A Novel SLM Method for PAPR Reduction of OFDM System

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Abstract—**Given that the conventional Selected Mapping (SLM) scheme needs to multiply pseudo-random phase sequences to the transmitted data meanwhile transmitting the whole side information, an exhaustive entropy and chaotic phase sequence based SLM method was proposed for reduction the peak-to-average power ratio (PAPR) of Orthogonal frequency division multiplexing (OFDM) in the paper. In the novel algorithm, exhaustive entropy was used to evaluate the randomness of phase sequence, chaotic sequences to reduce the large side information and improved Lorenz sequence digitalization method to enlarge sequence entropy, expanding the number of the candidate phase sequences vector space with the lower transmitted parameters of phase sequence. Simulation results show that different quantization methods of chaotic sequence have different exhaustive entropy and PAPR values. Furthermore, compared with the traditional SLM method, the new scheme proposed in the paper has better performance in reducing PAPR of OFDM system by about 0.1-0.5dB.**

Keywords–orthogonal frequency division multiplexing (OFDM); peak-to-average power ratio (PAPR); selected mapping (SLM); exhaustive entropy; chaotic sequences

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) as one of the key physical layer technologies for Long Term Evolution (LTE) is a technique with a long history that was not widely used in mobile communications in the past. With the advance in digital signal processing technology, work underway in next generation networks (NGN) exploits the advantages of using OFDM technique expected to provide immense improvements in wireless transmission capacity [1]. Wireless high data rate transmission is required more than before, as is known, but it will cause more severe inter symbol interference (ISI) if single-carrier modulation. Thus OFDM is an attractive technique in which the entire channel is divided into many narrow-band sub-channels robust to the frequency selective fading. However, one of the major drawbacks of OFDM is the high peak-to-average power ratio (PAPR) of the transmitting signal. It will cause the signal distortion because of the nonlinearity of high power amplifier (HPA). Thus, one of the most important researches is the PAPR reduction for the OFDM systems.

A lot of approaches have been proposed to deal with the PAPR problem. These techniques are firstly mentioned in [2]-[9] that achieve PAPR reduction obviously. The schemes can be classified according to whether they are multiplicative or additive and deterministic or probabilistic. Selected mapping (SLM) and partial transmit sequence (PTS) belong to the multiplicative and the probabilistic class. Because in both of the schemes, the transmitter generates a set of candidate data blocks and the phase sequences are multiplied to the input symbol sequences then the system selects one with the lowest PAPR for transmission.

As is well known that SLM is more advantageous than PTS. However, in order to improve the PAPR reduction performance, the computational complexity of SLM will become much larger as the increasing number of candidate phase sequences. It corresponds to the number of Inverse Fast Fourier Transformation (IFFT) required to generate the alternative OFDM signals. So with the invariable number of candidate phase sequences, how to decrease the computational complexity or improve the PAPR reduction performance of SLM has been well investigated these years such as [10]-[11].

It has been mentioned above that the transmitter needs to generate a set of random phase sequences in SLM method. However, the phase sequences are pseudo-random which will decrease the method effectiveness because SLM scheme belongs to the probabilistic class. So the higher random property strength of the candidate phase sequences will increase the probability of the signal with lower PAPR for transmission. Many techniques of evaluating the random property strength of a finite sequence have been proposed. A scheme to measure the exhaustive entropy of sequences was introduced in [13]. It is also known that transmitting the whole side information will increase the system complexity. So the sequence with strong randomness and simple expression is needed. Chaotic sequence produced by chaotic system has good random performance and correlation. It can be defined by only an iterative equation and several initial values without storing any sequence point value, thus it can reduce unnecessary transmitting redundant information. However chaotic sequence is analog signal and quantization need adopted. An appropriate quantization scheme is related to the entropy of chaotic sequences even the PAPR value of OFDM system. Thus a novel SLM scheme based on the exhaustive entropy and chaotic sequences is proposed in this paper. After the proper quantization method and evaluating the random property strength of phase sequences, a better pseudo-random performance of candidate phase sequences will be obtained. Then only several parameters need transmitted. It will make the SLM scheme more effective.

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II. EXHAUSTIVE ENTROPY AND CHAOTIC PHASE SEQUENCE

As the phase sequences generated by traditional SLM method are pseudo-random, it is necessary to improve their complexity to avoid large PAPR and the regular sequence to reduce the side information. One approach to the problem of evaluating the complexity of finite sequences is presented [12]. The adopted complexity measure called exhaustive entropy is related to the number of steps in a self-delimiting production process by which a given sequence is presumed to be generated. It is further related to the number of distinct substrings and the rate of their occurrence along the sequence. Another approach to the problem of considering chaotic sequences as phase sequences is also presented. The chaotic sequence adopted is generated by Lorenz chaotic system. The receiver only need three initial value and iteration times to recover the whole sequence. Thus it can reduce the side information to be transmitted.

A. Exhaustive entropy of a sequence

Before expatiating the subject of exhaustive process of a sequence, the concept of sequences production and reproduction should be introduced. It is expatiated by reference [12]. Thus it can be concluded that reproduction of a sequence is its simple copying procedure, but the last symbol in production of a sequence is innovative.

Reference [13] proposed a scheme to measure random property of a sequence with exhaustive entropy.

The percentage of the *i*th exhaustive component (including the last component which is not exhaustive) approximately equals to its probability p_i, then using the formula

$$H(s) = -\sum_i p_i \cdot \log p_i \tag{1}$$

random property of a sequence can be estimated, where $H(S)$ is the exhaustive entropy of the sequence S. Due to exhaustive process and maximal entropy theorem, if the exhaustive step of the sequence is much larger and the probabilities of all the components equals approximately, the exhaustive entropy of a sequence will be larger, and then the sequence random property will be stronger.

For example,

$$s_1 = \underbrace{0}_{1} \cdot \underbrace{0000000000000000\cdots\cdots 0}_{99}$$

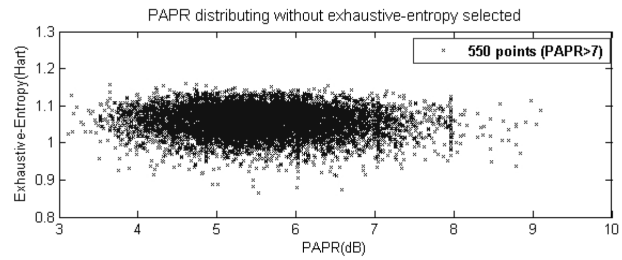
$$s_2 = \underbrace{1}_{1} \cdot \underbrace{0}_{1} \cdot \underbrace{1010101010101010\cdots\cdots 10}_{98}$$

$$s_3 = \underbrace{0}_{1} \cdot \underbrace{001}_{3} \cdot \underbrace{110}_{3} \cdot \underbrace{001110\cdots\cdots 0011101}_{91} \cdot \underbrace{01}_{2}$$

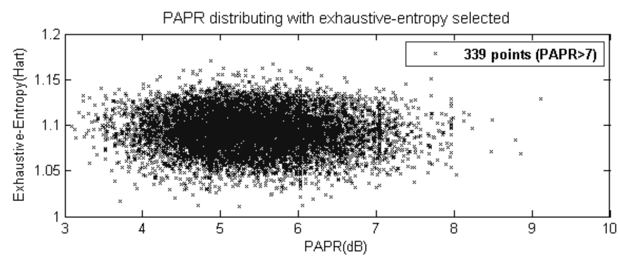
According to the formula (1), the exhaustive entropy of the sequence S_1, S_2, S_3 is 0.0243 Hart, 0.0486 Hart and 0.1826 Hart, respectively. These results coincide with analysis above.

Based on the analysis above and the principle of SLM, it can be presumed that the bigger the exhaustive entropy of a sequence is, the lower an OFDM system's PAPR will become.

Figure 1 describes the PAPR distributing based on exhaustive entropy with 64 subcarriers and 2 phase sequences for BPSK modulation. Fig.1(a) is the PAPR distributing without exhaustive entropy selected. There are 550 points distributed beyond the PAPR threshold 7. On the contrary, Fig.1(b) adopts the exhaustive entropy selected method. There are 339 points distributed beyond the PAPR threshold 7.



(a) PAPR distributing without exhaustive entropy selected



(b) PAPR distributing with exhaustive entropy selected

Figure.1 PAPR distributing based on exhaustive entropy with 64 subcarriers and 2 phase sequences for BPSK modulation

It can be seen that there are less points distributing with exhaustive entropy selected while PAPR>7 than without it. So it can be figured out that the scheme adopted will have a better performance than the conventional SLM scheme.

B. Generation of chaotic phase sequence

The mathematic model of Lorenz chaotic system is as follows

$$\begin{cases} \dot{x} = a(y - x) \\ \dot{y} = cx - y - xz \\ \dot{z} = -bz + xy \end{cases} \tag{2}$$

Where a, b and c are system parameters, when $a = 10$, $b = 8/3$ and $c = 28$, the system is in chaotic state with one of Lyapunov exponents $\lambda_n > 0$.

The Lorenz system can generate three dimensions real chaotic sequences with good randomness and only one of them is needed.

C. Quantitative methods of Lorenz sequence

For chaotic sequence, digitalization is needed to get binary phase sequence. Plenty of schemes have been proposed for quantization [14]. For simple, in some paper, the real sequence is mapped to range $[-0.5, 0.5]$ with the expression (3), and then the binary phase sequence is obtained by formula (4).

$$b_n = b_n - int(b_n) \qquad (3)$$

$$B_n = \begin{cases} 1 & b_n > 0 \\ -1 & b_n < 0 \end{cases} \qquad (4)$$

Where b_n is the sequence generated by Lorenz system, $int(b_n)$ is the integer of b_n, B_n is the binary sequence ready for using.

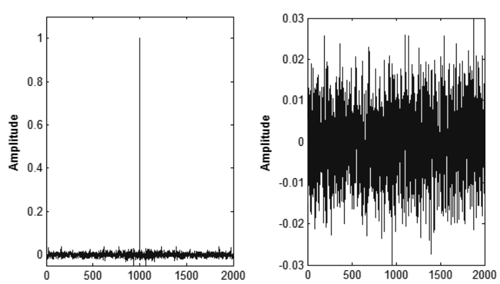
Another digitalization method proposed by [15] to get binary sequences from logistic map, and it is shown in equation (5).

$$T[x(n)] = \begin{cases} 0 & x(n) \in \bigcup_{k=0}^{2^m-1} I_{2k}^m \\ 1 & x(n) \in \bigcup_{k=0}^{2^m-1} I_{2k+1}^m \end{cases} \qquad (5)$$

Where $T[x(n)]$ is the quantification function and it is introduced to convert chaotic signals into binary stream cipher, m is an arbitrary integer $(m>0)$, and $I_0^m, I_1^m, I_2^m, \cdots$ are 2^m continuous equal intervals in $[0,1]$. After converting if the value is in the quantification interval whose beginning is odd, then it will be converted into 1 of binary sequences, and if not, it will be converted into 0. In this paper, Lorenz system is adopted as the original signal. For BPSK modulation, 0 is converted to -1.

The candidate phase sequences of SLM method must have strong randomness. Due to the good random statistical characteristics of chaotic signal, after converting the binary sequences both of the methods have balanced $[-1,1]$ sequences and the good related statistical properties. It is shown that the self-correlation and cross-correlation of the chaotic phase sequence in Fig.2.

It can be seen that the phase sequence has good correlation, for its self-correlation is close to a δ function and cross-correlation reaches to a zero function that will have an excellent performance in SLM method.



(a) Self-correlation (b) Cross-correlation

Figure.2 Correlation of the chaotic phase sequence

However, balanced $[-1,1]$ sequences and good related statistical properties are not enough for SLM candidate sequences. Fig.3 shows the entropy value of the two quantitative methods through Lorenz sequences. It is figured that Entropy 2 has the better entropy performance than Entropy 1. So it can be concluded that quantitative method adopting formula (5) will have a good PAPR reduction performance.

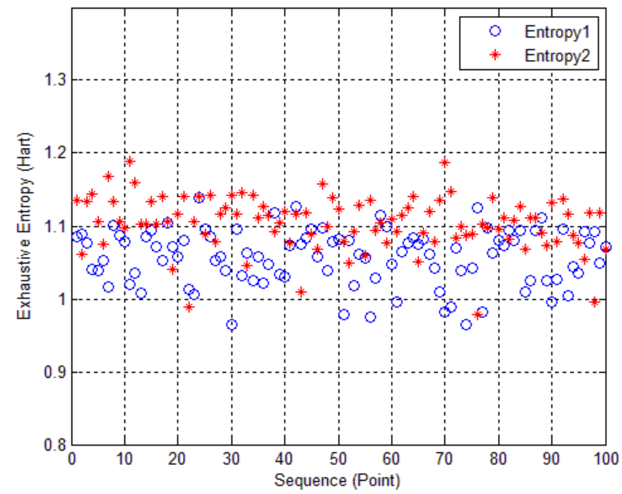


Figure.3 Entropy of binary sequences by different quantitative methods

III. A Novel SLM Scheme Based on Exhaustive Entropy and Chaotic Phase Sequence

An optimization of phase sequences with Lorenz chaotic sequences adopted based on exhaustive entropy is inserted among the approaches of the conventional SLM method. The block diagram of the modified SLM scheme of OFDM systems is shown distinctly in Figure 4. It can be seen that the phase sequences $B(U)$ is optimized before multiplied by X.

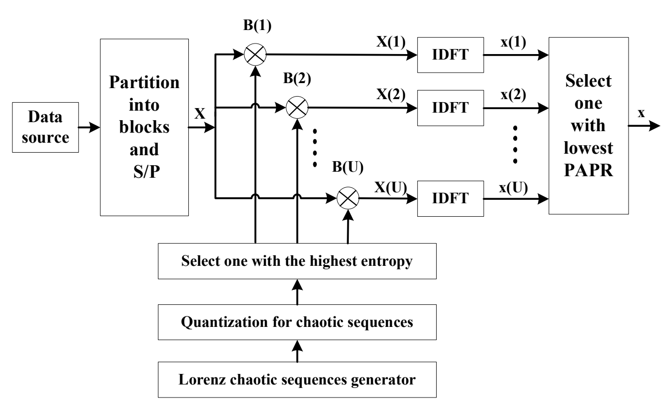


Figure.4 Block diagram of the exhaustive entropy based SLM scheme with chaotic sequence adopted of OFDM systems.

The detail of the modified SLM method as follows

1) The data source are transformed into $X = [X_0, X_1, \cdots, X_{N-1}]^T$ after modulation mapping and serial-parallel conversion where modulation can be BPSK, QPSK or QAM and N represents the number of carriers.

2) Define three initial value to get the Lorenz chaotic system started. Generate chaotic phase sequences

$$\mathrm{B}^{(\hat{\mu})} = \left[\mathrm{B}_0^{(\hat{\mu})}, \mathrm{B}_1^{(\hat{\mu})}, \cdots, \mathrm{B}_{N-1}^{(\hat{\mu})}\right]^T, (\hat{\mu} = 1, 2, \cdots, \mathrm{M}) \qquad (6)$$

where M is the number of phase sequences vector standby generated by formula (2) and (5).

3) Optimize $B^{(\hat{\mu})}$

Calculate the exhaustive entropy of $B^{(\hat{\mu})}$ based on formula (1)

$$H\left(B^{(\hat{\mu})}\right)=\left[H\left(B_0^{(\hat{\mu})}\right),H\left(B_1^{(\hat{\mu})}\right),\cdots,H\left(B_{N-1}^{(\hat{\mu})}\right)\right]^T \quad \left(\hat{\mu}=1,2,\cdots,M\right) \tag{7}$$

then select the maximum of $H\left(B^{(\hat{\mu})}\right)$ and make

$$B^{(i)}=B^{(\hat{\mu}')},\hat{\mu}'\in(1,M),i\in(1,U) \tag{8}$$

where U represents the number of phase sequences vector adopted by SLM method.

Record the iteration time t_μ

$$t_\mu=N\cdot\hat{\mu}',(\mu=1,2,\cdots,U) \tag{9}$$

The process above should be repeated for U times then it can be obtained

$$B^{(\mu)}=\left[B_0^{(\mu)},B_1^{(\mu)},\cdots,B_{N-1}^{(\mu)}\right]^T,(\mu=1,2,\cdots,U) \tag{10}$$

Record the whole iteration number $t=\{t_0,t_1,\ldots,t_{U-1}\}$ set.

4) Point multiplication is performed by source sequences and phase sequences set

$$\begin{aligned}X^{(\mu)}&=\left[X_0^{(\mu)},X_1^{(\mu)},\cdots,X_{N-1}^{(\mu)}\right]^T\\&=X\cdot B^{(\mu)}\\&=\left[X_0B_0^{(\mu)},X_1B_1^{(\mu)},\cdots,X_{N-1}B_{N-1}^{(\mu)}\right]^T\end{aligned} \quad (\mu=1,2,\cdots,U) \tag{11}$$

5) IFFT is performed for $X^{(\mu)}$ and the time domain signal is obtained

$$x^{(\mu)}=IFFT\left(X^{(\mu)}\right) \tag{12}$$

6) The signal with minimum PAPR selected from U time domain signals will be transmitted.

7) At last make

$$t=t_\mu \tag{13}$$

and then three initial value and iteration time t will be transmitted as the side information.

In the conventional SLM scheme, the side information will take N bit for transmission where N represents the number of subcarriers of OFDM system. However, the modified SLM method will only take $\log(NMU)$ bit for transmission. Thus it reduce the side information effectively.

IV. SIMULATION RESULTS AND ANALYSIS

The simulation for the proposed and the conventional SLM schemes is performed for the OFDM system. Results of computer simulations are presented to verify the superiority of the exhaustive entropy and Lorenz chaotic sequences based algorithm.

In the simulation, modulation mode is BPSK, signal sequences are 1000, phase factors are ±1 generated by Lorenz chaotic system, N is the subcarrier number, U is the number of phase sequences vector and M is the number of phase sequences vector standby for exhaustive entropy selected.

Figure 4 shows the PAPR distributing of traditional SLM method and exhaustive entropy based SLM method adopting chaotic sequence with $U=2,4,8,16$ respectively when $N=128$ and $M=8$. It can be figured out that the conventional scheme has well reduced PAPR by about 1dB along with U exponential growth and the optimization scheme proposed by the paper can further reduce PAPR by about 0.2dB even when U is getting higher.

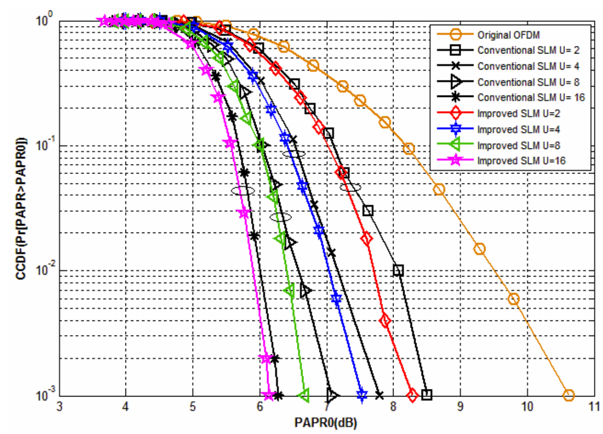


Figure.4 PAPR distributing based on exhaustive entropy adopting chaotic sequences in the different phase sequences number with N=128 and M=8

In Figure 5, the PAPR curves of traditional SLM method and exhaustive entropy based SLM method with new quantitative method(New-Q) and old quantitative(Old-Q) method respectively when $N=128$ and $M=8$. It can be known that the new quantitative method has a better performance in OFDM system. The optimization scheme proposed by the paper can also further reduce PAPR by the maximum of 0.3dB than the original digitalization scheme.

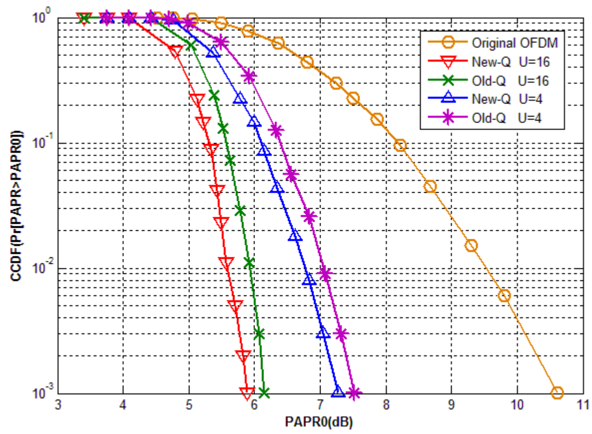


Figure.5 PAPR distributing based on exhaustive entropy adopting chaotic sequences in the different quantitative methods with N=128 and M=8

From the comprehensive comparison of the figures above, it can be obtained that the novel SLM method has a better PAPR reduction performance through new digitalization method and expanding the number of the candidate phase sequences vector space with the lower transmitted parameters of phase sequence.

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V. CONCLUSION

Although SLM scheme is one of the effective methods to reduce PAPR of OFDM signals, the sequences are pseudo-random which will decrease the method effectiveness. A novel SLM scheme for PAPR reduction has been proposed. It is adopted by exhaustive entropy to evaluate the randomness of phase sequence, chaotic sequences to reduce the large side information and new digitalization method to enlarge sequence entropy. It improves the performance with the same number of candidate phase sequences compared with the conventional SLM scheme. Simulation results show that the scheme has a better prospect in reducing PAPR of OFDM system by about 0.1-0.5dB with less transmitted parameters at the same time.

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