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FBMC (Filter Bank Multicarrier) Based MIMO (Multiple Input Multiple Output) System for E-health care Applications.

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Abstract: One of the main concern for e-health care system is the proper reception of the medical data that needs to be transmitted for better tele-diagnosis. For achieving this purpose, we introduce Filter Bank Multicarrier (FBMC) based Multiple Input Multiple Output (MIMO) system for the transmission of image data (medical image). FBMC offers various ways to overcome the known limitations of OFDM of reduced spectral efficiency and strict synchronization requirements. MIMO on the other hand provides the link reliability with the use of multiple antennas at the both end of the transmission link, thus leads to least erroneous reception of the medical image at the receiver. The performance has been further improved by changing the diversity order of the system. The designed communication system can even be integrated with the 5G communication standards. A MATLAB programme has been developed for the simulation of such a communication system, were the data to be transmitted is taken to be the medical image. The performance of the said system has been verified in terms of the Bit Error Rate (BER) and Power Spectral Density (PSD). The Peak Signal to Noise Ratio (PSNR) of the transmitted image and the image received at the receiver has also been calculated.

Keywords: Filter Bank Multicarrier (FBMC), Multiple Input Multiple Output (MIMO), Power Spectral Density (PSD), Bit Error Rate (BER).

I. INTRODUCTION

In addition to proper reception of transmitted data, supporting high data rate transmissions over limited radio spectrum with minimum power consumption is the main goal of new wireless communication systems [1]. The combination of two said features has led to development of various generations of communication. Of various available options the paper emphasizes on two techniques only. Filter Bank Multicarrier (FBMC) is the technical evolution of Orthogonal Frequency Division Multiplexing (OFDM) which is the prime candidate in current 4G LTE scenario. The underlying principle of OFDM and FBMC is same except that their sub-channels can be optimally designed in the frequency domain to have desired spectral containment. Second, FBMC systems do not require redundant Cyclic Prefix (CP) and thus are more spectral efficient. MIMO on other hand refers to the number of antennas. With each additional antenna we are able to create a separate link between the transmitter and receiver. It enhances the spectral efficiency of the system and channel capacity at low power [2]. When working in a wireless environment the data is subjected to the fading and with MIMO it is highly improbable that all the links will move into the deep fades. Thus with MIMO comes more reliable reception. The communication field has encompassed all other fields within itself and leads towards the formation of global village. E-health care system is one such field that is conjoined with communication for better diagnosis and efficient utilization of resources across the world. "Electronic healthcare refers to an internet based system wherein a patient can avail the services of an expert doctor available at other corner of globe" [3]. The transmission of medical information over the wireless links has always been the point of concern owing to credibility of the medical information. This paper gives the best possible solution to the transmission of the critical medical information as per the 5G communication standards only. The paper is organized as follows: Section II gives the brief literature review of the related work. Section III gives the mathematical preliminaries needed to understand the underlying techniques viz-a-viz the architecture of FBMC and MIMO. Section IV presents the proposed work. Simulation results and discussions are presented in section V. The paper concludes in section VI.

II. RELATED WORK

The current status of the two techniques that have been employed separately in various research works has been presented in this section:

Omri & Hasna in their work [1] have introduce a new power spectral efficiency (PSE) metric, to quantify the spectral efficiency and the total required power to cover a certain area with a predefined received signal quality. This metric offers the possibility to find the optimal transmission power in each base station to cover the total given area with the minimum total consumed power. The PSE metric describes the power spectral efficiency by giving the number of transmitted bits per time unit via frequency unit with consumed power unit. In addition, it offers the possibility to find the optimal transmission power in each BS, and hence the optimal number of required BSs to cover the total given area with the minimum total consumed power. The new metric is based specifically on deriving the average affected area by each BS and the average ergodic capacity expressions. In [4] authors have presented a novel power management mechanism for MIMO network interfaces on mobile systems, called antenna management. The key idea was to adaptively disable some of the antennas as well as their RF chains to reduce circuit power when the capacity improvement of using a large number of antennas is small. The number of active antennas is judiciously determined to minimize energy per bit while satisfying the data rate constraint. Authors have provided both theoretical framework and system design of antenna management.

Authors in [5] have performed the comparative analysis of three multicarrier modulation techniques namely OFDM, UFMC and FBMC on the basis of Peak To Average Power Ratio (PAPR) and Power Spectral Density (PSD). They have given the performance of various schemes on the basis of various simulation parameters like IFFT size, Bits per carrier and Modulation order. The FBMC has been concluded to have better PSD then OFDM. Authors in [6] have proposed high capacity and reversible data hiding system utilizing Pixel Repetition technique (PRT) for proper tele-diagnosis. The proposed system is capable of any sort of tamper detection. Authors in [7] have adapted digital watermarking for interleaving patient information with medical images, to reduce storage and transmission overheads. The text data is encrypted before interleaving with images to ensure greater security. The graphical signals are interleaved with the image. Two types of error control-coding techniques are proposed to enhance reliability of transmission and storage of medical images interleaved with patient information. Transmission and storage scenarios are simulated with and without error control coding and a qualitative as well as quantitative interpretation of the reliability enhancement resulting from the use of various commonly used error control codes.

In contrast to it the work present in this paper tries to fill the vacuum between the tele-diagnosis and transmission as it provides the energy efficient way of transmitting the medical images that will prove a boon to the e-health care system. In this paper main thrust is on the power consumption and spectrum efficiency while maintaining the image quality. The link reliability has been improved using the multiple antennas at both ends of the transmission link. Using multiple antennas give better performance i.e lesser bit error rate at lower power levels. While the spectrum utilization has been reduced using filter bank multicarrier. FBMC has all the inherent advantages of OFDM modulation and is spectrally more efficient then OFDM. FBMC/OQAM modulation scheme is gaining momentum since it does not transmit redundancy and takes advantage of pulse shaping techniques [8] .Thus it paves a way for design of air-interface for 5th generation wireless systems to meet ambitious throughput goals and to be spectrally agile.

III. PRELIMINARIES

The various preliminaries that need to be understood fully to appreciate the work done in this paper are as follows:

A. *Filter Bank Multi-Carrier(FBMC)*

In the past, orthogonal frequency division multiplexing (OFDM) has enjoyed its dominance as the most popular signalling method in broadband wired [9] and wireless [10] channels. OFDM is a special case of Multi-carrier modulation and forms the basis for 4G wireless communication system. In OFDM the used spectrum is divided into narrow sub-bands. Separate data is transmitted in each band using different carriers that are orthogonal to each other. Two carriers are said to be orthogonal if [11]

$$\frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi f_k t}\, e^{-j2\pi f_i t}\, dt = \frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi \frac{k}{T_{sym}}t}\, e^{-j2\pi \frac{i}{T_{sym}}t}\, dt$$

$$= \frac{1}{T_{sym}}\int_0^{T_{sym}} e^{j2\pi\left(\frac{k-i}{T_{sym}}\right)}\, dt \qquad (1)$$

$$= \begin{Bmatrix} 1, \forall\ integers\ k = i \\ 0, \quad otherwise \end{Bmatrix}$$

Where $\{e^{j2\pi f_k t}\}_{k=0}^{N-1}$ represents a complex exponential signals having various carriers at $f_k = \frac{k}{T_{sym}}$ and T_{sym} is the symbol duration or symbol length.

Power and rate of transmission in a band depends upon on the response of the channel in that band. Since the channel response is almost flat in each narrow band thus Inter Symbol Interference (ISI) gets eliminated to a greater extend. In contrast to ordinary multi-carrier modulation which uses the bank of modulators and de-modulators for the modulation of each carrier OFDM uses Inverse Discrete Fourier Transform (IDFT) to generate the composite signal. This simplifies the transmitter design. OFDM has promising future in wireless networks and mobile communications. Growth in number of worldwide customers for wireless networks and ever-increasing demand for large bandwidth has given birth to this technology [12]. OFDM has been adopted for various types of transmission systems such as Wireless Fidelity (WIFI), Worldwide Interoperability for Microwave Access (WIMAX), Digital Video Broadcasting (DVB), and Long Term Evolution (LTE) [13]. To warrant a performance of OFDM, there must be some means of dealing with the ISI effect over the multipath channel [11]. The OFDM guard interval can be inserted in two different ways. One is the zero padding (ZP) that pads the guard interval with zeros. The other is the cyclic extension of the OFDM symbol (for some continuity) with CP (cyclic prefix). CP is to extend the OFDM symbol by copying the last samples of the OFDM symbol into its front. This CP is a transmission overhead as it contains no information. FBMC has evolved from the conventional OFDM in which the inherit disadvantages of the OFDM are addressed by high quality filters that avoid both ingress and egress noises [14]. FBMC methods have their roots in the pioneering works of [15] and [16] who introduced multicarrier techniques over two decades before the introduction and application of OFDM to wireless communication systems. A general overview of the FBMC system model is shown in Figure 1.

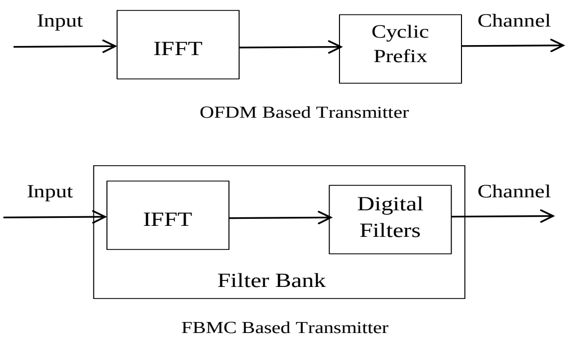

Figure 1: FBMC based Transmitter Design

B. *FBMC Architecture*

The transmitted signal in FBMC is the sum of the outputs of a bank of K filters, $f_{k,}$ whose length is given by L. Thus, at any given time instant m, the discrete-time baseband equivalent of the transmitted signal, x (m), is given by

$$x(m) = \sum_{n=-\infty}^{\infty} \sum_{k=0}^{K-1} d_{k,n} f_k(m, \tau n) \quad (2)$$

Once the signal has been transmitted, it undergoes a transformation which is determined y the channel impulse response h (m) and the noise w (m) obtaining, at the receiver side, a signal y (m) which is given by

$$y(m) = h(m) * x(m) + w(m) \quad (3)$$

Where * denotes the convolution operation. The received signal y (m) is then processed by a bank of K filters g_k (which are the matched filters to f_k) to obtain the output $r_{k,n}$ of this communications system

$$r_{k,n} = g_k(m) * y(m) | m = m_o(n) \quad (4)$$

Where m_0 (n) $=\tau_n + \tau_0$, which corresponds to the decision time at the receiver side and where $\tau_0$is the time index that maximizes |fk(m)*gk(m)|plus, possibly, the extra delay introduced by the channel. Provided that the coherence bandwidth of the channel is high enough, the input-output response of the filter bank system described in above equation, particularized at symbol-time n_0 and frequency k_0 can be well approximated by [17]

$$r_{k_o,n_o} \cong \sum_{n=-\infty}^{\infty} \sum_{k=0}^{K-1} H_k t_{k_o-k,n_o-n} d_{k,n} + w_{k_o,n_o}, \quad (5)$$

Where H_k is the k-th element of the K-point Fourier transform of the impulse response h (m), $w_{k0,\, n0}$ represents the noise sample, and $t_{k0-k,\, n0-n}$ is given by

$$t_{ko-k,no-n} = f_{k_o}(m) * g_k(m + \tau_{n_o}) | m = m_o(n) \quad (6)$$

And represents the transmultiplexer response, i.e., the ISI and Inter Carrier Interference (ICI) "footprint" centered at $k=k_0$ and $n=n_0$ obtained when a single symbol $d_{k0,n0}=1$is transmitted. FBMC without multitap or frequency-domain subchannel equalization can be considered similar to OFDM with a very short cyclic prefix [18].

C. *Multiple Input Multipe Output*

Multiple Input Multiple Output (MIMO) is a multiple antenna system. It is an extremely spectrum efficient technology that uses several antennas at both ends of the wireless link. MIMO is employed for diversity. It increases the data rates by transmitting several information streams in parallels at same transmit power. MIMO system utilizes the feature of spatial diversity by using spatial antennas in a dense multipath fading environment which are separated by some distance [19]. The MIMO system model can be mathematically represented as

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$$\begin{bmatrix} y1 \\ y2 \\ . \\ . \\ . \\ yr \end{bmatrix} = \begin{bmatrix} h11 & \cdots & h1t \\ \vdots & \ddots & \vdots \\ hr1 & \cdots & hrt \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ . \\ . \\ . \\ xt \end{bmatrix} + \begin{bmatrix} n1 \\ n2 \\ . \\ . \\ . \\ nr \end{bmatrix}$$

This can be written as $\bar{y} = H\bar{x} + \bar{n}$ where $\bar{y}$ is a r dimensional receive vector, H is (r x t) channel vector, $\bar{x}$ is a t dimensional transmit vector and $\bar{n}$ is noise vector. r is the number of receive antennas and t is the number of transmit antennas.

D. Orthogonal Space Time Block Code

OSTBC is employed at the source to transmit a signal to the destination [20]. In the space-time coded MIMO systems, bit stream is mapped into symbol stream $[\tilde{x}]_{i=i}^{N} i = 1$.A symbol stream of size N is space-time-encoded into $[\tilde{x}]_{i=i}^{N}$ t=1, 2, 3….T, where i is the antenna index and t is the symbol time index. Note that the number of symbols in a space-time code word is .T (i.e., N = NT × T). In other words $[\tilde{x}]_{i=i}^{N}$ t=1, 2, 3….T, forms a space-time code word. As N symbols are transmitted by a code word over T symbol times, the symbol rate of the space-time-coded system example shown in the figure is given as

R = N/T (Symbols / Channel use)

e.g consider 1x3 MIMO system with 1 receiving antenna and 3 transmitting antennas, transmitting 4 symbols in 8 time instants

Space ↓
$$\begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & x_1 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \end{bmatrix}$$
Time →

Net rate = $\frac{4}{8} = \frac{1}{2}$

The equivalent system can be represented as

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 & h_3 & 0 \\ h_2 & -h_1 & 0 & -h_3 \\ h_3 & 0 & -h_1 & h_2 \\ 0 & h_3 & -h_2 & -h_1 \\ h_1^* & h_2^* & h_3^* & 0 \\ h_2^* & -h_1^* & 0 & -h_3^* \\ h_3^* & 0 & -h_1^* & h_2^* \\ 0 & h_3^* & -h_2^* & h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \\ n_8 \end{bmatrix}$$

In [21] authors have made a comparison between space-time block codes and space-time trellis codes. Both are designed to achieve full diversity advantage over the MIMO wireless channels. However, there are some basic differences. For instance, space-time block codes are very easy to encode and decode (which is achieved using the simple linear processing receivers), whereas space time trellis codes require more complicated trellis-based decoders. Also, it is relatively easy to find and employ space-time block codes for more than two transmit antennas (although there may be a rate loss penalty), this is not the case for space-time trellis codes – they are most widely used for the case of two transmit antennas. These are clear advantages for space-time block coding. On the other hand, the resulting error rates of the space-time trellis codes are generally better than those of the space-time block codes. Thus it is observe that the space-time trellis codes outperform the Alamouti scheme, particularly when the number of states is increased. This is because space-time trellis codes provide a coding advantage in addition to providing full diversity when properly designed. In [22] authors have proposed a system implementing OSTBC with less BER and high SNR for 2X1 MISO system. The results obtained conclude that that OSTBC is the best approach when MIMO- OFDM data is being transmitted from wireless channel like Additive White Gaussian Noise (AWGN), it can also be concluded that it provides high SNR and less BER as compare to other techniques, the proposed model shows the observed BER and relative graph for proving that. The BER is 7181bits in 1201000 frames and as each frames are of 64*1020 bit in proposed work so it is very less.

IV. PROPOSED WORK

A MATLAB program has been written to simulate the proposed work. Upon successful execution of the program, the medical image of a patient is given as an input. After having received the necessary input the programme reads data from an input (image) file and forms an a-by b matrix where a and b is the height and width (in pixels) of the image respectively, the pixel value in the position (i,j) is represented as a binary number, this binary number can be then divided into its corresponding bits These data bits are then given to symbol mapper which assign symbols to bits. The data is then fed to Offset Quadrature Amplitude Modulation (OQAM) modulator. The even symbols are given to one component of OQAM and the odd symbols are given to another component of OQAM. The data is then upsampled by a factor of K (4 in this case) and then padded with guards on each side of a symbol. The data is then filtered with the designed prototype filter. FBMC combined with offset-QAM is considered, pointing out the crucial issue of subchannel equalization to compensate for the absence of cyclic prefix. The data is then given to the OSTBC encoder which encodes the data using orthogonal space time block code. This encoder maps the input symbols block-wise and provides the concatenated output code-word matrices in the time domain [23]. The data is then transmitted through independent MIMO Channels. At the receiver the data received is given to the OSTBC combiner which combines the input signal from all the receivers and channel estimate signal to extract the soft information of the symbols encoded by OSTBC encoder [23]. The data collected is then given to the QAM – demodulator which converts the real and imaginary stream of data back to the serial data .The data is then FFT fed to return the transmitted data. The demodulated data is then converted back to 8-bit word size data used for generating an output file of the simulation. The transmitted image and received images are compared in terms of their bit values to compute the total number of bits in error. The experimental results demonstrate that, with few hardware overhead, the proposed scheme can achieve significant improvement in power reduction and uses the spectrum efficiently.

Table1. Simulation parameters

S. No.	Parameters	Values
1	FFT Size	1024
2	Number of Guards	212
3	K(Oversampling)	4
4	Number of Symbols	100
5	Bits per Carrier	2
6	SNR	From 15dB to 30db

V. EXPERIMENTAL RESULTS

The medical image selected for transmission and the corresponding received image at the receiver is given Figure 2.Table I gives the BER Vs SNR values for 2*1 Antenna configuration along with the PSNR of received image with respect to transmitted image. Table II gives the values of BER and PSNR values for 2*2 Antenna configuration. The power spectral density of the FBMC transmit signal is plotted to highlight the low out-of-band leakage in figure 3. To verify that FBMC is spectrally more efficient than OFDM, the PSD of the OFDM symbol is also shown in figure 4.

SNR	Original Image	Received Image
15		
30		

Figure 2: Transmitted and Received Images for 2*1 Antenna Configuration

Table1 1. For 2*1 Antenna Configuration

S. No.	SNR	BER	PSNR
1	15	1.8902	32.4282
2	20	1.8902	39.7920
3	25	1.7421	45.8433
4	30	0.0000	50.4078

Table1 2. For 2*2 Antenna Configuration

S. No.	SNR	BER	PSNR
1	5	2.0122	27.5780
2	10	1.9001	35.7780
3	15	1.6209	42.6456
4	20	0.0000	50.4078

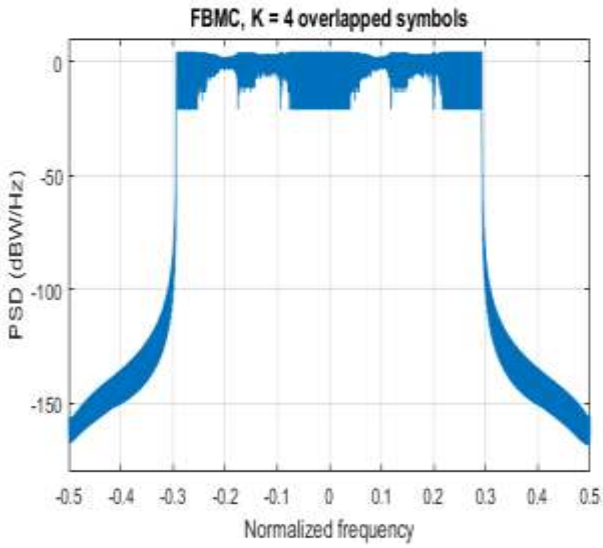

Figure 3: PDS of FBMC Image Sample

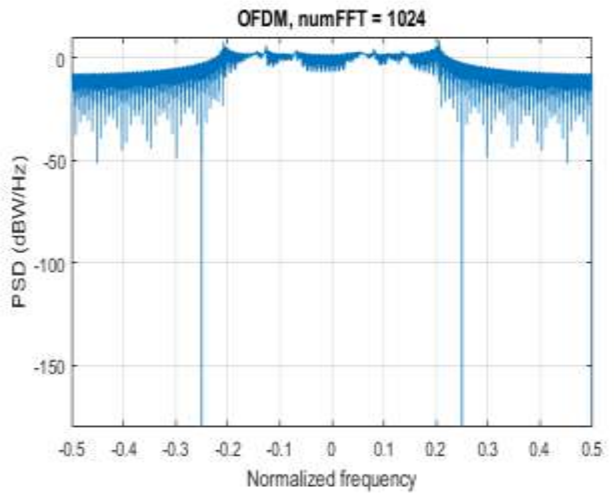

Figure 4: PDS of Typical OFDM sample

VI. Conclusion

In this paper a successful attempt to simulate and model a real time wireless communication system for applications in e-healthcare has been made. All the major components of an FBMC system have been covered. The basic concept and feasibility of FBMC along with its integration with MIMO system has also been demonstrated. The performance parameters like BER and PSNR have been evaluated for OQAM modulation technique. From the results it can be concluded that the proposed technique has lot of scope in e-healthcare systems. The work presented can be extended to the next generation communication system with a minimal signal processing changes while as the underlying modulation and transmission techniques will remain the same.

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