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# PAPR Reduction Method for OFDM Signal by Using Dummy Sub-carriers

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***Abstract*—** One of the disadvantages of using OFDM is the larger peak to averaged power ratio (PAPR) in its time domain signal. The larger PAPR signal would course the fatal degradation of bit error rate performance (BER) due to the inter-modulation noise in the non-linear channel. This paper proposes an improved DSI (Dummy Sequence Insertion) method, which can achieve the better PAPR and BER performances. The feature of proposed method is to optimize the phase of each dummy sub-carrier so as to reduce the PAPR performance by changing all predetermined phase coefficients in the time domain signal, which is calculated for data sub-carriers and dummy sub-carriers separately. To achieve the better PAPR performance, this paper also proposes to employ the time-frequency domain swapping algorithm for fine adjustment of phase coefficient of the dummy subcarriers, which can achieve the less complexity of processing and achieves the better PAPR and BER performances than those for the conventional DSI method. This paper presents various computer simulation results to verify the effectiveness of proposed method as comparing with the conventional methods in the non-linear channel.

***Keywords*—** OFDM, PAPR, dummy sub-carriers, non-linear

## I. INTRODUCTION

THE OFDM technique has been received a lot of attentions especially in the field of wireless communications because of its efficient usage of frequency bandwidth and robustness to the multi-path fading. From these advantages, the OFDM has already been adopted as the standard transmission technique in the wireless LAN systems and the terrestrial digital broadcasting system [1-2]. The OFDM technique is also considering as one of the candidate transmission techniques for the next generation of mobile communications systems. One of the limitations of using OFDM technique is the larger peak to averaged power ratio (PAPR) of its time domain signal [3]. The larger PAPR signal would cause the severe degradation of bit error rate (BER) performance due to the inter-modulation noise occurring in the non-linear amplifier. The simple solution to overcome this problem is to operate the non-linear amplifier at the linear region with taking the enough larger input back-off. However, this method degrades the power efficiency of non-linear amplifier, and has serious problem on battery consumption especially for the cases of mobile terminal and portable wireless LAN terminal. In order to maximize the power efficiency of the transmitter, the non-linear amplifier is typically forced to work at near its saturation region, which will lead to the degradation of BER performance due to the inevitably high non-linearity.

From these backgrounds, the PAPR reduction method is recognized as the essential research topic in the employment of OFDM signal in the wireless communications systems. Up to today, various kinds of PAPR reduction methods were proposed including the selected mapping method (SLM) [4], partial transmit sequence method (PTS) [5-6] and dummy sequence insertion method (DSI) [7]. All of these methods can provide the better PAPR performance by controlling the phase of data or dummy sub-carriers. The SLM and PTS methods control the phase of data sub-carrier and the DSI method controls the phase of dummy sub-carriers at the transmission side. First two methods are required to inform the phase information controlled for the data sub-carriers to the receiver as the side information (SI). The side information is required to inform the receiver by using the data channel with the higher signal quality for the correct demodulation of data information. From this fact, the transmission efficiency would be degraded in these two methods. On the other hand, the DSI method is required no side information while the transmission efficiency would decrease slightly due to the dummy sub-carriers. From this reason, the DSI method could be realized with less complexity as compared with the PTS and SLM methods. However, the conventional DSI method proposed in [7] employs the flipping algorithm where the phases of dummy sub-carriers are optimized by using the certain number of discrete predetermined phase values. From this fact, the conventional DSI method has a difficulty to achieve the better PAPR performance as compared with the SLM and PTS methods.

In this paper, we propose a novel phase optimization method for the DSI method by employing the time-frequency domain swapping algorithm, which can improve the PAPR performance. In addition to the time-frequency domain swapping algorithm, the flipping technique is also employed to reduce the complexity in the optimization of phase for the dummy sub-carriers. The proposed DSI method can achieve the better PAPR performance with almost the same complexity as that for the conventional DSI method.

In the following of this paper, Section II presents the system model to be used in the following evaluations. Section III presents the proposed phase optimization method for the

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dummy sub-carriers based on the time-frequency domain swapping algorithm and flipping technique. Section IV presents the various computer simulation results to verify the effectiveness of the proposed method as comparing with the conventional DSI method, and we draw some conclusions in Section V.

## II. System Model

Figure 1 shows the block diagram of OFDM system to be used in the following evaluation. In the figure, the modulated signal in the frequency domain is converted to the time domain signal by IFFT. The time domain signal is given by the following equation.

$$x_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j\frac{2\pi kn}{N}} \quad (1)$$

where N is the number of IFFT points and $X_n$ is the modulated data at k-th sub-carrier. The time domain OFDM signal is input to the non-linear amplifier after adding the guard interval (GI). The output of non-linear amplifier can be expressed by the following equation.

$$s_k = F[|y_k|]e^{j\{\arg(y_k)\}} \quad (2)$$

where, $y_k$ is the input signal of non-linear amplifier and F[ ] represent the AM/AM conversion characteristics of non-linear amplifier. The non-linear amplifier assumed in this paper is the Solid State Power Amplifier (SSPA) of which input and output relationship is modelled by the following equation.

$$F[\rho] = \frac{\rho}{[1+(\rho/A)^{2r}]^{1/2r}} \quad (3)$$

where, ρ is the amplitude of input signal, A is the saturated output level, and r is the parameter to decide the non-linear level. The phase conversion of the non-linear amplifier is assumed to be linear in the following evaluation. Fig.2 shows the AM/AM conversion characteristics of SSPA when changing the parameter of r in Eq.(3). The operation point of non-linear amplifier is defined by the Input Back-Off (IBO), which is given by the following equation.

$$IBO = 10\log\frac{P_{in}}{P_0} \quad (4)$$

where $P_{in}$ is the average power of input signal to the non-linear amplifier and $P_0$ is the input saturation power. The PAPR is defined by the following equation.

$$PAPR = 10\log\left(\frac{P_{max}}{P_{av}}\right) \quad (5)$$

$$P_{max} = \underset{k}{Max}|y_k|^2 \quad (6)$$

$$P_{av} = \frac{1}{N}\sum_{k=0}^{N-1}|y_k|^2 \quad (7)$$

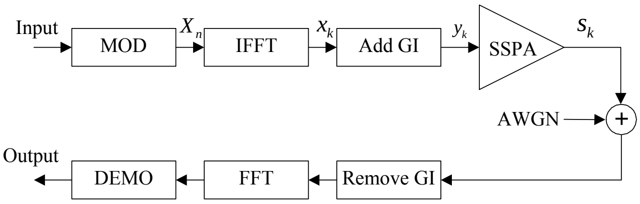



Fig. 1 Block diagram of OFDM system

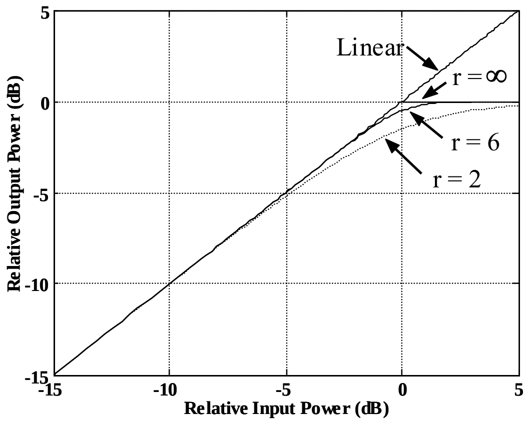



Fig. 2 Input-output relationship of SSPA

## III. Proposal of Phase Optimization Method

This section proposes the phase optimization method for the dummy sub-carriers so as to reduce the PAPR performance. Fig.3 shows the structure of proposed OFDM symbol represented in the frequency domain. The OFDM symbol consists of M data sub-carriers and L dummy sub-carriers that are placed at the both ends of data sub-carriers as shown in Fig. 3. The transmission efficiency of proposed DSI method becomes M/(M+L). In the proposed method, the phase values of dummy sub-carriers are optimized by using the time-frequency domain swapping algorithm and flipping technique, which can achieve the better PAPR performance with the less required number of iterations.

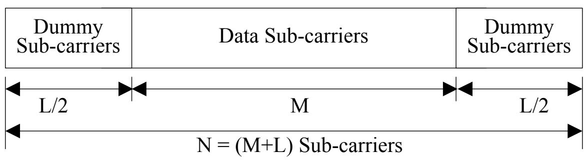



Fig. 3 Structure of proposed OFDM symbol

Figure 4 shows the block diagram of proposed phase optimization method. In the figure, N sub-carriers consisting of L dummy sub-carriers and M data sub-carriers in the frequency domain are converted to the time domain signal by IFFT. Then, the "Phase Optimization" module optimizes the phase of dummy sub-carrier so as to reduce the PAPR performance symbol by symbol. The "Phase optimization" module employs the time-frequency domains swapping algorithm [8]-[9] to optimize the phase of dummy sub-carriers. Since this algorithm is usually required a large number of iterations to achieve the optimum results, "Phase optimization" module also employs the flipping technique [7] to reduce the number of iterations.

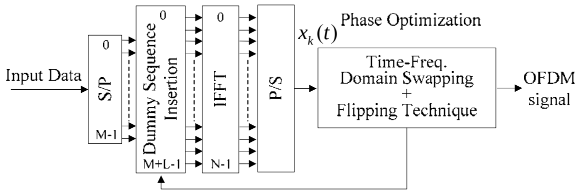



Fig. 4 Block diagram of phase optimization method

Figure 5 shows the flow chart of proposed method. In the proposed method, the target PAPR and the maximum number of iterations are firstly set. The time domain signal consisting of N sub-carriers, which corresponds to the signal before optimization, is given by Eq.(1). In Eq.(1), the initial dummy sub-carriers are given by the following equation.

$$X_n = e^{j\theta_n} \quad \begin{cases} n = 0,\cdots,(L/2-1) \\ n = (M+L/2),\cdots,(N-1) \end{cases} \tag{8}$$

where, $X_n$ has the constant amplitude and $\theta_n$ is given by the random phase.

The basic principle of this algorithm is to find higher peak level in the time domain signal of Eq.(1) than the reference level of S and calculate the error signal defined by the following equation as the i-th iteration.

$$e_k^{(i)} = \begin{cases} \left(\left|x_k^{(i)}\right| - S\right) \cdot e^{j\arg(x_k^{(i)})} & if \ \left|x_k^{(i)}\right| \geq S \\ 0 & if \ \left|x_k^{(i)}\right| < S \end{cases} \tag{9}$$

The reference parameter S is decided on the basis of the average power of input signal. The time domain error signal given by Eq. (9) is converted to the frequency domain signal by FFT, which is given by the following equation.

$$E_n^{(i)} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} e_k^{(i)} \cdot e^{-j\frac{2\pi kn}{N}} \tag{10}$$

By using Eq.(10), the phase values are calculated only for the dummy sub-carriers. The obtained phase value is subtracted from the original frequency domain signal given by Eq.(8). The phase optimization is processed only for the dummy sub-carriers and the data sub-carriers are kept the same as the original signal. The frequency domain signal to be used at the next iteration (i+1) is given by the following equation.

$$X_n^{(i+1)} = \begin{cases} e^{j\arg\left\{X_n^{(i)} - E_n^{(i)}\right\}} & n = 0,\cdots,(L/2-1) \\ X_n^{(i)} & n = L/2,\cdots,\left(M+L/2-1\right) \\ e^{j\arg\left\{X_n^{(i)} - E_n^{(i)}\right\}} & n = \left(M+L/2\right),\cdots,\left(N-1\right) \end{cases} \tag{11}$$

In the time-frequency swapping algorithm, Eqs.(8) to (11) are repeated up to reach the optimum results. In the proposed method, the flipping technique is also employed to reduce the number of iteration as similar to the conventional DSI method. In the flipping technique, the PAPR is calculated by changing the phase of each dummy sub-carrier as +1 or −1 sequentially. If the new PAPR is lower than the previous result, the new phase will retain as part of the final phase sequence. Otherwise, the phase reverts to its previous value. These processing will perform for all dummy sub-carriers. As shown in Fig.5, the time-frequency domain swapping algorithm and flipping technique will repeat up to reaching either of the predetermined target PAPR or the maximum number of iterations.

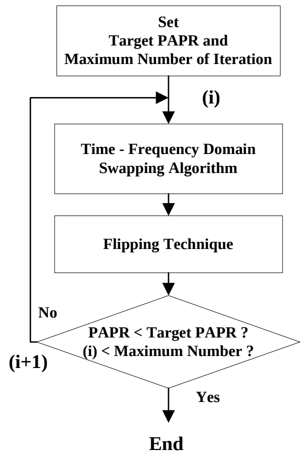



Fig. 5 Flow chart of proposed algorithm

## IV. Performance Evaluations

This section presents the various computer simulation results to verify the performance of proposed method. The simulation parameters to be used in the following evaluations are shown in Table 1.

Figure 6 shows the PAPR performance for the conventional DSI and proposed DSI methods when changing the number of dummy sub-carriers. The PAPR performance for the conventional OFDM is also shown in the figure as the purpose of comparison. In the figure, the PAPR performance is evaluated by using the Cumulative Distribution Function (CDF). From the figure, it can be observed that the proposed DSI method shows the better PAPR performance as increasing the number of dummy sub-carriers, while the transmission efficiency decreases. It can be also observed from the figure that the proposed DSI method can achieve the better PAPR performance than that for the conventional DSI method.

TABLE I
SIMULATION PARAMETERS

| | | |
|---|---|---|
| Modulation | 16QAM or 64QAM | |
| Demodulation | Coherent | |
| Allocated bandwidth | 10MHz | |
| Number of FFT points | 256 | 512 |
| Number of sub-carriers | 64 | 128 |
| Symbol duration | 6.4us | 12.8us |
| Guard interval | 0.64us | 1.28us |
| Number of dummy sub-carriers | 16 | 32 |
| Non-linear amplifier | SSPA | |
| Non-linear parameter of SSPA | r=2 | |

Figure 7 shows the PAPR performance both for the conventional and proposed DSI methods when changing the number of iteration. From the figure, it can be seen that the proposed DSI method with the larger dummy sub-carriers requires slightly larger number of iterations for the convergence of PAPR performance than that for the conventional DSI method. It can be also observed that the proposed DSI method can achieve the better PAPR performance than the conventional DSI method by the acceptable small number of iterations with less than 20 iterations even for the larger number of dummy sub-carriers.

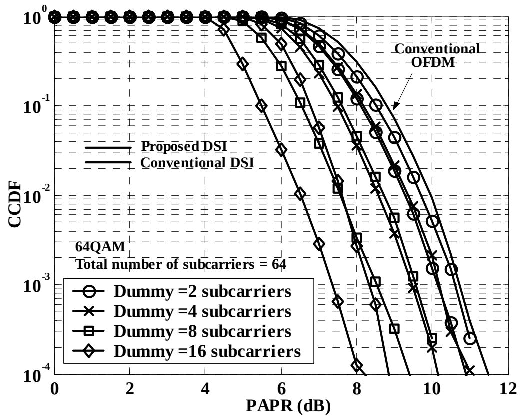



Fig. 6 PAPR performance of proposed DSI method

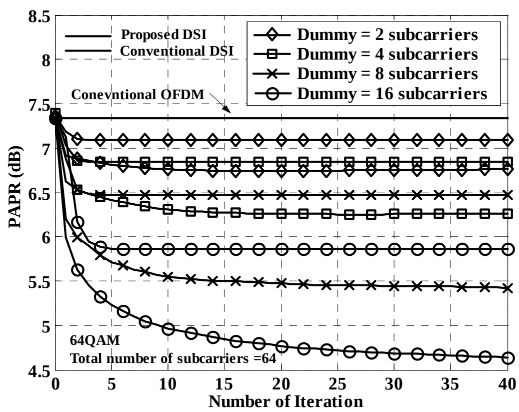
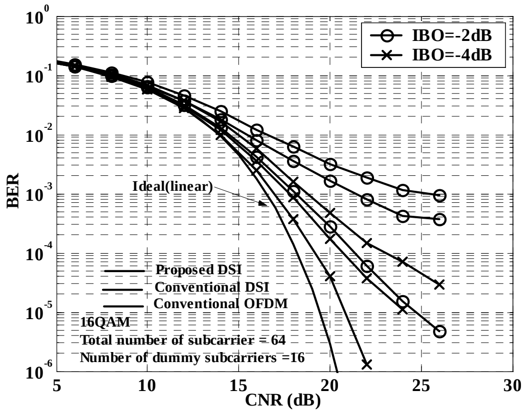
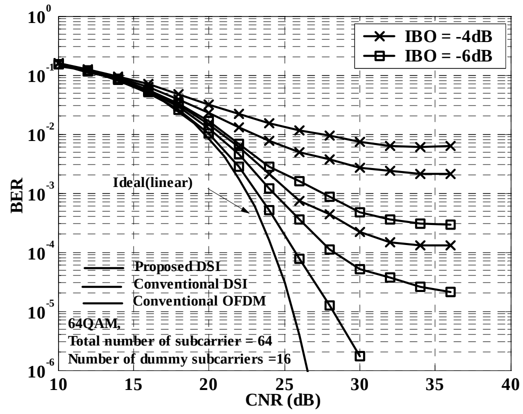



Fig. 7 PAPR performance versus number of iterations

Figure 8 shows the BER performances for the proposed and conventional DSI methods in the non-linear channel when the modulation methods are 16QAM and 64QAM. In the simulation, the number of total sub-carriers is 64 including 48 data and 16 dummy sub-carriers and the non-linear parameter r for SSPA is 2. Fig. 9 also shows the BER performances when the number of total sub-carriers is 128 consisting of 96 data and 32 dummy sub-carriers. The BER performances of conventional OFDM method are also shown in these figures. As for the modulation method of 16QAM, the proposed DSI method can achieve much better BER performance than those for the conventional OFDM and DSI methods. The proposed DSI method when IBO is –4dB, shows almost the same BER performance as that of Ideal performance. Here, Ideal means the BER performance in linear channel. As for the modulation method of 64QAM, the proposed DSI method when IBO is –6dB can achieve the much better BER performance than the conventional OFDM and DSI methods. From these results, it can be concluded that the proposed DSI method can achieve the better BER performance in the non-linear channel at the cost of small degradation of transmission efficiency.




(a) 16QAM

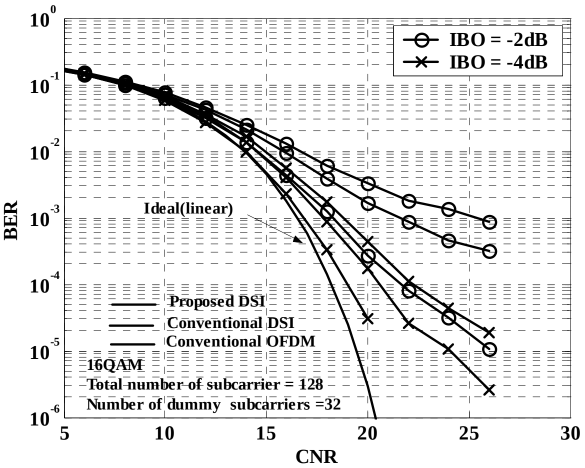



(b) 64QAM

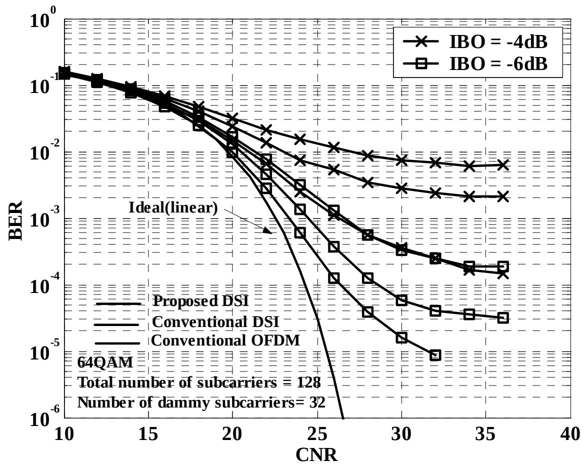
Fig. 8 BER performance of proposed DSI method in non-linear channel

## V. Conclusions

In order to maximize the power efficiency of non-linear amplifier for the transmission of OFDM signal, the power amplifier is usually forced to work at near its saturation region, which would lead to inevitably degradation of BER performance. In this paper, we proposed the PAPR reduction method for the OFDM signal by using the dummy sub-carriers. The feature of proposed method is to employ the time-frequency domain swapping algorithm and flipping technique for improving the PAPR performance with less complexity at the transmission side. From the various computer simulation results, we confirmed that the proposed DSI method could achieve the better PAPR performance and better BER performance in the non-linear channel than that for the conventional DSI method.




(a) 16QAM




(b) 64QAM

Fig. 9 BER performance of proposed DSI method in non-linear channel

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## REFERENCES

[1] IEEE Std. 802.11a, High-speed Physical Layer in the 5GHz Band,1999.

[2] IEEE 802.16 WG, "SC-FDE PHY Layer System Proposal for Sub 11GHz BWA", March 2001.

[3] D Dardari, V. Tralli and A Vaccari, "A Theoretical Characterization of Nonlinear Distortion Effects in OFDM Systems," IEEE Trans. on Comm., Vol. 48, no. 10, pp.1775-1764, Oct 2000.

[4] R. W. Bauml. R. F. H. Fischer and J.B. Huber, "Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping," IEEE Electro. Lett., vol. 32. no.22 pp.2056-2057, Oct. 1996.

[5] Leonard J. Cimini Jr., Nelson R. Sollenberger, "Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences", IEEE Communications Letters, vol. 4, no. 3 pp. 86-88, March 2000.

[6] S. H. Muller and J. B. Huber, "OFDM with reduce peak-to-average power ratio by optimum combination of partial transmit sequences," Electron. Lett., vol. 33, no. 5, pp. 368–369, Feb. 1997.

[7] Heung-Gyoon Ryu, Jae-Eun Lee and Jin-Soo Park, "Dummy Sequence Insertion (DSI) for PAPR Reduction in the OFDM Communication System," IEEE Transactions on Consumer Electronics, Vol. 50, No. 1, Feb 2004.

[8] M. Friese, "Multitone Signals with Low Crest Factor", IEEE Trans. Commun., vol. 45, pp. 1338–1344, Oct 1977.

[9] E. V. Der Oudera, Schoukens and J.Renneboog., "Peak Factor Minimization Using a Time-Frequency Domain Swapping Algorithm," IEEE Trans Instrum. Meas. vol.37, pp145-147, Mar 1988.