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FPGA-Based Realisation of SDR with OFDM Tranceiver

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ABSTRACT

Software-defined radio architecture is the key point of next generation communication systems in which some of the functional units are designed as software on a reconfigurable processor. This paper proposes the physical layer architecture of SDR with modified orthogonal frequency division multiplexing (OFDM). One of the main drawbacks of OFDM is that its high peak-to-average reduction (PAPR) ratio. The PAPR can be reduced using filtering and adaptive peak windowing method with Kaiser window. The adaptive window method finds the positions of maximum peak values using a peak detector in the signal and applies the window function with variable parameter. The radix 2 scalable N point FFT algorithm is used in the system. The mapping of the information signal is done with BPSK, PSK, and 16 QAM modulation. According to the signal-to- noise ratio (SNR) value, the type of modulation can be selected. Decoding of the OFDM signal in the receiver is done with Viterbi decoding algorithm. The communication system simulation is done in MATLAB and the baseband operations are implemented on Xilinx FPGA.

Keywords: Software-defined radio architecture, runtime reconfiguration, orthogonal frequency division multiplexing, communication systems

1. INTRODUCTION

The emerging trends in the wireless communication system have opened the way of 4^{th} generation (4G) communication systems. The seamless advantages of the 4G system can meet the customer demands. The 4G systems can support up to 1 Gbits/s with high security. One of the main challenges of the 4G system is its accessibility of heterogeneous network. For this, an efficient transceiver system is required. Software-defined radio (SDR) is an efficient radio, which is adapt to any situation.

Since SDR contains software functions, it can change the parameters at any time according to the situations. The SDR can be used for military applications, 4G, and next generation wireless communication for fast and accurate communication. SDR is the technique used for replacing hardware components into a software program, which reduces the complexities in the implementation and testing[1]. There are lots of advantages for the replacement of hardware to software, low complexity, high efficiency, improved functionality, less area, and power consumption, low manufacturing cost, etc. The software allows to change the parameters of the receiver at run time itself according to the application[2]. The reconfigurable architectures like FPGA, DSP, and general purpose processors are used as the design platforms.

OFDM is a modulation technique, which can be used in high data rate communication systems. It is a multi-carrier modulation system with high bandwidth efficiency and is robust to frequency selective fading[3]. One of the major drawbacks of the OFDM techniques is the highest peak-to-average power reduction (PAPR) ratio of the transmitted signal. It causes nonlinear distortion while passing through the power amplifier, hence reduces the BER performance. There are many algorithms used to reduce the peak power of the OFDM signal, such as clipping, filtering tone rejection, peak windowing, companding, selective mapping (SLM)[4,5], etc. Partial transmit sequence (PTS) etc[6]. The above algorithms give the moderate performance.

The peak windowing and the filtering methods are the simplest methods among the above mentioned algorithms. In clipping and filtering method, some data loss happens. The clipping process cuts off the high peaks in the signal. It affects the information signal. In the peak windowing method, the window cannot accommodate when the consecutive peaks come. In our proposing method, the adaptive window can accommodate at any place by changing the window parameter. This will reduce the losses in data and will improve the performance of the system. The filter will remove the out-of-band radiation of the signal[7-9].

All other methods have the system complexity and computational complexity[10]. The Viterbi algorithm is the fastest decoding algorithm using Trellis structure used for communication system application.

2. SDR ARCHITECTURE

Software-defined radios are flexible in nature. Even at run time these can adapt to the changes in the system[11]. The SDR is a basic platform for the cognitive radio in the system can automatically adaptto any changes in the environmental conditions. The general architecture of SDR is shown[12] in the Fig. 1. The physical layer operations depend on the

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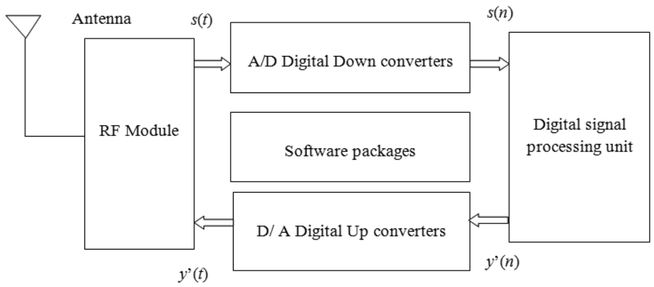

Figure1. SDR general architecture.

environmental conditions as well as the application. The SDR can change its parameters at any time without disturbing the other functions in the system. In SDR all functions are designed as software coding instead of hardware component. Therefore the system can update itself according to the needs at any time with low cost and complexity. The main functions of SDR are described.

2.1 Smart Antennae

The baseband controllers control the antenna operations. At the transmitter side, the antenna makes an interface between the network (NET) layer and the MAC layer on the receiver side. The antenna can achieve the signal by space division multiplexing.

2.2 RF Modules

The RF module is used to assist the smart antenna. The RF module is having the following functions, Digital frequency synthesizer, pre-amplifier, power output, RF conversion.

2.3 Digital up/down Converters

A/D is used to convert the digital signal into an analog signal. The signal from the antenna is in the RF range. Then the RF signal is converted into IF signal. The high speed converters are designed according to the sampling theorem. The up converters do the reverse operation of this.

2.4 Software Packages

SDR uses a distributed type of architecture and processes the information transmitted using common object request broker architecture (CORBA), protocol with control packages and system interface packages. There are two types of software downloaded used in SDR, static technology and semi-static technology[2].

2.5 Digital Signal Processing

The digital signal processing (DSP) functions can be implemented on an FPGA. All the physical layer functions like modulation/demodulation, encoding/decoding, and multiplexing/de-multiplexing will be performing in this block.

3. OFDM

The proposed architecture of OFDM is shown in the Fig. 2. The conventional system SLM techniques and filtering method have been used. Here filter with windowing methods have been used. This will reduces the ripples in the frequency response of the signal.

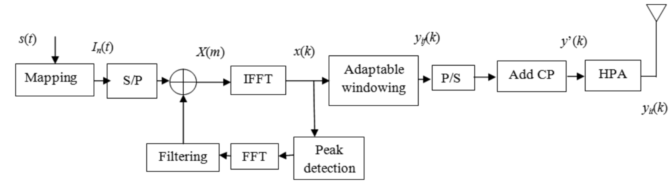

Figure 2. Proposed architecture of OFDM transmitter, filter with Kaiser window.

In the SLM scheme, the information bits have been divided into number of sequences in a particular order and one has to find the IFFT of each sequence separately. Then one can select one sequence with a minimum PAPR ratio[13-16]. In general, for each FFT requires $N/2\ log_2 N$ multiplications and $N\ log_2 N$ addition. The number of FFTs will increase, and then computational complexity also increases. In the proposed method, the FFT is calculated only one time for the input sequence and it is passed through the filter. The filter can reduce the out-of-band radiations in the transmitted signal.

In windowing techniques Kaiser window will show the best results. One of the disadvantages of the peak windowing method is that, when consecutive peaks come in the signal, then the window cannot apply continuously. In the proposed method, the widow is adaptive in nature. The adaptivity of the window allows changing the shape of the window. This can easily accommodate when the high peak appears. The peak detector in the system can find the positions of every peak. According to the peak value position one applies the Kaiser window function[17-18].

The filter passes the signal through the window. The window frequency response is given by the Eqns (9-11). The filter with window technique filters off the unwanted noise added in the information signals at the transmitter and helps to keep the side information of the signal. Most of the existing methods fail in the transmission of side information.

4. SYSTEM MODEL OF OFDM

The input of the OFMD system from the source is represented as s(t). The main processing steps in the OFDM system are described below

1. Mapping with BPSK/QPSK/16-QAM,
2. Serial to parallel conversion,
3. IFFT,
4. Find the peak locations,
5. Apply the filter,
6. Apply the Kaiser window, with varying β values,
7. Add cyclic prefix for reducing the inter carrier interference and passed through high power amplifier,
8. Transmitted through the AWGN channel,
9. Remove the CP,
10. De-mapping with BPSK/QPSK/16-QAM,
11. Decoding with Viterbi algorithm.

The detailed steps are explained. Generally the OFDM system has multiple sub-carriers. The number of multiple sub-carriers can be represented as M. Then the IFFT of the transmitted signal is given by the equation

$$x(k) = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} X(m) e^{j2\pi(m/M)} \quad 0 \le k \le M-1 \tag{1}$$

where, $j = \sqrt{-1}$, $X(m)$ = [$X(0)$, $X(1)$,………$X(M\text{-}1)$] is the input signal for IFFT and k is the discrete time index.The peak-to-average power ratio of the transmitted OFDM signal is given by,

$$PAPR = \frac{P_{peak}}{P_{average}} = \frac{\max\left|x(k)^2\right|}{E\left|x(k)^2\right|} \quad (2)$$

where, P_{peak} is the peak power of the transmitted signal and $P_{average}$ is the average power of the transmitted signal. In OFDM, the information signal is first mapped by using QPSK or BPSK modulation. The expression for both modulations can be expressed as[19-20].

4.1 Case (i): BPSK Mapping

In BPSK modulation, the signal is mapped with either 0 or 1.

$$I_n(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi(1-n)), n = 0,1 \quad (3)$$

For binary 0, $I_0(t) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t), n = 0$

For binary 1, $I_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t), n = 1$

where, f_c is the frequency of the Carrier wave. For M carrier signal the frequencies are $f_{c1} f_{c2\ldots\ldots} f_{M\text{-}1.}$ T_b is the Time period.

4.2 Case (ii) QPSK Mapping

In QPSK modulation the signal can be represented using four symbol, can be represented as

$$I_n(t) = \sqrt{\frac{2E_q}{T_q}}\cos(2\pi f_c t + \pi/4(2n-1), n = 1,2,3,4 \quad (4)$$

The signal can be represented as

$$\phi_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t)$$

$$\phi_2(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t)$$

4.3 Case (iii): QAM Mapping

The mapping of the system can also do using QAM modulation. The QAM was also designed using a function and it can be selected whenever it needs. Where, $I_n(t)$ is the modulated form of the information signal $S(t)$ from the source. After the modulation, the signal is passed through the IFFT.

The response of FIR filter is given by

$$y(n) = \sum_{k=0}^{M-1} h(k)x(n-k) \quad (5)$$

The frequency domain equivalent is equal to

$$Y(k) = H(k)X(k) \quad (6)$$

where, $Y(k)$ is the N point DFT and $k = \frac{2\pi m}{M}$

For linear phase FIR filter,

$$H(\omega) = \left|H(\omega)\right|e^{j\varphi(\omega)}\text{, where, } \varphi(\omega) = n\omega \quad (7)$$

The conditions for the linear phase FIR filter is

$$h(n) = \pm h(M-1-n) \text{ , n = 0 , 1 , 2, …….. } M-1 \quad (8)$$

The Eqns (5) – (8) represent the FIR filter design. The output response will show some ripples in the pass band and stop band. These ripples can be reduced using the truncation method. For this, one can use windowing techniques. Kaiser window can be used in this method. The response of the Kaiser window is given in the Eqn (9). The Kaiser window function is given by

$$w(l) = \begin{cases} I_0\left[\beta\sqrt{1-\left(\frac{1-L/2}{L/2}\right)}\right], 0 < 1 \le L \\ 0, otherwise \end{cases} \quad (9)$$

where, $I_0(.)$ is the zeroth order modified Bessel function of 1st kind, and β is the shaping parameter and is given by

$$\beta = \begin{cases} 0.1102(H-8.7), H > 20 \\ 0.5842(H-21)+0.07886(H-21), 21 \le H \le 50 \\ 0, H < 21 \end{cases} \quad (10)$$

and L is approximately equal to

$$L = H - 8/2.285\Delta\omega \quad (11)$$

After applying windowing function and filtering, the signal can be represented as $Y_{if}(k)$. Therefore the total filter response Eqn (6) become

$$\left.\begin{aligned} Y_i(k) &= X_i(k)J_i(k) \\ Y_{if}(k) &= Hd_i(k)X_i(k)J_i(k) \\ Y_{it}(k) &= H_i(k)X_i(k)J_i(k)W_i(k) \end{aligned}\right\} \quad (12)$$

where, $Y_i(k)$ is the filtered signal, $X_i(k)$ is the input signal from IFFT $J_i(k)$ is the impulse response of the filter, $Hd_i(k)$ is the response of the filter, $W_i(k)$ is the window function and $Y_{it}(k)$ is the transmitted OFDM signal. The transmitted signal is sampled by a factor U before transmitting the signal through the channel.

After the windowing function, the signal is added to the cyclic prefix for avoiding the interference in the OFDM signal. Some zeros are added with starting and ending of each symbol. The symbol can be represented as $y'(k)$. At the receiver side the zeros (CP) will be removed.

Consider the receiver side, the block diagram is shown in Fig. (3). Here, $v=n/U$.

OFDM has multi-path channel, at the receiver the over sampling response is given in Eqn (13).The Impulse response of receiving signal is given by, $g(n/U)$, n=0..... UM-1.

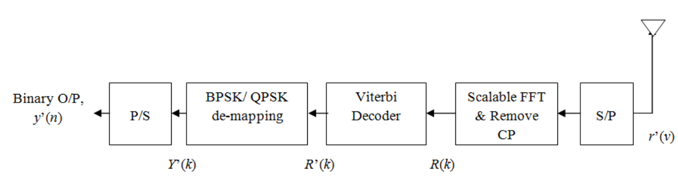

Figure 3. OFDM receiver architecture.

$$\left.\begin{aligned} r(n/U) &= y(n/U) \otimes g(n/U) + o(n/U) \\ y(n/U) \otimes g(n/U) &= \sum_{k=0}^{UM-1} y(k/U) h(\frac{(n-k)UM}{U}) \end{aligned}\right\} \quad (13)$$

where, $y(n/U) = x(n/U)h(n/U)w(n/U)$
where, $(n\text{-}k)_{UM}$ represents the (n-k) modulo UN, U is the over sampling factor, $r(n/U)$ is the received signal, $g(n/U)$ is the impulse response of the channel, $h(n/U)$ is the filter response and $w(n/U)$ is the window function. Then one has to find the FFT of the received signal and is given by

$$R(k) = \sum_{m=0}^{UM-1} r(n/U) e^{-j2\pi(km/UM)} \quad 0 \le k \le UM-1 \qquad (14)$$

where $r(n)$ is a product of $y(n)$, $g(n)$ and $o(n)$ is the noise. The $y(n)$ and $g(n)$ can be by calculating the FFT

$$\begin{aligned} y(n) &= \sum_{k=0}^{N-1} Y(k) e^{-j2\pi(kn/N)} \\ g(n) &= \sum_{k=0}^{N-1} G(k) e^{-j2\pi(kn/N)} \end{aligned} \text{, where, } 0 \le n \le N\text{-}1 \qquad (15)$$

After finding the FFT, the signal is passed through a decoder and demodulation. On the receiver side, Viterbi algorithm is used to decode the received signal.

5. VITERBI DECODER

On the receiver side of the OFDM Viterbi decoder is used. This algorithm finds the most likelihood state transitions in the Trellis structure. In OFDM, the Viterbi is used for decoding the sequence at the receiver and detects the sequence of symbols. The Viterbi algorithm mostly applied when the problem is formulated by a Markov chain[21-23].

Markov process can be represented as

$$P(\omega_{k+1} / \omega_k, \omega_{k-1}) = P(\omega_{k+1} / \omega_k) \qquad (16)$$

ω is representing different states.

The Viterbi decoder consisting of the branch metric unit (BM), add and compare unit, and one memory unit. The BM unit is used to calculate metrics in all branches from input data. The ACS unit will calculate the path metric of current states and two previous states. Then compare the two metrics and select the minimum metric. The memory unit is used to store all metric values. The output unit is used to transfer all the bits from right-side[23].

5.1 Algorithm

The steps involved in the Viterbi algorithm are include:

1. Initialise the parameters,
2. Branch metric calculation. (using Hamming distance),
3. Load the branch metric,
4. ACS,
5. Check whether the states end, if yes then go to step 6 otherwise go to step 3,
6. Check whether the trellis states end, if yes then go to step 7 otherwise go to step 2,
7. Collect the decoded bit,
8. End.

The process is a Markov chain if and only if the form a countable sequence set. The transitions in the chain can be represent either as a state diagram or using Trellis diagram. In Trellis the distance can be represented as

$$\sum_{p=0}^{P} \left\| Y_p - S_p \right\|^2 \qquad (17)$$

Viterbi algorithm increases the speed of the decoder and easily traces out the original signal. The final output of the Viterbi decoder is represented as $R'(k)$.

6. RESULTS

The Fig. 4 shows the simulation results. Here the modulations are taken as BPSK, QPSK. The FFT size can be varied according to the application. The FFT is scalable, can be varying any time. The simulation shows the comparison of the existing systems such as filtering and SLM method for a different variations. Also shows the variation of bit error rate (BER) with various point FFT. Table 1.

Table 1. Parameters used for simulation

Parameter	Size
FFT size	16, 64, 128
No of sub carrier	60
Modulation	BPSK, QPSK, 16-QAM
Window	Kaiser window

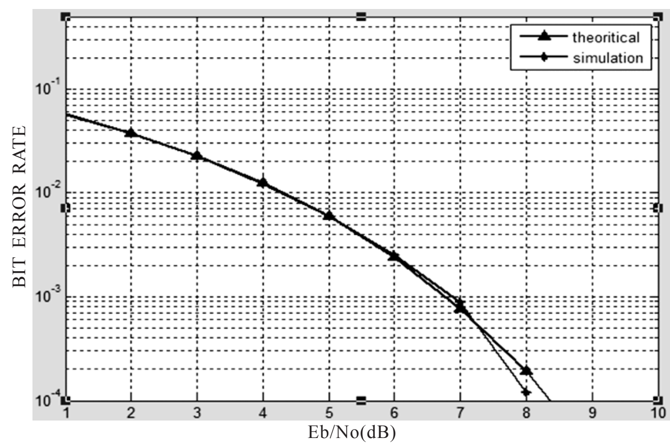

Figure 4. BER of BPSK (N= 128).

Figure 4 shows the BER curve for BPSK with N = 128 and the number of carrier signals = 60. The original signal and the simulated signal are shown in the Fig. 4. The simulated signal is almost related to the original theoretical signal. Therefore very less error rate happens at the receiver side. In Fig. 5 the BER performances of the QPSK and 16_QAM are presented. The OFDM performance is improved by using the window technique.

The Fig. 6 shows the BER curve using different channels. The AWGN channel gives better performance than Rayleigh for all modulations.

The Fig. 7 shows the BER performance of different modulations. This Figure shows the QPSK modulation and BPSK modulation with AWGN channel for various N values. The Fig. 8 shows the CCDF curve for peak power for BPSK modulation.It shows the PAPR curve of OFDM signal with N = 128

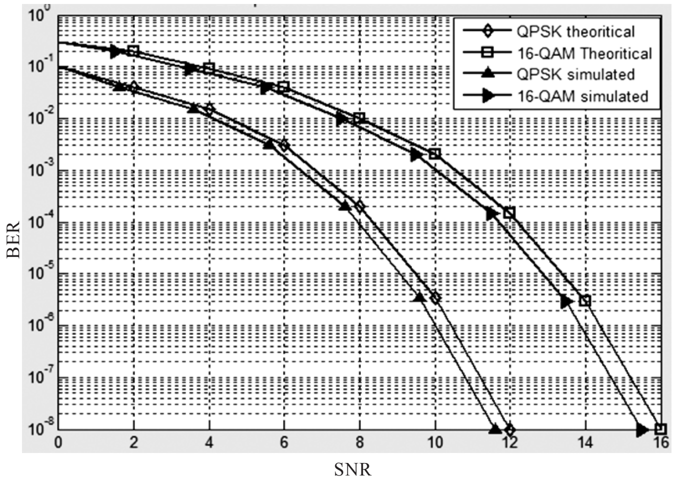

Figure 5. BER performance of OFDM with QPSK and 16-QAM.

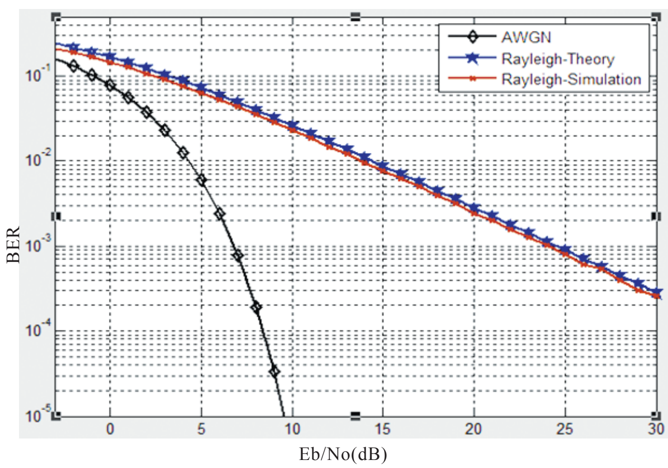

Figure 6. BER of BPSK using different channels

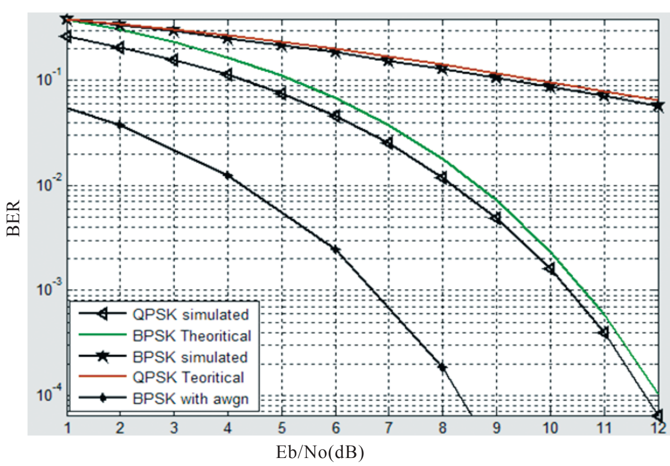

Figure 7. BPSK and QPSK for *N* =64 and *N* =128.

The complementary cumulative distribution function can be expressed as

$$CCDF = P_r(PAPR > PAPR_0) \quad (18)$$

This function is used to plot the PAPR and can be compare with the PAPR of various methods used previously. In Figs. (9) and (10) represents the spectra of OFDM signal with N = 64 and N = 128 at the transmitter side are represented. It shows the bandwidth usage of the transmitter. As N increases, the spectrum becomes narrower.

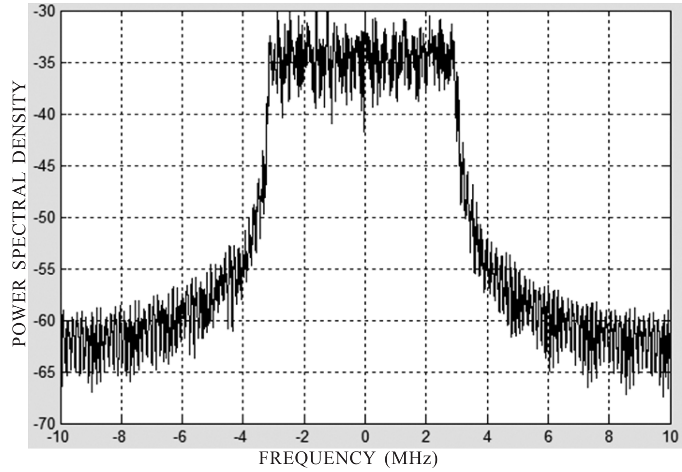

Figure 8. PAPR vs CCDF.

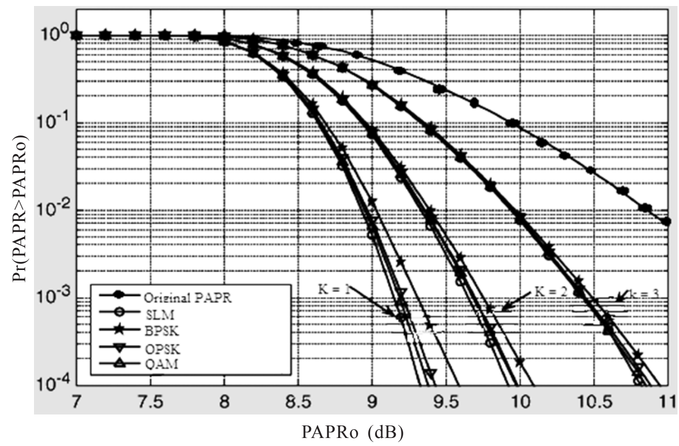

Figure 9. Spectrum of OFDM signal for *N*=64 at transmitter.

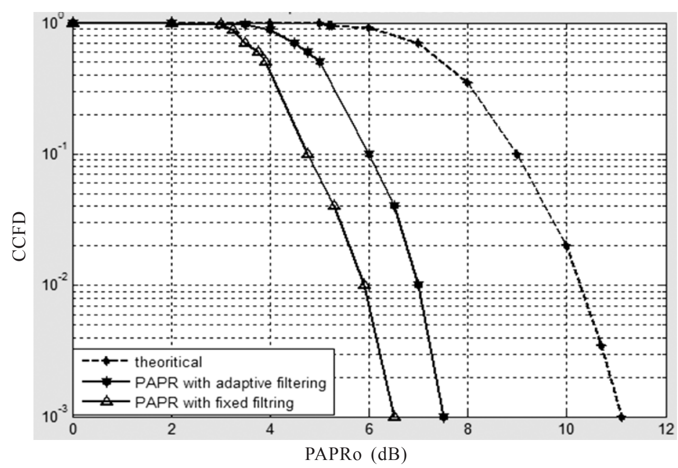

Figure 10. Spectrum of OFDM signal for *N* =128 at transmitter.

As to the FFT point varies, the calculations like number of additions and multiplications increases. The spectra of the OFDM signal varies according to the parameters of the Transceiver system.

The bandwidth of the transmitted signal also varies with the modulation technique used for mapping the OFDM signals.

Here three types of modulation are considered, BPSK, QPSK, and 16-QAM. The various curves are SLM technique[14-15] and three modulations with N = 64, N = 128, N =256. The proposed method with Kaiser window technique gives the better result than the SLM technique. For side information, separate channel is used. Also separate carrier signals are used.

The k value represents the number of points in the FFT. The BER performance of the proposed signal depends on the distortion in the signal. As the distortion decreases, the error rate also decreases. Both are correlated each other. The Fig. 11 represents a comparison of results of PAPR using various methods.

Figure 12 represents the PAPR performance difference between fixed-peak windowing and adaptable-peak windowing. The adaptable-peak windowing shows better performance (around 1dB) than the fixed- peak windowing.

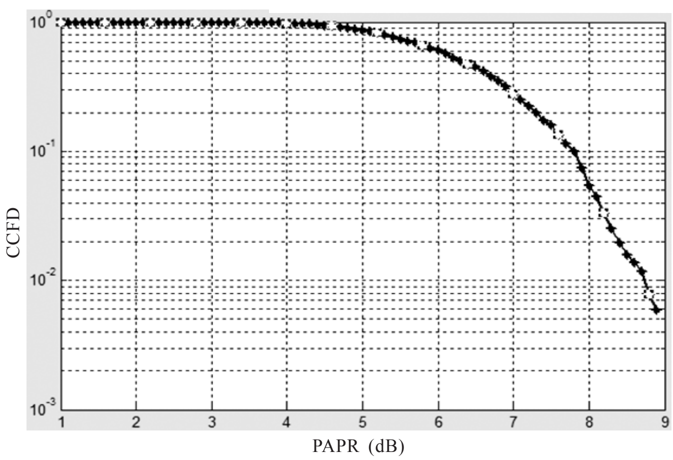

Figure 11. Comparison of PAPR with different modulations.

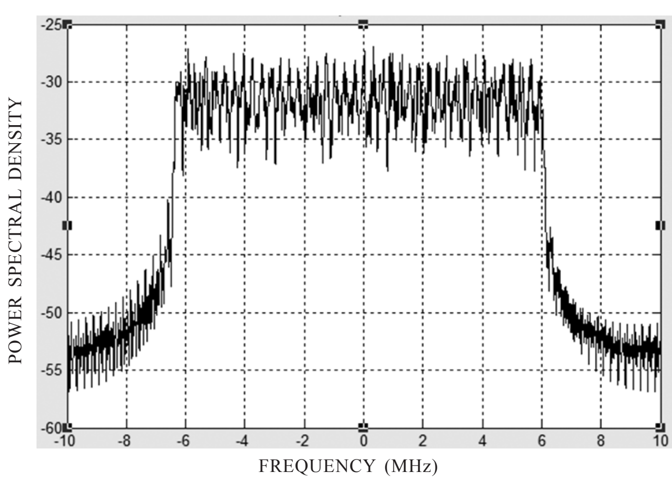

Figure 12. PAPR performance of fixed and adaptable window (CCDF curve).

7. CONCLUSION

In the proposed architecture, the filter with adaptive Kaiser window technique is used for the PAPR reduction. The advantages and disadvantages of the existing methods and the proposed methods are discussed. In clipping and filtering method, there are chances of distortions in the peak value of the signal. The fixed-peak windowing technique affected the signal-peak, when consecutive peaks appeared in the transmitted signal. In adaptable-peak windowing the window sizes can be adjusted by using shaping parameter and can fix the window properly according to the position of the peak. The filter used in the transceiver system reduces the out-of-band radiation of the signal.In this architecture, PAPR improved around 20 per cent to 30 per cent as compared to existing results. In the SLM method, computational complexity is large due to the multiple calculation of IFFT on the transmitter side. Here the computational complexity reduces and the simplest method used for the reduction is PAPR. This system can mainly be used for the military applications and future generation wireless communication systems.

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Ms Neenu Joseph has study of the whole existing systems related to the work, Analyse the new possibilities to improve the work, Proposed the new adaptive method for reducing the PAPR in OFDM systems, Compare the results with the existing system.

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