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Reducing PAPR in PRS-OFDM System Using Fraction Time-Selective (FTS) Envelope Modification

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Abstract— **Orthogonal Frequency Division Multiplexing (OFDM) is the most promising technique for next generation broadband wireless communication system. The major setbacks of OFDM signal are intercarrier interference (ICI) and high peak-to-average power ratio (PAPR). The purpose of this thesis is to develop mechanisms to reduce ICI and PAPR in OFDM systems. Partial response signaling OFDM (PRS-OFDM) with integer coefficient system has been developed to minimise the ICI. The carrier-to-interference power ratio (CIR) is enhanced by 2.6 dB to 5 dB compared to the normal OFDM. The PAPR has been reduced using Fraction Time-Selective (FTS) Envelope Modification technique. The FTS Envelope Modification PRS-OFDM managed to reduce the PAPR by 0.8 dB to 2.8 dB. Efficient bandwidth usage is achieved by manipulating the PRS-OFDM signal characteristics, where minimal side information (SI) is required due to restricted envelope modification factors.**

Index Terms—**ICI, OFDM, PAPR, PRS**

I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) is a successful technique in wireless communication system. OFDM has been successfully used in many environments, such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), and HiperLAN-II. In a classical orthogonal frequency division multiplexing (OFDM) system, the entire channel is divided into many orthogonal subchannels, and information symbols are transmitted in parallel over these subchannels with a long symbol duration to deal with frequency-selective fading of wireless environments.

However, it has been shown that intercarrier-interference (ICI) destroys orthogonality among subchannels. If not compensated for, the ICI will result in an error floor in the OFDM performance. Several methods have been proposed to reduce the effect of the ICI. One of the method is frequency-domain partial response signaling (PRS). Performing PRS in the time domain has been studied for single-carrier systems to reduce the sensitivity due to time offset without sacrificing the bandwidth. In the frequency domain, the PRS with correlation polynomial $F(D) = 1-D$ was used to mitigate the ICI caused by carrier frequency offset [1]. Nevertheless the summation from the PRS resulted in OFDM signal compression in the time domain [2]. Hence, this leads to the PAPR increment.

This paper is organised as follows. In Section II, integer coefficient PRS-OFDM is mentioned. The CIR and PAPR performance of PRS-OFDM are shown. In this paper, PAPR reduction approach known as Fraction Time Selective (FTS) Envelope Modification technique is used to reduce the PAPR of integer coefficients PRS-OFDM system. In Section III, this distortionless technique is described. Then, in Section IV, the simulation results of FTS Envelope Modification on PRS-OFDM system are presented. The PAPR reduction depends on the modification level and vector size being used.

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II. INTEGER COEFFICIENT PRS-OFDM SYSTEM

The implementation of PRS in OFDM system is illustrated in Fig. 1.

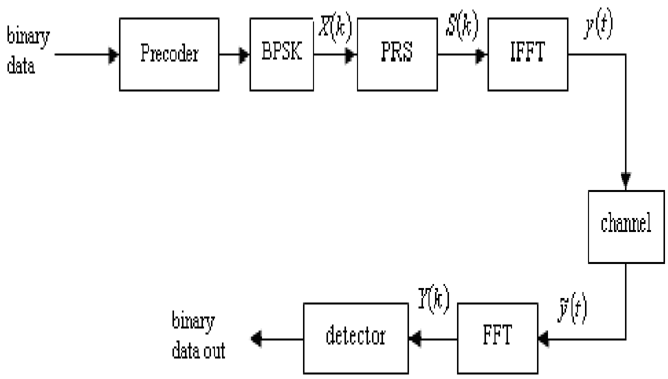

Fig. 1. Baseband model of PRS-OFDM system

To avoid error propagation in PRS, the binary data is precoded first before performing modulation. The signal sequence before PRS is expressed as $X(k)$ where k is subcarriers' index with k=0, 1, …, N-1 and N is given as the total number of subcarriers in OFDM system. By considering BPSK modulation, $X(k)$ consists of -1 and 1 values which, fulfill zero mean and independence conditions. Let $c(i)$ be the integer coefficients for PRS polynomial. The transmitted signal at the kth subcarrier can be expressed as

$$S(k) = \sum_{i=0}^{K-1} c(i) X(k-i) \tag{1}$$

where k=0, 1, …, N-1.

The number of coefficients or length of the polynomial is denoted as K. Without loss of generality, $E[X^2(k)]=1$ and $E[X(k)X(j)]=0$ for $k \neq j$ is assumed. By applying the principle of inverse Fourier transform, the general expression for PRS-OFDM transmission system in time domain, $y(t)$ can be expressed as

$$s(n) = \sum_{k=0}^{N-1} S(k)\, e^{j\frac{2\pi nk}{N}} \tag{2}$$

where n=0, 1, …, N-1.

The PAPR of PRS-OFDM signal is then defined as

$$\text{PAPR} = 10\log_{10} \frac{\max\left\{|s(n)|^2\right\}}{E\left\{|s(n)|^2\right\}} \text{dB} \tag{3}$$

In this paper, the integer coefficients of PRS for the respective polynomial length which maximised CIR are determined through exhaustive search. The benefit of using integer coefficients PRS-OFDM is reduced hardware processing complexity compared to using real-valued coefficient [3]. Table 1 listed the integer coefficients that are found in this work and the CIR gain tabulated from the PRS-OFDM compared to the conventional OFDM system [4]. K=2 has the lowest range of CIR gain while K=5 has the highest gain as the frequency offset is increased from 0 to 0.5. Although K=5 has the highest CIR gain but it's increment is small compared to the gain when K=4. Approximately 0.8% to 0.95% difference is obtained between the two lengths of K. Therefore, K=5 will be neglected in further analysis as shorter length of PRS is recommended and more suitable in the frequency-selective fading.

TABLE I
PRS-OFDM INTEGER COEFFICIENTS AND CIR GAIN COMPARED TO CONVENTIONAL OFDM SYSTEM

K	c_K	min. CIR gain	max. CIR gain
2	1, -1	2.6251 dB	4.0570 dB
3	1, -2, 1	3.0037 dB	4.6577 dB
4	1, -2, 2, -1	3.2056 dB	4.9604 dB
5	1, -3, 4, -4, 2	3.2365 dB	5.0004 dB

In the PAPR comparison study, complementary cumulative distribution function (CCDF) measurements of integer coefficients PRS-OFDM system are carried out. The CCDF of an OFDM signal for a given PAPR level is the probability that the PAPR of the OFDM frame exceeds a certain threshold, PAPR_o. This can be denoted as $\Pr(\text{PAPR} > \text{PAPR}_o)$. The effect of different length of partial response polynomials in reducing the PAPR is studied.

In this measurement, a total of 6 000 OFDM symbols are generated. At every OFDM frame, the PAPR is measured using the formula in (3). Fig. 2 shows the CCDF of integer coefficient PRS-OFDM system. Higher PAPR are produced by performing PRS on OFDM symbols as compared to conventional OFDM signals that have about 10^{-3} probability occurrence at PAPR equals 10 dB. At the same probability, K=3 has the highest PAPR with the value of 13.7 dB whereas for the case of K=4 and K=2 the PAPR are 10.6 dB and 12.6 dB respectively. PRS resulted from summation of other subcarriers signals in the frequency domain Hence, it can be deduced that PRS-OFDM can reduce ICI or enhance CIR at the expense of increased PAPR.

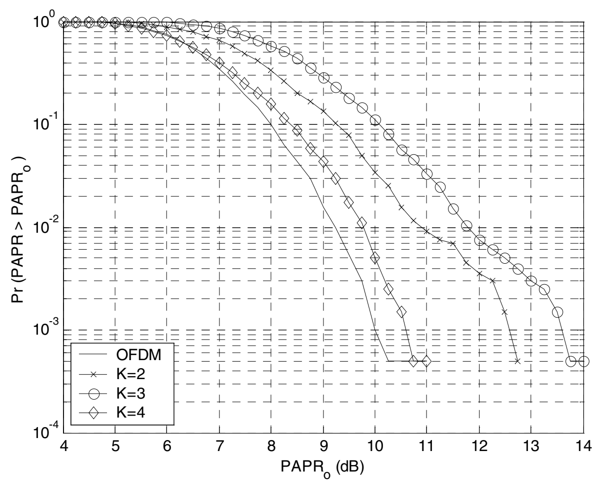

Fig. 2. PAPR comparisons of PRS-OFDM systems

In order to preserve the correlation between the subcarriers in PRS-OFDM system, time-domain manipulative PAPR reduction techniques are the most appropriate techniques to be used. In the next section we look into the development of distortionless PAPR reduction approach known as FTS Envelope Modification on integer coefficients PRS-OFDM system and the effectiveness of the proposed technique in reducing PAPR is elaborated in the following section.

III. FRACTION TIME-SELECTIVE (FTS) ENVELOPE MODIFICATION

Fig. 3 shows the application of FTS Envelope Modification for reducing the PAPR of PRS-OFDM. The FTS envelope modification is applied at the transmission part after performing IFFT. The details about FTS envelope modification approach in reducing PAPR of PRS-OFDM signal is illustrated in Fig. 4. The discrete PRS-OFDM signal, $s(n)$ is firstly partitioned into disjoint subblocks that are combined to minimised the PAPR. Let N be the vectorlength of $s(n)$ which is also equals to the IFFT length and M be defined as the number of disjoint subblocks. This algorithm required the factor of $\frac{N}{M}$ to be integers. For simplicity, adjacent subblock partitioning is chosen in this work [5]. Therefore, every subblock consists of equal index size of time-domain signal and can be represented as,

$$\begin{aligned} \boldsymbol{s} &= \{\boldsymbol{s}_1, \boldsymbol{s}_2, ..., \boldsymbol{s}_M\} \\ &= \{s_0, ..., s_{\frac{N}{M}-1}, s_{\frac{N}{M}}, ..., s_{N-1}\} \end{aligned} \quad (4)$$

As seen in Fig. 4, each transmit sequence is then modified with an modification factor, b_m, where $\{b_m, m=1, 2, ..., M\}$. The modified discrete time-domain vector can be computed as

$$\begin{aligned} \boldsymbol{s}' &= \{\boldsymbol{s}_1', \boldsymbol{s}_2', ..., \boldsymbol{s}_M'\} \\ &= \{b_1\boldsymbol{s}_1, b_2\boldsymbol{s}_2, ..., b_M\boldsymbol{s}_M\} \end{aligned} \quad (5)$$

The modification factor can be selected from $B^{(v)}$ where v indicate the size of vector $\boldsymbol{B}$.

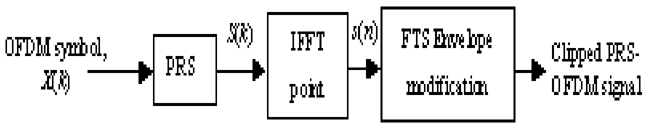

Fig. 3. Integer coefficient PRS-OFDM system with FTS Envelope Modification

PRS-OFDM signal has a feature of having low magnitudes at both ends of the time domain signal and high amplitudes at the middle range due to time-compression introduced by the PRS [2]. To simplify implementation, these characteristics are taken into considerations when developing FTS envelope modification technique. Therefore, in this technique, modification will only be performed in the middle range as this range has high peaks and not on both ends of the PRS-OFDM signal [2]. The first and last element of the weight factor $\boldsymbol{b}$ in (5) is assigned to 1. This can be interpreted, as no modification on both ends of the time domain signal. This would also mean that only the middle disjoint time-domain subblocks are selected for envelope modification. The magnitudes of the weight factors are set to modification, A where $A\leq 1$. In this work, the weight factor for every subblock is chosen based on $A=\sqrt{P_f}$, where P_f is the fraction of power to be transmitted. For example if P_f =50%, A=0.7071. In FTS envelope modification, the information in the PRS-OFDM signal will not be distorted as in the case of clipping [6]. Instead, only a fraction of the total power of the signal will be transmitted depending on the chosen weight factors The weighting factors are carefully chosen by the optimisation function that performs the algorithm to determine the optimised combination of the weighted FTS sequences, which produces the lowest PAPR.

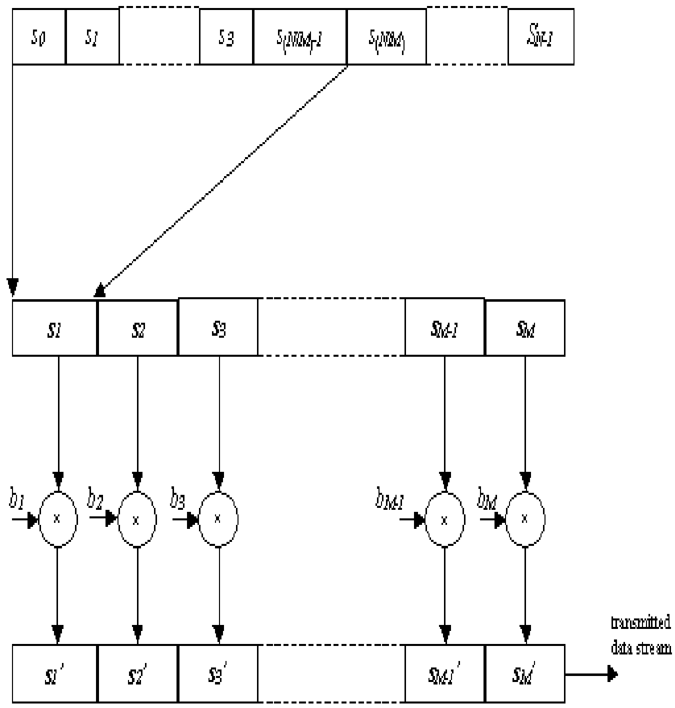

Fig. 4. Time-domain disjoint adjacent subblock partitioning in FTS envelope modification on PRS-OFDM system

After the modification factor combinations have been determined, the first combination will be applied to the disjoint subblock sequences. The PAPR will then be computed for the particular OFDM block and the iteration continues for every factor combination. Once PAPR has been calculated for all the weight combinations, the combination that gives the transmitted time-domain sequence the lowest PAPR will be selected for transmission.

This scheme requires the receiver to have knowledge about the generation of the transmitted OFDM signal. Thus, the weight factors must be transmitted as side information so that the receiver can correct the subcarriers appropriately. However, sending side information (SI) means introducing redundancy that may reduce system efficiency. Nevertheless, it should be pointed out the modification factor in the middle range are the only ones needed at the receiver as the weight factors at both ends are equal to 1 hence resulted in reduced SI transmission. Additionally, being a distortionless scheme, this technique also works with arbitrary type of modulation. In the next section, the PAPR performance of FTS Envelope Modification on PRS-OFDM system is investigated.

IV. PAPR Performance of FTS Envelope Modification PRS-OFDM System

In this study, the proposed FTS envelope modification is explored. Fig. 6 shows the PAPR performance when FTS envelop modification with M=4 is employed. Since modification factor at both ends are set to one, therefore, only two subblocks will be involved in the modification procedure. At 10^{-3} probability, PAPR managed to be reduced by about 0.8 to 2.8 dB depending on the length K. A reduction of 1.5 dB is achieved when K=2 is applied. Meanwhile, K=3 and K=4 has a reduction of 0.8 dB and 2.8 dB respectively. In this case, A has a value of 0.7071 and the PAPR reduction is subjected to magnitude A. The lower the A is, the more PAPR reduction is achieved as shown in Fig. 7. With A=0.7, the PAPR is 11.1 dB but lower PAPR is achieved at A=0.5 where the PAPR is 10 dB.

The effects of the subblock numbers, M and the modification factor vector size, v are also investigated in this work. The more M is, the less number of time-index sequence in a subblock. Nevertheless, from the PAPR performance in Fig. 8, both M=4 and M=8 has the same performance. It should be mentioned that high peaks occur in the middle portion of the time-index sequence of PRS-OFDM signal. Therefore, only the middle subblocks will be attenuated while the ends subblocks remained the same. Hence, the higher M is will not resulted in significant PAPR reduction.

Fig. 9 shows the PAPR performance when different size of vector v is used in FTS envelope modification. The more v is, the more PAPR is reduced. For example, at 10^{-3} probability, PAPR is reduced about 0.8 dB more when v=4 is employed in reducing PAPR of PRS-OFDM system compare to when v=2 is used. It shows that the added degree of freedom in choosing the combination modification factors provides an additional PAPR reduction. The PAPR reduction from the simulation results is sufficient in ensuring that the OFDM signals are within the dynamic region of the power amplifier (PA) in OFDM applications.

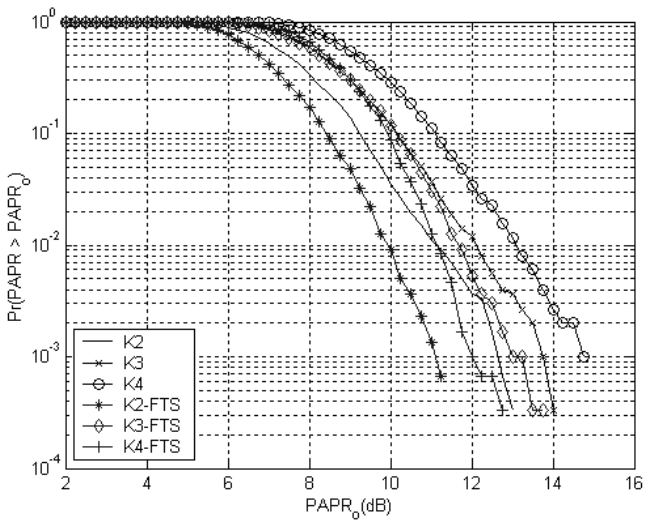

Fig. 6. PAPR performance of FTS Envelope Modification PRS-OFDM system

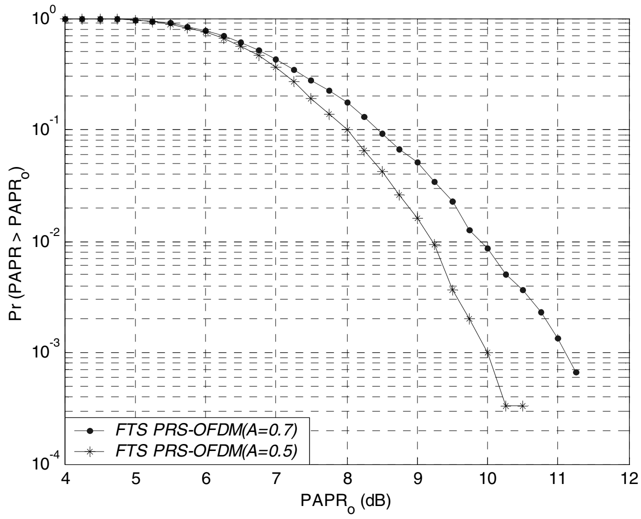

Fig. 7. PAPR performance of FTS Envelope Modification PRS-OFDM (K=2) system with different envelope modification magnitude, A

V. Conclusion

In this paper, PRS-OFDM system has been studied. Firstly, the effectiveness of PRS-OFDM system in enhancing CIR is investigated. Integer coefficient PRS managed to enhance further the CIR of OFDM system by about 2.6 dB up to 5 dB when the length of polynomial, K is 2, 3, 4, and 5 respectively.

However, PRS-OFDM suffers PAPR increment due to the PRS polynomial functions. Fraction Time-Selective (FTS) envelope modification is proposed to reduce PAPR in integer coefficient PRS-OFDM system. This technique is motivated from the PRS-OFDM time-domain characteristics. This distortionless technique is able to reduce the PAPR by 0.8 down to 2.8 dB at 10^{-3} CCDF. PAPR reduction depends on the modification level and vector size. We conclude that this reduced complexity system is feasible and can be applied in future broadband system development such as MIMO-OFDM system.

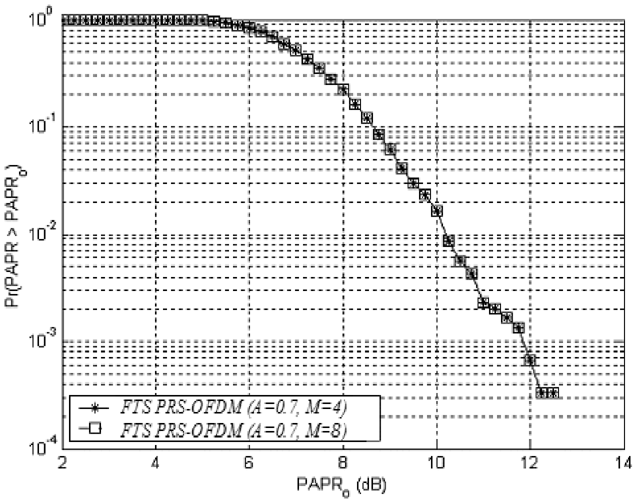

Fig. 8. PAPR performance of FTS Envelope Modification PRS-OFDM system with different subblocks number, *M*

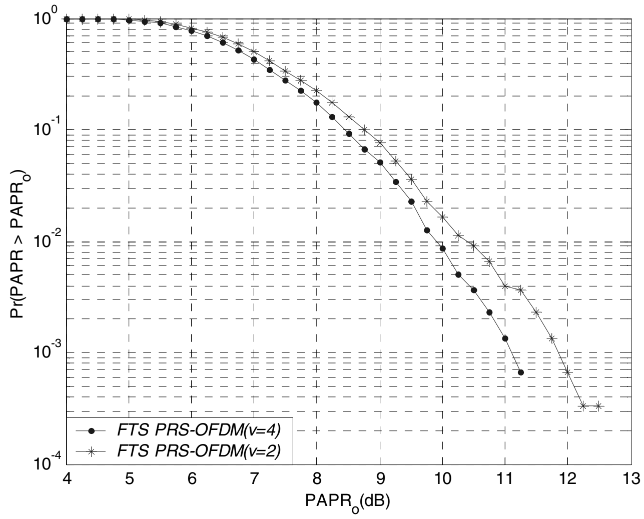

Fig. 9. PAPR performance of FTS Envelope Modification PRS-OFDM system with different modification vector size, *v*

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