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DESIGN AND PERFORMANCE ANALYSIS OF PRECODED OFDM TRANSCEIVERS FOR COGNITIVE RADIO

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ABSTRACT

The wireless spectrum being an scanty resource, needs to cater up for stipulated number of devices. But with wireless devices becoming pervasive, the provision of spectrum for such a substantial number seems to be an daunting task. Cognitive radio is a technology which uses the spectrum smartly by either sensing the spectrum hole in order to transmit the data or by sharing the available spectrum among two or more users. Hence cognitive radio is indispensible for the spectrum prerequisites. But the main problem is the phenomenon of cognitive interference. Precoded OFDM (Orthogonal Frequency Division Multiplexing) is found to have eliminate the interference by such a way that it gets cancelled as it is propagated. This work also comprises of the analysis of Throughput using MATLAB.

Keywords: *OFDM, Cognitive Radio, Dynamic Spectrum Usage, Overlay Networks, Precoding*

1. INTRODUCTION

Cognitive radio is a technology which is current burgeon area of research proves to solve the glitch of unavailability of spectrum. The cognitive radio is based on dynamically allocating the spectrum by recognizing the unused spectrum. Even though the spectrum can be easily perceived through the usage of blind spectrum estimation techniques the transmission without causing interference to other counter parts seems to be strenuous. Hence the system has to transmit messages without causing interference considering that the other system is entirely using the same spectrum. Consider a scenario where a user is currently occupying and transmitting messages using a spectrum K. This system is known as primary system while the transmitter and receiver are known as the primary transmitter and receiver respectively. In case if a new system enters the cell and find itself in a position of ideal state due to unavailability of spectrum. In such a case instead of waiting for the spectrum to be freed, provision can be made in order to transmit the message over the spectrum of the primary. This system which shares the primary's spectrum is known as the secondary system. Its transmitter is called as the secondary transmitter while the receiver is known as the secondary receiver. The main objective is to transmit the secondary message using the primary's spectrum without causing any sort of interference to the primary [1].

For such interference free transmission the secondary transmitter has to know the primary system message [2]. This is highly impractical as the primary could not even have idea about the presence of such secondary system [3]. Also in non-contiguous OFDM transmission of messages the primary and the secondary system has to perfectly synchronized in order to eliminate interference so that either of the system knows which are subcarriers to be used [4].

The Vondermonde Frequency Division Multiplexing (VFDM) scheme proposed in [5], [6], [7] is a propitious system which efficiently eliminates the interference at the primary receiver by precoding the message with a Vondermonde matrix. The major disadvantage being that the system requires the secondary to know the channel matrix [6].

Hence in previous work [8], a system which eliminates the interference has been proposed based on the precoding of messages. Also the system has been developed considering the fact that secondary receiver may not know the channel state information exactly.

2. OFDM

This section briefs about the OFDM system. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique which uses N sub carriers in order to transmit messages. In its initial architecture it consisted of N

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local oscillator which made it complex to implement. Hence a digital implementation of the subcarriers is carried out by using an IFFT structure.

The OFDM transmitter is shown in figure 1. The data is first encoded and then mapped to symbols. Once the mapping is carried out the serial data is converted to a parallel data which is then inverse Fourier transformed. Generally the Fourier transform is employed as butterfly structure, which enhances the speed of operation. Hence they are implemented as Inverse Fast Fourier Transform. After the IFFT the data are then converted back as serial data. The serial data is then transmitted through the channel.

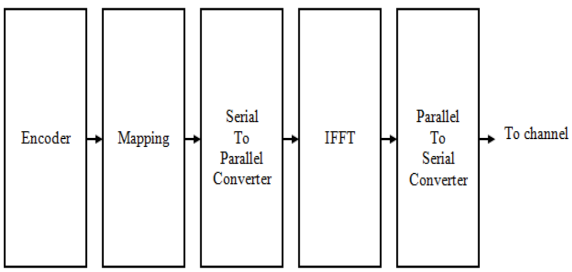

Figure 1: OFDM Transmitter

The receiver shown in fig 2 performs the inverse operation. Once the data has been reached at the receiver the serial data is converted to parallel data. The Fast Fourier transform is carried out which is the inverse of the IFFT operation. After FFT the parallel data is converted back to serial data. The message is demapped in order to convert symbol back to bits. The bits are then decoded in order to recover back the message bits. The following figure depicts the OFDM receiver operation.

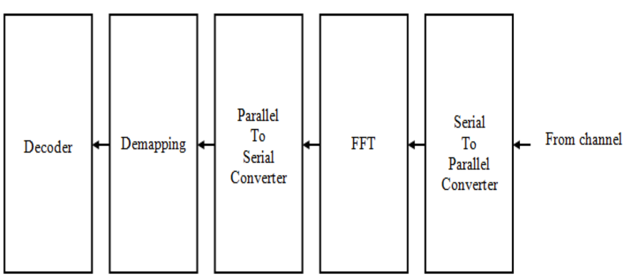

Figure 2: OFDM Receiver

Even though the conventional OFDM system cannot be used for serving cognitive radio prerequisites, they serve as basis for system involving cognitive radio.

3. VFDM SYSTEM

The Vondermonde Frequency Division Multiplexing is a system which eliminates the interference at the primary caused by the secondary.

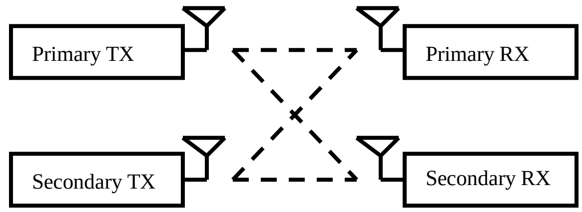

Figure 3. Cognitive Interference Channel

Consider a cognitive channel with primary and a receiver shown in fig 3. The primary transmits its message through its direct channel h_{11} and secondary through h_{22} . They cause interference to each other through their indirect channel h_{12} and h_{21} . Hence the message signals which are received at the primary receivers can be represented mathematically as

$$\Re_1 = H(h_{11})x_1 + H(h_{21})x_2 + n_1 \qquad (1)$$

And at the secondary receiver it is given as,

$$\Re_2 = H(h_{22})x_2 + H(h_{12})x_1 + n_2 \qquad (2)$$

Where the terms n_1 and n_2 represents the noise from other sources in the channel. In the equation (1) the notation $H(h_{ij})$ represents the channel between the i_{th} transmitter and the j_{th} receiver which modeled from the channel filter tap weights [8] as a Toeplitz matrix of order $(L+L_p)\times(L+L_p+L_c-1)$

$$H(h_{ij}) = \begin{bmatrix} h_1^{ij} & \cdots & h_{L_c}^{ij} & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & h_1^{ij} & \cdots & h_{L_c}^{ij} & 0 & \cdots & \cdots & 0 \\ \vdots & & \ddots & & \ddots & & & \vdots \\ \vdots & \cdots & 0 & h_1^{ij} & \cdots & h_{L_c}^{ij} & 0 & 0 \\ \vdots & & & \ddots & \ddots & & \ddots & 0 \\ 0 & \cdots & \cdots & \cdots & 0 & h_1^{ij} & \cdots & h_{L_c}^{ij} \end{bmatrix} \qquad (3)$$

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In the above relation h_m^{ij} represents the channel filter tap for $i = 1, \ldots, L_c$, L_c being the number of multipath components for the channel h_{ij}. (i.e. no two channels will have same value of $H(h_{ij})$).

The main problem at the primary receiver is the interference caused by the secondary channel through its indirect channel h_{21} . Hence for zeroing this effect the message has to be transmitted in such a way that it satisfies the following equation.

$$H(h_{21})x_2 = 0 \tag{4}$$

So that the message received at the primary receiver becomes

$$\Re_1 = H(h_{11})x_1 + n_1 \tag{5}$$

Hence in VFDM system the process carried out to eliminate the secondary interference is to multiply a Vondermonde matrix V so that the following Equation is satisfied.

$$H(h_{22})Vx_2 = 0 \tag{6}$$

There value V is obtained as a linear precoder value which is given by

$$V = \begin{bmatrix} 1 & \cdots & 1 \\ a_1 & \cdots & a_L \\ a_1^2 & \cdots & a_L^2 \\ \vdots & \ddots & \vdots \\ a_1^{N+L-1} & \cdots & a_L^{N+L-1} \end{bmatrix} \tag{7}$$

Where the term $\{a_1, \ldots a_L\}$ are the roots of the polynomial $S(z) = \sum_{i=0}^{L} h_i^{(21)} z^{L-i}$ with L+1 of the channel h_{22}. As already discussed even though the system eliminates the interference it is mandatory that the secondary receiver must have knowledge about the channel for which the transmitter is precoding.

4. PRECODED OFDM SYSTEM

The precoded OFDM proposed in previous work [8], is similar to that of the VFDM system except for the fact that the secondary receiver does not requires to know the channel state information but only in which mode the transmitter is being operated. The convention used in the work is that if the system works as a primary then the operating mode is 1. In case if the system is operated as secondary then the system is said to have a operating mode of 2. In order to make the primary interference free the values have to be precoded in such a way that they satisfy equation (6). But doing so would cause the message recovery at the secondary impossible with the values which has been precoded. Hence a property of IFFT is used which is nothing but if the second half of input of IFFT is given as repeat of first half then the output of IFFT will be zero at every even places. Mathematically it can be given as

$$F^{-1}(x(n))\Big|_{x(n)=x\left(n+\frac{N}{2}\right)} => X(2k) = 0 \tag{8}$$

Thus at zeros places the values can inserted so that it satisfies (6). Such values are called as root values. At receiver if the system is found to be operating as secondary then it removes the values at even position and carries out the conventional OFDM process.

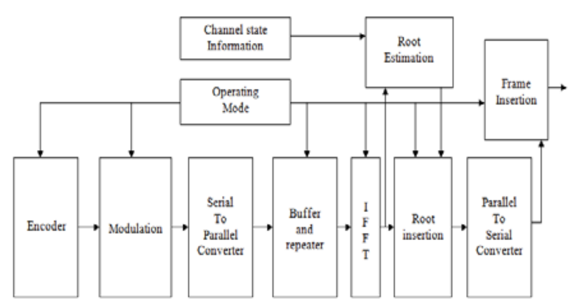

Figure 4. Precoded OFDM Transmitter

The transmitter block is shown in above figure. The operating mode is responsible for intimating the other blocks about the operating mode. The operating mode is 1 when the system has dedicated spectrum i.e. when the system is operating as primary. When the system is operating as secondary then the mode is said to be 2. The first block is the buffer which in operating mode performs no operation while being secondary it

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stores certain values which when propagated requires a 2N point IFFT as there is a additional bit insertion in the form of roots. Hence the buffer ensures that only N symbols are propagated to the IFFT block which is same as that of the operating mode 1.

The next block to the encoder is the constellation mapping which is used to map bits to symbols. The serial data is converted to parallel data if the operating mode is 1. In case the operating mode is 2 then the parallel data is repeated to satisfy the property of IFFT which is mentioned in (8).

In an OFDM system the mapped symbols are inverse Fourier transformed which is nothing but a digital implementation of subcarrier multiplication [3]. The Fourier transformed output are then sent for root estimation, where from the channel state information available the roots are estimated so the propagation of messages along with the indirect secondary channel. Once the roots are estimated then the values are inserted at even position where the IFFT outputs are zero. The frame bits are added in order to intimate the secondary about the operating mode of transmitter.

The frame consists of the data followed by mode field which specifies the current operating mode of the transmitter. The EXT field consist of additional information which is necessary for transfer control.

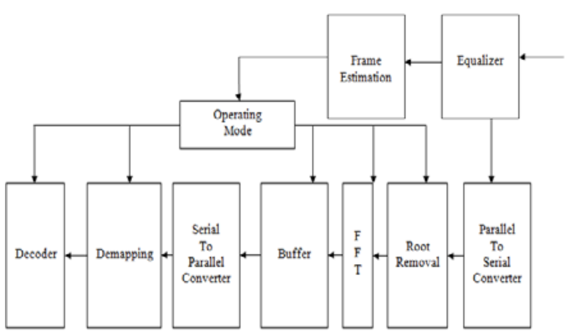

Figure 5: Precoded OFDM transmitter

At the receiver, the frame is removed and is processed by frame estimator which then sends the control signal to the buffer and the adaptive demodulation block. When the frame estimator finds that the mode is operated under cognitive channel condition it then intimate the buffer about the mode. The FFT process the data as normal after the precoder removal, which removes the values present at even samples. The buffer then stores the data and forwards upon receiving the next $\frac{N}{2}$ samples. The data is then subjected to demapping which then provides the information as output.

5. ENCODER

The effect of interference cancelled by the method provided in previous section. But the noise in the channel is dynamic and is not known to the either transmitter or receiver. Hence in order to combat this effect the encoder is block is generally added in a communication block. The two encoding schemes which have been found to achieve closer Shannon limits are Low-Density Parity Check codes (LDPC) and Turbo encoding. But for this work turbo encoding has been chosen given the fact the data rate of secondary can be increased simply by leaving an encoder block.

The conventional turbo encoder block is shown in the figure below.

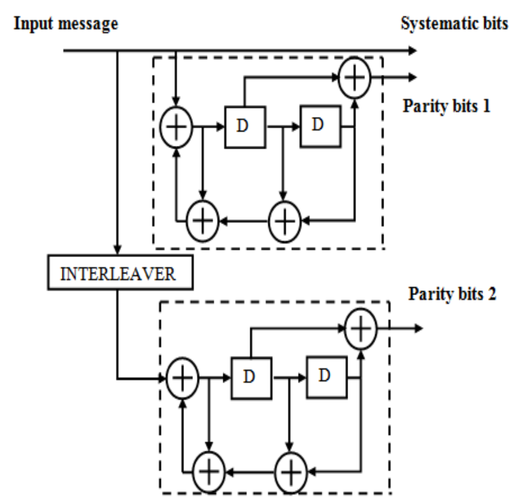

Figure 6: Conventional Turbo Encoder

The convention turbo encoding uses two recursive symmetric coders (RSC). The input for first RSC is directly given while the other RSC is provided with an input which has been interleaved [10]. The interleaving process is carried out in order to randomize the burst error. The D represents the shift register which shift the bits which are then Ex-ored.

The output parity bits and systematic bits are then concatenated. This turbo architecture can be

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dynamically modified by using a switch to improve data rate when operating at mode 2, along with the reduction of complexity. The architecture of the switched turbo encoding is figure 4.

The switched turbo encoding is similar to that of conventional turbo encoding the difference being that the proposed turbo coder interleaves after the RSC block which reduces the complexity to almost half of complexity of conventional encoder since it requires one RSC rather than two. Also the proposed block is capable of detaching a certain part and acts as a convolutional coder when it finds the operating mode to be 2 so that the data rate is increased.

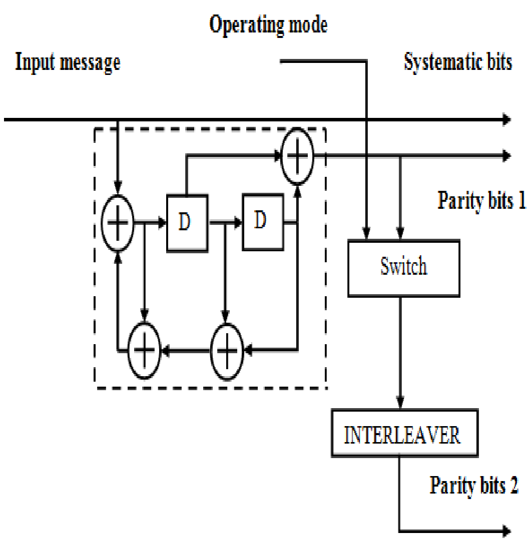

Figure7: Switched Turbo Encoder

The RSC operates as similar to that of the conventional coding and the switch is used to detach the interleaver block hence the code rate becomes ½ which is lesser than code rate of 1/3. Hence more data can be represented by the symbols.

6. IFFT ARCHITECTURE

The Inverse Fast Fourier Transform is the core of the OFDM system. The performance of the IFFT impacts on the performance of the entire system. Hence the design of the IFFT should operate as fast as could and the complexity of the system has to be low as possible. For such requirement the IFFT is implemented using CORDIC algorithm along with Pruning methodology. The Coordinate Rotational Digital Computer (CORDIC) is a low complex method of estimating the twiddle facto needed for the IFFT [11].

The FFT/IFFT block processes the data normally when operated under mode 1. But in case that they are operated under mode 2 a larger resource of IFFT/FFT is used inefficiently as there can be large number of null values involved.

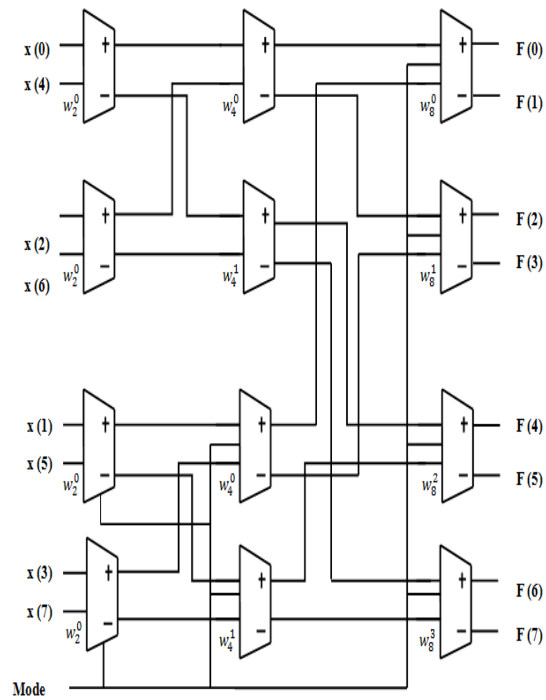

Figure8:FFT Pruning

Consider an 8-point FFT process which is used at the receiver shown in fig.5. When operated at mode 1 that is when the system is using a dedicated channel there is no need for precoding. Therefore, there is no nulled subcarrier which requires the FFT to function by conventional method.

But if the operating mode is 2, then there is unwanted multiplication and addition processes carried out. This can be avoided by means of deactivating the process of twiddle multiplication by means of a control signal based on the operating mode.

Thus the deactivation process can result in less resource usage as well reduce any error which can by caused due to noise introduced by the system.

7. ROOT ESTIMATION

This work also proposes a fast look ahead root estimation method. Roots are nothing but redundant values that are deliberately added so that the data along with message when propagated through indirect channel eliminates the interference. For the

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channel to be interference free the following equation has to be satisfied.

$$\begin{bmatrix} h_1^{ij} & \cdots & h_{L_c}^{ij} & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & h_1^{ij} & \cdots & h_{L_c}^{ij} & 0 & \cdots & \cdots & 0 \\ \vdots & & \ddots & & \ddots & & & \vdots \\ \vdots & \cdots & 0 & h_1^{ij} & \cdots & h_{L_c}^{ij} & 0 & 0 \\ \vdots & & & \ddots & \ddots & & \ddots & 0 \\ 0 & \cdots & \cdots & \cdots & 0 & h_1^{ij} & \cdots & h_{L_c}^{ij} \end{bmatrix} \times \begin{bmatrix} x_1 \\ k_1 \\ x_2 \\ k_2 \\ \vdots \\ x_{\frac{N}{2}} \\ k_{\frac{N}{2}} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ \vdots \\ 0 \\ 0 \end{bmatrix}$$

Simplifying the above equation would result in the following relation

$$\begin{bmatrix} h_2^{ij} k_1 & \cdots & h_{L_c}^{ij} k_{\frac{L_c}{2}} & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & h_1^{ij} k_1 & \cdots & h_{L_c}^{ij} k_{\frac{L}{2}} & 0 & \cdots & \cdots & 0 \\ \vdots & & \ddots & & \ddots & & & \vdots \\ \vdots & \cdots & 0 & h_1^{ij} k_m & \cdots & h_{L_c}^{ij} k_{m+\frac{L}{2}} & 0 & 0 \\ \vdots & & & \ddots & \ddots & & \ddots & 0 \\ 0 & \cdots & \cdots & \cdots & 0 & h_1^{ij} k_{\frac{L}{2}+1} & \cdots & h_{L_c}^{ij} k_{\frac{N}{2}} \end{bmatrix}$$

$$= \begin{bmatrix} -(h_1^{ij} x_1 + \cdots + h_{L-1}^{ij} x_{L-1} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ -(h_2^{ij} x_{\frac{L}{2}-1} + \cdots + h_{L-1}^{ij} x_{\frac{N}{2}} \end{bmatrix}$$

In the above equation the values $h_1^{ij}, h_2^{ij}, \ldots h_{L_c}^{ij}$ and $x_1, x_2, \ldots x_{\frac{N}{2}}$ are known values. Hence the value of $k_1, k_2, \ldots k_{\frac{N}{2}}$ can be estimated simply by solving the equation. For the roots to be estimated $\frac{L_c}{2} - 1$ values has to be assumed initially. This causes no problem since the root values has nothing to do with the recovery of message at the receiver. The implementation if employed normally would cause a major delay of transmission also would require synchronization with the receiver. This because the values estimated from the first equation would be required at the other parts in order to estimate other values. Hence a look ahead method is employed for this estimation.

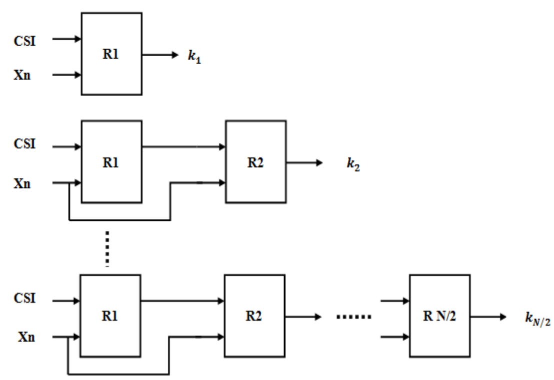

Figure 9: Look Ahead Root Estimation

As shown in the above figure each of the root values are estimated parallel without waiting for the previous root value to be determined. The complexity of this system is $\frac{N(N-1)}{2}$ times that of the normal implementation. But this complexity comes with the upper hand that it requires N times lesser cycles than normal root estimation. Once the root values are estimated they are inserted at the even position of the IFFT output. Then parallel data is converted back to serial data. The last part of the transmitter is the frame insertion. The message is appended with the operating mode information so that the receiver can come to know about the operating mode of the transmitter. If the receiver finds the frame information denoting the operating mode as 1 then normal OFDM process is carried out. In case it find it to be 2 then it removes the values at even position after equalizing and carries out conventional OFDM process.

8. BER PERFORMANCE

This section analyses the performance of the Primary OFDM system when precoded with that of the conventional OFDM and Primary system without precoding. First the performance of the system is considered for an AWGN channel. The BER is plotted against the signal to noise ratio (SNR) of the channel. The BER curve is shown in figure 8 for the proposed system.

As shown in the figure the theoretical interference free system is found to have low BER. When two system are used as cognitive systems, without precoding then the BER performance of the primary system is not satisfactory. Even though the proposed system have BER little higher compare to

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theoretical interference free system, when compared with that of the non precoded system the BER is much lower. The system performance is analyzed without encoding scheme for worst case performance of the channel. The constellation mapping used is 16bit QAM technique.

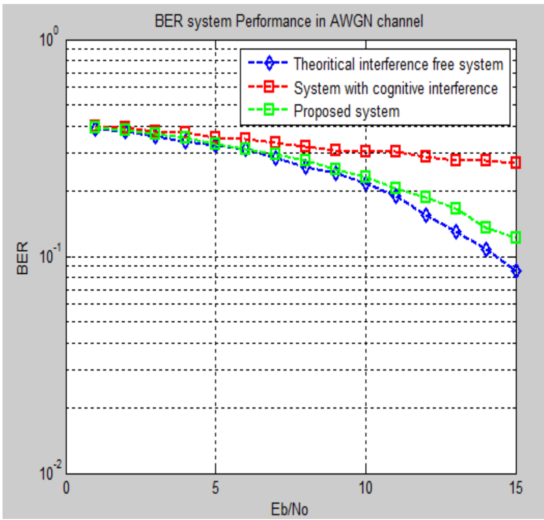

Figure 10: BER performance in AWGN channel

As in any communication system, not only the noise is the major phenomenon that impacts on BER, the ISI due to multipath propagation also poses a serious problem. Hence it is important to analyze the performance of the system in multipath channel. Hence the Rayleigh and Rician channel are considered for analysis.

The figure below shows the performance of the system in Rayleigh channel.

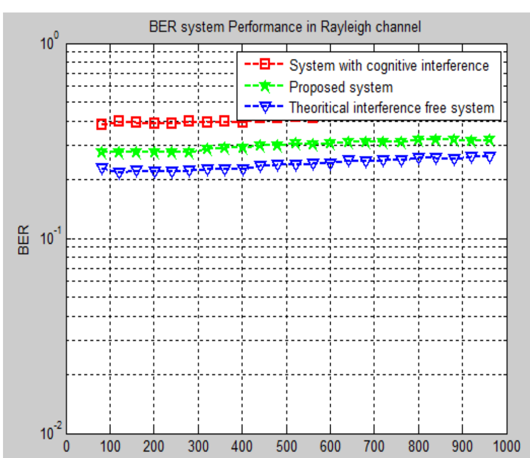

Figure 11: BER performance in Rayleigh channel

The BER is plotted against the Doppler shift measured in Hertz (Hz). The same system parameters are set as in case of AWGN channel. The cognitive interference is found to exhibit the maximum BER. The proposed system is found to have reduced the BER at the primary due to precoding.

The theoretical performance is having lower BER than the proposed system. Because in the proposed system the precoding which is carried out is done based on the channel state information available at the secondary receiver. This however cannot be stable all the time due to the random nature of noise which is added by the channel.

Next the system is evaluated for performance in a Rician modeled channel. The Rician model is similar to that of the Rayleigh channel except for the fact that the Rician channel has direct line of sight transmission along with other line of transmission. The BER performance of the systems in Rician channel is shown in the figure below for varying Doppler shift.

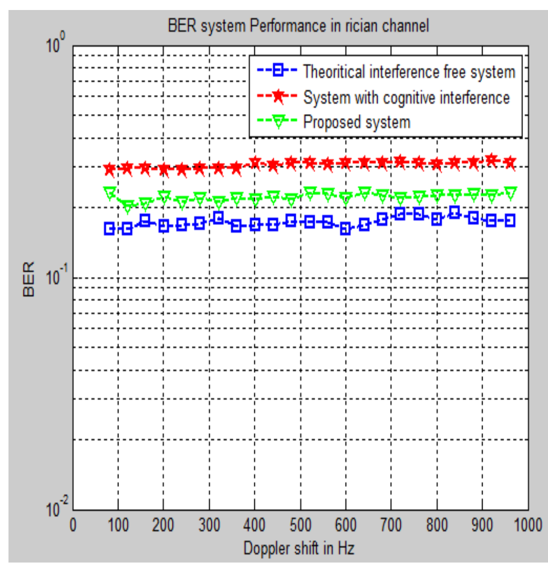

Figure 12: BER performance in Rician channel

The performance is similar to that as obtained in a Rayleigh channel. The proposed system seems to have reduced the BER from a value of 10e-0.5 to 10e-0.7. Also due to the fact that the Rician channel is modeled to have a line of sight transmission, there is no major deviation in the curves for variation in Doppler shift as obtained in Rayleigh channel.

9. THROUGHPUT CALCULATION

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The graph below shows the comparison of channel throughput of a conventional OFDM system and with that of a precoded OFDM system

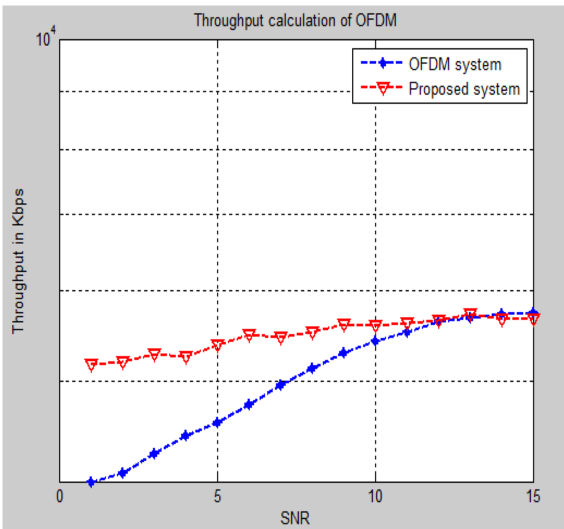

Figure 13: Throughput of the Channel

The values obtained from the above graph are given as table below.

SNR	2	4	6	8	10	12	14	15
OFDM	3.69	3.83	3.98	4.15	4.34	4.59	4.89	5.06
Precoded	5.20	5.25	5.49	5.46	5.61	5.62	5.72	5.06

It can be seen from the above table that the throughput has been increased from 3.69 to 5.20 at a SNR value of 2. This shows that by precoding an OFDM system the throughput of the channel is increased by 27.44% compared to conventional OFDM .

10. CONCLUSION

The cognitive radio is a technology which proves to be vital with the developing wireless systems. The precoded system is designed in order to reduce the cognitive interference caused by the secondary user to the primary user. The graphical results obtained corroborates that the precoded OFDM can be used to reduce the BER caused by the cognitive interference. Thus the system can be used to eliminate the interference barring the fact that the secondary transmitter must know the channel state information precisely. Also it shows that the throughput can be increased by precoding the OFDM system.

The future works includes the analysis of different encoding scheme for the system. Also the consideration for hardware realization of the system is to be made.

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