PAPR Reduction in OFDM-based Visible Light Communication Systems Using a Combination of Novel Peak-Value Feedback Algorithm and Genetic Algorithm

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Abstract. We propose an enhanced partial transmit sequence technique based on novel peak-value feedback algorithm and genetic algorithm (GAPFA-PTS) to reduce peak-to-average power ratio (PAPR) of orthogonal frequency division multiplexing (OFDM) signals in visible light communication (VLC) systems (VLC-OFDM). To demonstrate the advantages of our proposed algorithm, we analyze the flow of proposed technique and compare the performances with other techniques through MATLAB simulation. The results show that GAPFA-PTS technique achieves a significant improvement in PAPR reduction while maintaining low bit error rate (BER) and low complexity in VLC-OFDM systems.

1. Introduction

There have been many significant researches on the VLC systems. Compared with conventional radio frequency (RF) communication systems, VLC systems have many advantages such as higher transmission rates, no electromagnetic interference and higher security [1-2]. With respect to all these advantages, VLC has become a promising technology for future wireless communications.

In VLC systems, OFDM technique is employed to meet high-speed transmission requirement and to solve inter symbol interference (ISI) problem [3]. But the disadvantage of high PAPR in OFDM cannot be neglected. If VLC-OFDM signals have high PAPR, systems require all transmitter modules with wide linear operation ranges [4-5]. Otherwise, there will be non-linear distortion of signals when peak value of a signal goes into the nonlinear region of system’s components [6]. Light-emitting diode (LED) and power amplifier, which are typically important in transmitter modules, are difficult to design and costly to manufacture to obtain wide linear operation ranges [7]. So the problem of nonlinear distortion caused by high PAPR in VLC-OFDM systems must be solved.

Numerous methods have been investigated to reduce high PAPR of VLC-OFDM systems, including precoding [8], clipping [9-11], companding transform [12], tone reservation [13], selected mapping (SLM) [14], and partial transmit sequences (PTS) [1]. Among them, the partial transmit sequence (PTS) is one of the most potential technique which has no loss in the power and bit error rate (BER), and can significantly improve the PAPR. But it also needs large computational complexity. GA-PTS technique has been proposed to decrease the computational complexity. However, the performance degradation is serious. Reference [1] proposes a modified PTS technique which combines genetic algorithm with hill-climbing algorithm (GH-PTS) to improve PAPR performance. But GH-PTS can only change single phase factor in a phase factor combination in each iteration, so it...
easily gets stuck at local optimal solution. And the cost for computational amount is too much.

In this paper, we propose a new PTS technique called GAPFA-PTS to solve the above problems which combines genetic algorithm with a novel peak-value feedback algorithm. In this technique, phase factor combination will be continuously changed until it meets the ending condition. Once the optimized signal has lower PAPR than threshold value, the PFA manipulation will be ended no matter whether the current executions equal to the final executions. Compared with GH-PTS, GAPFA-PTS has advantages that it can optimize phase factor combination \([b_1, b_2, \ldots, b_n]\) by many times phase rotation in one PFA manipulation which can combat local optimal solution. The operation will be given in Sec.3 in detail.

The rest of paper is organized as follows. In Sec.2, VLC-OFDM system and PAPR in VLC-OFDM are analyzed. Sec.3 discusses GA-PTS technique and GAPFA-PTS technique in detail. The performance of GAPFA-PTS is analyzed in Sec.4 by comparing GAPFA-PTS with Optimization-PTS, GA-PTS and GH-PTS. In Sec. 5, the conclusion is given.

2. Papr in VLC-OFDM

2.1 System of VLC-OFDM

In VLC systems, signals are transmitted through an LED in form of optical power. In the receiver, a photo detector (PD) is employed to convert optical power signals into electrical signals. A DC bias voltage should be added before transmitting data because baseband-signal in VLC system must be real-valued to meet the requirement of the intensity modulation with direct detection (IM/DD).

VLC-OFDM system block diagram is shown in Figure 1. At the beginning, data are mapped into by using the QPSK mapping. Then, serial data is converted into parallel data. Next, pilot is inserted into the original data. Afterwards, data are processed by Inverse Fast Fourier Transform (IFFT) operation. So far the VLC-OFDM signal without PAPR reduction process has been obtained. It is critical to maintain the stability of the VLC-OFDM system. The following step is to mitigate the high PAPR of signals by applying GAPFA-PTS technique. After digital-to-analog conversion, the signal is emitted by LED emitter and received by a photo detector (PD). At the receiver, the original data is restored through the reverse operation of the transmission scheme.

![Figure 1. Diagram of VLC-OFDM system.](image-url)
2.2 PAPR of VLC-OFDM Signal

High PAPR is a common problem for OFDM signals. In VLC-OFDM systems, time domain signals $x_n$ can be expressed as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N} \quad n=0,1,...,N-1. \quad (1)$$

Where $X_k$ represents the frequency domain datum, $k$ represents the index number of sub-carrier, $N$ is the number of sub-carriers, and $n$ is the index number of the time domain signal.

PAPR is defined as the ratio of the maximum signal power to average signal power, it can be expressed as

$$P_{APR} = \frac{P_{peak}}{P_{average}} = \max_{n=0,1,...,N-1} \frac{|X(n)|^2}{E[|V(n)|^2]}, \quad (2)$$

When the maximum amplitudes of different sub-carriers appear at the same time, the peak power of the signal will appear and the signal has high PAPR.

The pros and cons of a PAPR reduction technique can be evaluated generally by cumulative distribution function (CDF) and complementary cumulative distribution function (CCDF). While, CCDF is more widely used to show PAPR distribution. Given a threshold value $z$, CCDF represents the probability that the PAPR of an OFDM symbol is greater than $z$. The CCDF is defined as

$$CCDF = P(P_{APR} > z) = 1 - F(z)^N = 1 - (1 - e^{-1})^N. \quad (3)$$

Where $N$ denotes the number of sub-carriers.

By comparing the CCDF in different situations, the advantage of the modified technique can be shown more intuitively.

3. The Proposed GAPFA-PTS Technique

GAPFA-PTS technique is based on genetic algorithm and peak-value feedback algorithm which is a local optimization of GA-PTS technique.

3.1 GA-PTS Technique

GA-PTS is proposed to decrease complexity of PTS technique. The genetic algorithm can be summarized as follows:

1) Select a key parameter $G$ as the largest genetic algebra which determines the system performance and the computational complexity. When the current genetic algebra $g$ is bigger than $G$, the genetic algorithm meets the ending condition.

2) Randomly choose $Q$ phase factor combinations as parent populations and each population indicates one phase factor combination $[b_1, b_2, ..., b_v]$. The current genetic algebra is set to $g = 1$.

3) Introduce the phase factor combination $[b_1, b_2, ..., b_v]$ to rotate disjoint V subblocks and obtain the optimum candidate signal by (4).

$$X = \sum_{n=1}^{v} b_n X_n. \quad (4)$$

4) Calculate PAPR of the signal after rotated by each parent population as fitness values. Then obtain offspring populations by genetic manipulation (Figure.2) and calculate its PAPR. Moreover, choose the populations with smaller PAPR in last parent populations and offspring populations as the next genetic algebra’s parent populations and set the genetic algebra to $g = g + 1$.

5) The step d) is repeated until genetic algebra $g$ meets the condition $g = G + 1$ where $G$ is set as the largest genetic algebra in step a). Then choose the best phase factor combination which possesses
the minimum PAPR as the final output \([b_1, b_2, ..., b_v]\).

The genetic manipulation makes PTS technique have good global search capability, but its local search capability needs to be improved especially in low complexity.

\[
\begin{align*}
\text{Parents} & \\
P1 & \\
P2 & \\
\downarrow & \\
\text{Crossover} & \\
01: & \\
02: & \\
\downarrow & \\
\text{Mutation} & \\
01: & \\
02: & \\
\downarrow & \\
\text{Offspring} &
\end{align*}
\]

**Figure 2.** Genetic manipulation.

### 3.2 GAPFA-PTS Technique

PFA is proposed to gain local search capability of GA-PTS technique. The process of PFA can be summarized as follows: (Setting parameters: set the cumulative number of executions for PFA recorded as \(c\); set the final number of executions for PFA as \(C\); set the threshold value as \(\theta\).

1) Through GA-PTS technique, we can find a phase factor combination \([b_1, b_2, ..., b_v]\) which makes \(x\) have a relatively optimal PAPR. Then we should compare the PAPR with threshold value \(\theta\): if PAPR \(\leq \theta\), set the cumulative number of executions \(c = c + 1\), and regard the current phase factor combination \([b_1, b_2, ..., b_v]\) as the final output; if PAPR \(> \theta\), continue to find the peak point of the signal and regard the peak point as the sampling point. The cumulative number of executions \((c)\) is attached to the initial value \(c = 1\);

2) Arrange \(V\) sub-blocks of the signal in a descending order by their value at the sampling point, and set the sequence number as \([i = 1, 2, 3, ... V]\). At this time, the maximum amplitude of the sub-block corresponds to \(V_i\);

3) All the sub-carriers on the \(V_i\) sub-block are multiplied by a phase factor -1, other phase factors are constant. As a result, the combination of the coefficients \([b_1, b_2, ..., b_v]\) is changed to \([b_1, b_2, ..., -b_v, ..., b_v]\), then set the changed combination coefficient as \([d_1, d_2, ..., d_v]\);

4) Compare the PAPR of the signal before rotated (set as \(P_{APR_1}\)) with the PAPR of the signal after rotated(set as \(P_{APR_2}\)). If \(P_{APR_1} > P_{APR_2}\), it will be regarded as an efficient operation, and cumulative number of executions is set to \(c = c + 1\). Otherwise it is an invalid operation, we should multiply the signals of second large block \(V_i\) by a weighting factor -1, and other phase factors stay unchanged, then set the PAPR as \(P_{APR_1}\); if \(P_{APR_1} < P_{APR_2}\), continue to operate the next block of data until we get a smaller PAPR compared with \(P_{APR_1}\); if all the rotated sub-blocks are not satisfied, we will consider the signal satisfied enough to transmit. Then we will set the cumulative number of executions to \(c = C + 1\). Obviously parameter \(c > C\), it meets the ending condition. So the current phase factor combination \([d_1, d_2, ..., d_v]\) is regarded as the best phase factor combination with lowest
5) Repeated Steps b) to d) until the PAPR of the signal after rotated meets the ending condition \((P_{APR} < \theta)\) or the value of \(c\) equals to the ending number \(C + 1\). At this time, the combination of the weighting coefficients \([d_1,d_2...d_e]\) can be regarded as the best phase factor combination with lowest PAPR.

The GAPFA-PTS is a further optimization of GA-PTS technique, combining the global search capability of GA-PTS and local search capability of PFA. Overall diagram of GAPFA-PTS is shown in Figure 3 and the superiority of the proposed algorithm are verified in the simulation (see section IV).

![Figure 3. Overall diagram of GAPFA-PTS.](image)

4. Simulation Results and Analysis

4.1 PAPR Performance and Analysis

We simulate 4 techniques where genetic manipulation is completed by applying adjacent divided and multiple-point crossover. Each crossover manipulation needs to select 2 populations within \(Q\) populations. So the crossover rate for each population is \(2/Q\). Moreover, we will do \(Q/2\) times crossover manipulations in each genetic manipulation. So the crossover rate \(P_{GA}\) is calculated by (5), in which \(Q\) is the number of populations and \(G\) is the final genetic algebra.

\[
P_{GA} = 1 - (1 - 2/Q)^{G/2}
\]  

Other parameters of PAPR simulation are summarized in TABLE 1.

Figure 4 shows the CCDF curves, where GAPFA-PTS technique is compared with GA-PTS technique, GH-PTS technique and Optimization-PTS technique.

Table 2 presents a comparison of four techniques which shows the computational amount and performance of PAPR reduction in detail. The threshold value of PFA is set as 7.1dB and the number

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TABLE 1

| Technique         | Computational Amount | Performance |
|-------------------|----------------------|-------------|
| GA-PTS            |                      |             |
| GH-PTS            |                      |             |
| Optimization-PTS  |                      |             |
| GAPFA-PTS         |                      |             |

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TABLE 2

| Technique         | Computational Amount | Performance |
|-------------------|----------------------|-------------|
| GA-PTS            |                      |             |
| GH-PTS            |                      |             |
| Optimization-PTS  |                      |             |
| GAPFA-PTS         |                      |             |
of rotation factors (set as W) is two as it is selected from -1,1.

**Table 1** PAPR performance simulation parameters.

| Parameter              | number |
|------------------------|--------|
| Modulation mode        | QPSK   |
| number of sub-carriers | \( N = 512 \) |
| Number of sub-blocks   | \( V = 16 \) |
| Number of symbols      | 1000   |
| Phase rotation factor  | \( b_v = -1,1 \) |
| Number of populations  | \( Q = 10 \) |
| Number of generations  | \( G = 4 \) |
| Number of PFA         | \( C = 10 \) |
| Crossover rate         | 0.988  |
| Mutation rate          | 0.01   |

![Figure 4](image_url)

**Figure 4.** The PAPR CCDF of GAPFA-PTS, GH-PTS, GA-PTS, Optimization-PTS Technique.

**Table 2** Comparison of the computational amount and PAPR performance.

| Technique                 | Computational Amount For Each Symbol | PAPR(dB) |
|---------------------------|-------------------------------------|----------|
| Original Signal           | 0                                   | 11.01    |
| Optimization-PTS \( (W=2, V=16) \) | \( W \times V = 65536 \) | 6.45     |
| GA-PTS \( (W=2, V=16, Q=10, G=4) \) | \( 2 \times Q \times G = 80 \) | 7.89     |
| GH-PTS \( (W=2, V=16, Q=10, G=4) \) | \( 2 \times Q \times G + V \times G = 144 \) | 7.64     |
| GAPFA-PTS \( (W=2, V=16, Q=10, G=4, C=10) \) | \( 2 \times Q \times G + 11497 / 1000 = 92.497 \) | 7.32     |

As it can be seen from Table 2 and Figure 5, although Optimization-PTS techniques has good
PAPR reduction performance, its computational amount is nearly 700 times as large as both GAPFA-PTS's and GA-PTS's, and the huge computational amount decreases applying feasibility. When $V = 16, Q = 10, G = 4$, the PAPR of signal processed by GA-PTS is 7.89dB, and the computational amount is 80. When $V = 16, Q = 10, G = 4, C = 10$, the PAPR of signal processed by GAPFA-PTS is 7.32dB, and the computational amount is 92.497. As an optimization of GA-PTS technique, GAPFA-PTS technique has better performance of PAPR reduction than GA-PTS technique by 0.57dB with the computational amount only increased by 12.497. When $V = 16, Q = 10, G = 4$, the PAPR value of applying GH-PTS is 7.64dB, and the computational amount of applying GH-PTS is 144. Compared with GH-PTS technique, GAPFA-PTS has better PAPR performance by 0.32dB and decrease 36% computational amount. It suggests that GAPFA-PTS technique is more efficient than GH-PTS technique with better PAPR performance and lower computational amount.

4.2 BER Performance

The BER performance is studied in an AWGN channel using the QPSK Modulation mode. Other parameters of this simulation are listed in TABLE 3.

From Figure 5, we can see that the BER curves of these PTS techniques are very close. Compared with the GA-PTS technique, the signal processed by GAPFA-PTS technique has nearly no extra BER lose. Moreover, the BER performance of GAPFA-PTS technique is better than GH-PTS technique because of its lower computational amount. So we can draw a conclusion that the improvement of PAPR performance costs nearly no extra BER loss for GAPFA-PTS technique.

| Parameter                  | number          |
|----------------------------|-----------------|
| Number of data symbols     | 1000            |
| Number of sub-carriers     | $N = 512$       |
| FOV at the receiver        | 60 [deg]        |
| Surface area of PD         | 1.0 [$cm^2$]    |
| Gain of optical filter     | 1.0             |
| Efficiency of photo electric conversion | 0.53 [A/W] |

![Figure 5](image-url) The BER curves of GAPFA-PTS, GH-PTS and GA-PTS.
5. Conclusion
In this paper, we have proposed a new PTS technique called GAPFA-PTS to mitigate high PAPR of OFDM-based VLC systems. This technique can efficiently search for optimum phase factors by applying PFA manipulations which have good local search capability. In these simulations, we have compared the GAPFA-PTS with GA-PTS, GH-PTS and Optimization-PTS for their PAPR performance. Compared with Optimization-PTS, GAPFA-PTS has an advantage in computational complexity. Compared with GA-PTS technique, the proposed GAPFA-PTS has an advantage in PAPR reduction performance. Compared with GH-PTS technique, the proposed GAPFA-PTS has an advantage in both PAPR reduction and computational complexity. While the BER performances of all techniques are close, So, we can draw a conclusion that GAPFA-PTS we proposed has better performance in mitigating PAPR of VLC-OFDM signal with no gain of BER than GA-PTS and GH-PTS technique.

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