Non-Linear Distortion Noise Control by Clipping and Filtering in Spectrum Sharing Systems

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Abstract—**This paper proposes a non-linear distortion noise control method for secondary systems in spectrum sharing. The proposed method is based on conventional clipping and filtering methods, and adaptively shapes distortion noise power to improve reception quality of secondary users with transmission power control. In this paper, optimal clipping levels to control in-band distortion noise are investigated, and then the spectrum property and BER performance with the clipping levels are evaluated. The results confirm that the proposed method can control the distortion power effectively in shared bands and realize secondary systems with less degradation of reception quality when sharing spectrum with transmission power control.**

Keywords-spectrum sharing, non-linear distortion, transmission power control, OFDM

I. INTRODUCTION

Recently wireless communication systems have required wider frequency bands to achieve higher data rate transmission in spite of limited frequency resources. Spectrum sharing is one of the key technologies to use them with much higher efficiency [1]-[3]. In this technology, a low-priority system, called a secondary system, uses unused bands which originally allocated to an existing system called a primary system. When they share the same bands, because a secondary system is required not to interfere with a primary system, its transmission power in the bands is reduced by transmission power control (TPC) [4]. While this method effectively works to reduce harmful interference, reception quality of secondary TPC users degrades remarkably because non-linear distortion noise arises throughout a transmission signal band due to high peak power components of OFDM signals. One of effective peak power reduction methods is clipping and filtering, which removes peak power components exceeding some fixed amplitude and out-of-band non-linear distortion noise caused by clipping [5][6].

This paper proposes a non-linear distortion noise control method for secondary systems under spectrum sharing environment with TPC. This method uses the clipping and filtering method and extracts the distortion noise from clipped OFDM signals with the optimal clipping level to make SNRs equivalent between TPC and non-TPC users of a secondary system. Furthermore, it adaptively shapes the extracted noise by filtering in response to the transmission power of each sub-carrier before power amplification. This adaptive distortion noise control can achieve both effective interference power reduction and better transmission performance in spectrum sharing systems with TPC for secondary users.

The outline of this paper is as follows: spectrum sharing systems are mentioned in Section II. Next, the proposed method is introduced in Section III. Optimal clipping levels used with the proposed method and transmission performance by computer simulations are revealed in Section IV. Finally, the conclusion is presented in Section V.

II. SPECTRUM SHARING SYSTEMS

Fig. 1 shows frequency bands shared with the primary and secondary systems including TPC bands in the secondary system. Although these bands are originally allocated to the primary system, the systems can share them because primary system bands are not always used temporally or spatially. In addition to unused bands of the primary system, the secondary system uses used bands as well if it doesn't interfere with the primary system. Therefore, in the TPC bands of the secondary system, the transmission power is required to reduce as shown in Fig. 1. However, if secondary TPC users use OFDM transmissions, high peak power components of OFDM signals cause the non-linear distortion power across a transmission signal band. This results in significant degradation of SNRs in the TPC bands of a secondary system. The proposed method can not only reduce interference power from secondary to primary systems but also make SNRs equivalent between TPC and non-TPC users of a secondary system.

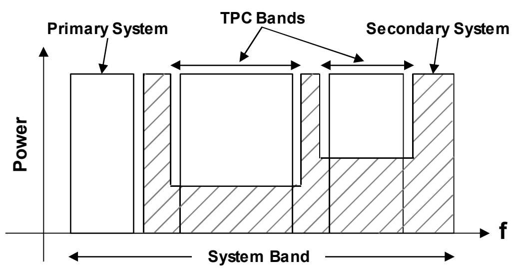
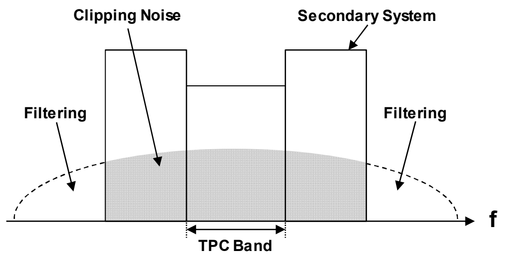


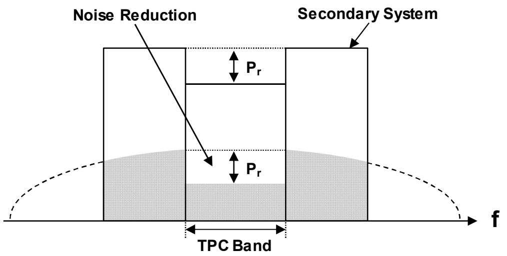
Figure 1. Spectrum sharing system with TPC

III. PROPOSED METHOD

The proposed method is for secondary TPC users and based on the clipping and filtering method. First, high peak power components of time-domain OFDM symbols which exceed a certain clipping level are detected. This clipping level P_{th} is set according to the transmission power, TPC bandwidths and input back-off values of transmission power amplifiers so as to equalize SNRs between TPC and non-TPC users of a secondary system. The most appropriate clipping level to equalize SNRs between the users is defined as the optimal clipping level in this paper. The optimal clipping level is adaptively predetermined by estimating non-linear distortion noise power from input back-off values and the nonlinearity of transmission power amplifiers. After clipping, the spectrum of clipping noise is generated by FFT of the detected signals. Second, this spectrum is shaped as shown in Fig. 2: out-of-band noise components are filtered by filling out-bands with zero in order not to interfere with adjacent systems (Fig. 2(a)). Besides, clipping noise in the TPC band of a secondary system is adaptively reduced according to the transmission power ratio P_r. The amount of its reduction is as much power as P_r of secondary TPC users (Fig. 2(b)). Finally, this spectrum processed in this manner is transformed into time-domain signals again by IFFT, and they are subtracted from original OFDM symbols.



(a) Out-band filtering



(b) Noise reduction in TPC band

Figure 2. Proposed spectrum shaping

As illustrated in Fig. 2, the spectrum shaping of clipping noise at the previous stage of power amplification allows for the processing of in-band signals as well as out-of-band signals. Therefore, this method can keep SNRs constant throughout a signal band even after amplification. This enables TPC users to yield almost the same reception quality as non-TPC users of a secondary system.

Fig. 3 shows the proposed OFDM transmitter for the secondary system with spectrum sharing and TPC. At first, this transmitter performs symbol mapping for modulation and coding schemes. The mapped signals are assigned to sub-carriers for the secondary system. The power of sub-carriers in TPC bands is reduced in response to P_r to avoid interference to the primary system. After this, the signals are transformed into OFDM symbols in time domain by IFFT. Next, it is processed by the proposed clipping and filtering method with the optimal P_{th}. In the end, a guard interval is added to each OFDM signal, which is followed by non-linear power amplification.

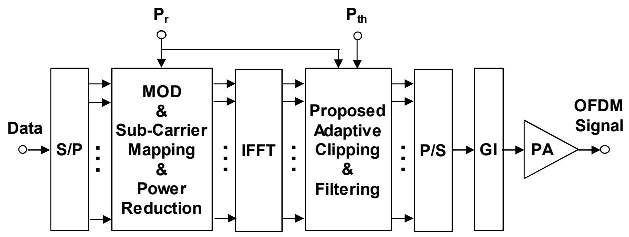


Figure 3. Proposed transmitter for the secondary spectrum sharing system

IV. SIMULATION RESULTS

A. Simulation Condition

Computer simulations were conducted to reveal optimal clipping levels used with the proposed method and evaluate transmission performance with the method. Tab. I shows simulation conditions: the modulation scheme was 16QAM, and the total sub-carrier number for OFDM transmission was 6000. The number of TPC sub-carriers, N_{TPC}, was set to 500 and 1500. The typical non-linear model of a power amplifier was used [7]. Its non-linear factor was set to 3.

TABLE I. SIMULATION CONDITIONS

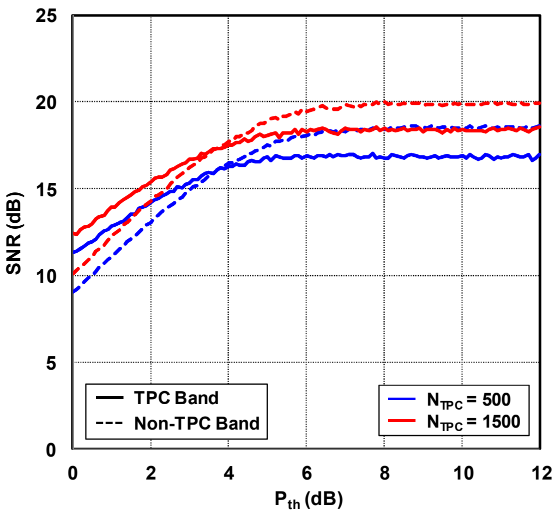
Modulation	16QAM
Total Sub-Carrier Number	6000
Number of TPC Sub-Carriers: N_{TPC}	500, 1500
Guard Interval	1024
Transmission Power Ratio: P_r	−3, −10 dB
Back-off	4, 6 dB
Non-linear Factor: p	3

B. Evaluation of Optimal Clipping Levels

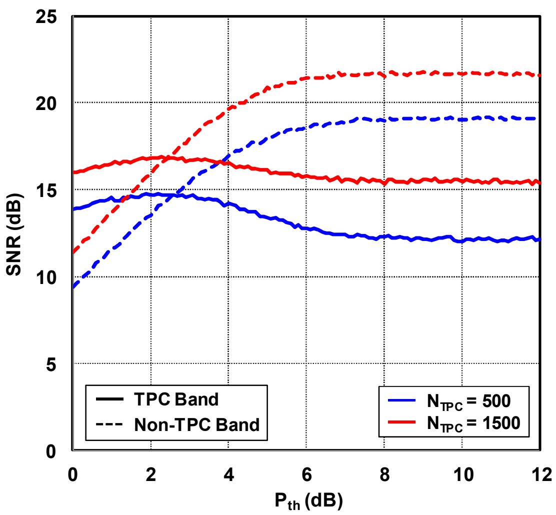
In the proposed transmitter, SNRs of TPC and non-TPC users of a secondary system are equalized before amplification. Thus, SNRs within a transmission band are unequalized at the output of amplifiers by distortion noise uniformly emanating from amplifiers owing to peak regrowth of OFDM signals after filtering. This degrades reception quality of TPC users especially. In order to control such distortion noise even after filtering and amplification, clipping levels must be properly set lower than input back-off values of amplifiers. Hence, the relation between P_{th} and SNRs were first evaluated to reveal optimal clipping levels by computer simulations.

Fig. 4 and 5 show the relation between P_{th} and SNRs. In the figures, solid and dashed lines indicate SNRs of TPC and non-TPC users of a secondary system, respectively. Each intersection point of the two lines with the same N_{TPC} is each optimal clipping level, which is shown in Tab. II and III.

These result demonstrate the following three aspects: 1) SNRs fall to a lower level when N_{TPC} and/or the back-off get lower, 2) a gap of SNRs between TPC and non-TPC users becomes larger as P_r gets lower, and 3) lower optimal clipping levels are required for lower P_r. This is because sub-carrier signals of TPC users are more severely damaged by distortion noise from power amplifiers in the case of using lower P_r than those of non-TPC users.



(a) $P_r = -3$dB

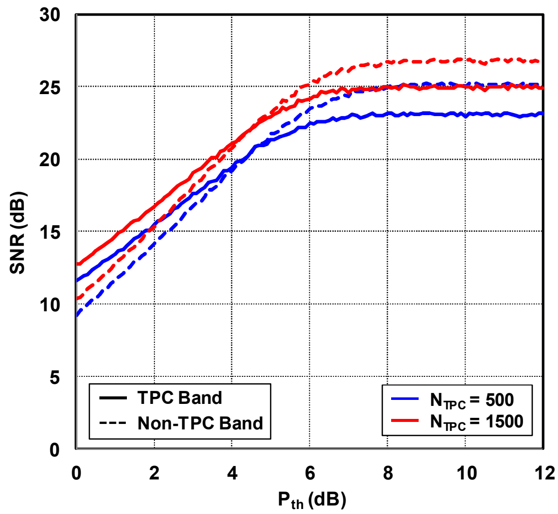


(b) $P_r = -10$dB

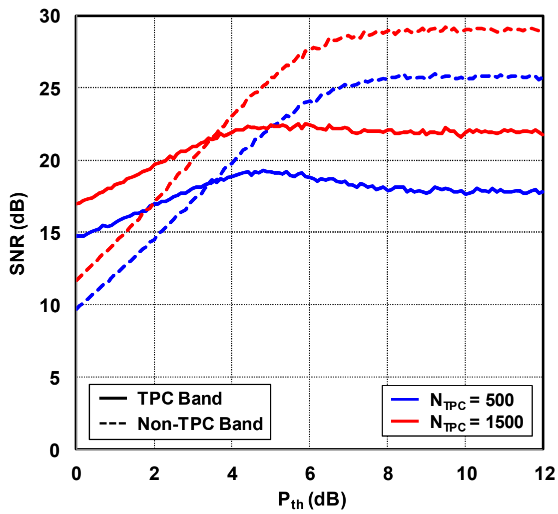
Figure 4. The relation between P_{th} and SNR (Back-off: 4dB)

TABLE II. OPTIMAL CLIPPING LEVELS

Back-off (dB)	N_{TPC}	P_r (dB)	Optimal P_{th} (dB)
4	500	−3	3.6
		−10	2.6
	1500	−3	3.7
		−10	2.4



(a) $P_r = -3$dB



(b) $P_r = -10$dB

Figure 5. The relation between P_{th} and SNR (Back-off: 6dB)

TABLE III. OPTIMAL CLIPPING LEVELS

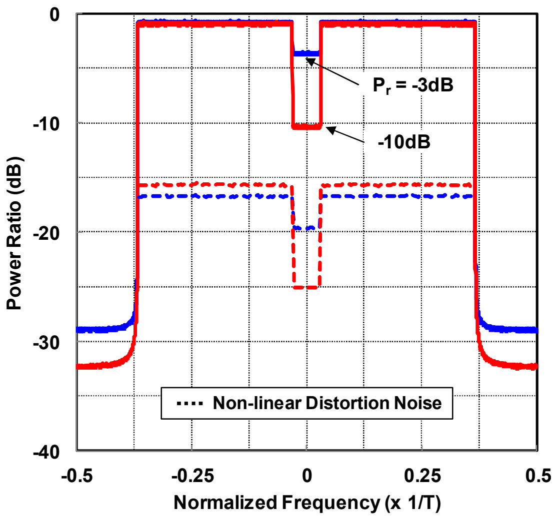
Back-off (dB)	N_{TPC}	P_r (dB)	Optimal P_{th} (dB)
6	500	−3	4.4
		−10	3.4
	1500	−3	4.5
		−10	3.5

C. Spectrum Property

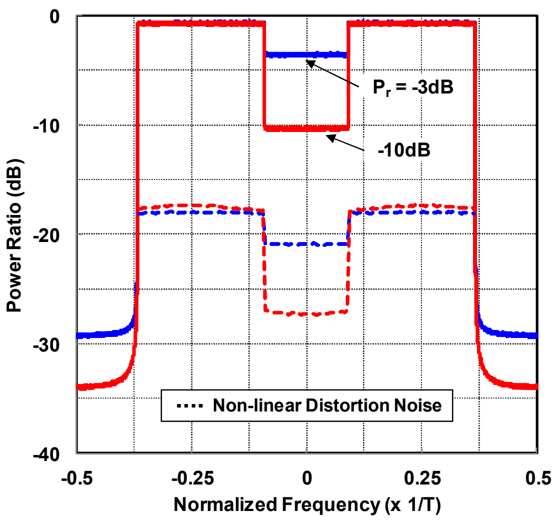
To confirm noise reduction effects of the proposed method for TPC users of a secondary system, spectrum properties were evaluated. The optimal clipping level shown in Tab. II and III is used under each simulation condition.

Spectrum properties with the proposed method are shown in Fig. 6 and 7. Solid lines depict transmission signal spectrums and dashed lines represent in-band non-linear distortion noise in the figures. Each optimal clipping level shown in Tab. II and III was set up according to N_{TPC}, P_r and the back-off value.

These figures all demonstrate that non-linear distortion noise with the proposed method is reduced to the same value as P_r, which confirms the proposed method can improve SNRs of secondary TPC users. Although a larger table of optimal clipping levels is needed in practical systems, its size can be reasonable.

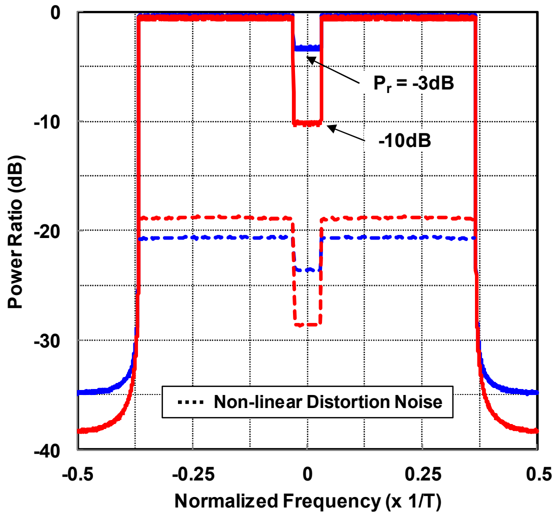


(a) $N_{TPC} = 500$

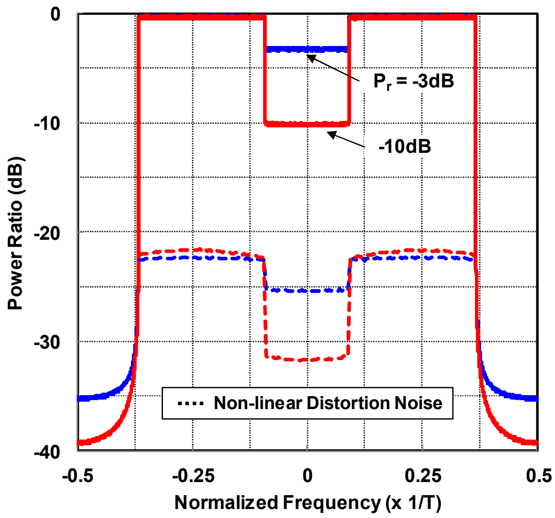


(b) $N_{TPC} = 1500$

Figure 6. Spectrum property (Back-off: 4dB)



(a) $N_{TPC} = 500$



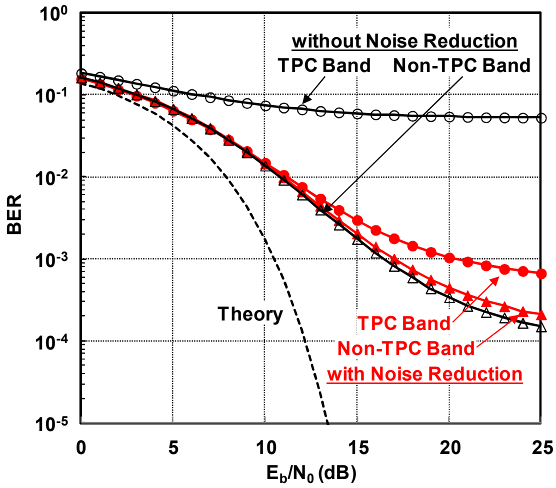
(b) $N_{TPC} = 1500$

Figure 7. Spectrum property (Back-off: 6dB)

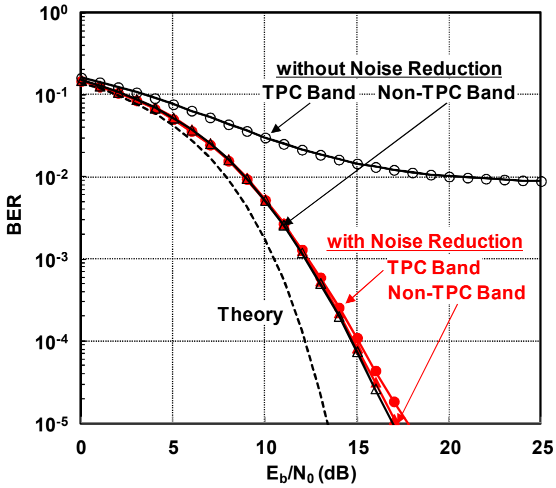
D. BER Performance

BER performances for TPC and non-TPC users of a secondary system with the proposed method were evaluated, which is shown in Fig. 8.

In Fig. 8, N_{TPC} and P_r are set to 1500 and −10dB, respectively. BER = 10^{-2} cannot be achieved in the TPC band without noise reduction, where the back-off value is set to 4dB as shown in Fig. 8(a). In addition, a large performance difference occurs between TPC and non-TPC users. On the other hand, the proposed method can remarkably improve BER performance and attain BER = 10^{-3} even for secondary TPC users, which is shown in Fig. 8(a)(b). These results prove the proposed method can offer almost the same BER performance to both TPC and non-TPC users of a secondary system.



(a) Back-off: 4dB



(b) Back-off: 6dB

Figure 8. BER performance

V. CONCLUSION

This paper has proposed a new clipping and filtering method to control non-linear distortion noise for secondary systems in spectrum sharing environments. The proposed method with optimal clipping levels adaptively controls clipping noise according to transmission power ratios, input back-off values and the nonlinearity of power amplifiers in order to equalize SNRs throughout a transmission signal band.

The results of computer simulations show the proposed method can control non-linear distortion noise and keep SNRs constant across a transmission signal band after power amplification. Furthermore, it can dramatically improve BER performance for secondary TPC users, which is approximately the same as that for secondary non-TPC users. These results confirm the proposed method can realize secondary systems with less degradation of reception quality under spectrum sharing environments with TPC.

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