Performance Analysis of WiMAX-OFDM Uplink System by PAPR Reduction using GNU radio

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***Abstract*—**Evolving broadband wireless technology has broadened the need for Worldwide interoperability for Microwave Access (WiMAX) or Long Term Evolution (LTE) that targets 4G services but such systems have a major drawback that is high Peak to Average Power Ratio (PAPR). The problem of PAPR cannot be removed completely from the end point systems but it has to be reduced to a minimal value to ensure proper transmission of signal. WiMAX technology has Orthogonal Frequency Division Multiplexing (OFDM) based physical layer which is an important technique for high speed data transfer services. This paper describes the implementation of WiMAX-OFDM based physical layer using GNU radio software. A major problem of OFDM systems is high PAPR. A high PAPR decreases the Signal to Noise Ratio (SQNR) of Analog to Digital converter (ADC) and Digital to Analog converter (DAC) while affecting and reducing the efficiency of the PA (power amplifier) in the transmitter. This paper presents a combined mechanism of channel coding, clipping and filtering as a PAPR reduction technique while reducing distortions in the signal transmission. During the experimental set up, PAPR for different modulation techniques have been evaluated and the result shows PAPR has been minimized remarkably. The proposed technique also draws how clipping levels are related to the PAPR reduction. The complete experimental set up is accomplished using GNU radio which is powerful, free and open source software for signal processing and implementing (Software Defined Radio) SDRs.

Keywords*—OFDM; WiMAX; GNU radio; PAPR; 4G; Wifi; IEEE; MIMO; SDR; USRP*

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (WiMAX) technology [20] has become one of the most popular and promising broadband wireless technologies over the past few years and researchers have been working on various fields of WiMAX. This technology is based on IEEE 802.16 standard that defines the features of 4G wireless systems and is Wireless Metropolitan Area Networks (WMANs) for point to multipoint wireless access. The 802.16d or 802.16-2004 version of WiMAX is used for fixed applications and provides a wireless equivalent of DSL broadband data and able to provide data rates of up to 75 mbps with a cell radii typically up to 75 km while the 802.16e or 802.16-e aims at the roaming or mobile users and provides data rates up to 15 mbps in a cell radii of typically between 2 to 4 km. WiMAX offers 10-16 GHz and 2-11 GHz spectrum for Line of Sight and Non Line of Sight environments [20].

WiMAX technology uses OFDM (Orthogonal Frequency Division Multiplexing) and MIMO (Multiple Input Multiple Output) techniques to provide high data rate to ensure high speed services [2, 23]. OFDM is described as a high data rate wireless transmission technique adopted in several wireless standards such as the IEEE 802.11 (LAN, WLAN etc.), IEEE 802.16 (MAN, WiMAX or LTE) standards, Digital Video Broadcasting and Digital Audio Broadcasting (DAB) [21]. OFDM uses a large number of closed spaced carriers that are modulated with low data rate. The signals in the scheme are orthogonal to each other and hence there is no mutual interference between the transmitted data streams and issue of selective fading has been eliminated [10]. OFDM signals exploit multiples of 128 carriers in a total signal bandwidth that may range from 1.25 to 20 MHz for WiMAX [23]. Although, OFDM has many advantages of high bandwidth efficient and robust to inter-symbol interference, it has a main disadvantage of very high Peak to Average Power Ratio (PAPR) [7], a well-known drawback in which the amplitude of the time domain OFDM signal varies since many subcarrier components are added via IIFT operation compare to that of single carrier systems. The problem of PAPR arises in the transmitter since the efficiency of power amplifier is critical due to the limited power in the mobile terminal [10]. The high peak values of the OFDM signal will push the amplifier enter into the non-linear region and this characteristic of HPA (High Power Amplifier) excited by a large input causes the out of band radiation that causes distortion in adjacent bands and in-band distortion that result in rotation, offset and attenuation on the received signal. In the literature various techniques have been proposed to minimize PAPR and researchers have used channel coding [20] as a PAPR reduction technique and to increase the performance of the OFDM system. It is shown that the use of this technique reduces PAPR. Clipping [22] clips the peak value of OFDM signal to some desired amplitude level in order to obtain minimum PAPR and it is a simple and effective technique which has a very low complexity. In order to eliminate the unwanted out of band frequencies after the clipping process, filtering technique is applied to maintain the actual signal band and reduce co-channel interference. The main objective of this paper is to present an efficient algorithm for WiMAX-OFDM based PHY layer system that will minimize PAPR with an improvement over other algorithms and low complexity in the system configuration.

This paper is managed as follows: Section 2 introduces the software used. Section 3 explains PAPR and its effects in an

OFDM system. Section 4 discusses the proposed PAPR reduction method. Section 5 analyzes the experimental results obtained and its discussions. Finally, the paper concludes in Section 6 with a conclusion.

II. GNU RADIO COMPANION

GNU radio companion [11] is a graphical user interface and free software development toolkit that includes signal processing blocks to implement SDRs and signal processing systems. It is a python-code generation tool that can be used with external RF hardware to create SDRs (Software Defined Radios) or without hardware in a simulation like environments. GNU radio is based on blocks and flow-graphs in which blocks process signals or the continuous data streams and have one or more input or output ports. It offers various common plotting and data visualization data sinks, including FFT displays, scope displays, error rate counter displays and symbol constellation diagrams. These blocks are generally used both for debugging radio applications and user-interfacing unit. GNU radio applications are based on flow-graphs which are a series of easily reconfigurable signal processing blocks connected together thus representing a data flow. The GNU radio applications are primarily written in Python and signal processing blocks are connected using C++. The software consists of a number of signal processing blocks in C++ that are easily adaptable to different network architectures and protocols to meet various functionalities of transmit and receive architecture. The simplified wrapper and interface generation compiler in GNU radio allows the Python code to communicate in C++. The system presented in this paper is set up using GNU RADIO software.

III. PAPR IN OFDM SYSTEMS

In OFDM, FFT is used to implement Discrete Fourier Transform (DFT) and IIFT can be used to implement Inverse Discrete Fourier Transform (IDFT) and both DFT and IDFT processes are useful for implementing orthogonal signals. The OFDM scheme converts a high speed serial data streams into a low speed parallel data streams. This is obtained by dividing a single channel into a multiple sub-channels which are orthogonal to each other. In the OFDM system, N-point IFFT is taken for the transmitted symbols XT[k], k=0,1,2,….,N-1 so as to generate x[n], n=0,1,2,…..,N-1, that represents the samples for the N orthogonal subcarrier signals [10].

Let y[n] denotes the received sample that corresponds to x[n] with the additive noise w[n] then it can be written as

$$y[n]=x[n]+w[n] \qquad (1)$$

Taking the N-point FFT of the received samples, y[n], n=0,1,2,….,N-1, the noisy form of transmitted symbols

$Y_T[k]$, k=0,1,2,…...,N-1 can be obtained in the receiver [10].

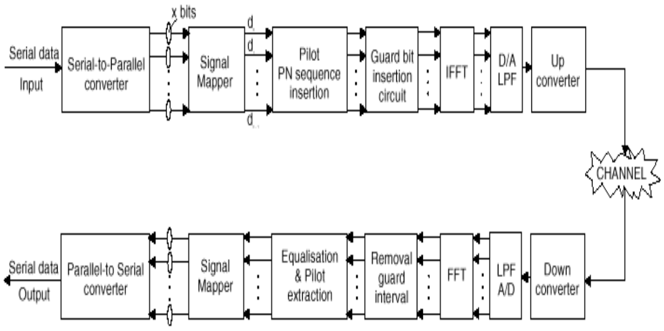

Fig. 1, OFDM multicarrier transceiver model [24].

The orthogonality [10] of the time limited complex exponential signal $e^{j2\pi f_k t}$, k=0,1,2,…,N-1, which represents the different subcarriers at $f_k = \frac{k}{T_{sym}}$ in the OFDM signal, where $0 \le t \le T_{sym}$ are defined as the integral of the product for their common period is zero. Mathematically, it can be written as

$$\frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi f_k t}.e^{-j2\pi f_i t}\,dt = \frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi\frac{k}{T_{sym}}t}.e^{-j2\pi\frac{i}{T_{sym}}t}\,dt$$
$$= \frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi\frac{(k-i)}{T_{sym}}t}\,dt$$
$$= \begin{cases}1, & \forall \text{ integer } k=i\\ 0, & \text{otherwise}\end{cases} \qquad (2)$$

The peak to average power radio (PAPR) of a transmitted signal is one of the major disadvantages in broadband wireless multi-carrier systems that exploit OFDM or MIMO-OFDM technique. The peak to average power ratio (PAPR) of an OFDM system is calculated as the ratio between the maximum power and the average power of the complex pass-band signal s(t), i.e.

$$PAPR\{s(t)\} = \frac{\max|Re(s(t)e^{j2\pi f_c t})|^2}{E\{|Re(s(t)e^{j2\pi f_c t})|^2\}} = \frac{\max|s(t)|^2}{E\{|s(t)|^2\}} \qquad (3)$$

PAPR in terms of dB is defined as:

$$\text{PAPR}=10\log_{10}\frac{P_{peak}}{P_{average}}\ \text{(dB)} \qquad (4)$$

A high peak-to-average power ratio (PAPR) can cause unwanted saturation in the power amplifiers. This causes the transmitter power amplifier (PA) to operate within the non-linear operating region leading to in-band distortion and out-of-band radiation. Distortion in the OFDM system acts as noise for the receiver and the out of band distortion causes cross talk since the subcarriers are not orthogonal anymore and induces co-channel interference. Therefore, the PA must operate with a large input power back-off so as to operate in the linear region [10].

IV. PROPOSED PAPR REDUCTION METHOD

The proposed PAPR reduction technique incorporates the feature that combines channel coding, clipping and filtering. The complete experimental set up is accomplished using GNU radio software. Although coding techniques as well as clipping techniques are widely employed and are different methods used for PAPR reduction in the literature, this paper focuses on their combined feature for better performance. The idea of employing filters after the clipper significantly reduces the out-of-band distortion in the clipped OFDM signal spectrum. The basic block diagram of proposed model architecture for PAPR reduction is shown in the *fig. 2*.

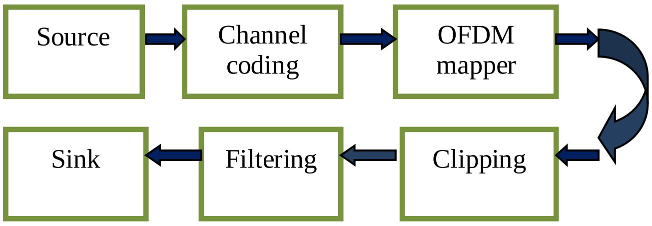

Fig. 2, Proposed uplink system model of coding, clipping and filtering for PAPR reduction.

The channel coding uses three techniques of scrambler, forward error correction code (FEC) and interleaving. Channel coding reduces bit error rate by attaching redundant bits in the transmitted symbols. Scrambler is used in order to reduce the length of strings of 0s and 1s in a transmitted signal, since a long string of 0s or 1s can cause transmission synchronization problems and can also be used as a cheap encryption technique. The channel encoder used in the experiment is a rate ½, k=7 CCSDS 27 (convolutional encoder) which performs convolutional encoding using CCSDS standard polynomial that provides performance better than other coders in terms of BER as well as PAPR reduction. The OFDM mapper takes input data streams in parallel lines and maps them into symbol constellations using different mapping schemes. Clipping clips the peak value of OFDM waveform that reduces the spectral efficiency of the multicarrier system. Clipping is chosen as an effective technique because of its simple and low complexity for PAPR reduction while filtering is implemented after clipping to eliminate the unwanted out-of-band frequencies by the clipping process.

V. EXPERIMENTAL RESULTS AND DISCUSSIONS

In this section, we evaluate and analyze the results obtained and assess the performance of our proposed scheme which is implemented using GNU radio. The experimental setup is built to do real time communication experiments as shown in fig. 3. Two separate USRPs are employed for transmission and reception. The system parameters considered for the WiMAX-OFDM are listed in Table 1. As highlighted in Section 4, the experimental set up of the proposed uplink system is shown in the fig. 4. The designed system consists of block of source signal that represents the original information to be transmitted, scrambler block to randomize transitions in the transmitted signal by shuffling the bits. The CCSDS encoder block provides excellent error correction performance and makes it ideal fit for high throughput applications for microwave transmission. The inter-leaver is used to correct burst errors and improve the performance of forward error correcting codes. When errors in a code-word exceed the capability of error-correcting code, it fails to recover the original code word. Interleaving shuffles the source symbols across several code words and thereby is creating a more uniform distribution of errors. The OFDM mod block modulates an OFDM stream. Based on the options of FFT length, occupied tones and cyclic prefix length, this block creates OFDM symbols using different modulation schemes. The rail block clips input values to a minimum and maximum value.

TABLE I. EXPERIMENTAL PARAMETERS CONSIDERED

Parameters	Values
Sampling rate	10M
FFT length	256
Packet length	96
Occupied tones	200
Bandwidth	7.86MHz
Cyclic prefix length	64
Modulation schemes	BPSK, QPSK, QAM16, QAM64, QAM256

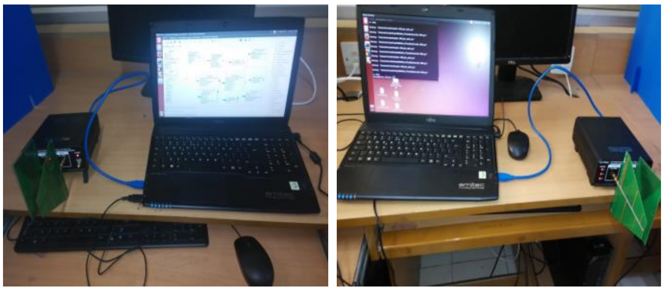

Fig. 3, Proposed real time experimental set up with two separate USRPs and Linux OS that runs GNU radio.

(a) Transmitter side (b) Receiver side.

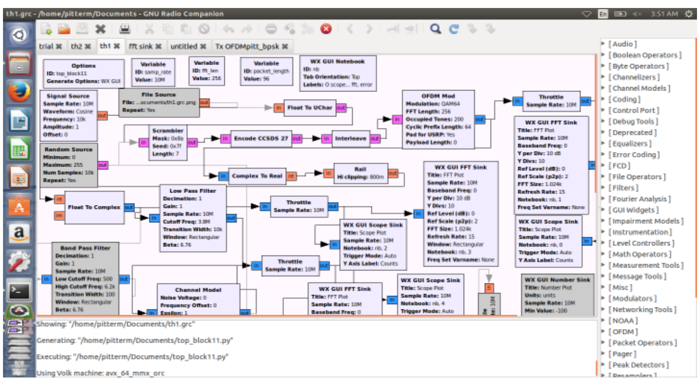

Fig. 4, Designed transmitter architecture for WiMAX-OFDM system.

In *Fig. 5* represents the OFDM modulated original information signal from the source. And it has been observed that the signal after the OFDM exhibits high peak to peak amplitude or high PAPR. After applying the proposed method, it is seen from the fig. 6 that the transmitted signal amplitude is reduced and allows us to maintain at the desired level thus minimum PAPR is obtained. Although clipping is a simple and low complexity method, it induces in-band and out-band radiations that distorts in the received signal and interference in the adjacent bands respectively. From *fig. 8* and *fig. 9,* the effect of in-band radiation as well as the out-band radiation can be clearly seen. However, the proposed method reduces the out of band radiations significantly as shown in *fig. 10.* Thus the proposed mechanism avoids co-channel interference and hence improves channel efficiency of the system.

Table 2 shows the measured values of WiMAX-OFDM physical layer after clipping to assess the reduction of PAPR performance for the proposed method. *Fig. 11* is the graphical representation of the PAPR as a function of clipping levels. During the experiment, we set different clipping levels and for each level, peak to peak amplitude as well as the average amplitude is measured with thorough inspection of the signals generated and respective PAPR is calculated using the methods described in section III. The experiment exploits different modulation schemes i.e. BPSK, QPSK, QAM16, QAM64, QAM256 and PAPR is evaluated for each scheme and it can be observed from the table that of the modulation schemes employed, QAM256 is the most efficient in PAPR reduction as well as in terms of error rate. Further from the table, it is observed that clipping level at 0.8 of 1.6 i.e. 50% of the signal amplitude yields the best PAPR reduction. It means that if we clipped the signal at 50% of the highest amplitude, PAPR reduction is maximum as compare to the other clipping levels. During the experiment, while employing BPSK scheme a total 3.32% of PAPR is reduced, 19% reduction for QPSK, 10.2% for QAM 16, 36.6% for QAM 64 and a total of 17.2% reduction for QAM 256 are obtained. And from this data table, it can be concluded that QAM 256 is the best of all other modulation schemes.

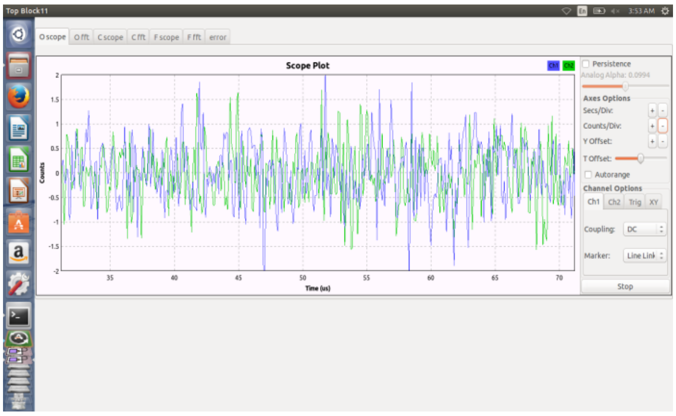

Fig. 5, Original transmitted OFDM signal waveform.

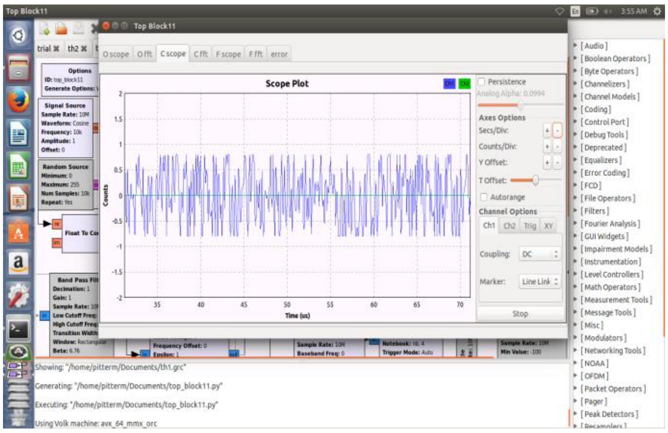

Fig. 6, Clipped and transmitted OFDM signal waveform.

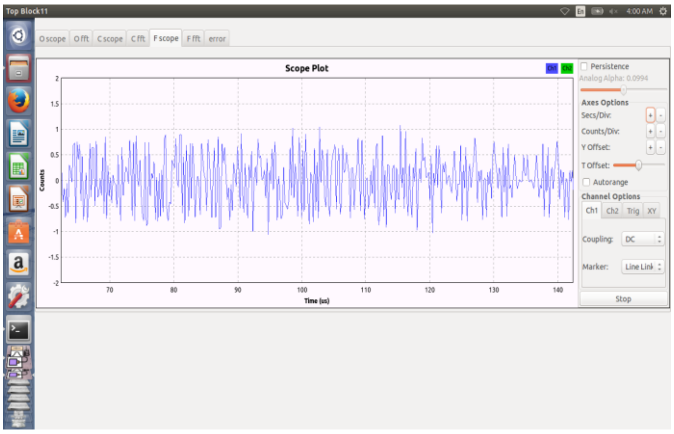

Fig. 7, Filtered OFDM signal waveform after clipping.

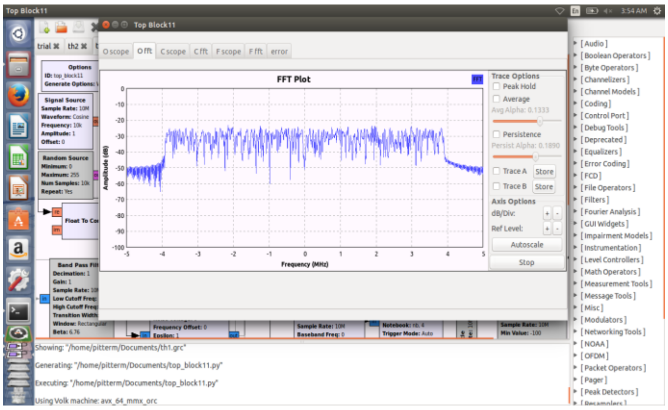

Fig. 8, Original transmitted OFDM signal spectrum.

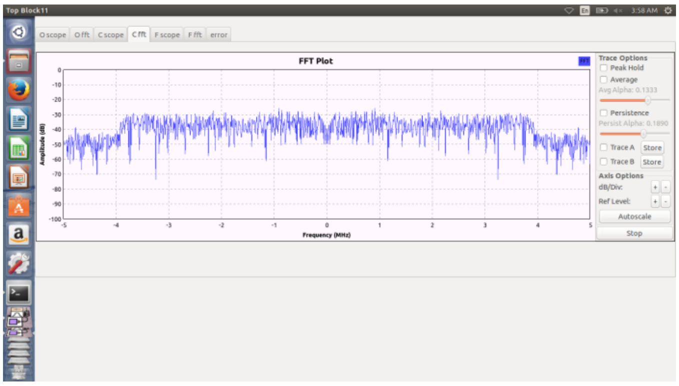

Fig. 9, Clipped OFDM signal frequency spectrum.

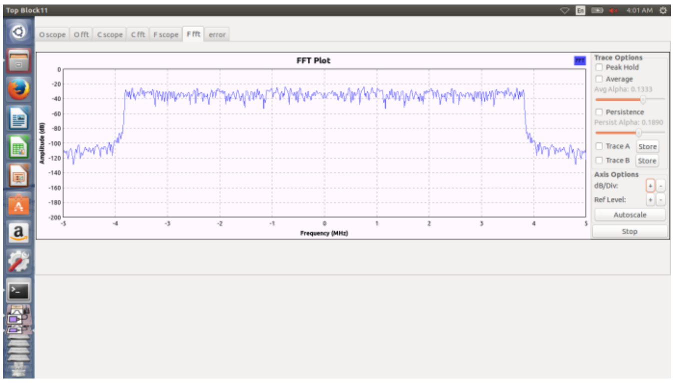

Fig. 10, Filtered OFDM signal spectrum after clipping.

TABLE II. OBTAINED RESULTS FOR WIMAX-OFDM PHYSICAL LAYER AFTER CLIPPING.

Modulation technique	Clipping level	Peak to peak amplitude	Average amplitude	PAPR
BPSK	1	-69.4 to -25	-43.09 to -29.44	10.58
	0.8	-68.42 to -25.66	-44.73 to -30.26	8.73
	0.6	-67.36 to -27.4	-44.17 to -31.51	9.96
	0.4	-70.36 to -31.25	-45.23 to -34.7	13.79
	0.2	-76.02 to -36.57	-51.21 to -40.03	12.48
QPSK	1	-68.75 to -26.31	-42.59 to -29.6	10.67
	0.8	-69.24 to -27.79	-44.67 to -30.72	8.95
	0.6	-68.25 to -26.8	-44.4 to -32.4	11.93
	0.4	-72.59 to -30.49	-47.26 to -34.76	11.34
	0.2	-77.43 to -35.82	-51.2 to -38.94	11.37
QAM16	1	-70.88 to -25.76	-43.42 to -27.79	8.33
	0.8	-70.55 to -26.31	-43.91 to -28.45	8.18
	0.6	-68.09 to -27.13	-43.91 to -31.25	10.46
	0.4	-75.06 to -29.6	-48.02 to -32.8	8.92
	0.2	-77.2 to -35	-52.43 to -38.28	8.89
QAM64	1	-69.5 to -25.7	-43.02 to -28.22	8.75
	0.8	-67.1 to -27.3	-44.24 to -29.27	7.07
	0.6	-69.4 to -25.98	-44.24 to -30.09	9.42
	0.4	-73.19 to -30	-46.71 to -33.05	9.99
	0.2	-77.63 to -37.17	-52.11 to -38.63	9.0
	1	-69.73 to -26.48	-46.21 to -26.64	4.88
QAM256	0.8	-68.91 to -26.97	-48.02 to -27.42	4.14
	0.6	-70.72 to -26.31	-49.5 to -28.61	4.52
	0.4	-72.69 to -29.7	-51.31 to -30.42	4.23
	0.2	-79.17 to -35.92	-56.31 to -35.42	4.2

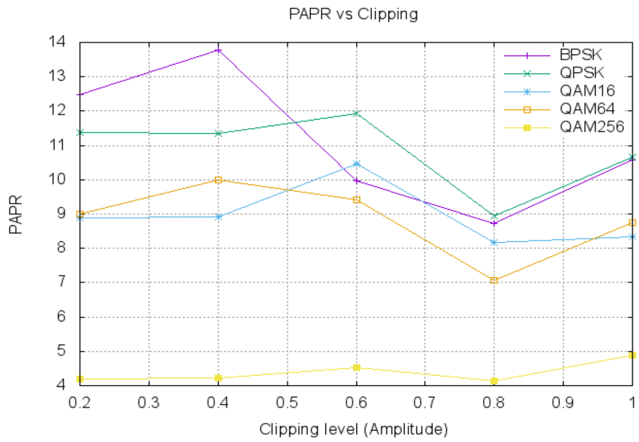

Fig. 11, Graphical representation of PAPR for the proposed method

VI. CONCLUSION

This paper presents the implementation of reconfigurable WiMAX-OFDM PHY layer for Peak to Average Power Ratio (PAPR) reduction using GNU radio software. This paper also describes and focuses on the importance of the feature that combines channel coding, clipping and filtering as a technique to reduce PAPR. It may be concluded from the results that PAPR values vary for different clipping levels and clipping at 50% of the highest amplitude of the original signal achieves maximum PAPR reduction. Also, it is seen that there is trade-off between modulation scheme and PAPR value that with the increase in modulation size also significantly reduces PAPR. Moreover, the problem that arises during the experiment of possible co-channel interference in the system is also eliminated by the proposed method. Thus, from the results as well as observations during the experiment it is concluded that the hybrid technique of channel coding, clipping and filtering reduces PAPR significantly and can be adopted for WiMAX-OFDM uplink system. Further works can be expanded to some alternative techniques that will further reduce PAPR as well as the in-band distortion that will be implemented in the real time environment using USRP (Universal Software Radio Peripheral) hardware components to implement SDRs available in the lab.

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