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Analysis and Simulation of Wavelet Carrier Modulation with Clipping Techniques in Mobile WiMAX

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Abstract

The implementation of OFDM results in relatively high Peak-to-Average Power Ratio (PAPR) due to IFFT process to generate orthogonal subcarriers. A number of studies have attempted to apply various techniques to minimize PAPR by applying the Wavelet transform as a substitution for Fourier transform. Another technique used to reduce the PAPR is clipping. In this journal, writer tried to apply the clipping technique on the Wavelet based OFDM in mobile WiMAX standard to obtain better performance. The results, Wavelet based OFDM has better immunity to noise and more resistant to Doppler shift than Fourier based OFDM. Sym 7 with Classical clipping and CR 1.2 can be applied on wavelet-based OFDM in mobile WiMAX.

Keywords: Clipping; Fourier; Mobile WiMAX; OFDM; PAPR; Wavelet

1. Introduction

One of the techniques used to minimize frequency selective fading is an Orthogonal Frequency Division Multiplexing (OFDM) [1]. OFDM will change channel condition from frequency selective fading into flat fading. But the implementation of OFDM results in high Peak-to-Average Power Ratio (PAPR) [1]. High PAPR, generated after IFFT process, will increases the complexity of the analog – to – digital and digital – to – analog converter and reduces the efficiency of the radio – frequency (RF) power amplifier [1-2].

Recently the Wavelet Transform has also been proposed as a possible transform to generate the sub channels in a multicarrier system [3]. In addition, Wavelet based OFDM does not require Cyclic Prefix (CP) [3-4], thus increasing the spectral efficiency, does not produce ripples, reduces complexity and leads to a better symbol rate, so there is no wastage of power for redundancy [4].

Besides that, there are several techniques that have been proposed by reference to reduce the PAPR such as clipping technique, block coding, selective mapping and tone reservation [1-2]. Among these techniques, the clipping technique is the simplest solution technique. Signal amplitude exceeds a desired threshold can be cut to the desired power level, so that no high PAPR [5].

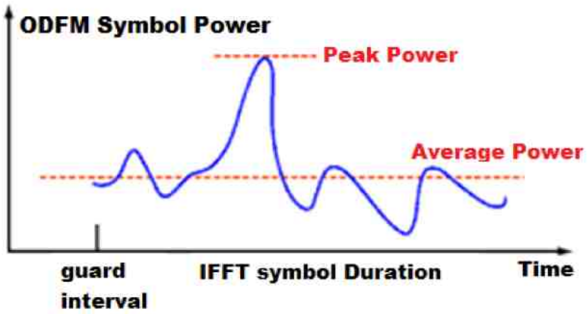


Fig. 1. PAPR

In this journal, clipping technique will be applied with the Wavelet based OFDM with the Wavelet based OFDM in mobile WiMAX standard. The purposes are to analyze the performances of wavelet based OFDM with any wavelet filters and any clipping techniques then comparing with Fourier based.

2. OFDM, Wavelet, PAPR And Clipping

2.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a modulation technique that uses multiple carrier frequencies (multicarrier) are mutually orthogonal to each other, so between adjacent subcarriers can be made without any inter-carrier interference (ICI) effects.

In the communication system, the orthogonal signals occur if these each signals stand alone without interfere each other. Two periodic signals are orthogonal when the integral of their product over one period is equal to zero [2, 6].

$$\int_a^b \varphi_p(t)\varphi_q{}^*(t)dt = 0 \tag{1}$$

Conventional OFDM used Fourier transform to generate the orthogonal subcarriers. The Fourier converts signals from the time domain to the frequency domain. On the transmitter side the OFDM using IFFT while at the receiver side using the FFT.

$$\text{IFFT:}\quad x(n) = \frac{1}{N}\sum_{n=0}^{N-1} x(k)e^{j2\pi\frac{nk}{N}} \tag{2}$$

$$\text{FFT:}\quad x(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi\frac{nk}{N}} \tag{3}$$

where:
N = IFFT ponts (subcarrier total)
x(k) = signal in frequency domain
x(n) = signal in tine domain

2.2 Wavelet

Wavelet is a short wave (small wave) which energy concentrated in a time interval to provide transient analysis capabilities, un-stationer or time-varying phenomena. Characteristics of wavelets is a short oscillatory, translational (shift), and dilation (scale).

There are two types of wavelet transform are Continue Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). The wavelet transform that used in the simulation is DWT. DWT is used to transform into discrete data.

Each wavelet filter has 2 High Pass Filter (Hi_R and Hi_D) and 2 Low Pass Filter (Lo_R and Lo_D) that filter size determined by orde and coefficient filter. IDWT process use Lo_R dan Hi_R filter. The input of detail coefficients are 16 QAM signal mapping (x) while the approximation coefficients are padding zero. After up-sampling, approximation coefficients convoluted with Low Pass Filter (Lo_R). while detail coefficients convoluted with High Pass Filter (Hi_R). Then summed both.

DWT process use Lo_D dan Hi_D filter. That filter reverse from Lo_R and Hi_R filter in IDWT. To obtain the approximation coefficients, the signal (s) is convoluted with Low Pass Filter (Lo_D) then downsampling. The approximation coefficients contain zero padding. Meanwhile, to obtain the detail coefficients, the signal (s) is convoluted with High Pass Filter (Hi_D) then downsampling. Detail coefficients contain the received signal (y).

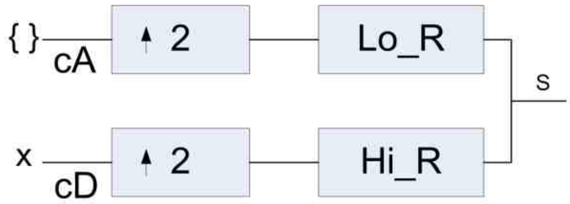


Fig. 2. IDWT Process

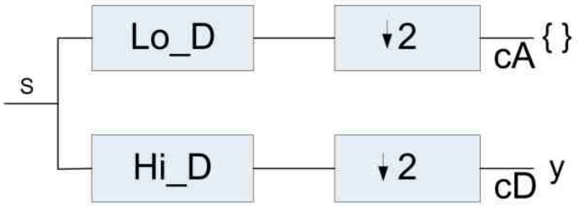


Fig. 3. DWT Process

2.3 Peak to Average Power Ratio (PAPR)

PAPR is the ratio between peak power of the signal with average power [5]. The higher PAPR causes signal quality decreased.

$$PAPR = \frac{P_{\max}}{P_{avg}} = \frac{\max|s(t)^2|}{E[|s^2(t)|]}$$

$$= \frac{\max\limits_{0\le t\le Ts}|s(t)^2|}{\frac{1}{Ts}\int_0^{Ts}|s^2(t)|dt} \quad \text{where } Ts = 1/Fc\ [1, 5] \tag{4}$$

2.4 Clipping

The simplest way to reduce PAPR is cut peak signal amplitude into a maximum level required. Although be a simple solution, clipping technique will be able to damage the signal so that it will change the shape and impact on bit error detection at the receiver side.

Clipping technique used in this journal are the classical clipping and smooth clipping with Eq. (5) and Eq. (6).

Classical clipping

$$f(r) = \begin{cases} r & ,r \le A \\ A & ,r > A \end{cases} \tag{5}$$

Smooth clipping

$$f(r) = \begin{cases} r - \frac{1}{b}r^3 & ,r \le \frac{3}{2}A \\ A & ,r > \frac{3}{2}A \end{cases} \quad \text{where } b = \frac{27}{4}A^2 \tag{6}$$

Another parameter that characterizes the clipping performance is clipping ratio that is given by Eq. (7), where σ is the rms level of the OFDM signals. In this journal using CR=1, 1.2, and 1.4.

$$CR = \frac{A}{\sigma} \tag{7}$$

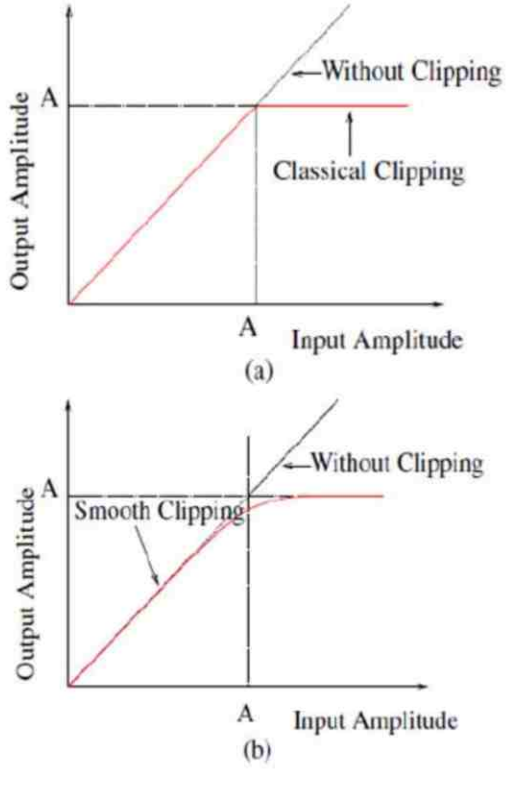


Fig. 4. (a) Classical Clipping (b) Smooth Clipping [1, 7]

3. Simulation and Performance Parameter

The analysis observe the downlink direction carrier frequency of 3.5GHz communication with mobile WiMAX standard. Simulations use different wavelet filters and any clipping techniques to find out which has higher performance than Fourier based.

In simulation, random data will be processed by convolutional coding with coderate ½ and interleaver before mapped by 16QAM mapper. Then, signal will be processed with STBC coder with Alamouti 2x2 algorithm. After that, incoming signals passed IFFT/IDWT block to generate orthogonal subcarriers.

Last, signal will be clipped before transmitted. Transmitted signal will be passed on channel AWGN and Rayleigh distribution. The system was tested outdoors (outdoor) with user speed 3km/h and 30km/h in pedestrian environment low delay spread. Performance parameters were observed graphs CCDF and BER against Eb/No.

3.1 Simulation Parameter

System simulation has OFDM parameters as shown in Table 1.

3.2 Block Diagram System

System will be simulated as block diagrams at Figure 5 and Figure 6 bellow.

3.3 Cumulative Complementary Distribution Function

PAPR described statistically by using Cumulative Complementary Distribution Function (CCDF), where CCDF = 1 - CDF. CDF is a cumulative value of PAPR $F(z) = 1 - \exp(-z)$. PAPR is calculated after the clipping process [1, 7].

CCDF:

$$P(PAPR > z) = 1 - P(PAPR \le z)$$
$$= 1 - F(z) = 1 - (1 - \exp(-z)) \quad (8)$$

3.4 Bit Error Rate

Bit Error Rate (BER) is the most important parameter in determining the quality of a system. The higher value indicates the BER performance of the system is getting worse, because the information received at the receiver side through many changes during transmission.

$$BER = \frac{BitError}{TotalBit} \quad (9)$$

Simulation repeat 15 times iteration to get result that closer to the truth. The number of minimum transmit bit to get specific BER can be calculate by Eq. (10) [5]:

$$B = \frac{10}{BER} \quad (10)$$

Table 1. Simulation Parameter

Parameter	**Mobile WIMAX**
FFT point	512
Cyclic prefix	¼
Modulation	16QAM
Interleaver	Row: 128, column: flexible
Convolutional Code	Inner-code (g_0=133_8, g_1=171_8, K=7)
Clipping Type	Classical Clipping and Smooth Clipping
Clipping Ratio	CR=1, CR=1.2, and CR=1.4
Wavelet Filter	Haar, Daubechies, Coiflets, Symlets, Biorthogonal, and Reverse Biorthogonal.
User velocity	3 km/h and 30 km/h

4. Wavelet Carrier Modulation with Clipping Techniques in Mobile WiMAX

4.1 Comparison BER of FFT and Wavelet OFDM

Wavelet daubechies (db) has N orde write as dbN. For N=1 called Haar and N=2, 3, 4, …45. Daubechies filter coefficient equals 2N. A daubechies with N orde has vanishing moment value equals N. Vanishing moment show the ability for representing polynomial attributes to define number of wavelet filter coefficient. dbN are asymmetric than another wavelet family.

User velocity or Doppler shift can be calculated by Eq. (11). From Eq. (11) get f_d=10Hz for 3km/h velocity and f_d=97Hz for 30km/h velocity.

$$f_d = \frac{f_c . v}{c} \cos\theta \quad (11)$$

Daubechies wavelet based OFDM is resistant to Doppler shift if compared with Fourier based. BER daubechies wavelet based OFDM have 4.106% degradation caused Doppler shift. That value is better than Fourier based, with 12.063% degradation.

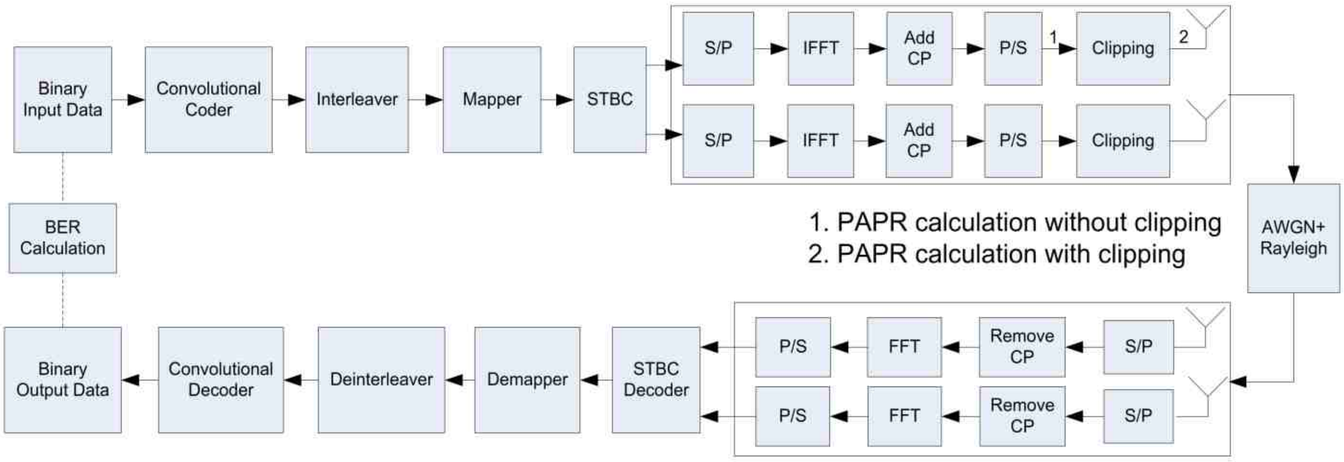


Fig. 5. 2x2 MIMO Fourier OFDM with Clipping

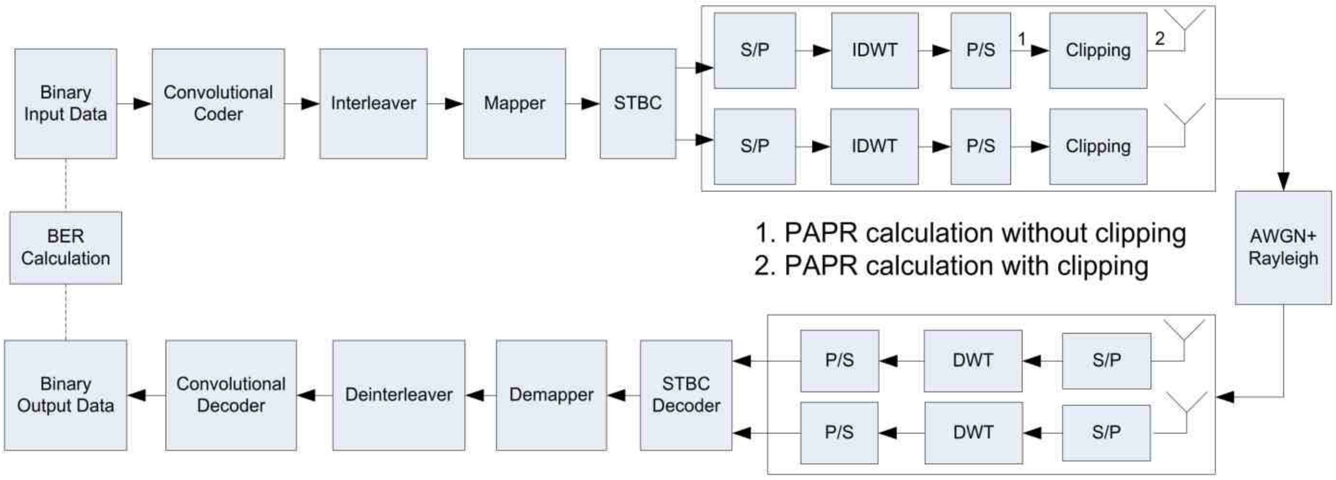


Fig. 6. 2x2 MIMO Wavelet OFDM with Clipping

Symlet (sym) has N orde write as symN where N=2, 3, 4,…45. Symlet wavelet filter coefficient same as daubechies equals 2N. Symlet is a modification daubechies filter but more symmetric. Symlet is more resistant to Doppler shift than daubechies, because its average 2.101% degradation.

Coiflets (Coif) has N orde write as CoifN, where N = 1,....,5. CoifN filter coefficient equals with 3dbN, example coif5 equals 3x dB5 filter coefficient. CoifN is more symmetric than debauchies. BiorNr.Nd and rbioNr.Nd are also orthogonal and symmetric wavelet filter, where Nr and Nd use to define orde and number of filter coefficient. Coiflet, biorNr.Nd and rbioNr.Nd also resistant to Doppler shift, average 3.064% degradation.

For all wavelet filters, the greater N orde is, the worse the BER. Due to higher spectral containment between sub channels, wavelet-based OFDM is better able to overcome the effects of narrowband interference and is inherently more robust with respect to ICI than traditional Fourier filters. For detail please see Figure 7, 8, 9 and Table 2

4.2 Comparison CCDF of FFT and Wavelet

For PAPR performance can be reviewed with CCDF graphic at 10^{-1}. PAPR in wavelet based OFDM always better than Fourier based OFDM. From Figure 10 and 11, Fourier has greatest PAPR around 9.316dB because high PAPR generated after IFFT process. Meanwhile haar, bior1.1 and rbio1.1 smallest around 2.68dB, impacted to BER for haar wavelet based OFDM better than Fourier based.

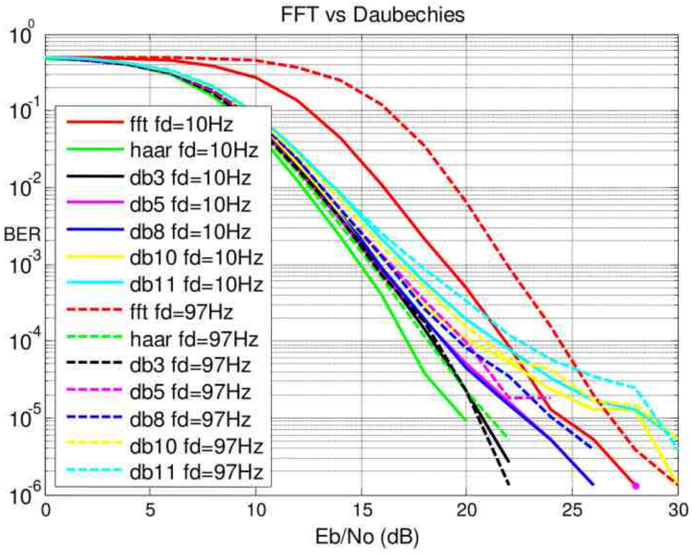


Fig. 7. BER FFT vs Daubechies

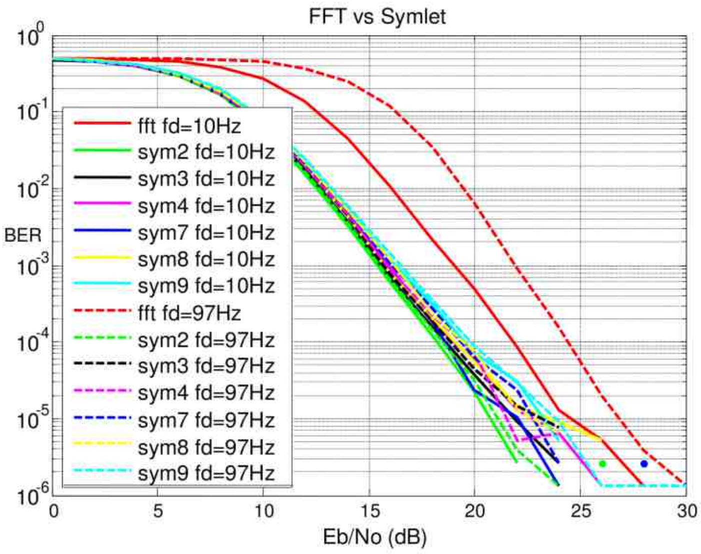


Fig. 8. BER FFT vs Symlet

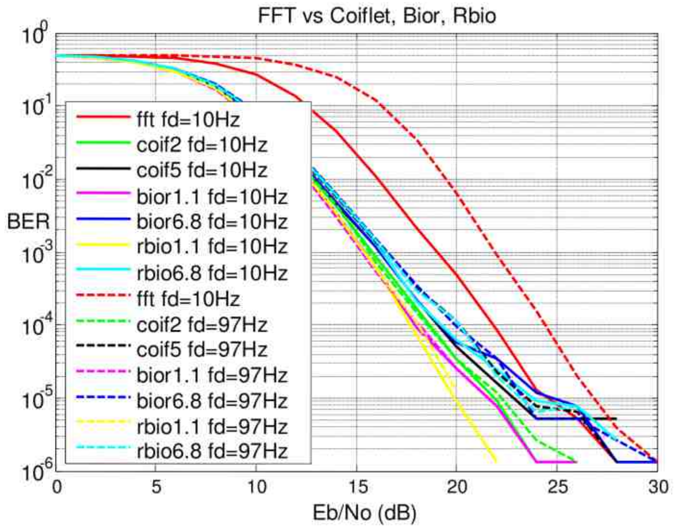


Fig. 9. BER FFT vs Coiflet, Biorthogonal and Reverse Biorthognal

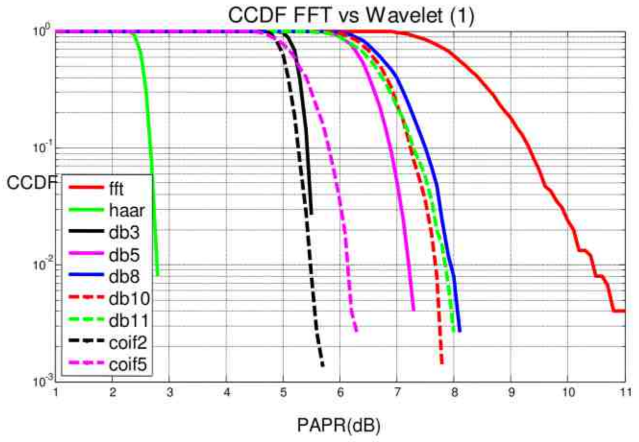


Fig. 10. CCDF FFT vs Wavelet (i)

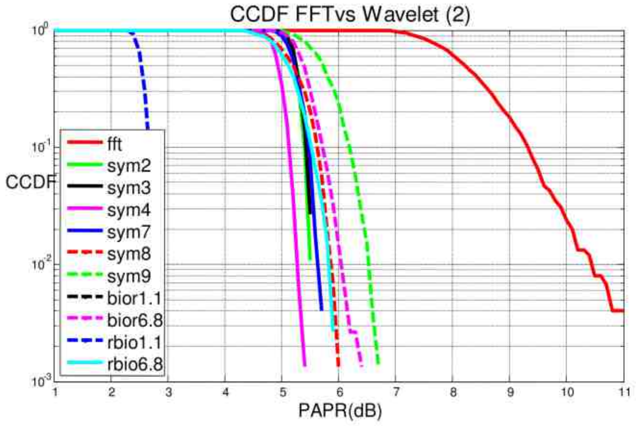


Fig. 11. CCDF FFT vs Wavelet (ii)

Table 2. FFT vs Wavelet

Transform	**Eb/No (dB)**		**PAPR(dB)**
	Fd=10Hz	**Fd=97Hz**	
FFT	21.794	24.423	9.316
Haar	17.175	18.178	2.68
db3	18.392	18.539	5.42
db5	18.934	19.941	6.883
db8	18.872	19.628	7.503
db10	20.15	20.9	7.242
db11	21.42	22.48	7.296
sym2	18.21	18.48	5.394
sym3	18.61	18.85	5.421
sym4	18.99	19.46	5.132
sym7	18.59	19.35	5.471
sym8	19.08	19.47	5.629
sym9	19.56	19.8	6.188
coif2	18.53	18.56	5.269
coif5	19.07	20.18	5.809
bior1.1	17.93	18.16	2.68
bior6.8	19.18	19.94	5.718
rbio1.1	17.69	18.11	2.68
rbio6.8	19.23	20.15	5.523

4.3 Comparison Classical and Smooth Clipping

From Figure 14, simulation with 10Hz Doppler shift and CR=1, Eb/No for FFT at BER 10^{-4} with *classical* clipping 25.861dB is better than smooth *clipping* 29.652dB. Meanwhile for wavelet based OFDM, example db10, classical clipping around 22.08dB and smooth clipping around 24.19dB. In average BER degradation from clipping process for all filter wavelet and Fourier with classical cliping 5.77% degradation is better than smooth clipping 11.32% degradation. This is due to when r signal at condition greater threshold A, so signal *clipped* with amplitude A level in classical clipping. Meanwhile in *smooth clipping,* when $r > \frac{3}{2}A$, signal *clipped* with amplitude A level. But when $r \le \frac{3}{2}A$, signal still clipped with amplitude $r - \frac{1}{b}r^3$ level.

From Figure 15, PAPR when clipped with classical clipping CR=1 reviewed in CCDF at 10^{-1} for FFT around 3.453dB compared with smooth clipping around 4.113dB. Meanwhile wavelet based OFDM, example dB10, PAPR with classical clipping 3.18dB and with smooth clipping around 3.94dB. In average PAPR classical clipping for all filter wavelet and Fourier around 3.052263dB and with smooth clipping around 3.586684dB.

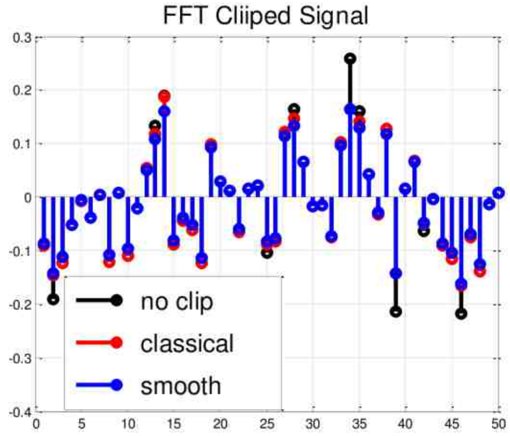


Fig. 12. Clipped Fourier Signal

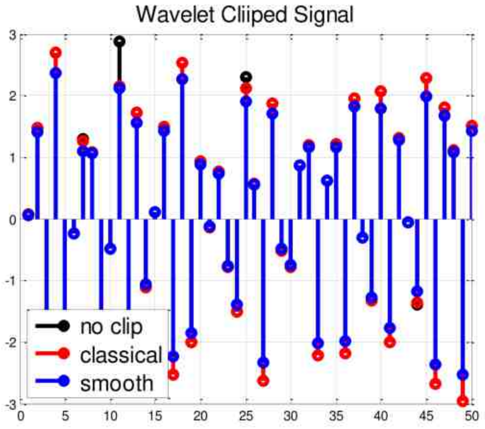


Fig. 13. Clipped Wavelet Signal

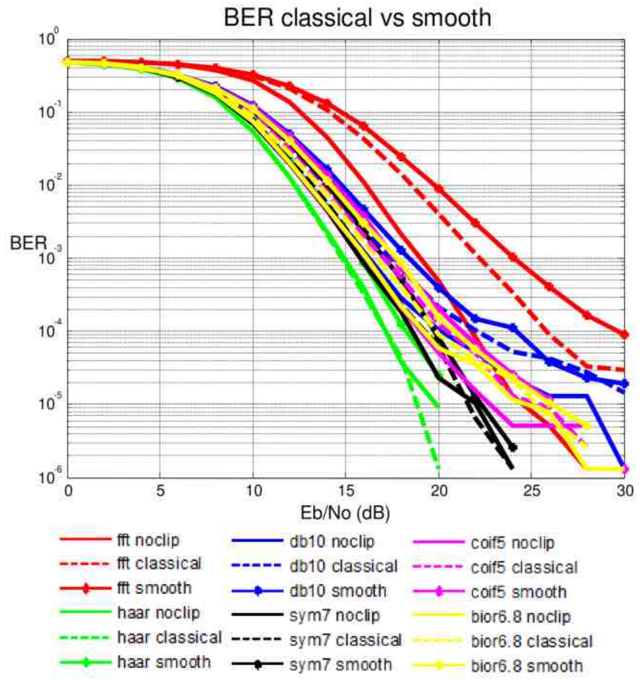
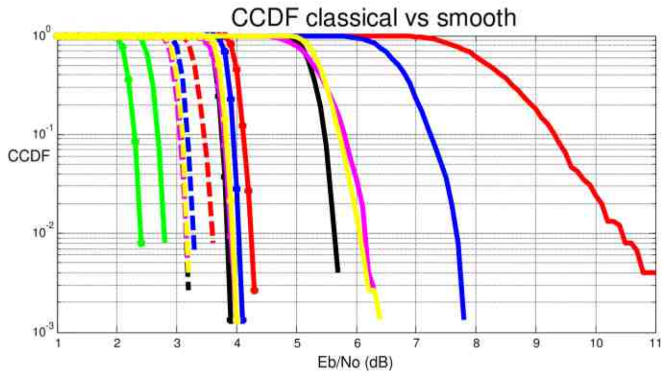


Fig. 14. BER Classical vs Smooth Clipping CR=1



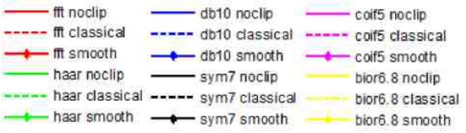


Fig. 15. CCDF Classical vs Smooth Clip CR=1

But not all wavelet filter have CCDF *classical* CR=1 better than *smooth clipping*, because haar bior1.1 and rbio1.1 filter have CCDF *smooth clipping* smaller than *classical clipping*. This due to haar, bior1.1 dan rbio1.1 signal not clipped because signal not in condition to clipped when classical clipping.

4.4 Classical and Smooth Clipping With Any Clipping Ratio

In this simulation will analyze using classical clipping and smooth clipping any level of Clipping Ratio. CR=1, 1.2, and 1.4. Clipping Ratio will set the threshold to determined signal level after clipping based on Eq. (7).

From Figure 16, average EB/No at BER 10^{-4} with classical clipping arranged from the smallest are no clip < CR=1.4 < CR=1.2 < CR=1. And from Figure 17, average PAPR at CCDF 10^{-1} with classical clipping arranged from the highest no clip > CR=1.4 > CR=1.2 > CR=1.

From Figure 18, average EB/No at BER 10^{-4} with smooth clipping arranged from the smallest are no clip < CR=1.4 < CR=1.2 < CR=1. At Figure 19, average PAPR at CCDF 10^{-1} with smooth clipping, arranged from the highest, are no clip > CR=1.4 > CR=1.2 > CR=1.

Table 3. Eb/No Classical and Smooth Clipping CR=1, 1.2, 1.4

Filter	no clip(dB)	Classical (dB)			Smooth (dB)		
		CR=1	CR=1.2	CR=1.4	CR=1	CR=1.2	CR=1.4
FFT	21.794	25.861	22.617	21.955	29.652	23.475	22.552
Haar	17.175	17.239	17.202	17.183	18.286	17.61	17.39
db10	20.15	22.08	20.2	20.24	24.19	20.66	20.36
sym7	18.59	19.25	18.86	18.84	19.79	19.64	19.16
coif5	19.07	20.48	20.16	20.13	21.29	20.35	20.32
bior6.8	19.18	19.88	19.5	19.44	20.86	20.23	19.52

Table 4. CCDF Classical and Smooth Clipping CR=1, 1.2, 1.4

Filter	no clip(dB)	Classical (dB)			Smooth (dB)		
		CR=1	CR=1.2	CR=1.4	CR=1	CR=1.2	CR=1.4
FFT	9.316	3.453	4.588	5.716	4.113	5.249	6.262
Haar	2.68	2.68	2.68	2.68	2.289	2.416	2.498
db10	7.242	3.18	4.45	5.71	3.94	5.033	5.723
sym7	5.471	3.072	4.42	5.47	3.747	4.355	4.687
coif5	5.809	3.052	4.402	5.61	3.781	4.498	4.885
bior6.8	5.718	3.1	4.397	5.6	3.818	4.505	4.858

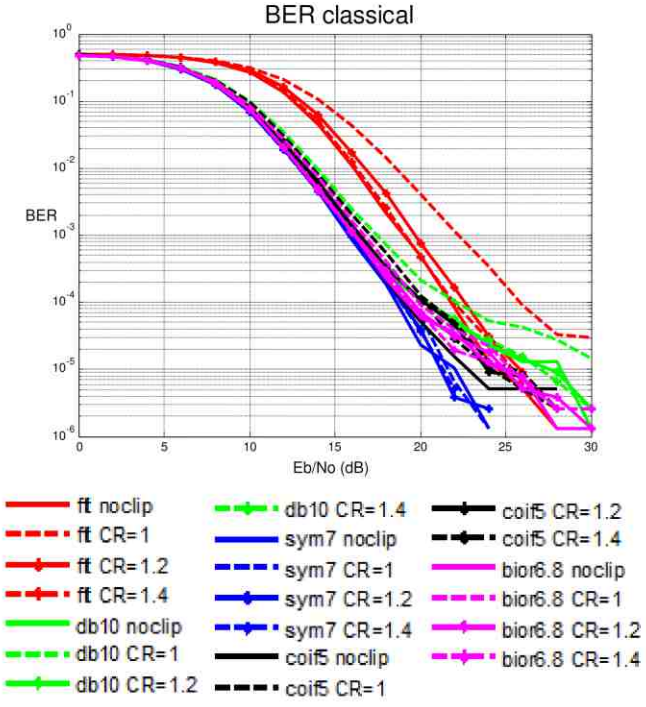


Fig. 16. BER Classical Clipping (CR=1, 1.2, 1.4)

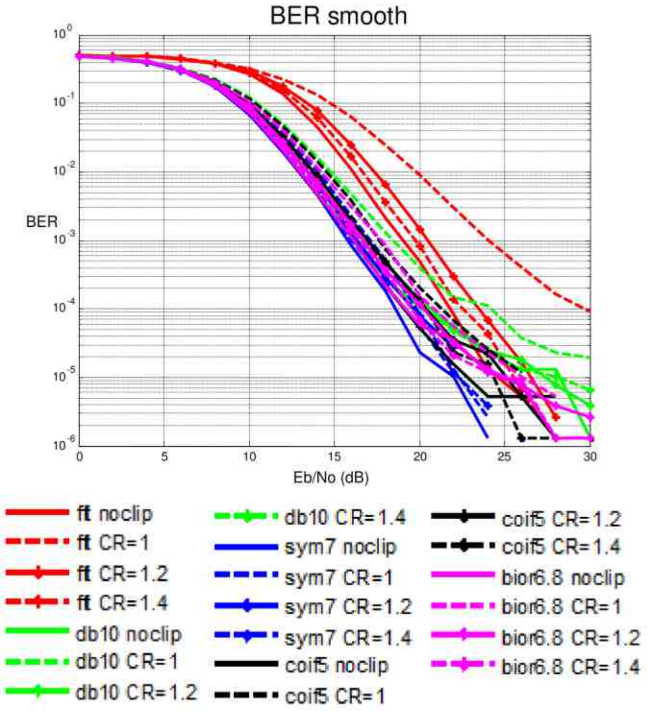


Fig. 18. BER Smooth Clipping (CR=1, 1.2, 1.4)

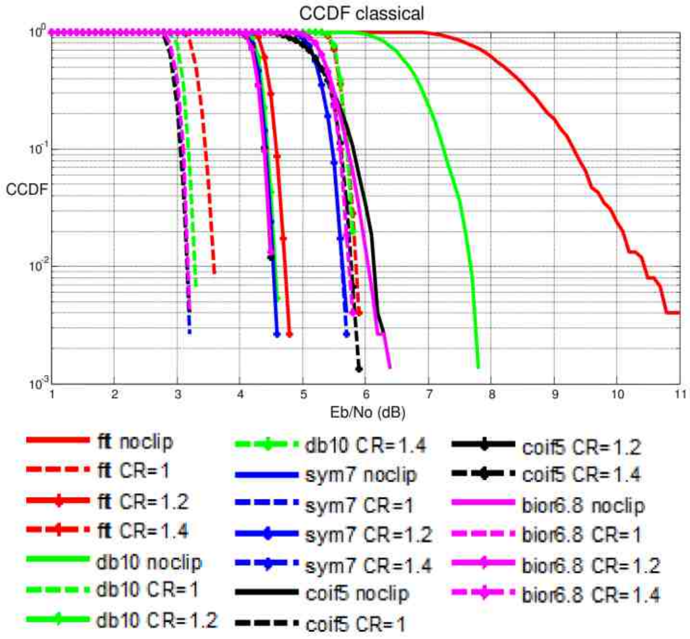


Fig 17. CCDF Classical Clipping (CR=1, 1.2, 1.4)

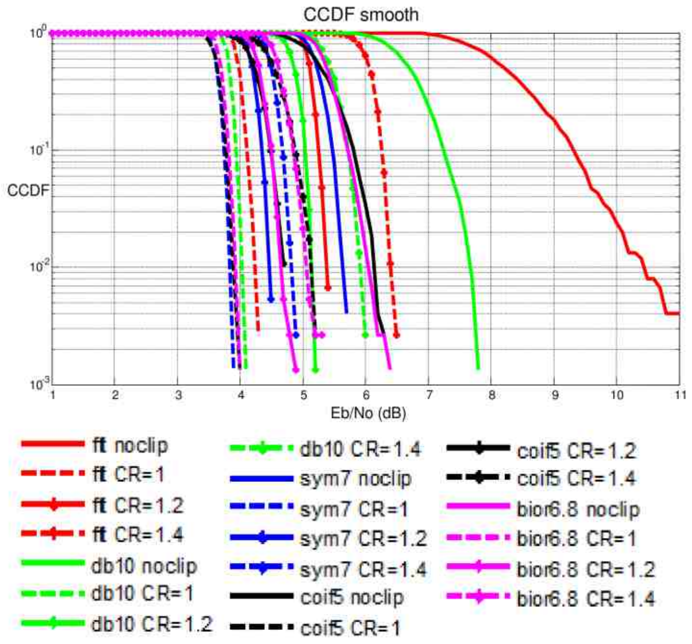


Fig. 19. CCDF Smooth Clipping (CR=1, 1.2, 1.4)

5. Conclusions

1. Wavelet based OFDM has a better immunity to noise and Doppler shift than Fourier based.
2. SymN is more resistant to Doppler shift and it is more symmetry.
3. For all wavelet filters, the greater N orde is, the worse the BER. Among simulated wavelet filters, Haar wavelet has the best PAPR and BER.
4. The performance of BER classical clipping is always better than the smooth clipping in any CR.
5. On haar, the bior1.1 and rbio1.1 *classical clipping* are not clipped in any CR because all signals are not exceeds threshold.
6. Sym 7 with classical clipping and CR=1.2 can be implemented on wavelet based OFDM. Because the difference of BER between Sym7 without any clipping and the one with classical clipping and CR=1.2 is small. Also the CCDF classical clipping and CR=1.2 better than smooth clipping.

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