreading code, i.e., the basic principle of VC is the same as the eigen-beam transmission in Multi-Input Multi-Output (MIMO) systems. The VC can be extended to MIMO transmission called MIMO-VC that achieves orthogonal parallel transmission over eigen-paths in frequency-selective MIMO channels, provided that channel state information (CSI) is known to both transmitter and receiver. Each eigen path has different channel gain and thus the VC needs to adopt an adaptive modulation to enhance transmission performance. A major drawback of the VC is that the transmit signal exhibits high peak-to-average power ratio (PAPR) which causes nonlinear distortion and/or power efficiency degradation at power amplifier, similarly to OFDM and CDM systems. Therefore, it is required to reduce PAPR of the transmit signal in VC systems.

As a solution to the PAPR problem, several techniques have been proposed such as clipping and filtering (C&F) and selected mapping (SLM) [2]. The C&F is a simple technique. However, it causes nonlinear distortion which destroys the orthogonal property of eigen channel in VC transmission and consequently degrades transmission performance. The SLM is a distortion-less PAPR reduction method which reduces the probability of high peak power occurrence by controlling the constellation data mapping of modulated symbols so as to minimize PAPR of the transmit signal. However, on the receiver side, it is needed to restore the original constellation data mapping to obtain information data. As a method to solve this problem, an SLM method with a self-synchronized scrambler (SLM-SS) has been proposed [2]. In SLM-SS, the transmit data sequence is randomized by a self-synchronized scrambler with a given generation polynomial using an initial bit pattern which is adaptively selected to minimize the PAPR. On the receiver side, original information data sequence is obtained by descrambling the received data, where a de-scrambler employs the same generation polynomial as the scrambler. However, when transmission errors occur, the above-mentioned descrambling calculation causes error propagation which degrades BER performance.

In this paper, we propose an SLM-SS method with the significant-bit scrambling for adaptive modulated MIMO-VC transmission systems, where only most significant bits of I- and Q-phase of each modulated symbol are scrambled to reduce PAPR and thus BER degradation caused by error propagation is effectively mitigated, while achieving almost the same PAPR reduction performance as conventional SLM-SS method.

2. MIMO vector coding transmission with adaptive modulation

Figure 1 shows the block diagram of VC system with an adaptive modulation (adaptive bit loading) for Single-Input Single-Output (SISO) frequency-selective channel, where **H** is K×N frequency-selective channel matrix defined as

$$\mathbf{H}=\begin{bmatrix} h(0) & 0 & 0 & \cdots & 0 \\ h(1) & h(0) & 0 & \cdots & 0 \\ \vdots & h(1) & h(0) & \ddots & \vdots \\ h(L-1) & \vdots & h(1) & \ddots & 0 \\ 0 & h(L-1) & \vdots & \ddots & h(0) \\ 0 & 0 & h(L-1) & \cdots & h(1) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & h(L-1) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (1)$$

L denotes the channel impulse response length. In VC, zero-padding guard interval (ZP-GI) is inserted into every transmission blocks to avoid inter-block interference, where ZP-GI length is N_g and thus the length of the transmit signal vector is denoted as $K=N+N_g$. At the receiver, ZP-GI is removed. In Fig.1, $\mathbf{s}=(s_1, ..., s_N)^T$ and $\mathbf{r}=(r_1, ..., r_K)^T=\mathbf{Hs}$ denote the transmit signal vector and the received vector, respectively. The eigen-vectors of channel autocorrelation matrix $\mathbf{H}^H\mathbf{H}$ are obtained by singular value decomposition of **H** or eigen value decomposition of $\mathbf{H}^H\mathbf{H}$, i.e.,

$$\mathbf{H}^H\mathbf{H}=\mathbf{V}\mathbf{\Lambda}\mathbf{V}^H, \qquad \mathbf{V}^H\mathbf{V}=\mathbf{I}_{NN} \quad (2)$$

where $\mathbf{V}$ is N×N unitary matrix whose i-th column vector corresponds to the i-th eigen vector. $\mathbf{I}_{NN}$ is N×N identity matrix. As in Fig.1, the de-multiplexed signal at the receiver is expressed as

$$\mathbf{y} = \mathbf{V}^H\mathbf{H}^H\mathbf{r} = \mathbf{\Lambda x} + \mathbf{V}^H\mathbf{H}^H\mathbf{n} \qquad \mathbf{\Lambda} = diag(\lambda_1, \lambda_2, \cdots, \lambda_N) \quad \lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_N \tag{3}$$

where $\mathbf{\Lambda}$ is diagonal matrix whose diagonal elements λ_i denotes the i-th eigen value. $\mathbf{n}$ is K dimensional noise column-vector. Equation (3) means that the VC achieves the orthogonal transmission in frequency-selective channel. The eigen-value corresponds to gain for each eigen-channel and thus the transmission performance is improved by using an adaptive bit loading algorithm where the best modulation scheme for each eigen channel is selected according to channel signal-to-noise power ratio (SNR).

The VC can be extended to MIMO system where multiple antenna elements are used at both transmitter and receiver. Figure 2 shows 2×2 MIMO channel, where the received signal vector and 2×2 MIMO channel matrix are given as $\begin{bmatrix}\mathbf{r}_1\\ \mathbf{r}_2\end{bmatrix} = \begin{bmatrix}\mathbf{H}_{11} & \mathbf{H}_{21}\\ \mathbf{H}_{12} & \mathbf{H}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{s}_1\\ \mathbf{s}_2\end{bmatrix} + \begin{bmatrix}\mathbf{n}_1\\ \mathbf{n}_2\end{bmatrix} = \mathbf{H}_m\mathbf{s} + \mathbf{n}_m$ and $\mathbf{H}_m \equiv \begin{bmatrix}\mathbf{H}_{11} & \mathbf{H}_{21}\\ \mathbf{H}_{12} & \mathbf{H}_{22}\end{bmatrix}$. $\mathbf{H}_{ij}$ is channel matrix of the path between i-th transmit antenna and j-th receive antenna. Similarly to SISO channel, eigen vectors of the autocorrelation channel matrix $\mathbf{H}_m^H\mathbf{H}_m$ is obtained by singular value decomposition of $\mathbf{H}_m$.

$$\mathbf{y} = \begin{bmatrix}\mathbf{y}_1\\ \mathbf{y}_2\end{bmatrix} = \mathbf{\Lambda}\begin{bmatrix}\mathbf{x}_1\\ \mathbf{x}_2\end{bmatrix} + \mathbf{V}^H\mathbf{H}_m^H\begin{bmatrix}\mathbf{n}_1\\ \mathbf{n}_2\end{bmatrix} = \mathbf{\Lambda x} + \mathbf{V}^H\mathbf{H}_m^H\mathbf{n} \tag{4}$$

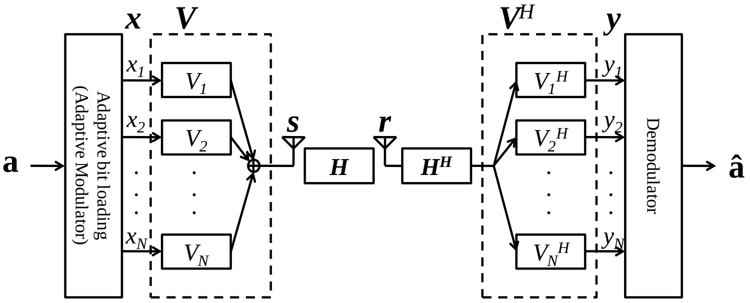


Figure 1: Vector coding system with adaptive bit loading.

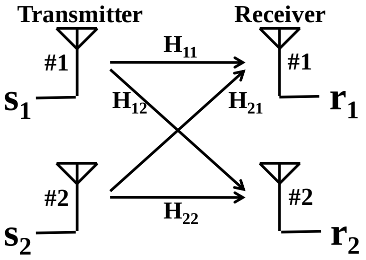


Figure 2: 2×2 MIMO channel.

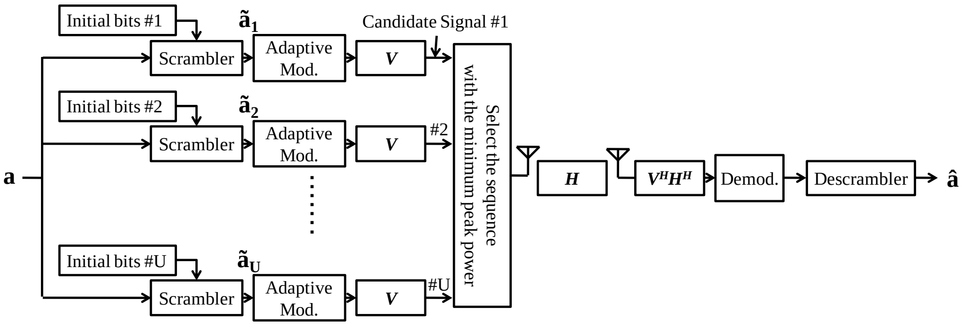


Figure 3: VC system with the conventional SLM-SS method.

3. Conventional SLM-SS method

Figure 3 shows block diagram of VC transmission with the conventional SLM-SS, where PAPR of the transmit signal is reduced by selecting the best candidate signal which exhibits the minimum PAPR from U candidate signals. In the SLM-SS, U candidate signals are generated by utilizing the property of self-synchronized scrambler, i.e., when different initial bit pattern is added to head of information data sequence as redundant bits, the scrambler generates different output sequence from case using other initial bit patterns, because the scrambler has feedback-type structure. In Fig.3, the information data sequence is randomized by a scrambler with the same polynomial and different initial bit pattern, and then we can obtain U different parallel output sequences, called candidate sequence. When the number of initial bits is denoted as J, the number of candidate sequences is given as $U=2^J$. The number of the transmitted data bits is N_b+J, where N_b is the number of information bits and J corresponds to the redundant side information. U different VC candidate signals are generated by using these candidate sequences as in Fig.3. The transmitter selects the VC signal with the minimum PAPR among U candidates. On the receiver side, after each data symbols are de-multiplexed and demodulated, the information data bits are obtained by descrambling the received data sequence, where descrambler uses the same polynomial as the scrambler. The problem in the conventional SLM-SS is that the descrambling calculation causes error propagation which degrades BER performance.

4. Proposed PAPR reduction method based on significant-bit scrambling

Figure 4 shows the VC system with the proposed SLM-SS method, where most significant bits of I- and Q- phase component of each adaptive modulated symbol are descrambled to generate the candidate sequences. As described in the previous section, the descramble calculation propagates the transmission error. To solve this problem, the proposed method scrambles only most significant (MS) bits of I- and Q-phase of modulated symbols to reduce PAPR on the transmitter side, where most significant bits for I-phases of 16QAM and 64QAM Gray coded constellation are depicted as red color in Figs.5(a) and (b), respectively. The same bit mapping is used for Q-phase component similarly to Fig.5. Using the proposed method, error propagation is mitigated on the receiver side, because only MS-bits are descrambled to obtain the original information data and there is no need to descramble the other bits. In addition, bit error probability for MS-bits is lower than those of other bits and thus the probability of error propagation occurrence can be decreased by the proposed method. Furthermore, it is expected that the proposed method can achieve PAPR reduction performance comparable to the conventional SLM-SS by selecting the minimum PAPR signal from the candidates. The VC transmission needs to employ an adaptive modulation in order to achieve sufficient performance improvement and thus the proposed method is effective in reducing PAPR of transmit signal in VC system with adaptive modulation. In this study, we employ an adaptive bit loading algorithm based on BER minimization criterion which selects the bit loading pattern minimizing BER under the constraint of the same data rate. Once the bit loading pattern is determined, the theoretical expression of BER performance in the proposed SLM-SS VC transmission is given as

$$BER=\frac{\sum_{i=0}^{N-1}p_{f(i)}(\lambda_i)f(i)}{\sum_{i=0}^{N-1}f(i)},\ \text{where}\ \begin{cases} p_2(\lambda)\approx\frac{M}{2}erfc\left(\sqrt{\frac{E_b}{N_0}\lambda}\right) & (\text{for } QPSK)\\ p_4(\lambda)\approx\frac{1}{2}\left[M\left[\frac{1}{2}erfc\left(\sqrt{\frac{4}{10}\frac{E_b}{N_0}\lambda}\right)-\frac{3}{32}\left\{erfc\left(\sqrt{\frac{4}{10}\frac{E_b}{N_0}\lambda}\right)\right\}^2\right]+\left[\frac{1}{4}erfc\left(\sqrt{\frac{4}{10}\frac{E_b}{N_0}\lambda}\right)-\frac{3}{64}\left\{erfc\left(\sqrt{\frac{4}{10}\frac{E_b}{N_0}\lambda}\right)\right\}^2\right]\right] & (\text{for} 16QAM)\\ p_6(\lambda)\approx\frac{1}{3}\left[M\left\{\frac{7}{48}erfc\left(\sqrt{\frac{1}{7}\frac{E_b}{N_0}\lambda}\right)\right\}+\frac{7}{24}erfc\left(\sqrt{\frac{1}{7}\frac{E_b}{N_0}\lambda}\right)+\frac{21}{48}erfc\left(\sqrt{\frac{1}{7}\frac{E_b}{N_0}\lambda}\right)\right] & (\text{for} 64QAM)\end{cases}$$

where M denotes the number of taps in the scrambler (if generation polynomial is Z^4+Z+1, M=3). *erfc(x)* is the complementary error function defined as $erfc(x)\equiv\frac{2}{\sqrt{\pi}}\int_x^{\infty}\exp(-u^2)du$. *f(i)* is an adaptive bit loading function that selects either 2, 4, or 6 bit which corresponds to QPSK, 16QAM, or 64QAM as the best modulation scheme for the i-th eigen-channel. It is noteworthy that the proposed method can be applied to MIMO-VC transmission with another adaptive bit loading algorithm based on the throughput maximization criterion.

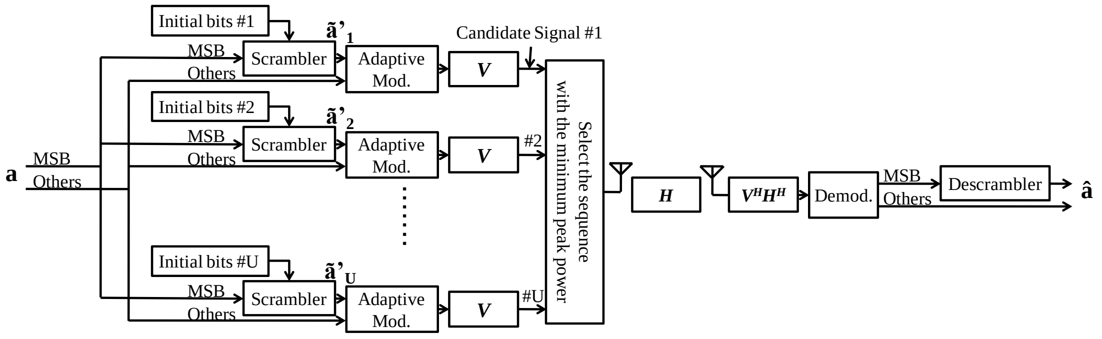
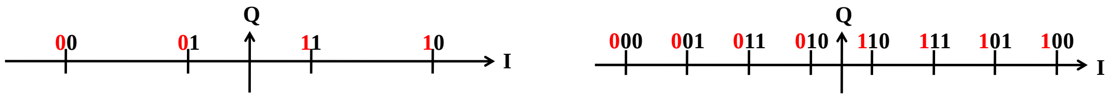


Figure 4: System configuration of the proposed SLM-SS method.



(a) 16QAM

(b) 64QAM

Figure 5. I-phase constellations of 16QAM and 64QAM symbols.

5. Performance evaluations and discussions

We evaluate the performance of a MIMO-VC system with the proposed PAPR reduction by computer simulations. The simulation parameters are summarized in Table 1. Block diagram of the VC with the proposed SLM-SS is the same as in Fig.4. We assume 2 by 2 MIMO frequency-selective channel and no correlation between the received signals at each antenna element. The received signal is affected by attenuated 6-path quasi-static Rayleigh fading and

AWGN, where normalized delay spread is $\tau/T=0.6$. The generation polynomial for the scrambler is Z^4+Z+1 whose number of taps is $M=3$. For simplicity, we assume that channel information is ideally estimated at the receiver and correctly fed back to the transmitter.

To clarify the effect of PAPR reduction in the proposed system, we define CCDF as a complementary function of cumulative distribution function (CDF). Figures 6 (a) and (b) show CCDF of the instantaneous power of the transmit signal in SISO-VC and 2×2MIMO-VC systems, respectively. From these figures, it can be seen that the proposed method achieves almost the same PAPR reduction performance as that of the conventional SLM-SS method. In the proposed method, the instantaneous power at $\mathrm{CCDF}=10^{-6}$ in SISO- and 2×2MIMO-VC systems are reduced by about 4.1dB and 3.7dB, respectively, as compared to case without PAPR reduction.

Figures 7 (a) and (b) show BER performance of the VC transmission in SISO and 2×2MIMO channels, respectively. From these figures, we can see that the proposed method achieves better BER performance than the conventional method in both SISO and MIMO adaptive modulated VC systems. This is because lower bits of I- and Q-phase component of each QAM symbol is never affected by descrambling. In addition, error probability of most-significant bits of I- and Q- phase is lower than other bits and thus the probability of error propagation occurrence is also decreased.

6. Conclusion

We proposed an SLM-SS method with significant-bit scrambling for I- and Q- phase of modulated symbols in MIMO adaptive modulated VC systems. Using computer simulations, we clarified that the proposed method achieves better BER performance than the conventional one, while almost the same PAPR reduction performance is obtained.

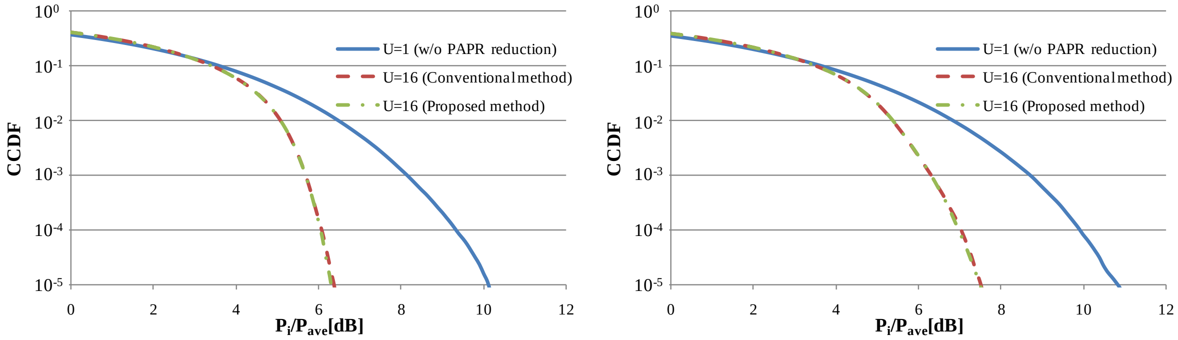
References

[1] S. Kasturia, et al, “Vector coding for partial response channels,” IEEE Trans. Inf. Theory, July 1990.

[2] M. Breiling, et al, “SLM Peak-Power Reduction without explicit side information,” IEEE Commun. Letters, vol.5. no.6, pp.239-241, June 2001.

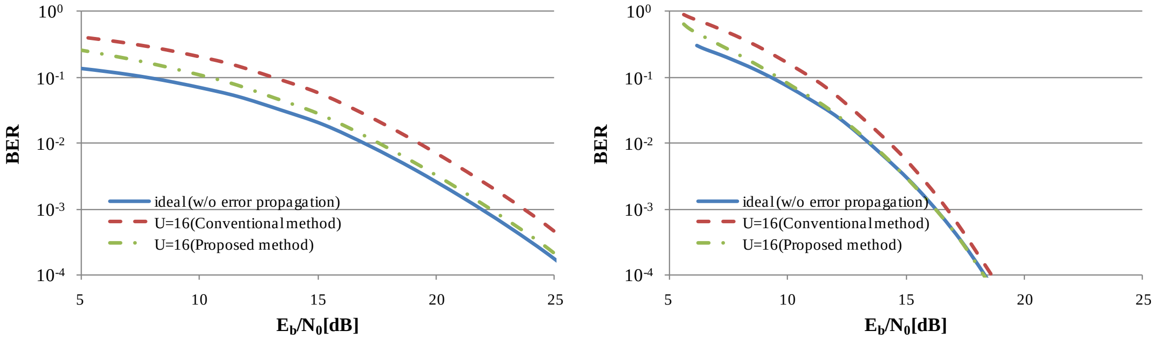
Table 1: Simulation Parameters

	SISO	2×2 MIMO
Data modulation	QPSK,16QAM,64QAM	
Number of data bits per VC block	64	32×2
Number of multiplexing vectors	N=32	
Number of SLM-SS candidate sequences	U=1,16	



(a) SISO (b) 2×2 MIMO

Figure 6: CCDFs of instantaneous power in VC system with the proposed PAPR reduction.



(a) SISO channel (b) 2×2 MIMO channel

Figure 7: BER performance of VC system with the proposed PAPR reduction.