SIDE INFORMATION POWER ALLOCATION FOR MIMO-OFDM PAPR REDUCTION BY SELECTED MAPPING

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ABSTRACT

Multiple-Input-Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) has been receiving a great deal of attention as a solution for high-quality service for next generation wireless communications. However one of main problems of Orthogonal Frequency Division Multiplexing (OFDM) is its high Peak-to-Average Power Ratio (PAPR) which seriously limits power efficiency of High Power Amplifier (HPA). In this paper, we present PAPR reduction technique of V-BLAST based MIMO-OFDM system. We use the Selected Mapping (SLM) technique as a PAPR reduction technique since it does not cause any signal distortion. As a special protection for Side Information (SI) of SLM technique, we propose SI power allocation technique. Simulation results show that proposed technique gives significantly better BER performance than ordinary SLM technique for MIMO-OFDM systems.

Index Terms— Orthogonal Frequency Division Multiplexing (OFDM), Multiple-Input-Multiple-Output (MIMO), Peak-to-Average Power Ratio (PAPR)

1. INTRODUCTION

The explosive growth of mobile wireless communications is producing the demand for high-speed, efficient, and reliable communication over the hostile wireless medium. In this context, Multiple-Input-Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) has been receiving a great deal of attention as a solution for high-quality service over such a medium. Orthogonal Frequency Division Multiplexing (OFDM) has several desirable attributes, such as high immunity to inter-symbol interference, robustness with respect to multi-path fading, and ability for high data rates, all of which are making OFDM to be incorporated in wireless standards like IEEE 802.11a/g/n WLAN and ETSI terrestrial broadcasting. On the other hand, the Multiple-Input-Multiple-Output (MIMO) configuration promises to increase capacity and performance with acceptable BER proportionally with the number of antennas [1] [2]. OFDM can be combined with the MIMO architecture to increase diversity gain and to enhance the system capacity on the wireless channel.

However, one of the major problems posed by OFDM is its high Peak-to-Average-Power Ratio (PAPR), which seriously limits the power efficiency of the transmitter's High Power Amplifier (HPA). This is because PAPR forces the HPA to operate beyond its linear range with a consequent nonlinear distortion in the transmitted signal. This distortion is viewed as a major impediment to progress by the RF system design community.

In this paper, we study PAPR reduction techniques for V-BLAST (Vertical-Bell Labs Layered Space Time) based Multiple Input Multiple Output-OFDM system. Among various PAPR reduction techniques, we choose the Selected Mapping (SLM) technique. SLM technique has been receiving great attention since it does not give rise to any signal distortion. One important issue of SLM technique is transmission of the Side Information (SI). The wrong detection of SI causes burst error. For this reason, SI should be carefully protected. Protecting SI by turbo code [3] or using diversity technique [4] has been proposed by other researchers. These techniques need redundancy and/or computational complexity. We propose SI power allocation technique for MIMO-OFDM system. In our approach, we allocate more power to SI to protect SI from the hostile wireless channel with slight power loss of other subcarriers. This technique is quite simple and does not need any redundancy. Simulation results show that the proposed technique shows a performance close to the case of Perfect Side Information at the Receiver (PSIR). In what follows, in section 2, we briefly explain about OFDM and PAPR. In section 3, we describe concurrent SLM PAPR reduction technique for MIMO-OFDM and propose Side Information (SI) power allocation technique to protect SI. We present simulation results and discussion in section 4 and our concluding remarks in section 5.

2. OFDM AND PEAK-TO-AVERAGE POWER RATIO

An OFDM signal of N subcarriers can be represented as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{j2\pi f_k t},\ 0 \le t \le T_s \tag{1}$$

where T_s is the duration of the OFDM signal and $f_k = \frac{k}{T_s}$. The high PAPR of the OFDM signal arises from the summation in the above IDFT expression. The PAPR of the OFDM signal in the analog domain can be represented as

$$PAPR_c = \frac{\max_{0 \le t \le T_s} |x(t)|^2}{E(|x(t)|^2)} \tag{2}$$

Nonlinear distortion in HPA occurs in the analog domain, but most of the signal processing for PAPR reduction is performed in the digital domain. The PAPR of digital domain is not necessarily the same as the PAPR in the analog domain. However, in some literature [5] [6] [7], it is shown that one can closely approximate the PAPR in the analog domain by oversampling the signal in the digital domain. Usually, an oversampling factor $L = 4$ is sufficient to satisfactorily approximate the PAPR in the analog domain. For these reasons, we express PAPR of the OFDM signal as follows.

$$PAPR = \frac{\max_{0 \le n \le LN} |x(n)|^2}{E(|x(n)|^2)} \tag{3}$$

3. CONCURRENT SLM AND SI POWER ALLOCATION TECHNIQUE IN MIMO-OFDM SYSTEMS

In this section, we briefly review concurrent SLM PAPR reduction technique and analyze the performance and propose a SI power allocation technique for providing special protection to the SI associated with the SLM technique.

3.1. Concurrent SLM

The concurrent SLM PAPR reduction technique was first proposed in [4]. Before discussing concurrent SLM, we briefly explain the SLM algorithm.

Let us assume $\mathbf{X} = \{X_1, X_2, \ldots, X_{LN}\}$ is a QPSK/MQAM modulated baseband signal block, where N is the number of subcarriers and L is an oversampling factor. $\mathbf{b_i} = \{b_{i1}, b_{i2}, \ldots, b_{iNL}\}$, $i = 1, 2, \cdots, V$, are V different phase sets to represent one signal block, $\mathbf{X}$, as a multiple signal block, where V is the total number of signal sets. Obviously, the number of elements in $\mathbf{b_i}$ is the same as the length of IDFT. If we multiply V different phase sets $\mathbf{b_i}$ with a signal block $\mathbf{X}$ and perform IDFT, then we can get V different OFDM signal sets from one signal block. Since PAPR of OFDM signal is very sensitive to phase variation, the V different signal blocks have different PAPRs. We choose the one which shows minimum PAPR and send it to the receiver through the channel. Side Information (SI) is necessary to decode the signal block since the receiver must know which phase set was chosen at the transmitter. Because of the high priority of the SI, SI is usually heavily protected by channel coding [3]. Several blind techniques with additional complexity have also been proposed [8] [9].

The concurrent SLM which was proposed in [4] means use the same phase set for all transmit antennas to reduce PAPR. In the original paper [4], the same SI is embedded for all of the antennas to protect SI by diversity features. How to choose one phase set for all of the transmit antenna is one of important criteria. In [4], authors use minimum average criterion. However, it was proved that the minimax criterion which was used in [10] shows better PAPR reduction capability. For this reason, in this paper, we use minimax criterion for concurrent SLM technique.

V-BLAST based MIMO system is used to allow maximum throughput. For this reason, we do not embed the same SI in all of the transmit antennas because it reduces data rate. We only embed the SI in the first/second symbols of the first antenna. And we use SI power allocation technique to protect SI. Additional details are provided in the next subsection.

3.2. Power Allocation Technique for SI

Since wrong detection of SI causes burst error, special protection for SI is necessary. Other researchers have proposed protection of SI by turbo code [3] and by diversity technique [4]. However, both approaches cause data loss and some level of complexity. In this section, we propose SI power allocation technique for V-BLAST based MIMO-OFDM systems. This means we allocate more power to SI to protect SI, with slight power loss of other subcarriers. As is well-known in the literature, the Bit Error Rate (BER) for the SLM technique can be shown to be [11]

$$P_{b,SLM} \approx P_b \cdot (1 - P_{e,SI}) + 0.5 P_{e,SI} \tag{4}$$

where $P_{e,SI} \approx P_b \cdot \lceil \log_2 V \rceil$ is the probability of erroneous detection of SI, and V is the number of phase sets in SLM. As a BER for the V-BLAST system, we can use the following asymptotic upper bound for the Zero Forcing (ZF) detection V-BLAST system [12].

$$\bar{P}_b \le \frac{\alpha_M}{\log_2 M} \left(\beta_M \frac{\bar{\gamma_b} \log_2 M}{M_t} \right)^{-(M_r - M_t + 1)} \tag{5}$$

where $\bar{\gamma_b}$ is average SNR, and α_M and β_M are chosen depending on modulation choice, M_t is the number of transmit antennas and M_r is the number of receive antennas, M is the number of signal constellation.

To get an approximate BER for ZF detection of V-BLAST, we use the following SNR distribution [12].

$$p_{\gamma_b}(\gamma) = \frac{M_t}{\bar{\gamma_b}(M_r - M_t)!} e^{-\frac{M_t}{\bar{\gamma_b}}\gamma} \left(\frac{M_t}{\bar{\gamma_b}} \gamma \right)^{M_r - M_t} \tag{6}$$

Then, BER of ZF detection V-BLAST can be approximated by

$$\bar{P}_b \approx \frac{\alpha_M}{\log_2 M}\int_0^{\infty} Q\left(\sqrt{\beta_M \frac{\gamma \log_2 M}{M_t}}\right) \cdot \frac{M_t}{\bar{\gamma}_b (M_r - M_t)!} e^{-\frac{M_t}{\bar{\gamma}_b}\gamma} \left(\frac{M_t}{\bar{\gamma}_b}\gamma\right)^{M_r - M_t} d\gamma \quad (7)$$

After that, (4) can be represented as

$$\bar{P}_{b,SLM} \approx \bar{P}_b \cdot (1 - \bar{P}_{e,SI}) + 0.5\bar{P}_{e,SI} \quad (8)$$

where $\bar{P}_b$ is from (7). For the proposed SI power allocation technique, if we allocate twice more power for SI than other subcarriers, we can represent (8) as

$$\bar{P}_{b,SLM}(SNR) \approx \bar{P}_b(SNR) \cdot (1 - \bar{P}_{e,SI}(2SNR)) + 0.5\bar{P}_{e,SI}(2SNR) \quad (9)$$

In (9), we assume the number of subcarriers is large enough so that we can neglect the power loss of other subcarriers.

4. SIMULATION RESULTS AND DISCUSSION

In this section, we present simulation results and compare the results with the analysis given in the previous section. As a channel model, we use 19 point exponentially decaying power profile frequency selective fading channel and 20 point guard interval for OFDM to change the effect of frequency selectivity to flat. Fig. 1 and Fig. 2 show BER performance

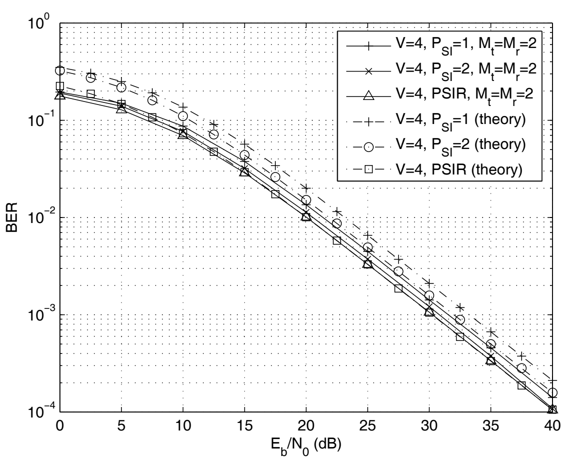

Fig. 1. BER performance of Concurrent SLM technique with SI power allocation, MIMO-OFDM-16QAM, $M_t = M_r = 2$

and BER approximation of Concurrent SLM technique with SI power allocation using (7), when we use MIMO-OFDM-16QAM, the number of subcarriers $N = 64$, $M_t = M_r = 2$

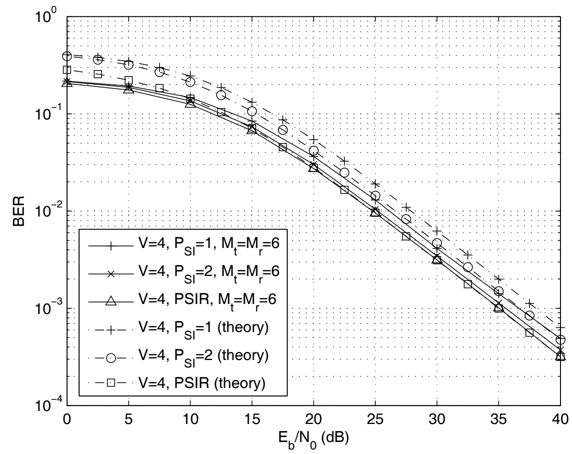

Fig. 2. BER performance of Concurrent SLM technique with SI power allocation, MIMO-OFDM-16QAM, $M_t = M_r = 6$

and $M_t = M_r = 6$. Since $V = 4$, we only reserve one symbol for SI. P_{SI} indicates how much more power we put into the SI. That is, if $P_{SI} = 2$, twice more power is put into the SI. The performance gap seems similar for all of the SNR range. Since it is difficult to see the performance difference from Fig. 1 to Fig. 2, we present magnified figures to show the performance difference.

Fig. 3 shows BER performance of Concurrent SLM technique with SI power allocation in the range of 20dB to 30dB, MIMO-OFDM-16QAM, $M_t = M_r = 2$. According to this, the BER performance penalty is around 1.3 dB. This reduces to around 0.6 dB if we use SI power allocation technique. Increasing $P_{SI} = 2$ to $P_{SI} = 3$ shows similar performance. However if we increase to $P_{SI} = 4$, the BER performance becomes worse.

In Fig. 4, we increase the number of antennas from $M_t = M_r = 2$ to $M_t = M_r = 6$. In this case, the SI power allocation technique shows better performance than the case of $M_t = M_r = 2$, and compared with PSIR, it shows only around 0.3 dB difference, when $P_{SI} = 3$. The reason is that if we use more transmit antennas, the power loss of other subcarriers is smaller. It is also worth noting that the more antennas share the same SI, so in this case, the SI gets higher priority compared to the case of $M_t = M_r = 2$. If we reserve more symbols as a SI, we can get much more performance gain by using the proposed Side Information power allocation technique. This SI power allocation technique does not cause any PAPR regrowth. The complete analysis and simulation results will be provided in our future work.

5. CONCLUSION

MIMO-OFDM is a prime technique for wireless communication systems. However, the PAPR problem of OFDM system

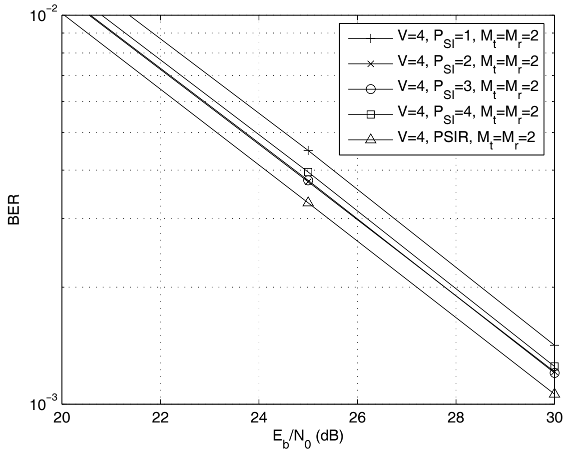

Fig. 3. BER performance of Concurrent SLM technique with SI power allocation in the range of 20dB to 30dB, MIMO-OFDM-16QAM, $M_t = M_r = 2$

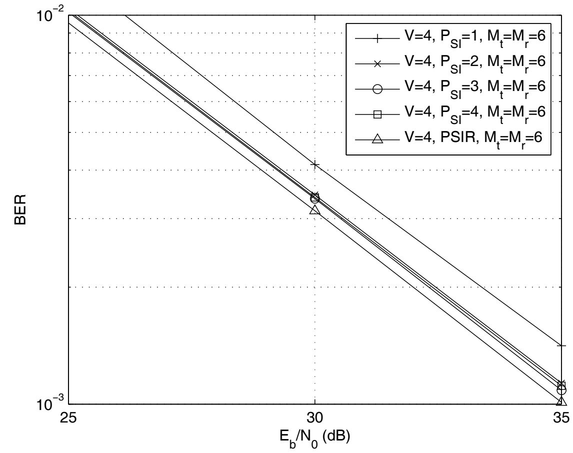

Fig. 4. BER performance of Concurrent SLM technique with SI power allocation in the range of 25dB to 35dB, MIMO-OFDM-16QAM, $M_t = M_r = 6$

seriously limits the power efficiency of HPA. In this paper, we presented a V-BLAST based MIMO-OFDM performance of SLM PAPR reduction technique, and proposed SI power allocation technique to protect SI of the SLM technique. The proposed SI power allocation technique is quite simple and effective, and we get more benefit when we use more transmit antennas and/or reserve more symbols as a SI.

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