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Partial transmitting sequence method based on trellis factor search

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Abstract: To obtain good trade-offs between complexity and performance on peak-to-average power ratio (PAPR) reduction in orthogonal frequency division multiplexing (OFDM) using partial transmitting sequence (PTS) schemes, a trellis structure based PTS factor search method is proposed. The trellis search is with a variant constraint length L_C, $1 \leqslant L_C \leqslant V-1$, where V is the number of PTS subblocks. The method is to decide a PTS factor by searching all the possible paths obtained by varying L_C consecutive factors. The trellis search can be viewed as a general PTS factor search model. If $L_C = V-1$, it is a full search, and if $L_C = 1$, it is an iterative search. Using different constraint lengths, trellis factor search PTS exhibits different PAPR reduction performances. A larger L_C results in a better performance and $L_C = V-1$ results in the optimum. However, a larger L_C requires more computation. This helps to choose a good trade-off between complexity and performance.

Key words: peak-to-average power ratio (PAPR); partial transmitting sequence (PTS); trellis search

Orthogonal frequency-division multiplexing (OFDM) systems have distinct advantages over single-carrier systems in nonideal channels. However, the transmitted signals in OFDM exhibit a property of high peak-to-average power ratio (PAPR)[1]. This results in some clipping distortion caused by the nonlinear power amplifier, and the system performance is degraded.

Many algorithms have been proposed to reduce the PAPR, e. g., selected mapping (SLM)[2], partial transmitting sequence (PTS)[3], coding[4], and digital clipping[5]. The PTS is one of the methods that does not result in additional distortion and it is a relatively practical scheme for the solution of the PAPR problem.

The principle of the PTS is to partition the input subcarrier block into some pairwise disjoint subblocks, to modulate each subblock respectively, and to combine the modulated signals into a signal with a low PAPR result for transmission. For the same subblock number and the same weighting factor set for signal combination, the performance of PTS for PAPR reduction is largely dependent on factor search methods. Among all the factor selections, the optimization of the factors obtained by a full search results in the best performance, but the complexity of the full search is the highest and sometimes the complexity even makes the search impossible. Some suboptimum solutions, such as the iterative method and the random try method in Ref. [6], result in some performance degradation, but the complexities of their implementation are relatively low.

In this paper a trellis PTS factor search method is proposed and its performance is investigated. The trellis PTS factor search can be viewed as a general PTS factor search model that includes the full search and the iterative search methods. Using the trellis method with a variable constraint length, we can find a good trade-off between the performance in PAPR reduction and the complexity in factor selection.

1 PTS Method

The principle structure of PTS method is shown in Fig. 1 as that in Ref. [6].

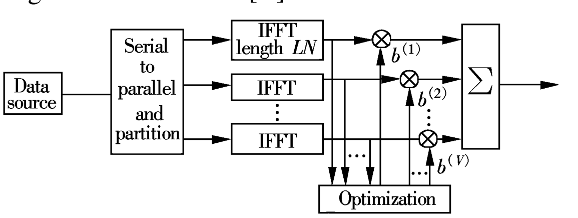

Fig. 1 Partial transmit sequence approach

In the PTS approach[3], the information bearing subcarrier block $\boldsymbol{X}$ is partitioned into V pairwise disjoint subblocks or clusters $\boldsymbol{X}^{(v)}$, $v = 1, 2, \ldots, V$. All subcarrier positions in $\boldsymbol{X}^{(v)}$ that are already represented in another subblock are set to zero. For a system with N subcarriers, each subblock can be looked at as a block length N with data in its assigned subcarriers

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and zeros in the other subcarriers. Mathematically, this is $\boldsymbol{X} = \sum_{v=1}^{V} \boldsymbol{X}^{(v)}$. An *LN*-point inverse fast Fourier transform (IFFT) is performed on each subblock, where L is an oversampling factor.

Then, a weighting factor vector $\boldsymbol{b} = \{b^{(1)}, b^{(2)}, \ldots, b^{(v)}\}$ is introduced to combine the V modulated subblocks, and the combined result is

$$\breve{\boldsymbol{x}} = \sum_{v=1}^{V} b^{(v)} \boldsymbol{x}^{(v)} \tag{1}$$

where vector $\boldsymbol{x}^{(v)}$ is the modulated version of $\boldsymbol{X}^{(v)}$. The objective of the PTS method is to choose a vector $\boldsymbol{b}$ to reduce the PAPR of $\breve{\boldsymbol{x}}$, and the optimum parameters for an MC or OFDM symbol are given by

$$\breve{\boldsymbol{b}} = \arg\min_{\boldsymbol{b}} \left(\max \left| \sum_{v=1}^{V} b^{(v)} \boldsymbol{x}^{(v)} \right| \right) \tag{2}$$

The factors $\{b^{(v)}\}$ are assumed to be pure rotations denoted as

$$b^{(v)} = \exp\{\mathrm{j}\varphi^{(v)}\} \tag{3}$$

which can be selected from an infinite number of phase φ. Simulations indicate that a restriction to four rotation angles already allows a significantly reduced peak power[3], and the set $\{\pm 1, \pm j\}$ is often used for the factor restriction for its easy implementation. It is reported in Ref. [7] that employing optimal binary phase sequences (OBPS), in which the phases are quantized to $\{\pm 1\}$, shows a satisfactory PAPR reduction.

For a given subblock number V and a given phase set restricted to W angles, the optimum solution, i. e., the best performance of the PTS for PAPR reduction, can be reached by using a full search method. However, the computational complexity C for the optimization is related as

$$C = W^{V-1} \tag{4}$$

which is exponential to the subblock number and is the highest in all the factor search schemes. In Eq. (4) the exponent being $V-1$ arises from the fact that the first bit can be fixed without any performance loss. For a large number of subblocks, the computational burden makes the full search unsuitable.

Several methods have been suggested to reduce this complexity issue with suboptimum solutions, such as the iterative algorithm and the random try method[6], the amplitude cancellation method[8], the orthogonal projection-based approach[9], the 2-layered scheme[10], and the adaptive PTS[11], and all of these methods are to find good trade-offs between the performance and the complexity. The iterative algorithm is relative simple, which is to reduce the number of trials needed to find a set of phase rotation factors for a relatively low PAPR by using a flipping and trying method bit by bit. The iterative method shows some performance degradation compared to the optimum and the complexity is linear to the subblock number.

In the following, a new trellis factor search method for the optimization of PTS is proposed. By using a variable constraint length, the trellis search supplies optimum and some suboptimum solutions of a PTS problem.

2 Trellis Factor Search

To find a good trade-off between the PTS performance on PAPR reduction and the complexity in the process of PTS phase factor selection, we propose a trellis search method for PTS factor optimization taking advantage of trellis structures.

2.1 Trellis structure

Two examples of the trellis search are based on the structures illustrated in Fig. 2. The nodes in each line indicate all the phase factors $b^{(1)}, b^{(2)}, \ldots, b^{(v)}$, and the nodes in each column denote W possible values, $\{1, \mathrm{e}^{\mathrm{j}2\pi/W}, \ldots, \mathrm{e}^{\mathrm{j}2\pi(W-1)/W}\}$, e. g., $\{1, -1\}$ for $W=2$ and $\{1, j, -1, -j\}$ for $W=4$, of a factor. The trellis search is like the Viterbi decoding method for convolutional codes. The difference is that the criterion for this trellis search is not a distance or a posterior probability as in Viterbi decoding but the resulted peak power of a selected path. The included factors in the dashed frames of Fig. 2 are like the detection delay in a Viterbi process, and we call the number of included factors in each frame constraint length and denote it as L_{C}. It can be seen that, as two examples, the constraint lengths in the figure are three.

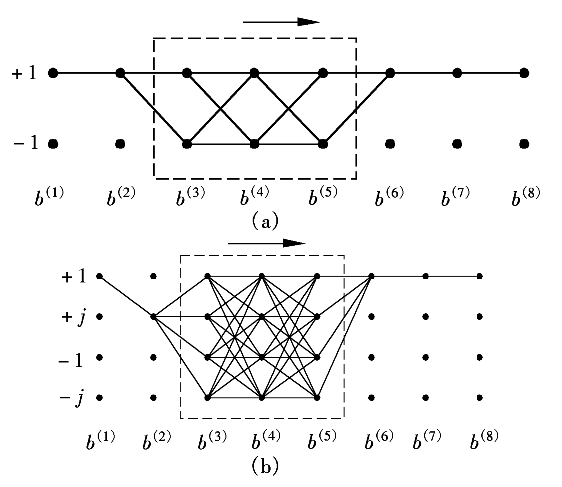

Fig. 2 Trellis search for PTS factor optimization.
(a) $W=2$; (b) $W=4$

2.2 Trellis search process

A trellis search PTS with V subblocks and constraint length L_C is implemented by the following steps:

① Perform V oversampling IFFT operations on the V subblocks.

② Set all the phase factors to 1's and compute the peak power of the combined signal. Retain $b^{(1)}$ as the final value.

③ Make a full search on $b^{(2)}$ and the following successive $L_C - 1$ factors, maintaining the other $V - L_C$ factors simultaneously, and recompute peak powers of combined signals resulting from these $W^{L_C} - 1$ new factor sequences respectively. In each computation, compare the present peak power result with the previous value, discard the higher one and the corresponding sequence, and memorize the sequence with the lower peak power and its peak power value. The sequence with the lowest peak power of the W^{L_C} paths is obtained, where the paths include the retained path before the full search. Retain $b^{(2)}$ as the decided value.

④ Decide $b^{(3)}$ by performing the same process as in step ③.

⑤ Continue the process in this shape until all the factors are decided.

In the above process, we let the first factor $b^{(1)}$ be 1 always, which results in no performance loss for a full search. Fig. 2 illustrates the process of step ④ to decide $b^{(3)}$. After all the factors are decided, the combined signal appending with the factor sequence information is transmitted, and the transmitted signal will exhibit a relatively low peak power.

2.3 Complexity of trellis search for PTS

The computational complexity of a trellis search method C_{Tr} with constraint length L_C, V subblocks, and W possible factor values is given by

$$C_{Tr} = (W_{L_C} - 1)(V - L_C) + 1 \qquad (5)$$

It is clear that the complexity coincides with that of the full search when $L_C = V - 1$ and the $V - 1$ step iterative method when $L_C = 1$.

2.4 Universality of trellis search

The trellis search method can be looked as a unit representation of PTS factor search including the full search optimization and the iterative method. For a PTS approach with V subblocks, if the trellis search is with constraint length $V - 1$, it is a full search, and if it is with constraint length 1, it is a $V - 1$ step iterative method. The relationship between the trellis search, the full search and the iterative method can be seen clearly from Fig. 3, where the frames denote the feasible space of the optimization problem for PTS and the width of the arrows in these frames denotes the constraint length in the factor search.

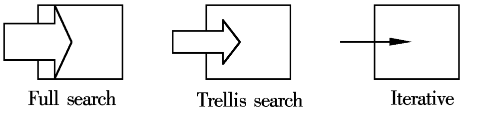

Fig. 3 Relationship illustration of trellis search, full search and iterative method for PTS

3 Performance of Trellis Factor Search PTS

Fig. 4 illustrates some performances of the PTS method in PAPR reduction for OFDM using trellis search with variant constraint length L_C's. The results are obtained by simulations. The simulated OFDM system is with $N = 64$ subcarriers and QPSK modulation. Eight subblocks and $W = 2$ is used for the PTS method in the simulation. As comparisons, the performance of full search PTS, i. e., the optimum PTS result, and the performance of iterative PTS are also shown in the figure. The PAPR reduction performances in the figure are indicated by a statistical property, saying complementary cumulative distribution function (CCDF), of PAPR of the baseband transmitted OFDM signals, where the CCDF of PAPR in y denotes the probability that PAPR is larger than y and, generally, y is a value in dB.

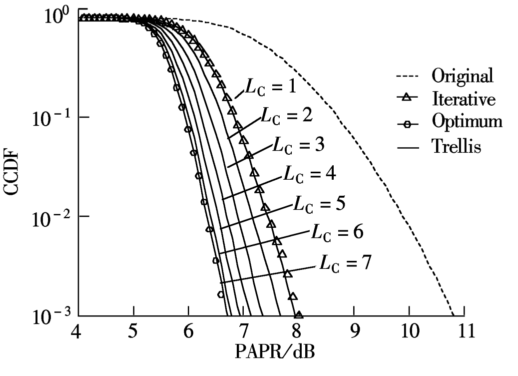

Fig. 4 PTS performance using trellis search with constraint length L_C ($N = 64$, QPSK, $V = 8$, $W = 2$)

It can be seen that when the constraint length L_C increases, the performance of peak power depression improves. In the case of $L_C = 1$ the trellis search results in the same performance as a 7-step iterative method, and in the case of $L_C = 7$ the trellis search results in the same performance as the full search. These results are expected. For each unit increase of the constraint length, the first one supplies the largest gain, and the following increased constraints supply decreasing gains. At the level of CCDF being 1%, as an example, when $L_C = 1$, which is actually a 7-step iterative search, the PAPR is 2.7 dB lower than the original input, and from $L_C = 2$ to $L_C = 7$ the performance gains are about 0.28, 0.26, 0.20, 0.16, 0.13, and 0.07 dB per constraint length increase respectively. All the performances of the trellis search PTS with variant constraint lengths are in the gap between the optimum performance and the iterative PTS. This supplies many selections of trade-offs between the performance of the PTS and its complexity.

4 Conclusion

The PTS method can reduce peak power of OFDM signals effectively, and the main burden in PTS is the factor optimization for the lowest PAPR of the transmitted signals. All the suboptimum PTS methods are to find good trade-offs between the performance of PTS in PAPR reduction and the complexity in factor search. The proposed trellis factor search method with a variable constraint length provides many trade-offs of PTS performance and complexity. We can select a proper constraint length according to the performance need of a system and the complexity of its implementation. The trellis factor search is also a unit model, which includes the full search and the iterative method for PTS.

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基于格形因子搜索的部分传输序列方法

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摘要: 为了得到部分传输序列降低 OFDM 信号峰均比方案中复杂度和性能之间的良好折衷, 提出了一种基于格形结构的部分传输序列因子的搜索方法. 这种格形搜索有一个可变的约束长度 L_C, $1 \leqslant L_C \leqslant V-1$, V 为部分传输序列子块的数目. 该方法通过搜寻格形结构中可能的路径来决定部分传输序列的因子, 而这些路径通过改变 L_C 个相邻因子的值得到. 格形搜索可看作一个统一的传输序列因子搜索模型, 当 $L_C = V-1$, 为全局搜索; 当 $L_C = 1$, 为单步迭代搜索. 采用不同的约束长度, 格形搜索在抑制峰均比方面呈现出不同的性能, L_C越大其性能越好, 而 $L_C = V-1$ 对应最优的结果. 同时较大的 L_C 需要更多的计算. 这些结论有助于在复杂度和性能之间找到一个好的折衷.

关键词: 峰均比; 部分传输序列; 格形搜索

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