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Original Research Paper

Multicarrier Modulated Signal for Cognitive Radio with Low Peak-to-Average Power Ratio

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Abstract: Multi-Carrier communication is considered as the potential candidate for 4G-LTE networks. The major drawback concerned with multi-carrier communication is high Peak-to-Average –Power-Ratio (PAPR) as various carriers are added via IFFT operation. High PAPR still requires a lot of attention due to non-linearity in power amplifiers. In this paper we have generated a multi-carrier signal with Digital Video Broadcasting (DVB-T2) parameters and calculated its PAPR using Complementary Cumulative Distribution Function (CCDF).A novel hybrid technique is proposed in which we have combined the filtering and companding techniques with Selective Level Mapping (SLM) to obtain a significant reduction in PAPR. The CCDF plots depict the performance of proposed technique is better than existing art of techniques.

Keywords: *Cognitive Radio (CR), DVB-T (Digital Video Broadcasting for Terrestrial television), MCM (Multicarrier modulation), Orthogonal variable Spreading Factor (OVSF), Orthogonal Space Time Block Encoder (OSTBC)*

1. Introduction

The data traffic growth in cellular based mobile broad-band networks brusquely the need for higher spectral efficiency and better spectrum usage. One of the solutions to meet this increasing demand for more bandwidth is to shift the existing radio technologies to higher bands of unlicensed spectrum. Multi-carrier Cognitive Radio proves to be the enabling technology to exploit the unused spectrum band by accessing the unlicensed secondary users (Sus) to dynamically access the licensed spectrum owned by primary users (Pus) on the basis of some agreement or on an opportunistic basis. Multi-Carrier modulation in Cognitive Radio technology helps in decreasing the equalization complexity and overcoming frequency selective fading [1]. The prime representative of Multicarrier modulated signal is OFDM (Orthogonal Frequency Division Multiplexing) which has proved quite advantageous in implementing Cognitive Radio [2,3]. The main purpose of implementing OFDM in Cognitive Radio is to ensure orthogonality among sub-carriers. OFDM based Multi-carrier modulation has gained too much importance in the modern communication technology, that it is considered best choice for next generation wireless systems. Multi-Carrier modulation leads to several sinusoids and time domain OFDM is the sum of these sinusoids. Therefore, multi-carrier CR systems are known to have high Peak-to-High-Power-Ratio (PAPR). The high PAPR degrades the efficiency of power amplifiers and decreases the Signal-to-Quantization- noise ratio of Analog to Digital Converters and Digital to Analog converters. This imposes a non-linear distortion over a communication channel. Thus PAPR problem need to be tackled in more efficient manner in CR systems. So far, numerous proposals have been made to deal with the PAPR problem in CR systems.

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In literature various techniques have been proposed for reduction of PAPR. The simplest method involves clipping of OFDM signal before amplification. Clipping induces non-linearity in power amplifiers leading to both inbound and outbound distortion and also destroying the orthogonality among the sub-carriers [4]. The coding techniques select the codeword for the minimization of PAPR [5]. Techniques like Partial Transmit Sequence (PTS), Tone Reservation (TR) require the transmission of side information to the receiver [6].In the existing techniques, the in-band and out-band distortion caused by clipping and filtering techniques is predominant when performed individually .To overcome this drawback in Multi-carrier Cognitive Radio, a hybrid technique of Selective Level Mapping and Clipping have been proposed. Moreover, the phases of the carriers are also preserved using Selective Level Mapping and OVSF coding, in order to maintain the orthogonality of the carriers. Furthermore, the incorporation of OSTBC encoder in the proposed technique makes it suitable for 4G-LTE A standards.

The rest of Paper is organized as: Section II briefly discusses the multi-carrier modulated signal for cognitive radio. In section III the PAPR reduction of MCM signal of cognitive radio is discussed. Section IV represents the DVB-T standard used in the paper. The Results and Discussions are presented in section V. Section VI concludes the paper.

of a doctor and give him consultation. In this paper, we showed some of our applications in different areas of medicine.

2. Multicarrier Modulated Signal for Cognitive Radio

The apparent spectrum scarcity is a problem which needs a radical solution. Cognitive Radio, being a dynamic spectrum access technique, provides a paradigm of opportunistically using the spectrum bands which are used by the licensed users (primary users) in a limited manner [7].CR is a smart radio which can learn from the radio environment and can adapt to the environment by changing its communication protocols and parameters. It has to perform a cognitive cycle to use the unused spectrum bands in an opportunistic manner [8]. Cognitive radio has attracted both national and international interests [2]. The IEEE 802.22 standard on wireless regional area network (WRAN) and the Wireless Innovation Alliance including Google and Microsoft as members are some of the international initiatives which have been developed to unlock the potential in the "White Spaces" of the television (TV) spectrum. In 2013, FCC has approved Google's plan to operate a database that would allow unlicensed TV broadcast spectrum to be used for wireless broadband and enables sharing among many users. The development of the Cognitive Radio concept is posing multitude of open research challenges. Presently, significant efforts are made by various academicians and industrial researchers in order to implement the CRs in practical fields.

Broadly, there are three major types of cognitive radio systems: interleave, underlay and overlay CR systems. In the interleave cognitive radio systems, the secondary users detect the presence of primary user's signal through spectrum sensing and transmit only when there is no primary user transmission. In the underlay cognitive radio systems, secondary users are allowed to communicate along with primary users only as long as the interference created to the primary system is below some predefined threshold level. Further, in the overlay systems, the secondary users transmit simultaneously with the primary users. Actually, the secondary user can split its power for secondary communication part and the remainder of the power to assist primary transmissions by relay operation. DS-CDMA is a spread spectrum modulation technique which is used in underlay cognitive radio systems where the secondary CDMA users spread their data using a signature sequence. MCM schemes such as Orthogonal Frequency Division Multiplexing (OFDM) and Filter Bank Multicarrier Modulation (FBMC) have been considered as strong candidates for the physical layer of interweave cognitive radio systems [8]. Multicarrier Modulation is bandwidth efficient transmission technique. Specifically, MCM technique (OFDM) has various inherent properties which can help in realization of CR .The properties which make OFDM the best physical layer technique for Cognitive Radio are as under:

- Inherent FFT operation of OFDM eases spectrum sensing in frequency domain
- Ease in waveform shaping by simply turning off some subcarriers
- Ease in getting adapted to the varying environment.
- Easily supports the other techniques like MIMO, Smart antennas, etc.
- Ease in interoperability
- Easily supports multiuser access by assigning groups of subcarriers to different users.

Inspite of all the above advantages, the use of MCM in Cognitive Radio poses a serious problem of high PAPR (Peak-to-average power ratio).This problem needs a radical approach to reduce PAPR so as to increase the performance of the system. The proposed hybrid technique reduces the PAPR of Multi-Carrier signal significantly with lesser degree of complexity.

The current paper incorporates the use of MIMO technology in Cognitive Radio systems to exploit the different paths between PU and SU while spectrum sensing. OSTBC encoder is used to exploit transmit diversity and for high reliability. Further, we spread the Multicarrier modulated signal using Orthogonal Variable Spreading Factors (OVSF).OVSF codes are chosen in such a way that 90 degree phase shift occurs between two consecutive points in the MIMO channel. The 90 degree phase shift leads to the significant reduction of PAPR of the multi-carrier modulated signal.

3. PAPR reduction of MCM signal of Cognitive Radio

PAPR is the ratio of the peak power to the average power of a given signal. Since, the Multicarrier modulated signal is actually the sum of several individual signals which are modulated over different orthogonal subcarriers, thus when all these subcarriers are added up constructively at the transmitter, the resulting power increases while the average power remains low. This leads to a high peak power leading to a very high PAPR. The dynamic range of the power amplifiers should be large enough to accommodate large PAPR values. Otherwise, the power amplifiers may saturate resulting in degradation of system performance. But the component cost of the D/A converters and power amplifiers increase with the increase in the dynamic range [9].

Consider a collection of data symbols X_n , n= 0,1,….., N-1 denoted by a vector $X = [X_0, X_1, \dots, X_{N-1}]^T$ which is called as data block. The complex baseband representation of a multicarrier modulated signal having N subcarriers is given by:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n . e^{j2\pi n\Delta t}, 0 \leq t < NT \quad (1)$$

where Δf represents the carrier spacing,

NT denotes useful data block period.

The PAPR of the multicarrier modulated signal is given by

$$PAPR = \frac{\max_{0 \leq t < NT} |x(t)|^2}{1/NT \int_0^{NT} |x(t)|^2 dt} \quad (2)$$

The L times oversampled time domain signal samples x can be obtained as under

$$x_k = x(k.T/L) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n . e^{j2\pi kn\Delta fT/L} \quad (3)$$

where $k = 0,1, \dots NL - 1$

Now the PAPR computed from L-times oversampled time domain signal samples is given as under

$$\text{PAPR} = \frac{\max_{0 \leq k \leq NL-1} |x_k|^2}{E\{|x_k|^2\}} \quad (4)$$

The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold. The horizontal and vertical axes represent the threshold for the PAPR and the probability that the PAPR of a data block exceeds the threshold, respectively. Thus, it can be roughly understood that the closer the CCDF curve is to the vertical axis, the better its PAPR characteristic.

Mathematically, the CCDF of the original signal sequence $PAPR$ above threshold $PAPR_0$ is written as:

$$Pr(PAPR > PAPR_0). \quad (5)$$

Accordingly K statistical independent waveforms, CCDF can be written as:

$$[\{Pr(PAPR > PAPR_0)\}]^K \quad (6)$$

$$= 1 - 1(1 - e^{PAPR_0})^K \quad (7)$$

So, that the probability of PAPR that exceeds the same threshold will drop to a small value

Various methods used in the literature to reduce PAPR of Multicarrier modulated signal are:

1. *Clipping and Filtering*: This technique is the simplest technique for PAPR reduction. It involves amplitude clipping limiting the peak envelope of the input signal to a predetermined value. Clipping causes in-band signal distortion and out-of-band radiation resulting in poor performance of the system. Filtering can be used to cope the out-of-band radiation but filtering itself leads to increase in peaks. This technique is easy to implement, but it creates signal distortion. So, in this paper the clipping is combined with Selective Level Mapping to create a new hybrid technique for the reduction of PAPR in multi-carrier modulated signal.
2. *Companding*: This technique introduces compression of the signal at the transmitter and expansion of the same signal at the receiver. Companding technique shows better performance than clipping because inverse companding (expanding) can be applied at the receiver end to reduce distortion. Companding can either be A-law companding, μ-law companding or exponential companding. A-law companding technique performs slightly better than μ-law companding. Actually, μ-law companding technique enlarges only small signal so that the average power increases. In exponential companding, both large and small signals are adjusted keeping the average power at same level. Exponential companding causes lesser side lobe generation than μ-law companding.
3. *SLM (Selective Mapping) method:* In this technique, the transmitter generates a set of different data blocks, all representing the same information as the original block and selects the most favorable for transmission. Actually, the input data is multiplied by random series and resultant series with the lowest PAPR is chosen for transmission. To allow the receiver to recover the original data, side information of the selected phase is needed to be sent to receiver. At the receiver, the reverse operation is performed to recover the original data. This technique is quite popular but if number of phase rotation increases then complexity increases.The good side of selected mapping method is that it doesn't eliminate the peaks, and can handle any number of subcarriers. For implementation, the SLM technique needs U IDFT operations, and the number of required side information bits is $[\log_2 U]$for each data block

DVB-T is the DVB European based consortium standard for the broadcast transmissions of digital terrestrial TV. The concept of Cognitive Radio and DVB-T are progressing hand-in-hand since the inception of use of TV band on Cognitive basis by FCC. Here a simple multicarrier modulated signal is generated using DVB-T parameters for use in cognitive radios. In case of DVB-T, there are two modes of operation: 2K and 8K mode. The total number of carriers in 2K and 8K are 2048 and 8192 respectively. The 2K mode has greater subcarrier spacing of about 4 kHz but the symbol period is much shorter. The 8K mode with a subcarrier spacing of about 1 kHz is much less susceptible to Doppler effects. In mobile reception, the 2K mode is better because of the greater subcarrier spacing. The DVB-T standard allows for flexible control of the transmission parameters. The guard interval can be adjusted within a range of 1/4 to 1/32 of the symbol length. It is also possible to select the type of modulation. Actually, DVB-T contains the following types of carrier: Inactive carriers (set to zero amplitude), Payload carriers, continual pilots, and scattered pilots and TPS carriers. The payload carriers are the carriers used for the actual data transmission. The continual pilots are used in the receiver as phase reference and for automatic frequency control (AFC). The scattered pilots are scattered over the entire spectrum of the DVB-T channel and constitute a sweep signal for the channel estimation. The TPS (Transmission Parameter Signaling) carriers represent virtually a fast information channel via which the transmitter informs the receiver about the current transmission parameters [10]. The number of these different types of carriers in 2K and 8K mode are given in the table:

Table 1.1. Different Types of Carriers in DVB-T (2K and 8K mode) [10]

Type of Carrier	2K mode	8K mode
Total Carriers	2048	8192
Used Carriers	1705	6817
Scattered Carriers	142/131	568 / 524
Continual Pilots	45	177
TPS Carriers	17	68
Payload Carriers	1512	6048

The parameters used for generation of signal are given in table 1.2. Using these defined values, we assign values to the different variables (parameters).

Table 1.2. Parameters of DVB-T Signal in 2 K Modes [10]

Parameter	Value
Mode	2K
Available bandwidth	8MHz
Number of Carriers (K)	1705
Value of carrier number K_{min}	0
Value of carrier number K_{max}	1704
Duration of symbol part (T_U)	$224\mu s$
Duration of guard interval (Δ)	$56\mu s$
Allowed guard interval (Δ/T_U)	$1/4$
Symbol Duration ($T_S = \Delta + T_U$)	$280\mu s$
IFFT/FFT length	4096

4. Results and Discussions

4.1 Generation of Multicarrier modulated signal for Cognitive Radio Using DVB-T2 (mode 2K) parameters

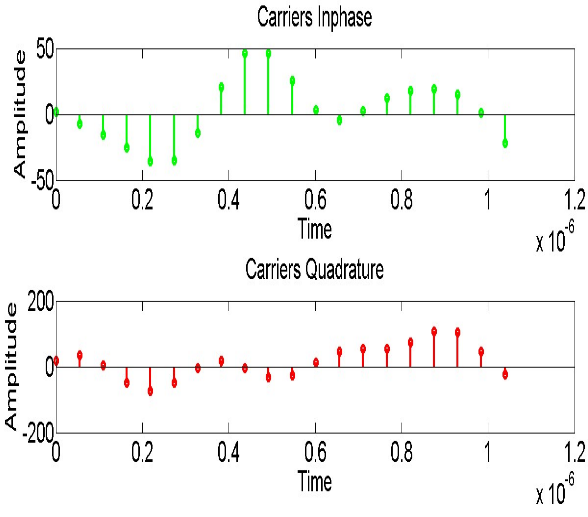

Figure 1. Time Response of Information Carrying Signal

Here we assign values to the different parameters as per 2K mode of DVB-T. First we generate data and subcarriers to carry the generated data Here zeroes are appended to information carrying signals so as to achieve oversampling and to centre the spectrum. The time response of information carrying signals is given in Fig.1 where the in-phase and quadrature components of the carriers are plotted. Further the frequency response of the baseband signal is given in figure 2.

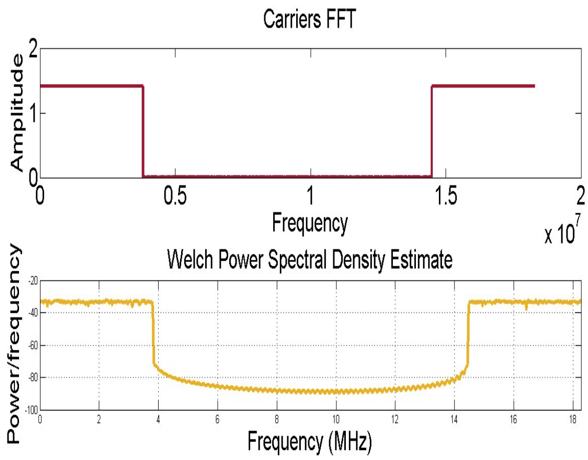

Figure 2. Frequency Response of Baseband Signal

We perform digital to analog conversion on the baseband signal. This is done in order to produce continuous time signal which is useful for analyzing the features of multicarrier modulated signal. So, the baseband signal is passed through a transmit filter. The output of transmit filter is plotted in time domain as shown in figure 3. This figure gives a precise idea of the nature of continuous signal in time domain.

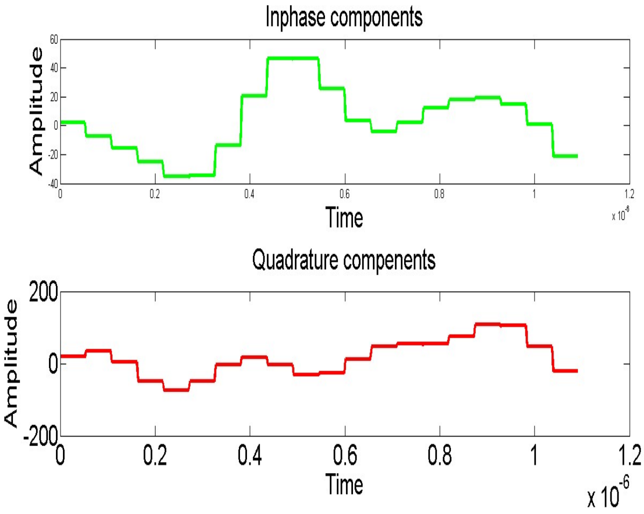

Figure 3. Time Response of Output of Transmit Filter

The output of transmit filter is plotted in frequency domain as well as shown in figure 4.

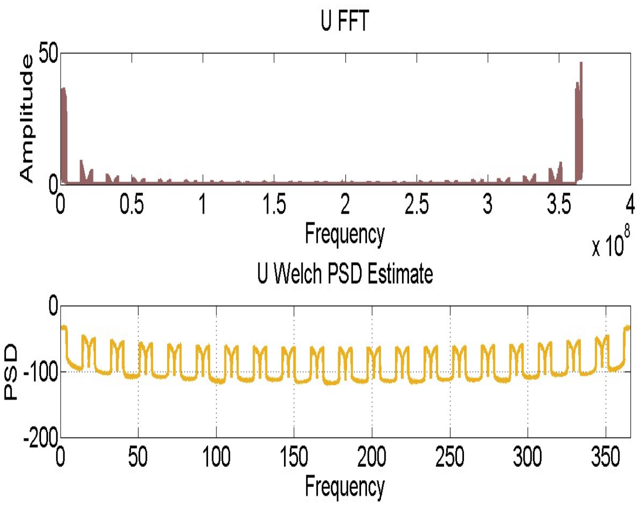

Figure 4. Frequency Response of Output of Transmit Filter

Then we consider a reconstruction filter. Butterworth filter of order 13 and cut off frequency ≅ 1/T is selected as a reconstruction filter. We pass the output of transmit filter through this Butterworth filter. The output of reconstruction filter in time domain is shown in figure 5. Further, the output of reconstruction filter in frequency domain is shown in the plot shown if figure 6.

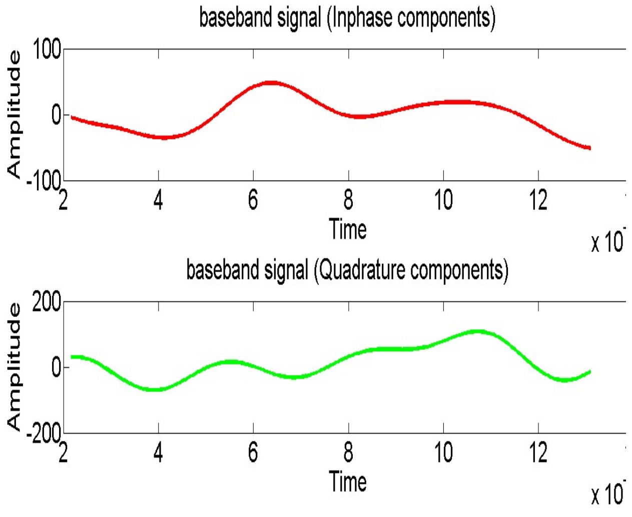

Figure 5. Time Response of Output of Butterworth Filter

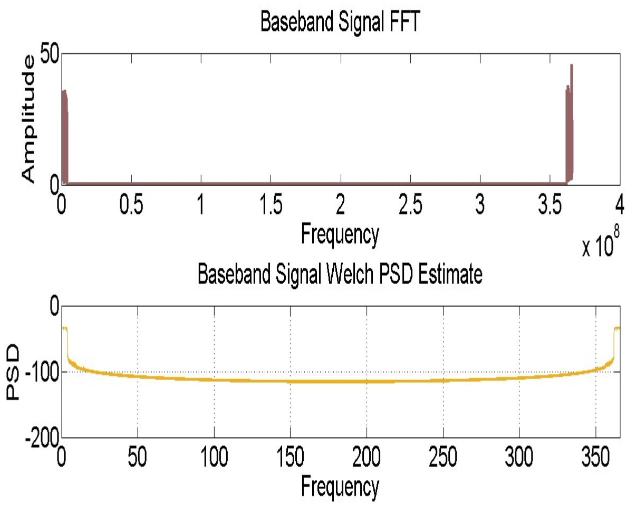

Figure 6. Frequency Response of the Output of Butterworth Filter

Further Quadrature multiplex double sideband amplitude modulation is performed. This leads to the formation of the resultant multicarrier modulated signal.

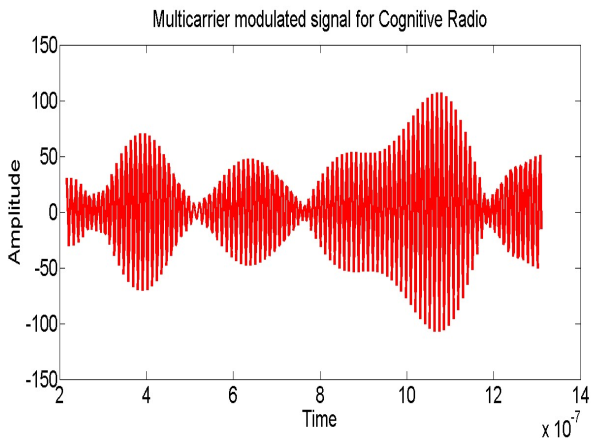

Figure 7. Time Response of Multicarrier Modulated Signal

Thus, the aim to generate a multicarrier modulated signal based on DVB-T (2K mode) parameters is accomplished. The time response of resultant multicarrier modulated signal is given in figure 7. Further we consider that this type of signal can be used for transmission by cognitive radio device. The frequency domain response of the generated multicarrier modulated signal is given in figure 8.

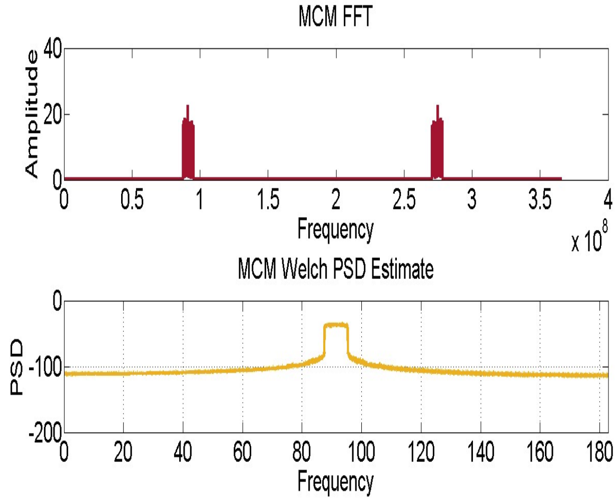

Figure 8. Frequency Response of Multicarrier Modulated Signal

4.2 Improvement in the PAPR reduction of multicarrier modulated CR signal using various techniques

The Multicarrier modulated signal is very useful in Cognitive Radio. Multicarrier techniques can combat hostile frequency-selective fading encountered while communication. The robustness against frequency selective fading is very attractive, especially for high-speed data transmission. But there are some disadvantages of multicarrier communication as well like high PAPR. The above generated multicarrier modulated signal has also high PAPR as visible from Figure 7. Some requisite steps are needed to be taken so as to reduce the PAPR problem.

To incorporate the advantage of using OSTBC and OVSF in cognitive radio, we apply the OSTBC and OVSF to generated DVB-T (2K) parameters multicarrier modulated signal. We choose samples per frame = 81924 and spreading factor=64. We pass the signal through OSTBC encoder with numTx=2, 3,4. At the end, we calculate CCDF and plot it using the system objects of MATLAB. The results are shown in figure 9. Here using OSTBC for Multicarrier modulated signal in CR proves advantageous. Here same signal is encoded differently into different streams which are later transmitted over multiple antennas. This leads to reliable communication between PU and SU. In Figure 10, both the OSTBC and OVSF are used to produce better communication between PU and SU. OSTBC performs encoding of multicarrier modulated signal while OVSF performs spreading of the signal. Further from Figure 9 and Figure 10, it is clear that higher order antennas must be used to have improvement in PAPR reduction.

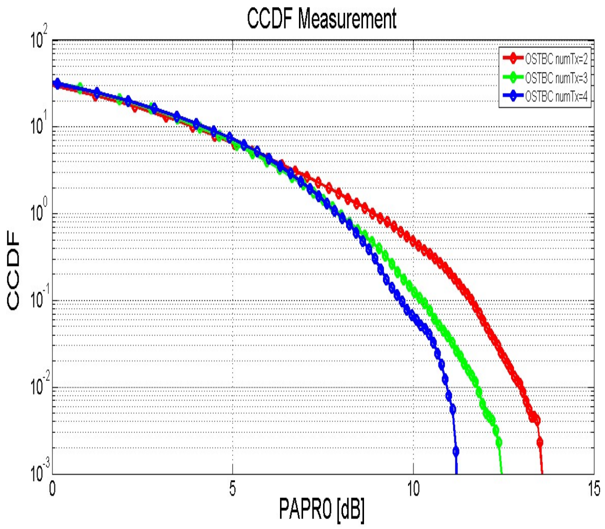

Figure 9. CCDF of the Multicarrier Modulated Signal using OSTBC with numTx=2, 3, and 4.

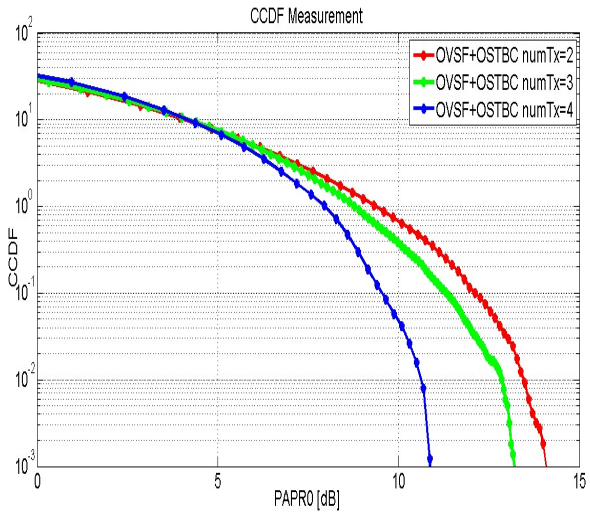

Figure 10. CCDF of the MCM Signal Using OSTBC and OVSF with numTx=2, 3, and 4

Along with these above mentioned logics, a few techniques are applied to reduce the PAPR of multicarrier modulated signal. First clipping-filtering in applied. It reduces the PAPR by approximately 2.6 dB. This technique, inspite of being simple, results to distorted signal transmission. So, a technique called as companding is used which not only adjusts the power levels of multicarrier modulated signal at the transmitter, but also adjusts the signal at the receiver too. From Figure 11, it is clear μ −law companding reduces PAPR by about 8 dB. A-law companding provide slightly better result than μ – law companding. Companding has many disadvantages too like distortions in transmission. So, scrambling method is applied on MCM signal.

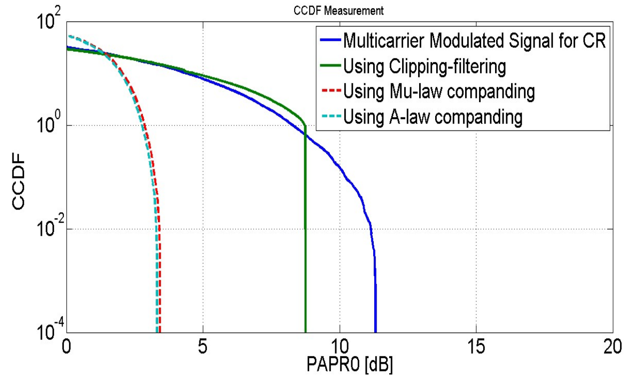

Figure 11. PAPR Reduction of MCM using Clipping-filtering and Companding Techniques

We apply SLM on the generated multicarrier modulated signal and we vary the route numbers in order to have better results. From the Figure 12, it is clear that PAPR of multicarrier modulated signal of CR is reduced from 12.3dB to about 8.5dB which is a quite significant change. Also increasing route numbers results in decrease in the PAPR of multicarrier modulated signal.

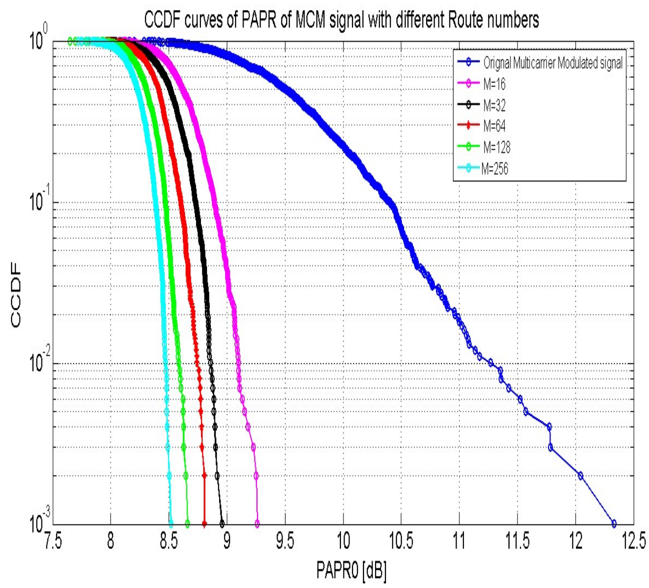

Figure 12. PAPR Reduction of MCM Using SLM with Different Route Numbers

Now a hybrid method is proposed to reduce the PAPR of Multicarrier modulated signal of CR. This hybrid technique incorporates the idea of clipping-filtering in SLM. The multicarrier modulated signal of CR is first clipped, then filtered and after this, we use the SLM technique to reduce the PAPR of multicarrier modulated signal of CR. The results are shown in figure 13.

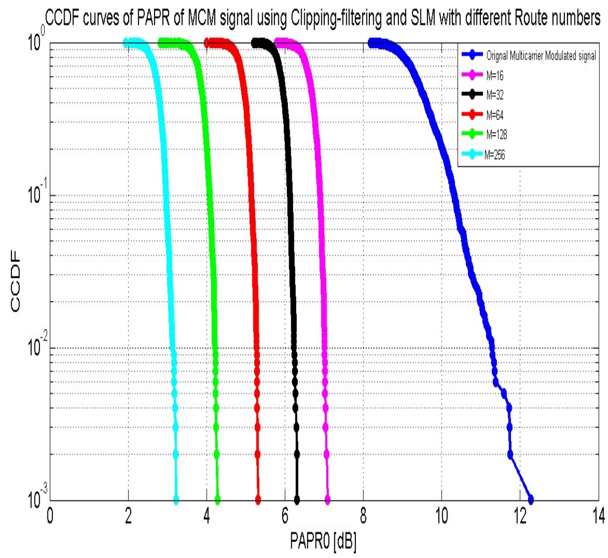

Figure 13. PAPR of MCM using Hybrid Technique

The results of figure 12 and figure 13 can be summarized in the form of table as shown in table 1.3. PAPR of Original generated Multicarrier modulated signal of CR =12.3dB.

Table 1.3: Comparison of PAPR Values for Different Route Numbers

Different Route Numbers	PAPR (dB) values using SLM	PAPR (dB) values using Hybrid SLM and Clipping-filtering
M=16	9.25	7.1
M=32	8.95	6.3
M=64	8.8	5.3
M=128	8.65	4.3
M=256	8.5	3.2

The above results prove that the hybrid technique shows better results than individual techniques, but this is not true always. Here, hybrid technique showed significant improvement by reducing PAPR of multicarrier modulated signal to 3.2dB which is overall PAPR reduction of about 9.1dB.

5. Conclusion

Multicarrier modulated signal is very attractive technique for high-speed data transmission. Cognitive Radio supports MCM for transmission of data. But high PAPR has a detrimental effect on the performance of system. Here in this paper, we have used OVSF to spread multicarrier modulated signal which is supported by underlay CR systems. Further, OSTBC technique is also used to exploit the MIMO technology for better system performance. In this paper, various techniques are used to reduce the PAPR. Companding technique shows better results than clipping-filtering technique. Further, SLM technique is applied on multicarrier modulated signal showing better results with the increase in route numbers. In this paper, a hybrid technique is proposed where the concept of clipping-filtering technique and SLM technique are used together to reduce the PAPR of generated signal. This hybrid technique shows significant PAPR reduction of about 9.1dB with M=256. Hybrid techniques incorporating more than one concept show better results than when the techniques are used individually, but this is not true in all cases.

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