

# Sub-Band Filter in Universal Filtered Multi-Carrier Transceiver for Cognitive Radio Network

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**Abstract** Modern wireless mobile communication system concentrates on effective utilization of frequency band and efficient modulation technique for side lobe elimination. Frequency bands are effectively utilized by using Cognitive radio networks. Cognitive radio network (CRN) is one of the intelligent technologies to solve spectrum scarcity. Universal Filtered Multi-Carrier (UFMC) is the potential multi-carrier modulation technique for the fifth generation (5G) wireless communication networks, as it detains the side lobes of spectral component and also reduces the effect of inter-carrier interference. In this paper, we design the UFMC transceiver whose parameters are adjusted in response to the challenge of side lobe removal. To this end, we first estimate the Peak-to-Average power Ratio (PAR), optimum sub-band filter length at the transmission and the bit error rate (BER) at the reception. The proposed UFMC transceiver can be applicable for the detection of unused spectrum by exploiting the autocorrelation properties of received signal. Finally we verify the performance of proposed UFMC transceiver for the application of CRN by computer simulation.

**Keywords** Universal Filtered Multi-Carrier (UFMC) · Side lobe reduction · Cognitive radio networks (CRN) · Cyclo-stationary Feature Detection (CFD) · Sub-band filtering · Peak-to-Average power Ratio (PAR)

## 1 Introduction

In this world, growth of modern wireless communication technologies plays vital role. Due to this growing technologies and various application most of the frequency bands are congested. This leads to the problem of spectrum scarcity. We mean, the effective

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utilization of frequency band is one of the urge tasks nowadays. Based on this task Dr. J. Mitola had been proposed the technology of CRN [1]. By using the technology of CRN, the occupancy of frequency spectrum can be detected and intelligently allocate the free spectrum for other applicants.

Federal communication commission (FCC) has approved the concept of CRN for the spectrum efficiency. In recent days CRN concept is paying more attention to resolving the challenges of the spectrum scarcity by allowing the primary spectrum to the secondary spectrum whenever it is not used [2]. CRN is the intelligent system. The roles of CRN play by two parameters, Primary user and secondary user. Primary users are the authorized person who allocated to access the frequency band. Whenever the Frequency bands are not utilized by the primary users, secondary users can access this frequency band via CRN.

Recent wireless communications also have the problem of finding suitable multi-carrier modulation technique for side lobe leakage and inter symbol interferences. Nowadays researcher is looking for the best way to reduce the system complexity as well as the improvement in the accessing methods. The multi-carrier modulation technique, especially the orthogonal frequency division multiplexing (OFDM) [3], plays vital role in the high data rate communication. It has an assortment of applications. In the perspective of wideband communication, OFDM has abundant advantages. Specifically, it has a simple receiver by introducing cyclic prefix for canceling inter-symbol interference [4]. Because of this cyclic prefix i.e., guard bands, frequency bands are wasted comparatively (Table 1).

Variety of multi-carrier modulation techniques were proposed for 5G mobile communication. Filter Bank Multi-carrier (FBMC) uses a set of non-overlapping filters. This method ultimately charts the classical frequency division multiplexing (FDM) concept [5]. For many applications, FBMC may be more complicated than OFDM. Based on the structure of multi-carrier modulation, let us discuss the developing concept towards the advanced techniques, particularly based on sub-band filtering [6]. Universal filtered multi-carrier (UFMC) modulation techniques have exposed the possible improvement in the

**Table 1** Summary of notations and symbols

Notations	Descriptions
$s(z)$	Input signal in z-domain
$N$	Number of sub-band
$K$	Number of subcarriers
$L$	Filter length
$P_n(z)$	Filtered sub-band signals
$Q_n(z)$	Down-sampled sub-band signals
$P_{kn}(z)$	QAM operation performed using an inverse DFT
$S_{kn}(z)$	Transmitted UFMC signals
$H_n(z)$	Subfilter
$H_m(Z)$	mth user sub-band filter matrix
$N_{car}$	$N$ point carrier signals
$h_i$	Impulse response of modulation matrix
$\Gamma$	Clip impulse introduced at the filter
$Pr_{clip}$	Probability of clip noise
$r(z)$	Received signal in z-domain
$T_{in}$	Toeplitz matrix
$M$	Symbols in each block

spectral utilization without cyclic prefix and due to reduced frequency domain guard bands. It is the new waveform modulation technique proposed for the 5G mobile communication systems [7]. It accumulates the advantages of OFDM and FBMC, removes their shortcomings at the same time. In FBMC, the filtering is done on each sub-carrier and in OFDM, filtering is done over the entire frequency band. However, UFMC balances filtering function of the two waveforms [8]. The major feature of this scheme is to detain the side lobes of spectral component and also to reduce the inter-carrier interference by applying sub-band basis filtering. In which, the sub-carriers are non-orthogonal [9, 10] Hence, synchronization is not required. UFMC modulation allows increasing the spectral efficiency of high data rate transmission, both through the lack of time domain guard periods and the reduced frequency domain guard bands.

This paper is organized as follows. Section 2 discusses the existing system model. Section 3 describes the analysis of noise associated with the UFMC transmitter. In Sect. 4, 5 and 6, the Proposed receiver performance and its application of spectrum sensing is analyzed. Finally, the simulation results are discussed in Sect. 7 and the work is concluded in Sect. 8.

## 2 System Model

We consider cognitive radio network application here. The spectrum sensing process is done with the help of cyclo-stationary feature detection method which is performed by proposed UFMC transceiver.

### 2.1 Cognitive Radio Networks

The radio architecture of the CRN must be design such a way that good grade of flexibility and quick sensing capability. Such a dynamic spectrum access systems are ready to offer better bandwidth utilization. The basic idea of the system is to access the frequency spectrum by the secondary user whenever that particular frequency band is not utilized by the primary user. Once the primary user return to access the frequency band, the respective secondary user should relieve the frequency band to the primary user without causing interference. CRN functioning based on [11] classification of co-operative and non-co-operative communication network also. In co-operative communication, the relay user manages this cognitive behavior between the primary user and the secondary user. This relay user informs the sensing message to the secondary user, to consume the unused frequency band without causing interferences.

### 2.2 UFMC Transmitter

UFMC is a multi-carrier system, which digitally designs the conventional filter band approach. In this section, we analyze the multi-rate signal processing transmission with the modified UFMC transmitter [12]. It accepted as high-performance signal processing tools that could significantly enhance the spectrum efficiency and accessibility of future wireless communication [13]. Furthermore, necessary flexibility to regulate the subcarrier allocations provides reconfigurability well appreciated in data rate.

### 2.3 Sub-Band Filtering

Let's denote the message sequence  $s(n)$  analyzed with the operation of L-channel UPMC transmitter in Z-domain. The expression of the Z-transform for various intermediate signals in Fig. 1 is mentioned below,  $S(z)$  input sequence is decomposed into n sub-band sequences,  $P_n(z)$  is represented as,

$$P_n(z) = H_n(z)S(z) \tag{1}$$

The down-sampled sub-band signal is mathematically represented by Eq. (2), each down-sampled sub-band signal consist of special spectral characteristics like energy levels and perceptual importance. By exploiting these characteristics the signals are encoded for transmission.

$$Q_n(z) = \frac{1}{L} \sum_{l=0}^{L-1} H_n(z^{\frac{1}{L}} W_L^l) S(z^{\frac{1}{L}} W_L^l) \tag{2}$$

$$\hat{P}_n(z) = Q_n(z^L) \quad \text{where } 0 \leq n \leq L - 1 \tag{3}$$

The replica of the sub-band signal at the receiver end is represented as. The down-sampled sub-band signals vector  $q(z)$  is,

$$q(z) = [Q_0(z) \quad Q_1(z) \quad Q_2(z) \quad \dots \quad Q_{L-1}(z)]^T \tag{4}$$

The sub-band filter matrix is denoted as [12],

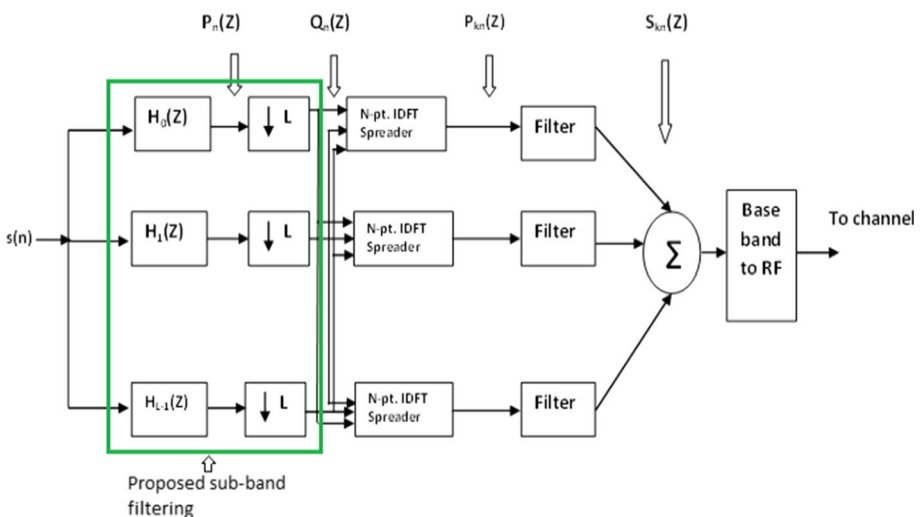


Fig. 1 Modified UPMC Transmitter

$$H^m(z) = \begin{bmatrix} H_0(z) & H_1(z) & \dots & H_{L-1}(z) \\ H_0(zW_L^1) & H_1(zW_L^1) & \dots & H_{L-1}(zW_L^1) \\ \vdots & \vdots & \ddots & \vdots \\ H_0(zW_L^{L-1}) & H_1(zW_L^{L-1}) & \dots & H_{L-1}(zW_L^{L-1}) \end{bmatrix} \tag{5}$$

Eqn (2) can be compactly expressed in the form,

$$q(z) = \frac{1}{L} \left[ H^m \left( z^{\frac{1}{L}} \right) \right]^t s^m \left( z^{\frac{1}{L}} \right) \tag{6}$$

### 2.4 Multi-Carrier Modulation Process

Using an Inverse Discrete Fourier Transform (IDFT) multiple QAM operations is performed [14]. The input sequence divided into two set of components as real and complex numbers. The real numbers consists of DC and tone  $N_{car}$  and the complex number quadrature modulated towards 1 to  $(N_{car} - 1)$ . After quadrature modulated it yields  $N = 2 N_{car}$  real samples. This structure is called as an N-point IDFT.

The average energy of each transmitted sequence is normalized to unity, the total signal energy of the  $(m + 1)$ th symbol is,

$$|H|^2 = N \sum_{i=0}^N h_i^2 \tag{7}$$

Since  $N = 2N_{car}$  the transmitted  $m$ th symbol disturbed by its consecutive  $(m + 1)$ th symbols. At this point, we can degree the signal to total distortion ratio (STDR) by,

$$STDR = N_{car} \sum_{i=0}^N h_i^2 / \sum_{i=\gamma+1}^N (i - \gamma) h_i^2 \tag{8}$$

## 3 Noise Analysis

### 3.1 Filtering the Clip Impulses

White noise in the frequency domain is developed by the clip in the time domain. Practically, the subcarrier carrying large amount of information can cause more destructive to the system [15]. But, the subcarriers carrying small amount of information is harmless to the system. But, the 5G system requires high data rate with minimum error statistics. To minimize error in the system the clipping noise should be filtered out. Signal to clip ratio (SCR) is one of the corrective measure related to this clip error sequence. This SCR sequentially follows the SNR.

### 3.2 SCR Zero at DC Condition

When the SNR decreases monotonically from DC, with frequency, the clip noise should then be filtered by Eq. (9), which has a double zero at DC, has unity gain at  $fsamp/4$ .

$$F(Z) = -aZ + 1 - \frac{a}{Z} \quad (9)$$

$a$  is the constrained values for various the digital operations. This make parallel to serial conversion. Parallel to serial converter design is simplified by this method of implementation. If the  $n$ th sample magnitude exceeds the threshold clip level, it is clipped and half the clip noise subtracted from the  $(n - 1)$ th and  $(n + 1)$ th samples. Suppose both  $(n + 1)$ th and  $n$ th samples exceeds the threshold level, they have to be clipped off and half of the clip noise should be subtracted from  $(n + 2)$ th and  $(n - 1)$ th samples.

In multi-carrier modulation technique, some of the upper subcarriers are not used the successive samples, in which the threshold levels cannot be defined completely. In this situation, in order to process the each symbol, the entire amount of clip noise should be subtracted from the second and second to last samples respectively. It is treated very rarely [19]. Because of line attenuation, the effect on average clipping impulse is negligible.

### 3.3 At Some Higher Frequency: SCR Zero

At low frequencies of no interest, if the SNR does not decrease monotonically, the zero of the filter should be moved up to subcarrier  $n_0$ ,

$$n_0 = \frac{N}{2} \cos^{-1} \left( \frac{1}{2a} \right) \quad (10)$$

All multi-carrier modulation technique must therefore decide on some Peak-to-average power reduction (PAR) and be prepared to deal with the clips that occur if the signal exceeds that.

If the PAR is set at  $n$ , the probability of clip is,

$$\Pr_{clip} = \sqrt{\frac{2}{\pi}} \int_n^{\infty} e^{-s^2/2} ds \quad (11)$$

and the average energy in a clip is,

$$E_{clip} = \sqrt{\frac{2}{\pi}} \int_n^{\infty} s^2 e^{-s^2/2} ds \quad (12)$$

The probability of a clip occurring in a symbol is,

$$\Pr_{clipsymb} = 1 - (1 - \Pr_{clip})^N \quad (13)$$

the average rate at which IDFTs must be performed is,

$$R_{idft} \approx f_{symb} [1 + 2\Pr_{clipsymb} + 3\Pr_{clipsymb}^2 + 4\Pr_{clipsymb}^3] \quad (14)$$

### 3.4 PAR & Out-of-Band Power Reduction

Power spectral density is the perfect measure of the maximum allowable output signal at the UFMC transmitter, but not its total power. By filtering the clip errors, the peak to average power reduction obtained. Filtering is ‘transparent,’ to the system i.e., both

transmitter and receiver can perform is without any synchronizations [16]. In the system, signal energy rise up to high frequencies without coherency, where the SNR is usually lower. In out-of band power reduction [17], the dummy tones at the border of the band are modulated with a weighted combination of the data on some adjacent tones (Figs. 2, 3).

After superposition, the transformed signal is up-converted, and propagated. Finally, the UFMC transmitted signal can be mathematically expressed as,

$$s_{kn} = \sum_{i=1}^k T_{in} \frac{Q_n}{[(N+M-1) \times N]} \frac{P_{kn}}{[N \times L_i]} [L_i \times 1] \tag{15}$$

### 4 Modified UFMC Receiver

The simplest way of retrieving the transmitted UFMC signal at the receiving end, the coded sub-band signals are first recovered by demultiplexing and decoders are used to produce approximations of the original down-sampled signals [16].  $\hat{P}_n(z) = Q_n(z^L)$  The decoded signals are then up sampled by a factor of L and passed through filters  $G_0(z)$ ,  $G_0(z)$  and  $G_{L-1}(z)$ , whose outputs are then added yielding  $r(z)$

#### 4.1 Receiver Processing

After receiving the UFMC transmitter signal, the received signal undergone into multiple signals processing based on the receiver blocks to recover the original signals back. This functions explained by various mathematical expression as below,

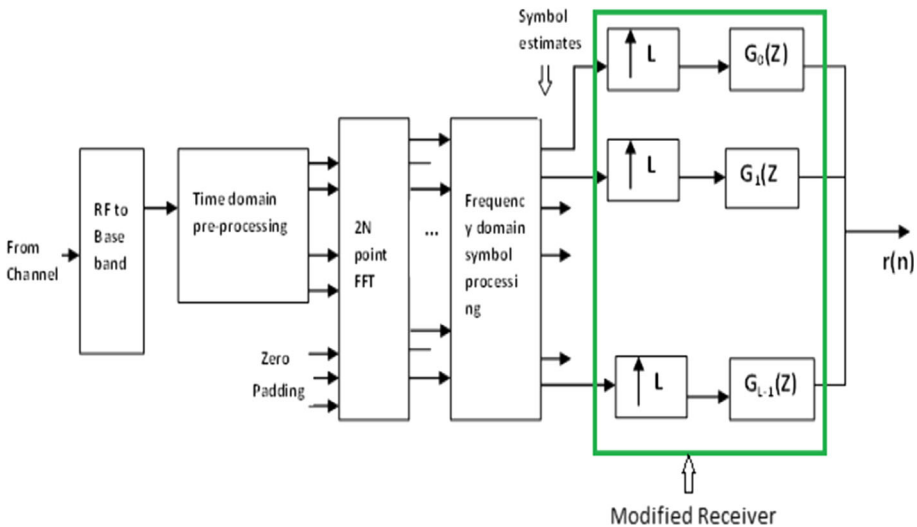


Fig. 2 Modified UFMC Receiver

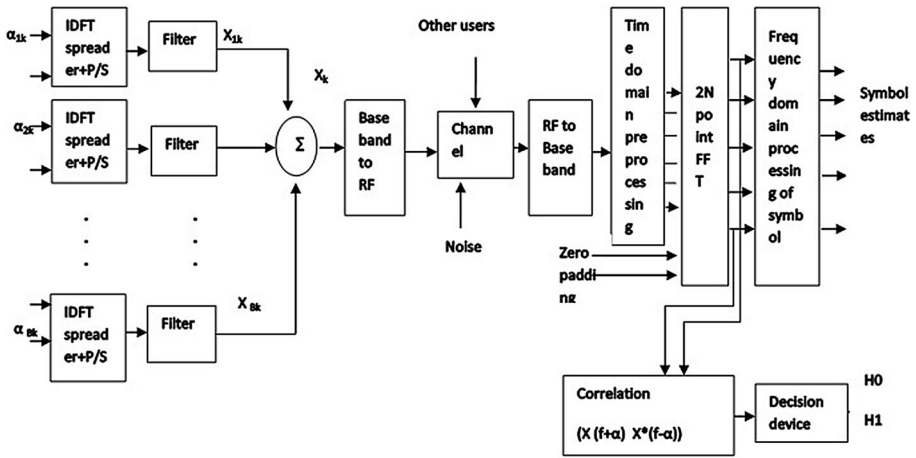


Fig. 3 Modified UFMC Transceiver for Spectrum Sensing

$$r(z) = \sum_{n=0}^{L-1} G_n(z) \hat{P}_n(z) \tag{16}$$

This can be expressed in a matrix as,

$$r(z) = g^t(z)p(z^L) \tag{17}$$

The vector representation of the sub-filter at the receiver end is,

$$g(z) = [G_0(z) \quad G_1(z) \quad \dots \quad G_{L-1}(z)]^t \tag{18}$$

### 4.2 Alias Free Condition of UFMC

Let's denote the conditions for alias free operation of the L-channel filter from Eq. (17), the modulated version of the output signal are given by,

$$r(zW_L^n) = g^t(zW_L^n)q(z^L W_L^{nL}) = g^t(zW_L^n)q(z^L) \tag{19}$$

where  $0 \leq n \leq L - 1$

This can be expressed in a matrix as,

$$r^m(z) = [r(z) \quad r(zW_L) \quad \dots \quad r(zW_L^{L-1})]^t \tag{20}$$

Using Eq. (17) and (18) in Eq. (20),

$$r^m(z) = G^m(z)q(z^L) \tag{21}$$

Mathematical representation of  $G_m(z)$  is the synthesis filter matrix.



$$G^m(z) = \begin{bmatrix} G_0(z) & G_1(z) & \dots & G_{L-1}(z) \\ G_0(zW_L^1) & G_1(zW_L^1) & \dots & G_{L-1}(zW_L^1) \\ \vdots & \vdots & \ddots & \vdots \\ G_0(zW_L^{L-1}) & G_1(zW_L^{L-1}) & \dots & G_{L-1}(zW_L^{L-1}) \end{bmatrix} \tag{22}$$

By combining above equations, we can achieve the input–output relationship of L-channel filters,

$$r^m(z) = \frac{1}{L} G^m(z) [H^m(z^{\frac{1}{L}})]^t s^m(z^{\frac{1}{L}}) \tag{23}$$

Eqn (23) is approximated as,

$$r^m(z) \approx \frac{1}{L} G^m(z) [H^m(z)]^t s^m(z) = F(z)x^m(z) \tag{24}$$

where,  $F(z) = \frac{1}{L} G^m(z) [H^m(z)]^t$  is called the transfer matrix relating the input signal  $s(z)$  and its frequency modulated version  $s(zW_L^n)$ ,  $1 \leq n \leq L - 1$ , with the output signal  $r(z)$  and its frequency modulated versions  $r(zW_L^n)$ ,  $1 \leq n \leq L - 1$ . The filter process alias free if the transfer matrix  $F(Z)$  is a diagonal.

$$F(z) = \text{diag} [ F(z) \quad F(zW_L) \quad \dots \quad F(zW_L^{L-1}) ] \tag{25}$$

In the diagonal matrix, the first element is called as distortion transfer function caused at the sub-band filters.

Substituting Eqs. (16) to (18) in Eq. (24)

$$r(z) = \sum_{n=0}^{L-1} G_n(z) Q_n(z^L) \tag{26}$$

$$r(z) = \sum_{n=0}^{L-1} G_n(z) \frac{1}{L} \sum_{l=0}^{L-1} H_n(zW_L^l) s(zW_L^l) \tag{27}$$

Let us assume the gain at the output,

$$a_l(z) = \frac{1}{L} \sum_{n=0}^{L-1} H_n(zW_L^l) G_n(z), \quad 0 \leq l \leq L - 1 \tag{28}$$

the received signal can be represented as,

$$r(z) = \sum_{l=0}^{L-1} a_l(z) s(zW_L^l) \tag{29}$$

$l$ th Aliasing term can be represented as  $s(zW_L^l)$ ,  $a_l(z)$  is the gain at the output. If  $a_l(z) = 0$ ,  $1 \leq l \leq L - 1$ , for all possible inputs the aliasing effect can be completely removed at the output sequence.

## 5 Spectrum Sensing

UFMC transceiver is one of advanced modulation technology for 5G technology and also it is applicable for CRN. In CRN, spectrum sensing is the important fact. This can be done by various methods like energy detection, matched filter and feature detection. Since we concentrate on feature detection, here we discussed about the cyclo-stationary feature detection (CFD) method [18]. In CFD, the periodic features of the signal are processed from the received signals particularly, power spectral density of the featured signals. Major advantage of this method of detection is it can detect the signal even at low signal to noise ratio (SNR) i.e., autocorrelation property of received signal differentiate the signal from the noise.

## 6 Proposed System Model

The proposed design of UFMC transceiver is being used for the application of spectrum sensing in CRN. Because of this proposal the system complexity is also reduced. This proposed system model is verified by the function of peak to average power ratio at the transmitter side and at the receiver side out of band leakage is being reduced than the existing system. Simulation results prove that the proposed system is perfectly suitable for the CRN application. In the proposed system, the peaks of spectral correlation function represent the presence of primary users.

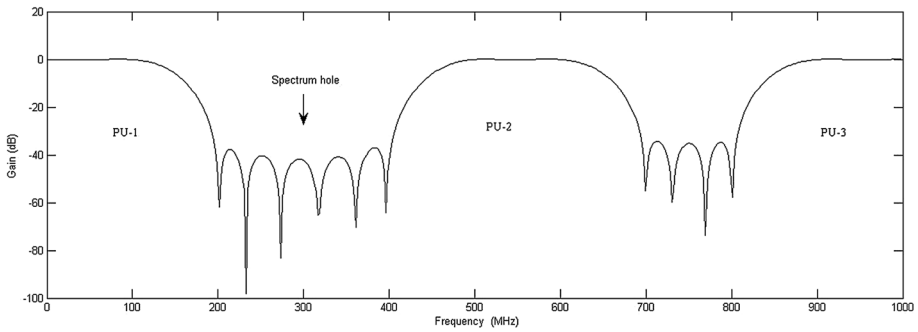
In CRN, at primary user, the received signal is processed and it is converted into baseband signal to continue the communication. But at the secondary user, the particular frequency band is sensed by using the CFD algorithm, i.e., the spectral properties of the signals are estimated from the received signal say autocorrelation function. This leads the system to find spectral correlation function. In the proposed system, the peaks of spectral correlation function represent the presence of primary users.

The proposed system designed with the frequency bands of 1–1000 MHz. The frequency band 1–150 MHz, 400–600 MHz and 850–1000 MHz are allocated to the primary user 1, 2, 3. Remaining frequency bands are not utilized by any other user. The vacant spaces are called as spectrum hole. This unused spectrum can be detected by using CFD algorithm. Presence of primary users was obtained by the peaks of spectral correlation function.

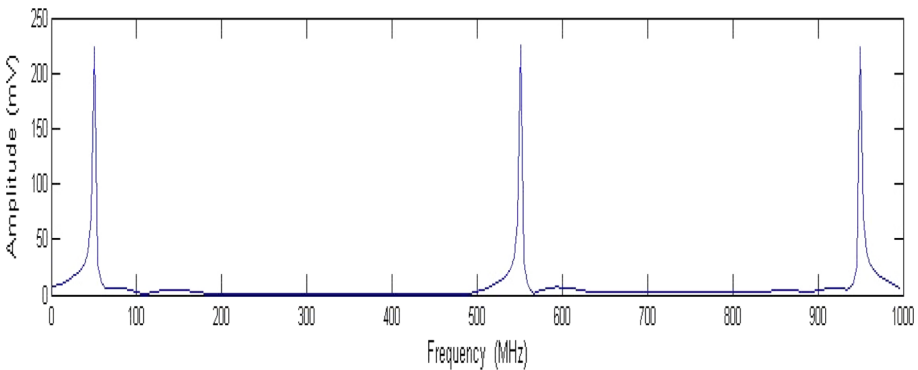
This proposed system also used for the elimination of out of band leakage. Most of the spectrums are underutilized because of this out of band leakage. This may cause the interference on the radio frequency signals or on primary user signal. By using the concept of sub-band filtering, all these problems can be eliminated. This is being tested with the existing UFMC and Orthogonal Frequency Division Multiplexing (OFDM).

## 7 Simulation Results and Discussions

Figure 4, depicts the gain response of received signal processed by the proposed system. In which the following frequency bands are allocated to the primary users respectively, 1–150 MHz for primary user-1, 450–650 MHz for primary user-2 and 850–1000 for primary user-3.



**Fig. 4** Sensing of spectrum hole



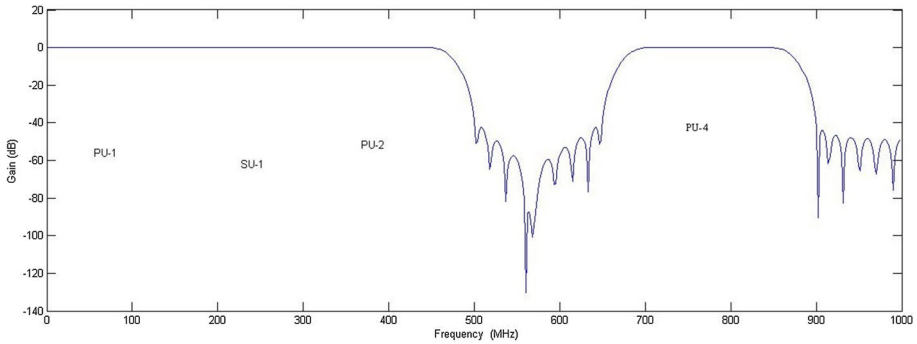
**Fig. 5** Detection of spectrum hole

Figure 5 shows the primary user availability via the power spectral peaks, at the frequency band of 1–150 MHz, 450–600 MHz and 850–1000 MHz. Residual frequency bands are unused. The unused frequency bands are detected as a spectrum hole. Hence, by using proposed system, we detected the spectrum holes.

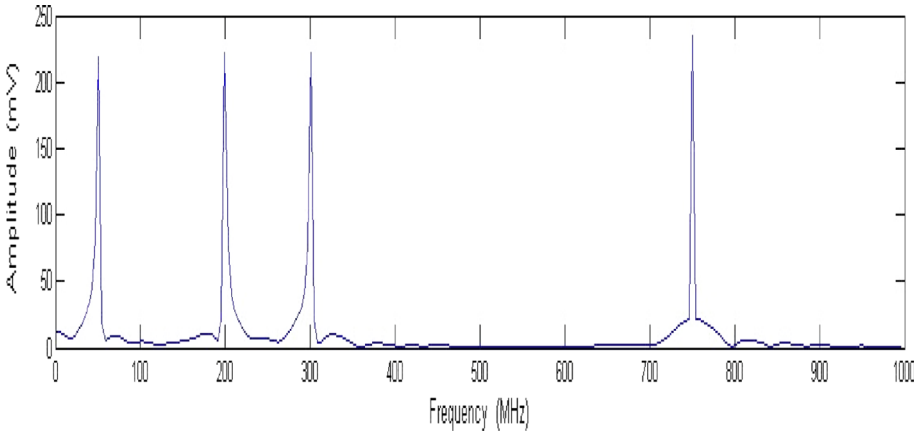
Figure 6 shows that the new secondary user is allocated to access the 151–449 MHz after detecting the spectrum hole.

Figure 7 illustrates the availability frequency band 451–649 MHz and 851–999 MHz in the following performance

Figure 8 depicts the power spectral density of proposed system with existing system. This picture infers that in existing system along with main lobes, side lobes are also concentrated whereas in our proposed system, all out of band side lobe components were rejected using proposed sub-band filtering effect. Upon simulation achieved PAR for existing system is 8.2379 dB whereas our proposed system shows 7.19 dB. Hence due to the rejection of side lobes PAR has been reduced in our proposed system than the existing one.



**Fig. 6** Secondary user allocation on the detected spectrum hole



**Fig. 7** Spectrum sensing in CRN

Figure 9 Shows the PSD comparison of existing OFDM system with the proposed sub-band filter in OFDM system. It is observed that in proposed sub-band filter OFDM, power spectral density of side lobes suppressed from  $-30\text{dBW/Hz}$  to  $-80\text{dBW/Hz}$ . Upon simulation, due to out of band rejection, the PAR reduced from 8.8843 to 8.3541 dB in existing and proposed sub-band filter in OFDM respectively.

Figure 10 represents BER Vs SNR comparison of proposed UFMC with other multi carrier modulation techniques like FBMC and OFDM. At 15 dB SNR, BER is  $10 \times 10^{-3}$ ,  $5 \times 10^{-3}$ , and  $1.4 \times 10^{-3}$  for OFDM, FBMC and proposed modified UFMC respectively. Hence, it is proved that our proposed modified UFMC is the superior one in bit error rate reduction.

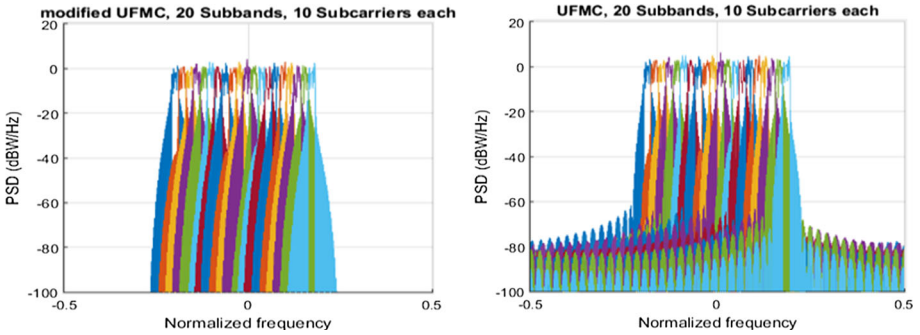


Fig. 8 PSD comparison between proposed modified UFMC & existing UFMC

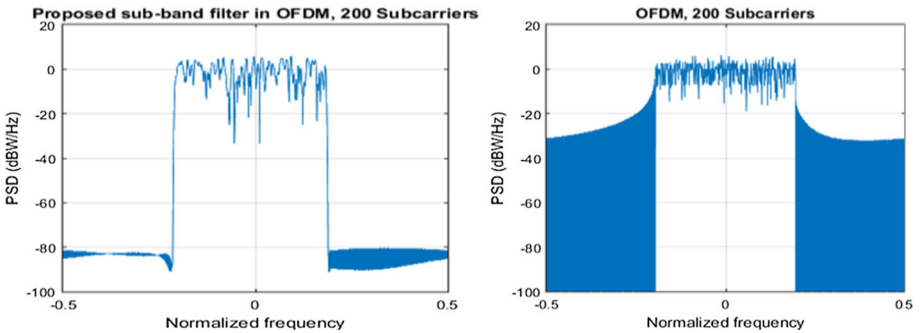


Fig. 9 PSD comparison between the proposed sub-band filter in OFDM & existing OFDM system

Fig. 10 Bit error rate analysis for various 5G signature waveform

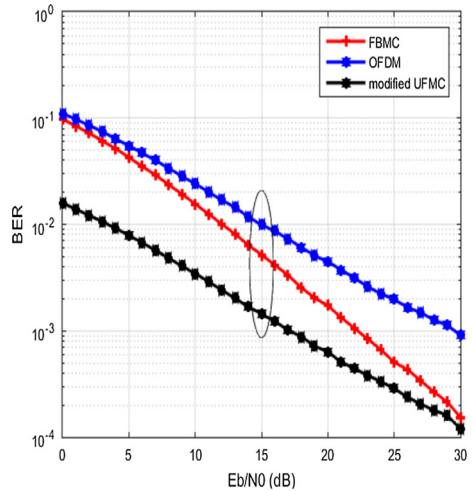
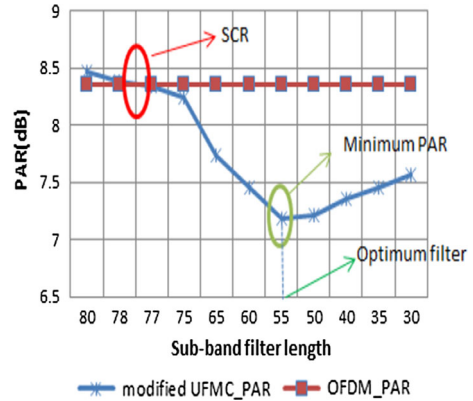


Figure 11 depicts the modified sub-band modulation technique for optimum filter length at which the minimum PAR 7.19 dB for proposed modified UFMC is achieved whereas the OFDM system achieves a constant PAR of 8.3541 dB irrespective of filter length. Also, from the graph, it is observed that the crossover point between OFDM and proposed

**Fig. 11** Analysis of modified UPMC transceiver for optimum filter length



modified UPMC shows the severity of signal to clip ratio (SCR) at a sub-band filter length of 77–78. Hence, filter length 55 can be considered as an optimized length which possesses the minimum value PAR of 7.19 dB.

## 8 Conclusion

In this paper, we have proposed a modified UPMC transmitter and receiver by introducing an optimum sub-band filtering concept for the application of CRN. Simulation results also prove that the proposed system is suitable for out-of-band leakage as well as the reduction of PAR. Clip impulses associated with the transmitter degrades the function of UPMC transmitter. The proposed system can be applicable for the removal of clip impulses associated with the transmitter, it also eliminated by optimum designing of the sub-band filter length. Hence, the proposed modified work can be suitable for the successful generation of the 5G signature waveform. This paper also tested the performance of spectrum sensing in cognitive radio networks in congestion with modified UPMC transceiver. Hence, it is proved that the proposed system is well suitable for the CRN applications.

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