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Short-span interleaving based selected mapping

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Abstract: A novel interleaving based selected mapping (SLM) scheme to depress the relatively high peak power of transmit signals in multicarrier communications is proposed. In the scheme, a group of bit-level interleavers spanning only a few bits are used to produce multiple sequences representing the same information, and one of the sequences resulting in the lowest peak-to-average power ratio (PAPR) is selected for transmission. The implementation of the scheme including the structure of the short-span interleaver is illustrated. The performance of this PAPR reduction scheme is investigated by simulations. This scheme exhibits a good PAPR reduction performance, and for signals of high level modulation, such as 16QAM and 64QAM, it approaches the best performance of all SLM schemes. Compared to the conventional interleaving SLM, this short-span interleaving SLM results in a very short time delay, requires very few register units for buffering, and can be easily implemented by hardware.

Key words: multicarrier communications; peak-to-average power ratio; selected mapping; interleaving

Multicarrier communication systems have distinct advantages over single-carrier systems in nonideal channels[1]. However, the transmitted signals in multicarrier communications exhibit a high peak-to-average power ratio (PAPR)[2]. The analog hardware at the transmitter requires an expensive high-power amplifier (HPA) to avoid clipping or soft thresholding that causes nonlinear output. The power consumption of an HPA depends largely on its peak power output rather than on the average output power, and thus, handling occasional large peaks leads to low power efficiency.

Many algorithms have been proposed to reduce the PAPR, e. g., selected mapping (SLM)[3], partial transmitting sequence[4], coding[5], and digital clipping[6]. The SLM is a relatively simple scheme for a practical solution that reaches a good tradeoff between complexity and performance. In an SLM process, multiple multicarrier frames representing the same information are generated, of which the frame with the lowest PAPR is selected and transmitted.

Based on the principle of SLM, there exist some methods to generate the multiple frames that represent the same information, e. g., phase rotation[3], scrambling[7,8], and interleaving[9,10].

Interleaving reorders the input sequence either in bit or in symbol level and generates different sequences. There is no need for mathematical or logical computation in the interleaving process. However, it requires additional buffer devices and induces a time delay. In the previous papers that use interleavers to reduce PAPR of multicarrier signals, the span of the interleavers is the length of the bit/symbol sequence of a block or several blocks[10]. A long interleaver means a large memory and a long time delay.

In this paper we try to investigate the performance of interleavers with short spans, by using the SLM method, in PAPR reduction. It is clear that an interleaver with a shorter span needs fewer register units for buffering and results in a shorter time delay.

1 Selected Mapping Method

SLM was proposed by Bäuml et al. [3], and it is a type of statistical method used for PAPR reduction of multicarrier modulation.

In the SLM approach, K statistically independent sequences are generated from the same information and the sequence with the lowest PAPR is transmitted. Fig. 1 shows the principle structure of the transmitter using the SLM method for PAPR depression, where $K-1$ transformations, $T_1, T_2, \dots, T_{K-1}$, $K-1$ inverse discrete Fourier transforms (IDFTs) and a selection are additional operations compared to the original multicarrier system. To recover data, the receiver has to know which transformation has actually been performed on the transmitted frame. The straightforward method is to transmit the number k representing the index of the transformation as side information (SI) to the receiver.

By using the SLM method, the transmitted signal exhibits a better PAPR performance than the original

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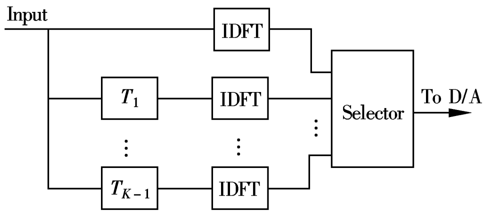

Fig. 1 Selected mapping for PAPR depression in multicarrier system

signal. If the complementary cumulative distribution function (CCDF) of the original sequence is $P\{R_0 > Y\}$ and all the K sequences are independent and identically distributed (i. i. d), the CCDF of the sequence with the lowest PAPR will be

$$P\{R > Y\} = (P\{R_0 > Y\})^K \tag{1}$$

This is the best performance that an SLM method can achieve, which is based on the assumption that all the frames representing the information are statistically independent. Thus, the probability of the PAPR exceeding some threshold can be made as small as possible at the expense of additional IDFT's.

How to generate these K frames in the SLM method is the most important operation in the process. It has been mentioned that if the K frames are statistically independent, the SLM approaches the best PAPR depression performance. There exist some methods to generate the K frames that represent the same information, e. g., phase rotation, scrambling, and interleaving.

Interleaving is to reorder or permute the bits or symbols of the input sequence and generate a different sequence. The process of interleaving is to write and read a sequence in different ways, and there is no mathematical or logical computation in the process. The interleaving scheme requires additional buffer devices and induces a time delay.

If the sequences produced by the interleavers are statistically independent, the PAPR depression performance will achieve the result given by Eq. (1). A random interleaver (RI) permutes the input sequence in a pseudo random order and can produce an approximately independent sequence, so a random interleaving scheme is the best to reduce the PAPR of the transmitted signal. It is reported that, for a multicarrier system with a large number of subcarriers, an SLM using random bit or symbol permutation approaches the best performance of SLM methods[10]. But to use random interleaving, it is necessary to store and transmit the permutation orders. Periodic block interleaving is to write the sequence into a matrix column by column and read it row by row, which is simple to implement. The periodic interleaving exhibits some performance degradation compared to the random interleaving. For multi-level modulation, bit-level periodic block interleaving supplies a much better PAPR reduction capacity than the symbol-level interleaving.

2 Short-Span Interleaving SLM

In the above section and previous papers that use interleavers to reduce PAPR of multicarrier signals, the span of the interleavers is the length of the bit/symbol sequence of a block or several blocks. A long interleaver requires a large memory and results in a long time delay. If an interleaver with a short span exhibits a good performance in PAPR reduction, the interleaving based SLM methods will be more interesting and practical for PAPR reduction in multicarrier communications. In the following we propose a bit-level interleaver with short span for PAPR reduction and in the next section we evaluate its performance for PAPR reduction by some simulations.

The short-span interleaver is to produce multiple frames representing the same information by reordering the bits of each group of the input sequence, where each group consists of a few consecutive bits. The short-span reordering can be implemented by the structure illustrated in Fig. 2. The span of the interleaver shown in the structure, e. g., is 4, and other spans can be implemented using similar structures. If the interleaver spans S bits, it can produce $K = S\cdot(S-1)\cdot(S-2)\cdot \ldots \cdot 1 = S!$ sequence branches at most. An input bit frame is partitioned into groups of S bits, and then each S bits in a group is reordered in the same shape to generate a new frame.

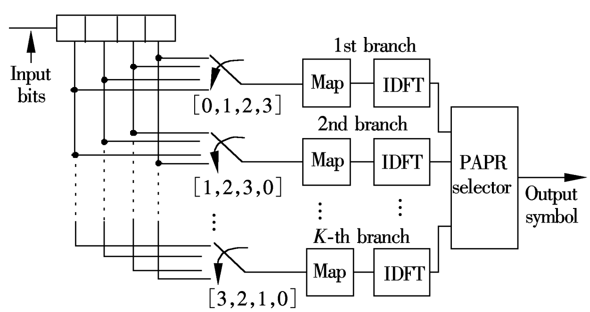

Fig. 2 Transmitter structure using short-span interleaving SLM for PAPR reduction

A reordered sequence for the sequence $[X_0, X_1, \ldots, X_{S-1}]$ can be represented as $[X_{\pi_0}, X_{\pi_1}, \ldots, X_{\pi_{S-1}}]$, where $\pi_i \in \{0, 1, \ldots, S-1\}$ for $i = 0, 1, \ldots, S-1$ and $\pi_i \neq \pi_j$ for $i \neq j$. If the input sequence of length N, denoted as $X = X_0, X_1, \ldots, X_{N-1}$, is represented as

$$X_{0,0}, X_{0,1}, \ldots, X_{0,S-1}, X_{1,0}, X_{1,1}, \ldots, X_{1,S-1}, \ldots, X_{m,0}, X_{m,1}, \ldots, X_{m,S-1}, \ldots \tag{2}$$

the output is

$$X_{0,\pi_0}, X_{0,\pi_1}, \ldots, X_{0,\pi_{S-1}}, X_{1,\pi_0}, X_{1,\pi_1}, \ldots, X_{1,\pi_{S-1}}, \ldots, X_{m,\pi_0}, X_{m,\pi_1}, \ldots, X_{m,\pi_{S-1}}, \ldots \tag{3}$$

where m is an integer less than N/S and $X_{m,k} = X_{mS+k}$. The reordering is implemented by different connections to these registers. It is clear that the bits in each group of the sequence transmitted in the first branch illustrated in Fig. 2 is ordered with $[\pi_0, \pi_1, \pi_2, \pi_3] = [0, 1, 2, 3]$, in the second branch $[\pi_0, \pi_1, \pi_2, \pi_3] = [1, 2, 3, 0]$, and in the K-th branch $[\pi_0, \pi_1, \pi_2, \pi_3] = [3, 2, 1, 0]$.

Each output branch of the interleaver is mapped into a symbol frame followed by an IDFT operation. From these results, the IDFT output with the lowest PAPR is selected for transmission.

The receiver decides which interleaving operation has been performed on the received frame according to the SI that the received signals append, and performs a corresponding deinterleaving operation after a DFT and symbol-to-bit demapping operations. The deinterleaver in the receiver possesses the same structure as the interleaver in the transmitter. Deinterleaving is to reorder each S bits of the frame corresponding to the interleaving at the transmitter side; e. g., if an interleaving operation with order [3, 2, 1, 0] was performed on the frame in the transmitter, the deinterleaver lets the output order be [3, 2, 1, 0], and if an interleaving operation with order [2, 3, 1, 0] was performed on the frame, the deinterleaver lets the output order be [3, 2, 0, 1]. The output of the deinterleaver is transmitted into the following device, a channel decoder or a conventional deinterleaver.

The short-span interleaver needs S register units, each for a bit, and results in a delay of $S-1$ bits. For a short span S, both the register and the delay are trivial compared to a block interleaver spanning a frame. This is the main advantage of the short-span interleaver used for PAPR reduction. The implementation of the short-span interleaver is also very simple.

3 Performance

We evaluate the performance of the proposed short-span interleaving in PAPR reduction by some examples.

We consider an interleaver spanning $S = 4$ bits first. Given a multicarrier system with 256 subcarriers including $256m$ bits, where m is the bit number of a symbol transmitted in a subcarrier, we generate new bit sequences by reordering the bits in each group comprised of four consecutive bits in the same shape. We use circular bit shifts in all the groups to generate new sequences, so by performing $K-1$ circular shift operations we produce K sequences, including the original one, representing the same information for selection, where K is S at most. Then all the bit sequences are mapped into symbol sequences, followed by IDFT operations, and finally, the output of the IDFT with the lowest PAPR is selected and transmitted into the next device.

Fig. 3 shows the PAPR reduction performance by using such a short-span reordering on a multicarrier system with 256 subcarriers and 16QAM modulation. It can be seen that, for such a system, this method exhibits a very good PAPR reduction performance, which is even close to that of the random bit permutation spanning the total bits of the input frame. It is known that the random bit permutation approaches the best performance that the SLM method can achieve.

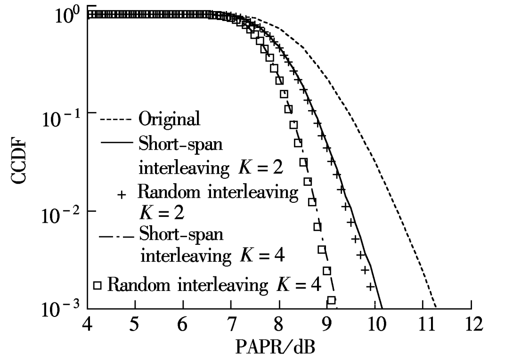

Fig. 3 PAPR CCDF of 16QAM multicarrier signals using short-span ($S=4$) interleaving SLM

For QPSK modulated multicarrier signals, the performance of the short-span interleaving is shown in Fig. 4. It can be seen that, in this case, the short-span interleaver works much worse than the random permutation, and it also shows a poorer PAPR reduction performance than a periodic block interleaver.

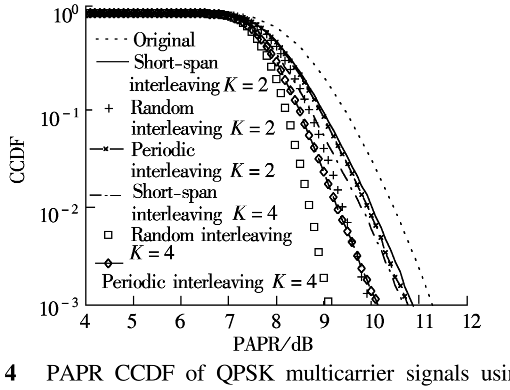

Fig. 4 PAPR CCDF of QPSK multicarrier signals using short-span ($S=4$) interleaving SLM

Fig. 5 shows the PAPR reduction performance by using such an interleaver with a span $S=8$ bits on multicarrier systems with QPSK, 16QAM, and 64QAM modulation, respectively. This figure shows similar results to Figs. 3 and 4. The interleaver is effective in PAPR reduction for 16QAM and 64QAM modulated signals but it is not effective for QPSK modulated signals.

It can be seen from these simulations that, based

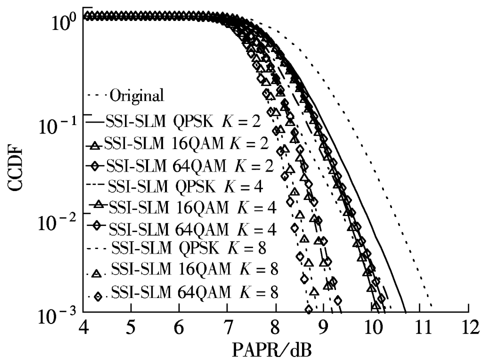

Fig. 5 PAPR reduction performance comparison using short-span interleaving SLM (SSI-SLM) ($S=8$)

on the SLM method, an interleaver with a span even as short as 4 bits exhibits a very good performance in PAPR reduction for high level modulated multicarrier signals, such as 16QAM and 64QAM, but it does not work well for low level modulated signals, such as QPSK. This can be explained by the fact that a bit has more effect on a low level modulation than on a high level modulation.

4 Conclusion

It is concluded that, based on the SLM method, a bit-level interleaver with a short span works well in PAPR reduction for high level modulated multicarrier signals, such as 16QAM and 64QAM. Considering that QAM modulations are often used in multicarrier systems, this method is practical for implementation. This method requires very few buffer elements for interleaving and results in a very short time delay.

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基于短跨度交织的选择性映射

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摘要: 为了抑制多载波通信中发送信号相对较高的峰值功率,提出了一种新的基于交织的选择性映射方案. 在该方案中,采用一组交织跨度仅为几个比特的比特级交织器来产生多个表示相同信息的序列,从中选择对应信号峰均比最低的序列作为发送的序列. 描述了该方案的实现方式以及这种短跨度交织器的结构. 通过仿真考察了该映射方案在降低多载波信号峰均比方面的性能. 结果表明该方案在抑制峰均比方面呈现出很好的性能,对于高阶调制信号,如 16QAM 和 64QAM,它甚至达到选择性映射所能实现的最佳性能. 与传统的基于交织的选择性映射方案相比较,这种基于短跨度交织的选择性映射方案产生非常短的时间延迟,只需要很少的缓冲寄存器,且易于用硬件实现.

关键词: 多载波通信;峰均比;选择性映射;交织

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