

Fast Dummy Sequence Insertion Method for PAPR Reduction in WiMAX Systems

Peerapong Uthansakul, Sakkarin Chaokuntod, and Monthippa Uthansakul

Abstract—In literatures, many researches proposed various methods to reduce PAPR (Peak to Average Power Ratio). Among those, DSI (Dummy Sequence Insertion) is one of the most attractive methods for WiMAX systems because it does not require side information transmitted along with user data. However, the conventional DSI methods find dummy sequence by performing an iterative procedure until achieving PAPR under a desired threshold. This causes a significant delay on finding dummy sequence and also effects to the overall performances in WiMAX systems. In this paper, the new method based on DSI is proposed by finding dummy sequence without the need of iterative procedure. The fast DSI method can reduce PAPR without either delays or required side information. The simulation results confirm that the proposed method is able to carry out PAPR performances as similar to the other methods without any delays. In addition, the simulations of WiMAX system with adaptive modulations are also investigated to realize the use of proposed methods on various fading schemes. The results suggest the WiMAX designers to modify a new Signal to Noise Ratio (SNR) criteria for adaptation.

Keywords—WiMAX, OFDM, PAPR, Dummy Sequence Insertion method.

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) is a technique to provide high spectrum efficiency [1] by increasing density of subcarriers. The advantages of OFDM are robust to ISI (Inter Symbol Interference) and multipath fading. With these benefits, OFDM technique has been adopted for many standards such as DAB (Digital Audio Broadcasting) system, DVB (Digital Video Broadcasting) system, wireless LAN (IEEE 802.11x), WiMAX, etc. However, it is a nature of OFDM signal to face the problem of high PAPR (Peak to Average Power Ratio). This deficiency occurs when the peak power is much higher than the range of amplifier, resulting in a clipping of the peak signal. Hence, larger linear range of amplifier must be required to protect the

clipped signal. In practice, the cost of such an amplifier is very expensive and also the energy consumption is inefficient.

In literature, many methods have been proposed to solve a problem of high PAPR. For example clipping method [2-3], this method is very simple by clipping the parts of the signals which are outside the allowed region. The disadvantage of this method is to provide the low performance of BER. In [4-5], SLM (SeLective Mapping) method multiplies the several phase sequences in OFDM data after IFFT operation and selects the sequence of the lowest PAPR to transmit. But this method necessarily requires the side information on phase rotation to transmit along with user data to the receiver. It results in lower data rate. In [6-7], PTS (Partial Transmit Sequence) method is similar to SLM method but its difference is on multiplying the phase factor after IFFT operation. For DSI (Dummy Sequence Insertion) method [8-9], it employs the dummy sequence adding to the data in order for PAPR reduction. This method is simpler than SLM and PTS methods because it does not require side information. For WiMAX system, it is more practical to apply DSI than SLM or PTS. This is because SLM and PTS require the change in air interface protocol but not for DSI. Moreover, the data frame of WiMAX affirmably supports the ease of applying DSI method. According to IEEE 802.16, the data frame of OFDM signal is allocated by 256 subcarriers which is composed of 192 data subcarriers, 1 zero DC subcarrier, 8 pilot subcarriers, and 55 guard subcarriers. Therefore, the dummy sequence can be added within the slot of 55 guard subcarriers without degradation of user data.

To obtain the suitable dummy sequence, DSI method has to perform the iterative procedure by changing the possible sequences until its PAPR is under the desired threshold. The delay due to iterations is unpredictable and it is changed from one data frame to another. This causes an unnecessary delay added in the system and also it provides the unreliability on data rate transmission. In this paper, the new approach of DSI to find suitable dummy sequence is proposed. It does not require any iterative procedures so the fast PAPR reduction can be achieved. The proposed method is also convenient to implement because the suitable dummy sequence is obtained by a close-form solution.

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For wireless applications, the signals are transmitted over propagation environments to the receiver. Ideally, there is only noise adding on signals which is referred as AWGN (Additive White Gaussian Noise) channel. However, such a condition has hardly been met under indoor environment [10-11]. In literatures on PAPR reduction techniques, the system performances were only considered by AWGN channel. Therefore, it is wondered whether these techniques are able to be implemented for any propagation environments. Also in this paper, the indoor propagation model based on Stanford University Interim is adopted to generate the wireless channel for WiMAX signals using PAPR reduction technique. The BER (Bit Error Rate) performance is evaluated to justify the real influence caused by PAPR reduction technique. In addition, the effect of amplifier is also considered by adopting the solid state power amplifier model [12].

In summary, the contributions of this paper are i) the original proposal of PAPR reduction based on DSI method ii) the close-form solution of proposed method which does not require either delays or side information and iii) its performances under various fading schemes.

The remainder of paper is organized as follows. Section II firstly provides the basic concept of DSI method and then the proposed technique is presented. In Section III, the details of WiMAX system models are given including data frame, adaptive scheme, channel model and amplifier model. These models are ground for simulating the results in Section IV. Finally, the conclusion of this paper is presented in Section V.

II. FAST DUMMY SEQUENCE INSERTION METHOD

A. Basic concept of DSI method

This method is simpler to implement than SLM method because it is not necessary to transmit side information. The block diagram of basic DSI method is shown in Fig. 1. The input data stream is divided into parallel B bits in the serial to parallel converter. Then, D-bit dummy sequence is added. Dummy sequence may be selected from correlation sequence or complementary sequence [13] to reduce PAPR. If the PAPR is lower than threshold value, it is transmitted. Otherwise, another dummy sequence is inserted instead of old sequence until its PAPR is lower than desired threshold level. The comparator is able to measure PAPR after IFFT processing so it wastes a significant delay to achieve an expected PAPR.

B. Proposed DSI method

The new approach to find the suitable dummy sequence without the use of iterative procedure is to estimate the close-form solution of dummy sequence when knowing the input data sequence. The block diagram of proposed DSI method is illustrated in Fig. 2. As seen in Fig. 2, only the block of proposed algorithm is required while deleting the iterative loop shown in Fig. 1. The following task presents the derivation of close-form solution.

Assuming one OFDM frame having N subcarriers, then the signal after IFFT operation is given by

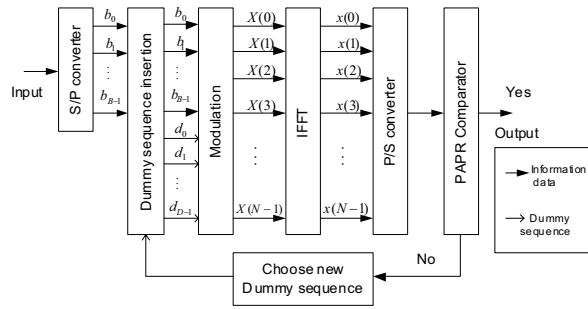


Fig. 1 The block diagram of basic DSI method

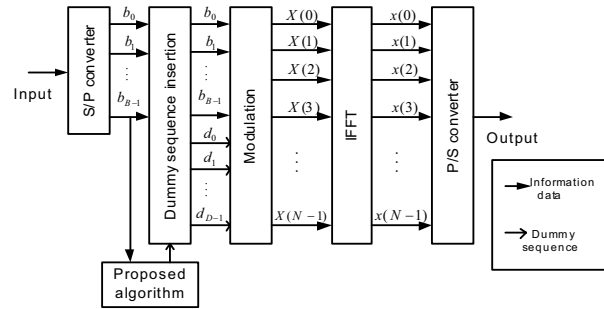


Fig. 2 The block diagram of proposed DSI method

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

Where $X(k)$ is the input signal sampled at k th time whose amplitude and phase are determined by modulation types.

From (1), the PAPR can be defined as

$$PAPR = \frac{P_{peak}}{P_{av}} = \frac{\max |x(n)|^2}{E[|x(n)|^2]} \quad (2)$$

Where $E[\cdot]$ is the operation of expectation.

By assigning the dummy sequence into D subcarriers, then the expression in (1) can be rewritten into a matrix form as shown in (3).

$$\mathbf{x} = \mathbf{W}_{N-D} \mathbf{X}_{N-D} + \mathbf{W}_D \mathbf{X}_D \quad (3)$$

where

$$\mathbf{W}_{N-D} = \frac{1}{\sqrt{N}} \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & e^{j2\pi/N} & \cdots & e^{j2\pi(N-D-1)/N} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & e^{j2\pi(N-1)/N} & \cdots & e^{j2\pi(N-1)(N-D-1)/N} \end{bmatrix}$$

$$\mathbf{W}_D = \frac{1}{\sqrt{N}} \begin{bmatrix} 1 & \cdots & 1 \\ e^{j2\pi(N-D)/N} & \cdots & e^{j2\pi(N-1)/N} \\ \vdots & \ddots & \vdots \\ e^{j2\pi(N-1)(N-D)/N} & \cdots & e^{j2\pi(N-1)(N-1)/N} \end{bmatrix}$$

Note that \mathbf{X}_D and \mathbf{X}_{N-D} is the vector of dummy sequence and input signals which are allocated at the first $N-D$ subcarriers and the last D subcarriers of OFDM frame, respectively.

As noticed in (2), the problem to find a suitable dummy sequence is established by

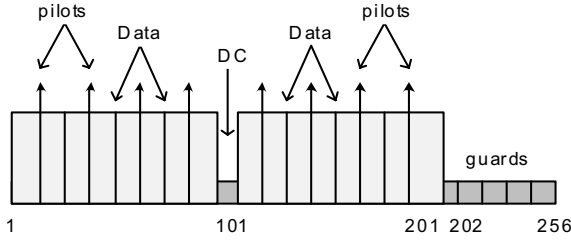


Fig. 3 Channel allocation of WiMAX data frame

$$\mathbf{X}_D = \arg \min_{\mathbf{x}_D} \left(\max \left\{ |x(n)|^2, \forall n \right\} - E[|x(n)|^2] \right), \forall n \quad (4)$$

Considering (4), the best PAPR is equal to 1 when $|x(n)|^2$ is close to $E[|x(n)|^2]$ for all n . Hence, the optimal problem can be rewritten as

$$\mathbf{X}_D = \arg \min_{\mathbf{x}_D} \left(\sum_n \left(|x(n)|^2 - E[|x(n)|^2] \right) \right) \quad (5)$$

Applying (3) into (5), then the summation of peak deviations from average value is expressed as

$$J(\mathbf{X}_D) = \left(\mathbf{W}_{N-D} \mathbf{X}_{N-D} + \mathbf{W}_D \mathbf{X}_D - \sqrt{E[|x(n)|^2]} \mathbf{1}_{N \times 1} \right)^H \cdot \left(\mathbf{W}_{N-D} \mathbf{X}_{N-D} + \mathbf{W}_D \mathbf{X}_D - \sqrt{E[|x(n)|^2]} \mathbf{1}_{N \times 1} \right) \quad (6)$$

Where $(\cdot)^H$ is the conjugate and transpose operation and $\mathbf{1}_{N \times 1}$ is the $N \times 1$ column vector whose each entry is equal to 1.

By taking $\partial J(\mathbf{X}_D) / \partial \mathbf{X}_D = 0$, the optimal solution can be found by

$$\mathbf{X}_D = (\mathbf{W}_D^H \mathbf{W}_D)^{-1} \mathbf{W}_D^H \left(\mathbf{W}_{N-D} \mathbf{X}_{N-D} - \sqrt{E[|x(n)|^2]} \mathbf{1}_{N \times 1} \right) \quad (7)$$

From (7), the suitable dummy sequence signals can be achieved. It is clearly seen that there is no need of either using iterative procedure or sending side information. In such a way, the fast and simple processing can be implemented for WiMAX systems. In addition, the proposed PAPR reduction is able to be applied on any available WiMAX protocols.

The solution in (7) is required to know only the average power of signal which can be calculated by Parseval's theorem as shown in (8).

$$\begin{aligned} E[|x(n)|^2] &= \frac{1}{N} \sum_{n=0}^{N-1} |x(n)|^2 \\ &= \frac{1}{N^2} \sum_{k=0}^{N-1} \sum_{k'=0}^{N-1} X(k) X(k')^* e^{j2\pi(k-k')/N} \\ &= \frac{1}{N} \sum_{k=0}^{N-1} |X(k)|^2 = E[|X(k)|^2] \end{aligned} \quad (8)$$

Where $(\cdot)^*$ is the conjugate operation.

It is noticed in (8) that the average power of signal after IFFT operation is the same as average power of input signal which depends on its modulation technique. For WiMAX systems, there are four modulation types used for adaptive schemes; 2-PAM, 4-QAM, 16-QAM and 64-QAM. Then it is easy to estimate the average power of each modulation by considering its signal constellation.

TABLE II
NUMBER OF ITERATIONS REQUIRED FOR FINDING DSI IN EACH OFDM FRAME, $D=8$

Modulation types	DSI Methods	Average	Standard Deviations	Maximum iterations
2-PAM	Method 1	2.548	18.695	241
	Method 2	1.482	3.768	31
	Proposed	1	0	1
4-QAM	Method 1	1.510	4.224	241
	Method 2	1.060	1.341	31
	Proposed	1	0	1
16-QAM	Method 1	2.382	15.799	241
	Method 2	1.446	3.532	31
	Proposed	1	0	1
64-QAM	Method 1	8.35	37.317	241
	Method 2	2.858	6.926	31
	Proposed	1	0	1

III. SYSTEM MODELS

A. WiMAX data frame

WiMAX data frame employs OFDM format with 256 subcarriers. The detail of WiMAX data frame is described by IEEE 802.16e shown in Fig. 3. As seen in this figure, the guard band interval is allocated by 55 subcarriers. As a result, the DSI method is able to add the dummy sequence into these subcarriers without any data interruptions or data rate degradations. Hence, the maximum DSI insertion is available for $D = 55$.

B. Adaptive modulation schemes

For modulation types of OFDM signals, all four modulation types (2-PAM, 4-QAM, 16-QAM and 64-QAM [8]) according to adaptive modulations in WiMAX system are undertaken here. Also the rule of adapting modulation types at BER is as following, 2-PAM for SNR < 8 dB, 4-QAM for SNR at 8-10 dB, 16-QAM for SNR at 11-18 dB and 64-QAM for SNR > 18 dB.

C. Propagation model

The channel model for fixed wireless communication is considered here. The SUI (Stanford University Interim) [13] channel models are adopted in simulation. SUI channel models consist of low delay spread, moderate delay spread and high delay spread. In this paper, the SUI-3 channel is selected which its definition is shown in the Table I.

D. Amplifier model

As mentioned on high PAPR for OFDM signal, the serious problem is occurred when implementing a practical amplifier on such a system. To realize this effect, the amplifier model is necessary to be included in simulation. This paper adopts the concept of solid state power amplifier [12] which is expressed in (9) and (10).

$$s(n) = F[|x(n)|] e^{j \arg(x(n))} \quad (9)$$

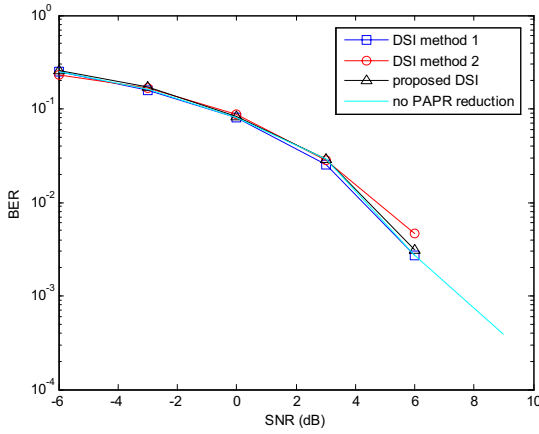


Fig. 5 BER performance for proposed DSI method, method 1, method2 and no PAPR reduction, 2-PAM modulation

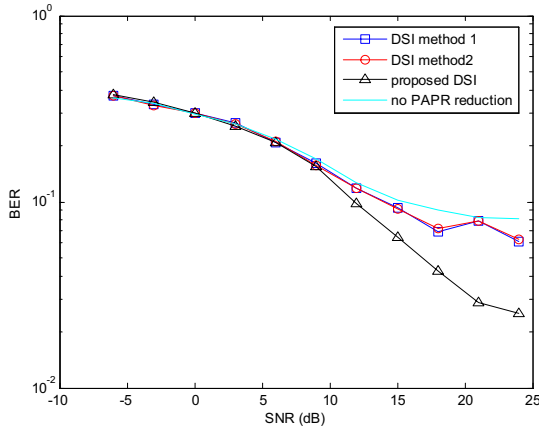


Fig. 6 BER performance for proposed DSI method, method 1, method2 and no PAPR reduction, 16-QAM modulation

$$F[\rho] = \frac{\rho}{[1 + (\rho/A)^{2\beta}]^{1/2\beta}} \quad (10)$$

Where ρ is the amplitude of input signal, A is the saturated output level, and β is the parameter to decide the non-linear level. In simulation, A is set to 8 and β is set to 2 for all simulations.

IV. SIMULATION RESULTS

In this paper, the results of proposed DSI method are compared with the other DSI methods presented in literatures. We select two methods from [14] referred here as method 1 and method 2 because they offer the best performance in PAPR reduction. Method 1 obtains the dummy sequence from changing bit by bit while method 2 gains the dummy sequence from input information. Both methods require the iterative procedure to get the suitable sequence for each OFDM block. In simulations, the length of dummy sequence is set to 8, $D = 8$, and the threshold level is 15 dB for both methods.

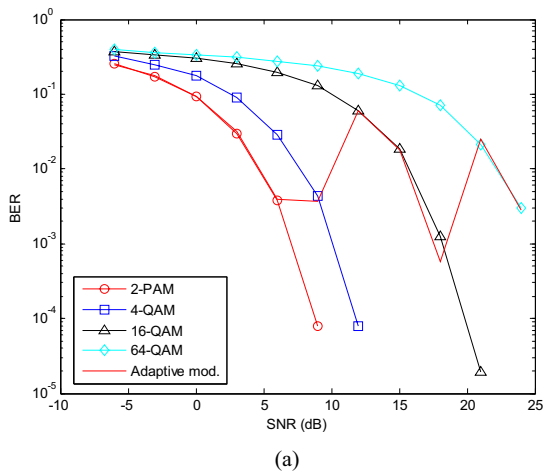
Fig. 4 presents the complimentary cumulative distribution function of PAPR for proposed DSI method in comparing with method 1 and method 2. As seen in Fig. 4, all PAPR reduction methods provide lower PAPR than the system using no PAPR reduction method, for all modulation types. The proposed DSI method with $D = 8$ has its capability of reducing PAPR as similar to other DSI methods presented in literatures but its advantageous is no iterative processing required to find the suitable dummy sequence. The authors did more simulations on Bit Error Rate (BER) but still the results provide the same performance when using proposed method, method1 and method 2. Hence, for saving space in this paper, the BER performance is not presented here. Also noticed in Fig. 4, the results of proposed method with $D = 8$ and 55 are compared. The better performance is achieved when more subcarriers are assigned by dummy sequence. In addition, the performance of $D = 55$ implies the best PAPR reduction in WiMAX systems because of the maximum limit of guard interval in WiMAX data frame.

The number of iterations required for finding the dummy sequence in each OFDM frame, $D = 8$, is presented in Table II. As expected, method 1 requires the most number of iterations because this method tries bit by bit until getting the desired solution. For method 2, it utilizes the input information so that the number of iterations is much less than method 1 but still higher than proposed method. The results in Table II show the undesirable delays caused by method 1 and method 2 whereas the proposed method does not cause any delay. These delays are unpredictable and cause the system with unreliable transmission rate. Therefore, the choice of using proposed method seems to be more practical.

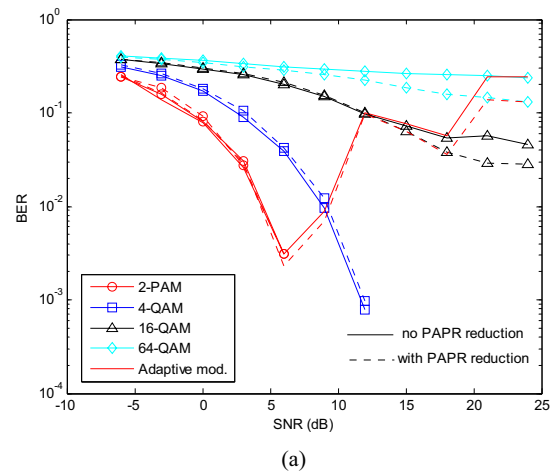
Fig. 5 and 6 show BER performance for proposed DSI, DSI method 1, DSI method 2 and no PAPR reduction for 2-PAM and 16-QAM respectively. Only two modulation types are shown because the rest types provide the similar trend. As seen in Fig. 5 and 6, BER performance of proposed technique is similar to the other methods. However, BER performance of all PAPR reduction techniques is better than no PAPR reduction when modulation types is changed from 2-PAM to 16-QAM. The effect of high PAPR is more pronounced for more number of constellations, M-QAM. This is because the high order of modulation increases high peak power then it causes the signal clipped by amplifier.

Fig. 7 shows BER performance of each modulation under AWGN and indoor channels. As seen in Fig. 7(a), the adaptive modulation works very well in AWGN channel but it fails under indoor channel. In Fig. 7(b), BER performance of adaptive scheme is worse when SNR is higher. Also the performance of each modulation is worse when the system is operated under indoor channels. This reveals the truth that adaptive modulation cannot be well performed under indoor environments.

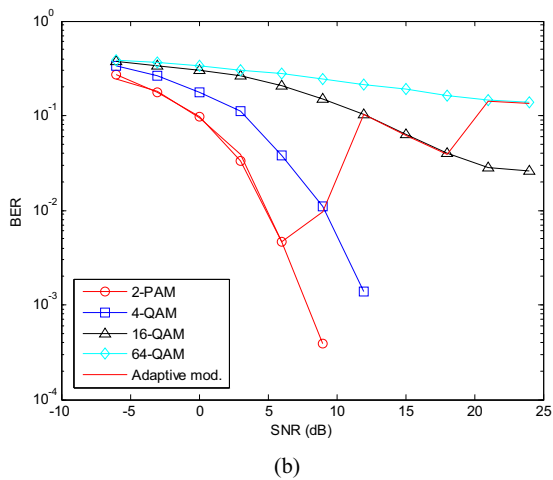
Fig. 8 shows the effect of using PAPR reduction technique for OFDM signals under indoor environment channel when the saturated output level of amplifier is equal to 12 and 8. It is noticed that PAPR reduction technique does not improve the BER performance for 2-PAM and 4-QAM modulations. For 16-QAM and 64-QAM, the use of PAPR reduction technique



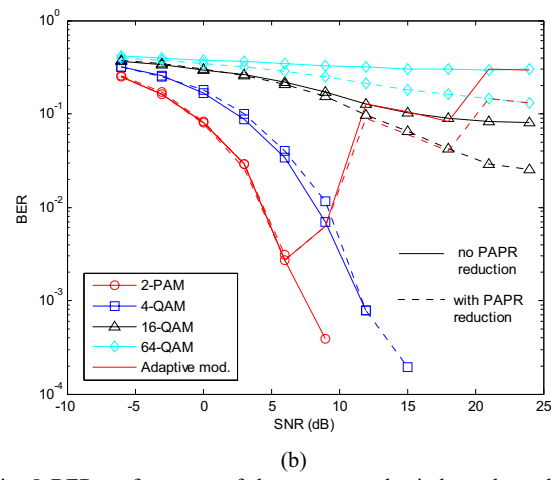
(a)



(a)



(b)



(b)

Fig. 7 BER performance of the system under (a) AWGN and (b) Indoor channels

Fig. 8 BER performance of the system under indoor channel with (a) $A=12$ and (b) $A=8$

benefit the BER performance and this is more pronounced when SNR is high. However, to use PAPR reduction technique for adaptive modulation is useless. The results suggest that the new rule of adaptive modulation is seriously required for implementing in indoor channel. Also in this figure, the effect of amplifier with different saturated outputs is investigated. The lower BER performance is achieved by $A=12$ because the saturated output level of $A=8$ is shorter thus the signals are clipped more than the level of $A=12$. It is interesting to observe that the use of PAPR reduction technique provide the similar BER performance for both $A=8$ and 12. This well indicates that the use of PAPR reduction technique is helpful for operating under indoor environments.

V. CONCLUSION

In this paper, the new method for PAPR reduction based on DSI method is proposed. This method does not require the iterative procedure to find the suitable dummy sequence. Therefore, the proposed method is able to offer the faster PAPR reduction in comparing with the other DSI methods in literatures. The simulation results confirm that the proposed

method provides the similar performances as other DSI methods. Without delay and no required side information, the proposed method is practically interesting to be applied on WiMAX systems. Moreover the proposed method is more increase BER performance of system than DSI methods in literatures. The simulation results also reveal that the use of PAPR reduction technique improves the system performance for some modulation schemes. In addition, it is useless to apply PAPR reduction technique for adaptive scheme under indoor channel unless the criteria of adaptation are modified. These results are helpful for OFDM researchers to be aware of using the system under indoor propagation environment.

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