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THEORY AND METHODS OF SIGNAL PROCESSING

PAPR Effect Remedy in OFDM-Based Wireless Systems[1]

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Abstract—An enhancement proposition for a Terrestrial Digital Video Broadcasting (DVB-T) systems is discussed in this work. DVB-T physical layer uses a powerful technique namely Orthogonal Frequency Division Multiplexing (OFDM) technique, which has been used to combat the channel's effect. However, it has a major drawback that degrades its efficiency; namely Peak-to-Average Power Ratio (PAPR). Two criteria have been used for this purpose; BER curves and CCDF curves in order to distinguish the powerfulness of those propositions in reducing the PAPR effect. In fact, a powerful special averaging technique results are compared to previously published propositions, namely based on wavelet transformations and the one that is based on the pulse width modulation. A mathematical model has been drawn in order to check both of the CCDF and the BER curves, and simulated at same channel limitations and specifications. The proposition gives extra 35% noise immunity over our previously published work that is based on entropy wavelet, and an enhancement of over 25% from the CCDF point of view in combatting the PAPR. Furthermore, a complexity reduction has been attained by decreasing the side information transmission in compared with the work in the literature.

Keywords: OFDM, PAPR, wavelet transform, entropy, clipping, SLM

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INTRODUCTION

As found in the literature, the Terrestrial Digital Video Broadcasting (DVB-T) is a part of the DVB standard that is initiated in 1993, which has been proposed in order to support the need of higher data rates applications. Due to that it has some special limitations in use on the physical layer level such as in the codec design, the framing duration and sampling rates,..., etc., the design issues have arises and attracted the researchers interest [1–3].

In this work, a speaker verification case study has been taken into consideration under the DVB-T standard. Furthermore, a proposition is made to enhance its performance based on combating a well-known problem found in the literature, namely Peak-to-Average Power ratio (PAPR). The DVB-T standard takes into its consideration the broadcasting issues, which has been evolved from the analog to the IP and IOS systems through the digital era in the last decades. This is due to satisfy the users demand these days, which burden a heavy load on the researchers shoulders to fulfil these requirements. One of the researchers' interest areas are the nonlinear devices and their effects on the overall systems data rates, where there is a trade-off between the systems performance and the non-constant signals that affects the Input Back-Off (IBO) points [4–7].

The DVB-T standard proposes the need of the orthogonal frequency division multiplexing (OFDM) technique to fulfil the need of supporting the higher data rates, which has a simple implementation by making use of the inverse fast Fourier transformation (IFFT), enhances the noise immunity by using the parallel transformation and reduces the bandwidth comparing to the channel coherence bandwidth, and combat the frequency selective behaviour of the channel by the proposition of using the orthogonal subcarriers and the addition of the cyclic prefix criterion [8, 9].

In order to enhance the performance of such systems, the PAPR should be studied thoroughly, which is considered as one of the main drawbacks for the OFDM based systems [10–12]. This deficiency appears due to the coherence addition in the IFFT stage in order to perform the OFDM symbol [9]. Broadcasting systems that are based on OFDM will offer high data rate transmission even under very harsh channel limitations, [13, 14]. As a consequence, such enhancement will be attained by combatting such problem. The work in [15–18] have dealt with the OFDM other drawbacks, such as time, frequency,

[1] The article is published in the original.

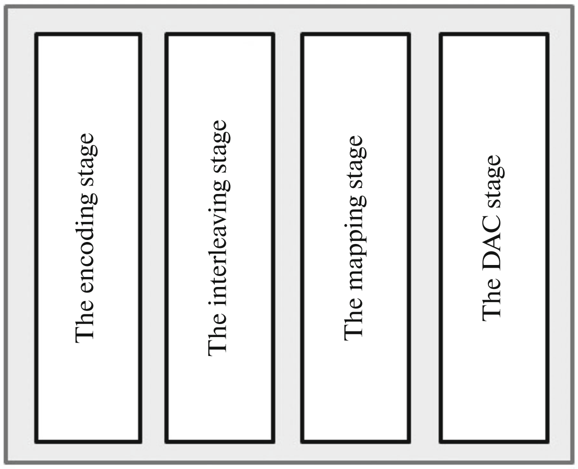

Fig. 1. DVB-T system's main stages.

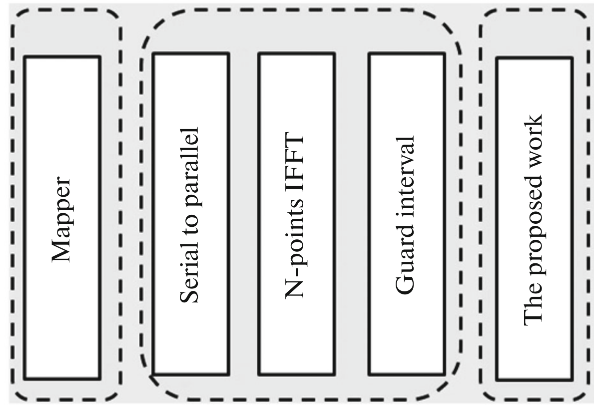

Fig. 2. The enhanced mapping stage.

phase shift effect on either the level of subcarriers or the channel effects; i.e. either the intersymbol interference or the intercarrier interference.

The authors are taken into their consideration the need of studying the PAPR effect and proposing a proper solution compared to literature. They published different works since 2012 to reach the target of enhancing the data rate transmission for variety wireless systems, [10–12, 19]. In such propositions the authors start working on the relation between the PAPR and the number of subcarrier, and then the use of linear coders for this purpose, after that the need of the neural networks in order to the learning process of classifications, then the use wavelet transformation and its relations with the FFT and finally the use the pulse width modulation and the special averaging techniques. Thus, the motivation is existed in order to check the performance of our propositions and to ease the adoption over the world standards.

In this work, a new proposition has been made to overcome the PAPR effect of a speaker verification based system using a special averaging technique. Then, the extracted results will be compared with previously published works in [8, 10, 19, 20]. This is due to that as mentioned in [21], that the speaker verification issue is important and it is an active research area for many years.

The validation of our proposition will be based on checking the immunity against the channel noises by the bit error rate (BER) factor and checking the probability of the peak powers that may exceed a certain SNR dB threshold by the complementary cumulative distribution function (CCDF) curves. Then compare these results either to our previously published work based on the wavelet entropy or to some works in the literature.

The rest of this work is structure to cover the system block diagram in Section 1, to give the simulation results and discussion in Section 2, and to conclude the proposition in the last section.

1. SYSTEM BLOCK DIAGRAM

A. Introduction

The transmitter part of DVB-T speaker verification based on the OFDM is depicted below in Fig. 1, where the OFDM stage has been imposed before the digital to analog conversion process. It consists of four main stages; the encoding stage that is consists of the outer and inner encoders respectively the RS and the convolutional ones; the interleaver stage either the outer or the inner ones; the mapping stage which consists of the one based on the systems specifications and the OFDM one, as mentioned in the ETSI standard; finally the DAC stage.

As mentioned earlier, the OFDM process falls in the mapping stage and before the DAC stage, where OFDM is used making use of the parallel transmission instead of a sequential one, i.e. using very tight adjacent N orthogonal subcarriers. As a consequence, the available bandwidth is utilized efficiently.

The scope of this work is to investigate the DVB-T system and to enhance its performance by combating the PAPR effect. Thus, our target falls between the mapping stage and the DAC stage, where the final process in the mapping stage is performing the OFDM symbol. Therefore and to fulfil our objectives, the mapping stage that is shown in Fig. 1 has been enhanced and will be depicted in details in Fig. 2.

Mathematically, the processed signal that passed through the enhanced mapping stage will be described below in (1) as:

$$S(t) = \cos\left\{(2\pi f_c t)\left(\frac{1}{N}\sum_{k=-\infty}^{\infty}\sum_{c=0}^{N-1} d_c \exp\left(\frac{j2\pi ct}{T}\right) p_s(t-kT)\right)\right\}. \quad (1)$$

Here, the up-conversion frequency is described by f_c, the OFDM symbol will combined by the processed data d_c with a maximum N-point values, the windowing process will be attained by the shifted pulse, $p_s(t-kT)$, T is stands for the symbol period.

At the receiver side, the author will deal with the signal that passed through a dense channel that has an additive Gaussian noise for simplicity, $N(t)$ with pth propagation paths, and described as follows:

$$R(t)= \sum_{p=1}^{M} D_p(t)\cos\left\{(2\pi f_c(t-\tau_p(t)))\frac{1}{N}\sum_{k=-\infty}^{\infty}\sum_{c=0}^{N-1} d_c \times \exp\left(\frac{j2\pi c(t-\tau_p(t))}{T}\right) p_s((t-\tau_p(t))-kT)\right\} + N(t). \quad (2)$$

In Eq. (2), the attenuated signal due to the noisy channel is represented by $D_p(t)$ in received path.

B. The Proposed Work

The main objective in this work is to mitigate the effect of the PAPR values that will limit the use of nonlinear devices. Thus and based on our previously work that is based on the wavelet transformation in [8], the authors achieved around 99% of reducing the CCDF curves at 20 dB. This is in addition to additional reduction over the work in the literature from 23.6 to 51.3%. Thus, in this work there is another proposition that is based on adaptive convolutional approach to compare with. Furthermore and based on the published work in [10] that proposes the PWM as a solution to transform the OFDM symbols to constant envelope ones, an extra 42.5% CCDF values enhancement has been achieved at the probability of 2% over the conventional work. This is in addition to enhance the PAPR effect reduction over the literature from 11 to 72.1%.

At the level of BER enhancements, the DWT-based work gives a 72% percent enhancement at the threshold of 20 dB, which enhances the BER with around the 81% over the conventional work that is based on the FFT.

For the PWM-based work, SER has been modified and enhanced over the conventional work from 9.3×10^{-4} to 8.7×10^{-4}.

As found in [9], generally the PAPR arises after the coherence summation of the N-IFFT signals to form the OFDM symbol, which could be mathematically expressed as:

$$\mathrm{PARP} = 10\log_{10}\frac{\left|\cos\left\{(2\pi f_c t)\left(\frac{1}{N}\sum_{k=-\infty}^{\infty}\sum_{c=0}^{N-1} d_c \exp\left(\frac{j2\pi ct}{T}\right) p_s(t-kT)\right)\right\}\right|^2}{\frac{1}{NT}\int_0^{NT}\left|\cos\left\{(2\pi f_c t)\left(\frac{1}{N}\sum_{k=-\infty}^{\infty}\sum_{c=0}^{N-1} d_c \exp\left(\frac{j2\pi ct}{T}\right) p_s(t-kT)\right)\right\}\right|^2 dt}. \quad (3)$$

Where the nominator defines the maximum power and denominator defines the average power of an OFDM symbol. The start point begins from the published work in [20], where a relationship has been derived previously and linked the IFFT points to the PAPR value. Both of Figs. 3 and 4 show the flowchart of the previously published work procedures.

In this work, a new proposition has been made in order to overcome the PAPR effect. The performance of this pposition has been compared with both of DWT-based and PWM-based proposition and with the literature.

The new proposition will be adaptive convolutional-based, where its procedure will be depicted in Fig. 5 as shown below.

From Fig. 5, the proposition can be divided into the pre-processing stage, the peak detection stage and the post processing stage. In the pre-processing stage, the read symbol will be de-noised based on different wavelet transformation families such as Biorthogonal, Daubechis, Symmlet, Coiflet and Haar wavelets. Among those families, three main criteria have been proposed to distinguish their performances such as mean square error (MSE), signal to noise ratio (SNR) and the peak SNR (PSNR). The peak detection stage

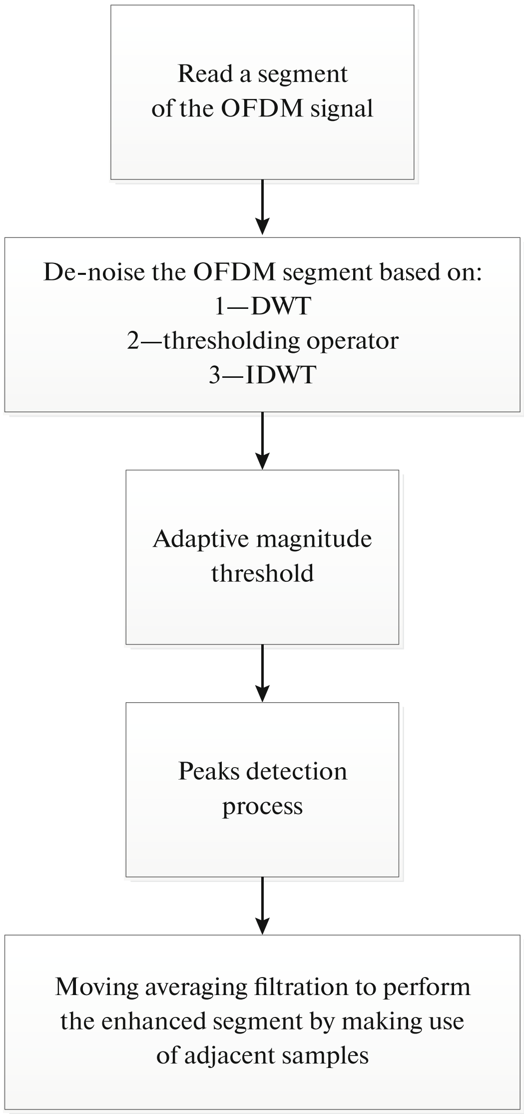

Fig. 3. The DWT-based proposed work flowchart.

contains three processes, deriving the affected symbol in order to allocate the signal change. Converting the derived symbol into a sign based shape by making use of the sign selection criterion. Finally, convolve the [−1, 1] pattern with the signed symbol in order to allocate the peaks in the original symbol. In the last stage namely the post processing stage, the generated symbol will be thresholded adaptively using the thresholding criterion, which has been proposed by making use of three different statistics

$$T_{\text{adaptive}} = \frac{\left(\text{Symbol}_{\max} + \text{Symbol}_{\text{avgabs}} + \text{Symbol}_{\text{dev}}\right)}{k}. \quad (4)$$

Where, the symbol maximum is given by $\text{Symbol}_{\max}$, and Its mean and standard deviation are denoted by $\text{Symbol}_{\text{avgabs}}$ and $\text{Symbol}_{\text{dev}}$, respectively. Finally, the

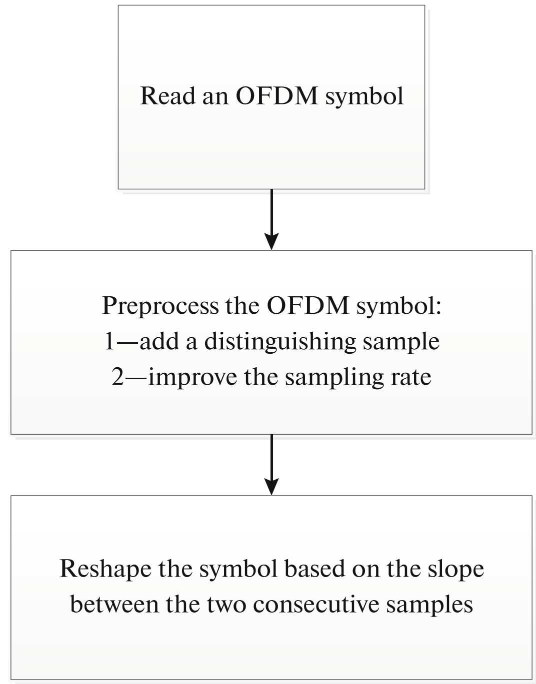

Fig. 4. The PWM-based proposed work flowchart.

k factor is responsible for the process adaptiveness and be chosen according to the system's specifications.

Finally, the peak averaging filters will reformulate the allocated peaks based on averaging the sample and its surroundings ones this is in order to insure that the amended value will not to exceed the calculated threshold.

The attained comparison results will be depicted in Fig. 6. This comparison was held between the original OFDM signal and the modified work that is based on the adaptive convolutional work, where the stars stand for the samples that are affected by high PAPR values and exceed the determined threshold. From this figure, the calculated threshold is set as 1000, thus the modified signal will has values less than this threshold. From the depicted results, the maximum value of the modified signal is found as 907.8734.

2. SIMULATION RESULTS AND DISCUSSION

Based on the system block diagrams those were depicted in Figs. 1 and 2, the system specification has been limited to:

—OFDM mapper (64 QAM modulation technique, 8192-IFFT point (6817 information carriers) with spacing of 1.116 kHz, GI duration is 112 μs, Information duration 784 μs);

—DVB-T system (8000 mode, 212 MHz bandwidth, Coding rate of 0.667);

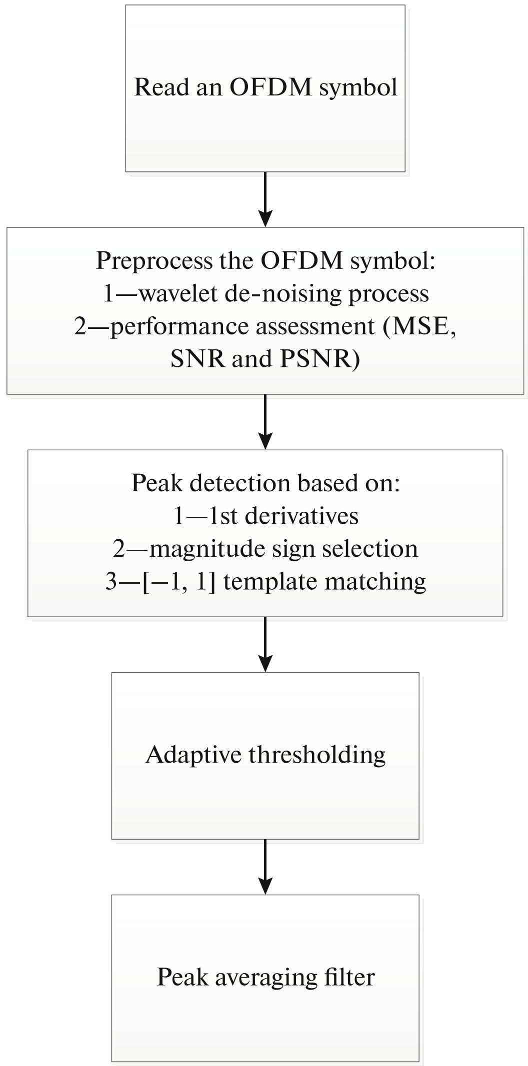

Fig. 5. The adaptive convolutional-based proposed work flowchart.

—Baseband data (Recorded signals for 22 different users).

The DVB-T system has been imitated by making use of the MATLAB simulator, which allows testing the performance of the proposed work. As mentioned earlier, the check of the proposed work performance will be based on two criteria; namely CCDF and BER. In Figs. 7 and 8, a comparison will be held between our published work and a comparison between the proposed work and the literature respectively.

Furthermore, Fig. 9 will depict the results of BER comparison between our proposed work and our previously published work in [8, 10]; the Wavelet-based and PWM-based.

From the extracted information from Fig. 8, it is clearly shown that the PWM-based work gives very promising results that shows the peaks that will pass the 12 dB threshold reduced from 89.6×10^{-2} to almost 5.34×10^{-2}. This means that an achieved enhancement of 94% is attained over the original signals without any propositions, where the worst enhancement is achieved under the proposition of the wavelet transformation which gives only 60% over the conventional work. Moreover, the proposed work reserves an in-between results and gives an enhancement of 83.3% over the conventional work and extra 13.3% over the wavelet transformation work.

This figure shows a huge improvement over the published work in the literature, which falls between 83.04 and 83.75% at the threshold of 12 dB.

The criterion of checking the powerfulness against the channel noise is shown in Fig. 9, where could be attained by the BER curves. It is clearly depicted from Fig. 7 that the proposed work does not perform as well as the PWM-based work, but in combatting the error rates it is the best. At threshold of 15 dB SNR, the pro-

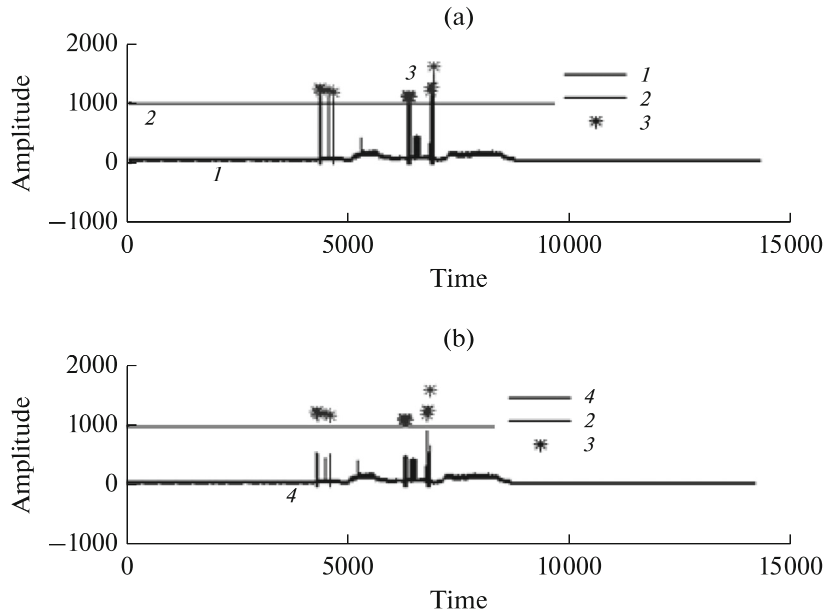

Fig. 6. Adaptive convolution-based work results: (a) OFDM peaks detection using convolution-based approach; (b) modified OFDM; (*1*) OFDM signal, (*2*) threshold value, (*3*) peaks, (*4*) adaptive OFDM signal. Asterisks denote peak values: maximum value equals to 907.8734, minimum value equals to −32.1536.

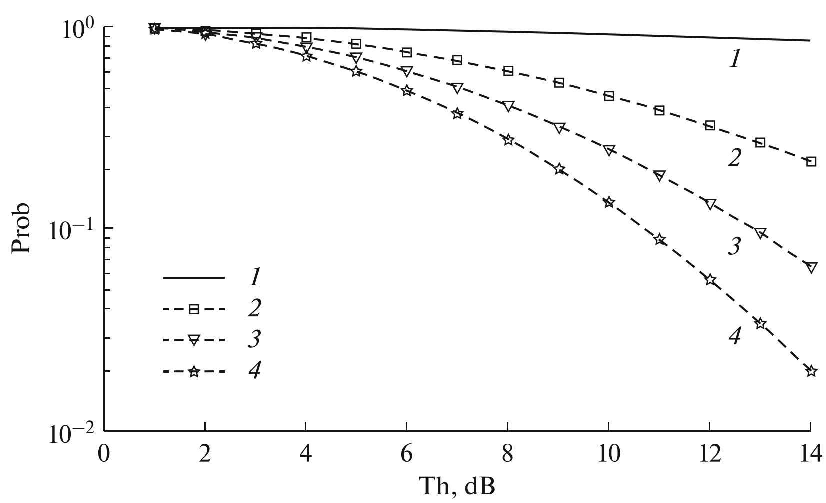

Fig. 7. 64QAM-based CCDF comparison curves; (*1*) the original signal, (*2*) wavelet-based work, (*3*) the proposed work, (*4*) PWM-based work.

posed work enhances the link reliability of 77.89% over the original system. This is in addition to an extra 68.66% over the enhancement that is achieved from the proposition of the wavelet transformation and an extra 36.34% over the PWM-based work. From the depicted results previously, the QoS has been improved by overcoming the PAPR effect and enhancing the link reliability.

CONCLUSIONS

In this work, the PAPR problem has been studied and investigated in order to enhance the DVB-T system's performance. PAPR will limit the use of nonlinear devices in any wireless system due to the high peak power to average and the needed dynamic range. A new proposition has been made for this purpose and based on a special averaging technique, which consists

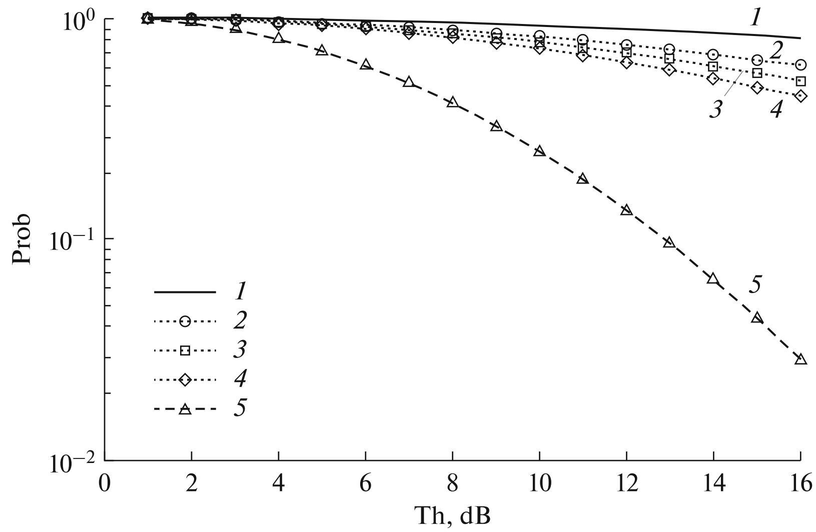

Fig. 8. 64QAM-based CCDF comparison with the literature; (*1*) the original signal, (*2*) SLM-based work, (*3*) PTS-based work, (*4*) clipping-based work, (*5*) the proposed work.

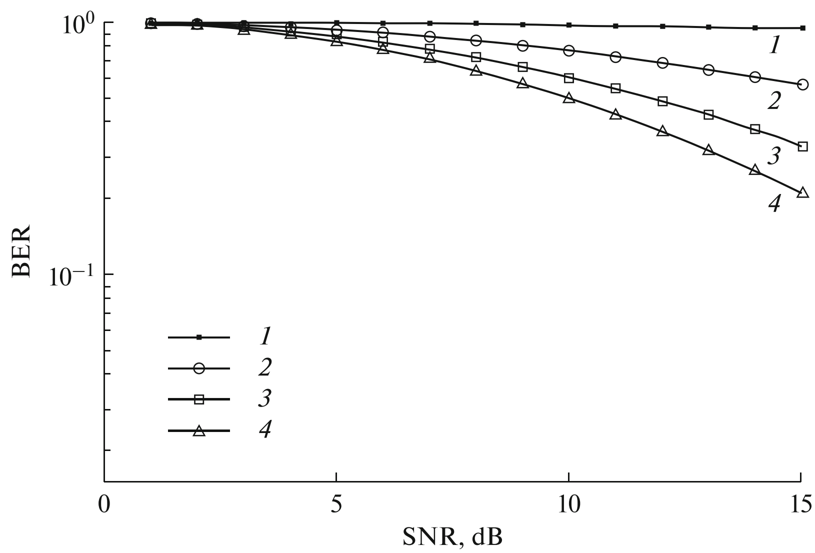

Fig. 9. 64QAM-based BER comparison curves; (*1*) the original signal, (*2*) wavelet-based work, (*3*) PWM-based work, (*4*) the proposed work.

of three different stages to have wavelet transformation, a globally statistical adaptive detecting algorithm; and the moving average filter process.

In order to check the proposition performance, it has been compared either with our published proposition or with the work in the literature. From the simulation results and at the 2% threshold of probability, the proposed work gives an extra 60% enhancement over the conventional work and reduces the 20 dB threshold to 8 dB. Therefore and as a comparison with the literature, the proposed work has been compared with the selective mapping technique, the clipping technique, and with the partial-transmit-sequence technique. The proposed work shows a powerful enhancement over the clipping technique reaches the 75%, while it just has 20% enhancement over the partial-transmit-sequence. Furthermore, and to prove the proposition reliability, it has been compared with two previously published work, the wavelet transform-based work and the PWM-based one. As a comparison, the PWM-based work gives better enhancement than the proposed work in-terms of the CCDF curves, but the proposed work enhances the BER of the system. The PWM-based work reduces the probability of exceeding the 16 dB threshold to 59.76×10^{-4} where it was 81.48×10^{-2} in the conventional work, where it is just around 3.5% extra enhancement over the proposed work. Thus, as a trade-off the proposed work enhances the system reliability and losses a round 3.5% of its powerfulness in combatting the PAPR. This means that, the proposed work gives around 79% extra PAPR reduction than the conventional work. Comparing it with the wavelet transform-based work, it gives an extra enhancement reaches to the 78.8% which almost equal to the one from the PWM-based work. Consequently, the proposed work reliability and validity has been checked and proved in terms of the attained results from the CCDF curves and the BER curves.

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