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Frequency Domain MMSE one-tap Equalizer for FBMC-OQAM System

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Abstract

The need for higher data rate in the modern communication world leads to the development of multicarrier modulation. OFDM, the most popular MCM technique, has some disadvantages like inefficiency due to the insertion of cyclic prefix, spectral leakage among the subchannels due to the poor stopband attenuation of prototype filter etc. Due to these drawbacks of OFDM, a Filter Bank based Multi Carrier system with Offset Quadrature Amplitude Modulation has been proposed. The analysis and synthesis filter banks in FBMC- OQAM system is designed using exponential modulation of a single prototype filter which is designed using frequency sampling method of filter design. In the presence of fading channels, Frequency Domain MMSE one-tap equalizer is designed. Simulation results for Vehicular A and Pedestrian B channels show that the proposed equalizer gives better results for BER performance for the system.

Keywords: *FBMC-OQAM, Frequency Domain MMSE one-tap Equalizer, MCM, OFDM, Transmultiplexer*

1. Introduction

The demand for higher data rate in the present and future wireless communication system has attracted multicarrier modulation (MCM) which provides much flexibility in multipath fading channels in communication systems. In MCM, each subband of the whole wideband frequency selective channel can be approximately considered to have flat-fading only, which leads to simple equalization techniques at the receiver where in single carrier modulation (SCM), complex equalization is needed.

The popular MCM technique, Orthogonal Frequency Division Multiplexing (OFDM) [1] is used in Digital Video Broadcast (DVB), Digital Audio Broadcast (DAB) and Asymmetric Digital Subscribe Line (ADSL) etc. OFDM has some advantages like high spectrum efficiency, ISI reduction using cyclic prefix (CP) etc. The drawbacks of OFDM led to the development of filter bank based multicarrier (FBMC) system where the subchannel filters in the system can have good stopband attenuation which leads to lesser frequency leakage between the subchannel filters. The FBMC system idea is derived from the concept of transmultiplexer [2], [3]. Better spectral shaping of subchannel filters can be utilized for simplifying the equalization at the receiver without the use of CP. FBMC-OQAM system uses Offset Quadrature Amplitude Modulation (OQAM) [4]. This modulation achieves orthogonality between the adjacent subchannels which leads to less adjacent channel interference.

The FBMC-OQAM system spreads in the frequency domain the original data stream over different subcarriers. This modulation achieves orthogonality between the adjacent subchannels which leads to less adjacent channel interference. However, through a frequency selective fading channel, all the subcarriers have different amplitude levels and different phase shifts which results in a loss of the orthogonality among users and then generates Adjacent Subchannel Interference (ASI). At the receiver, the received sequence must be "equalized" by using one tap adaptive equalizer per subcarrier to make up for the phase and amplitude distortions caused by the mobile radio channel.

To combat the ASI, various basic detection techniques such as Maximum Ratio Combining (MRC), Equal Gain Combining (EGC), Orthogonal Restoring Combining (ORC) or Minimum Mean Square Error (MMSE) may be used. This last technique, based on the MMSE criterion applied independently on each subcarrier achieves better

performance. This paper describes a detection technique based on the MMSE criterion applied per user which provides performance improvements of the FBMC-OQAM system.
In this paper, an FBMC-OQAM system is simulated. A filter bank is formed from a single prototype filter by exponential modulation. The prototype filter is designed using frequency sampling method of filter design [5]. Data bits from a source are first transformed to OQAM modulated symbols and are given to the 64-subchannel filterbank. The multicarrier signals from the transmitter are transmitted through AWGN channel, ITU vehicular A channel and Pedestrian B channel [8]. For the ISI channels, frequency domain MMSE equalization [7] is done at the receiver using pilots, transmitted along with the transmitted symbols by block type pilot arrangement (BTPA) pilot transmission.
This paper is organized as follows. Section 2 gives the concept of transmultiplexer which is the basic for FBMC system. Section 3 gives the implemented FBMC-OQAM system model with description of OQAM modulation, prototype filter design method and formation of exponential modulated filterbank. Section 4 gives the proposed frequency domain MMSE one tap equalization for FBMC-OQAM System used to combat the multipath effects in fading channel. Simulation results are discussed in Section 5 and concluding remarks are given in Section 6.

2. Transmultiplexer-FBMC Principle

The concept of transmultiplexer leads to the development of FBMC system. The transmultiplexer can be considered as a system that converts from time division multiplexed (TDM) version of a signal to a frequency division multiplexed (FDM) version, and back.

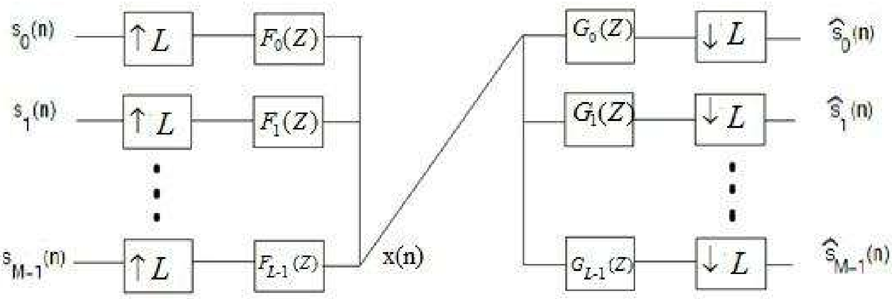

Figure 1: Transmultiplexer

Figure 1 shows the block diagram of a transmultiplexer. The input TDM signal $s_0(n)$, $s_1(n)$, . . ., $s_{M-1}(n)$ is divided among each branch of the transmultiplexer and each $s_k(n)$'s spectrum is compressed by the upsampler with upsampling factor L and there will be images of the compressed spectrum of inputs. The predesigned synthesis filter $F_k(z)$ filters out the desired compressed spectrum components from all of the images and are combined to form x(n) and is transmitted. So, in transmultiplexer, the input TDM signal becomes FDM signal at the transmitter output. At the receiver side, the combined input spectrum is divided into corresponding input spectrums using predesigned analysis filters and using downsampler with downsampling factor L, the compressed spectrum will be expanded to retrieve the original input signals. So, the initial TDM signal is obtained back. According to the relationship between the number of inputs *M* and the upsampling factor L, the transceiver can be classified into minimally interpolated (L = M), over interpolated (L > M) and under-interpolated (L < M). The first case is non redundant and is used in most of the cases. The second one has redundancy which reduces the bandwidth efficiency of the system. In the last case, some information will be actually lost, so can't be used for practical applications. This transmultiplexer concept is the basic for FBMC system. So, in an FBMC system, there will be 2 sets of filter banks. Synthesis filterbank at the transmitter and analysis filterbank at the receiver.

3. FBMC-OQAM System

The concept of transmultiplexer leads to the development of FBMC system. The transmultiplexer can be considered as a system that converts from time division multiplexed (TDM) version of a signal to a frequency division multiplexed (FDM) version, and back. Figure 2 shows the FBMC- OQAM system. The main processing blocks in this direct form representation of FBMC-OQAM system are OQAM pre-processing, synthesis filter bank, analysis filter bank, and OQAM post-processing.

3.1. OQAM pre/post processing

In the OQAM preprocessing, the first operation is a simple complex-to-real conversion, where the real and imaginary parts of the QAM complex-valued symbol ck, 1 where *k = 0, 1, . . ., M-1* are separated and time staggered by half the symbol period.

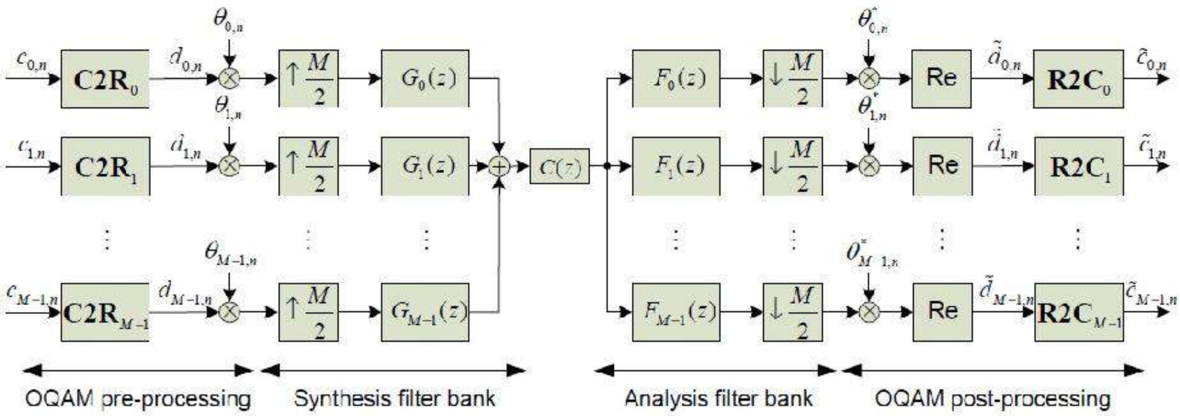

Figure 2: FBMC-OQAM System

The complex-to-real conversion increases the sample rate by a factor of 2. The next operation is the multiplication by $\theta_{k,n}$ sequence where $\theta_{k,n} = j^{(k+n)}$. Since the adjacent values in a single subchannel and in the adjacent subchannels are multiplied with powers of j (by $\theta_{k,n}$), they will be orthogonal to each other. So, adjacent subchannel interference free transmission can be ensured. In the OQAM-post processing, the first operation is the multiplication by $\theta_{k,n}^*$ sequence and is followed by the operation of separating the real part. The second operation is real- to complex conversion, in which two successive real-valued symbols (with one multiplied by j) form a complex-valued symbol $\tilde{c}_k$, n. The real-to-complex conversion decreases the sample rate by a factor 2.

3.2. Synthesis and Analysis Filter Banks

As shown in the Figure 2, OQAM modulated symbols are transmitted to M upsamplers with upsampling factor $M/2$. Then they are passed to the synthesis filterbank and combined for transmission. After passing through the channel C (z), the received signal is filtered using analysis filter bank and then downsampled by a factor of $M/2$.

All the subchannel filters in synthesis filter bank $G_k(z)$ are formed by the exponential modulation of a single real-valued linear phase FIR prototype filter G_0 (z) with impulse response $p(m)$. The k^{th} synthesis filter is defined by,

$$g_k(m) = p(m)\exp\left[j\frac{2\pi k}{M}\left(m - \frac{L_p - 1}{2} \right) \right] \tag{1}$$

Where $m = 0, 1, ..., L_p - 1$ and L_p is the filter length. The k^{th} analysis filter can be obtained by using perfect reconstruction (PR) condition and is defined by,

$$f_k(m) = g_k^*(L_p - 1 - m) = g_k(m) \tag{2}$$

3.3. Prototype filter design

Prototype filter decides the amount of interference between the different subchannels and between the symbols itself. Therefore, the prototype filter can be designed in such a manner that the system guarantees perfect reconstruction (PR) or near perfect reconstruction (NPR).

In this paper, frequency sampling method of filter design is used to design the prototype filter. In frequency sampling method of filter design, the impulse response coefficients can be obtained by inverse Fourier transform of K M samples from the desired frequency response of the filter where K called overlapping factor (we took $K = 4$) is the number of samples in a single prototype filter passband and M is the total number of subchannels required. The closed-form representation of an L_p -length prototype filter p (m) can be represented as

$$p(m) = \frac{1}{N}\left[k_0 + 2\sum_{i=1}^{L_p - 1}(-1)^i k_i \cos\left(\frac{2\pi i m}{KM} \right) \right] \tag{3}$$

Where $m = 0, 1,.., L_p - 1$. Therefore, the overall filter length becomes $L_p = KM - 1$. Now the aim is to find out the coefficients k_i ($i = 0, 1, ..., K - 1$) in such a manner that the filter has a good stopband behavior in order to initially avoid the interference between the subchannels [6].

From [6], the conditions for finding the values of k_i 's which give a prototype filter having good stopband behavior (lesser crosstalk) can be obtained as $k_0 = 1$, $k_0 + 2\sum_{i=1}^{K-1} k_i = 0$ and $k_l^2 + k_{K-l}^2 = 1$

4. Frequency domain MMSE one-tap equaliser

AWGN channel is the most basic channel model considered in any communication model. In mobile radio channels, Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a fading signal. ITU-R (International Telecommunication Union – Radio communication sector) recommendation is commonly used as an empirical channel model. The ITU wideband channel can be described using a tapped delay line model, where each tap is characterized by a delay and an amplitude coefficient. ITU-R recommends 6 channels for 3 cases (indoor, pedestrian and vehicular) and 2 different delay spreads (Channel A- low delay spread, Channel B- medium delay spread). Based on the expected percentage of occurrence of each of these 6 models, the Wi-MAX forum recommends using just 2 models (Vehicular A and Pedestrian B channel models) out of the six ITU models. So, the system performance in those 2 fading channel models is to be studied. The specification for the Vehicular A and Pedestrian B channels are given in Table 1 and Table 2 respectively.

Table 1: Specification for vehicular A channel

Relative Delay (ns)	Relative Delay (ns)
0	0
310	-1
710	-9
1090	-10
1730	-15
2150	-20

Table 2: Specification for pedestrian B channel

Relative Delay (ns)	Relative Delay (ns)
0	0
200	-0.9
800	-4.9
1200	-8
2300	-7.8
3700	-23.9

The FBMC-OQAM system block diagram with frequency domain equalization is shown in Figure 3. For performing the frequency domain equalization, the channel transfer function's inversion should be done at the receiver. For estimating the channel state information, training symbols known at both the transmitter and receiver (pilots) can be used. The Block Type Pilot Assignment (BTPA) is shown in Figure 4 where pilots are transmitted for all subcarriers at a particular time instant (black dots) for a fixed block of transmitted data (white dots). Estimates of channel transfer function are calculated once per block and are used until the next pilot symbol arrives.

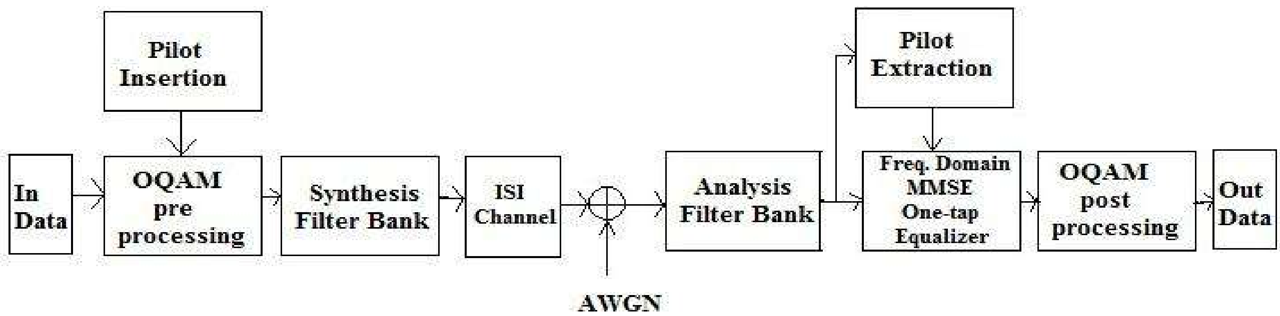

Figure 3: FBMC-OQAM System with Frequency Domain MMSE one-tap Equalizer in fading

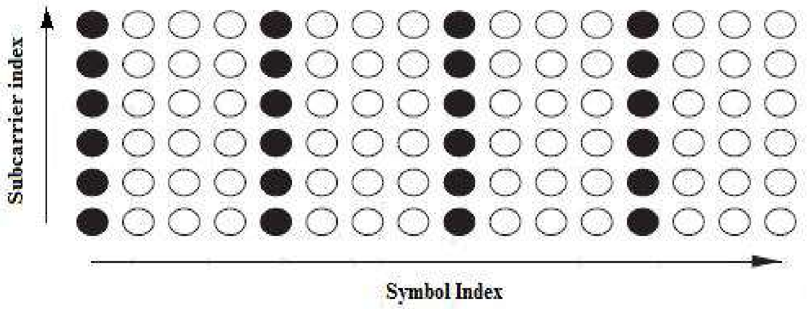

Figure 4: BPTA Transmission

Since FBMC-OQAM is a multicarrier modulation technique, channel fading in each subchannel can be considered as frequency-flat fading. So, channel frequency response in each subchannel needs to be estimated. The received signal in frequency domain at the receiver $Y(n)$ is given by

$$Y(n) = X(n)H(n) + W(n) \;;\; 0 \leq n \leq M - 1. \quad (4)$$

Where, $X(n)$ is the transmitted signal $W(n)$ is AWGN, $H(n)$ is the channel transfer function at subchannel n and M is the number of subchannels. MMSE equalization minimizes the mean square error between transmitted signal and the estimated output for each subcarrier. This provides a better balance between ISI and noise enhancement. The estimates of channel frequency response of the subchannels $\widehat{H}(n)$ can be calculated as,

$$\widehat{H}(n) = \frac{Y(n)}{X(n)} = H(n) + \frac{W(n)}{X(n)} \;;\; 0 \leq n \leq M - 1 \quad (5)$$

MMSE equalization minimizes the mean square error between transmitted signal and the estimated output for each subcarrier [7]. This provides a better balance between ISI and noise enhancement. For n^{th} subcarrier, MMSE equalization weight $p(n)$ is given by

$$p(n) = \frac{H^*(n)}{|H(n)|^2 + SNR^{-1}} \;;\; 0 \leq n \leq M - 1 \quad (6)$$

By applying MMSE frequency domain one tap equalization, from the received signal $Y(n)$, the estimate of the transmitted signal $\hat{X}(n)$ is obtained by

$$\hat{X}(n) = p(n)Y(n) \quad (7)$$

Here $p(n)$ is chosen so as to minimize $J(n)$ which represents the mean squared error (MSE) between the equalized output $p(n)Y(n)$ and the transmitted symbol $X(n)$.

$$J(n) = E(|p(n)Y(n) - X(n)|^2) \quad (8)$$

5. Simulation results

An FBMC-OQAM system is designed for 64 subchannels (M=64). 64000 bits from a source is transmitted OQAM preprocessing block. OQAM modulated signals are given to the analysis filterbank. Prototype filter is designed using frequency sampling method of filter design. Synthesis filterbank is formed by exponential modulation of the single prototype filter. The output from the analysis filterbank is combined and transmitted to the channel. 3 types of channels are considered. Only AWGN channel, Vehicular A channel, Pedestrian B channel are those 3 channels considered. The received signal at the receiver is equalized using Frequency Domain MMSE one-tap equalizer. Channel state information is estimated using pilots (BTPA transmission). The equalized signals are passed to the analysis filterbank and then OQAM demodulated to reconstruct the transmitted symbols. BER performance of this FBMC-OQAM in AWGN channel, Vehicular A channel and Pedestrian B channel are analyzed.

BER performance of FBMC-OQAM system with and without Frequency Domain MMSE one-tap equalization in vehicular A and pedestrian B channel are shown in Figure 5 and Figure 6 respectively. It can be seen that the proposed equalization in FBMC-OQAM system gives very good BER performance for the system in Frequency selective channels also. Without equalizer the entire received bits are erroneous and are not recoverable. By the use of the proposed equalizer, BER can be reduced significantly. The system with only AWGN channel has a BER rate of about 10^{-5} at an SNR of 16 dB. With Frequency domain MMSE one tap equalizer, BER of the system is 0.5×10^{-5} at 16 dB SNR in Vehicular A channel and 0.5×10^{-5} at 20 dB SNR in Pedestrian B channel.

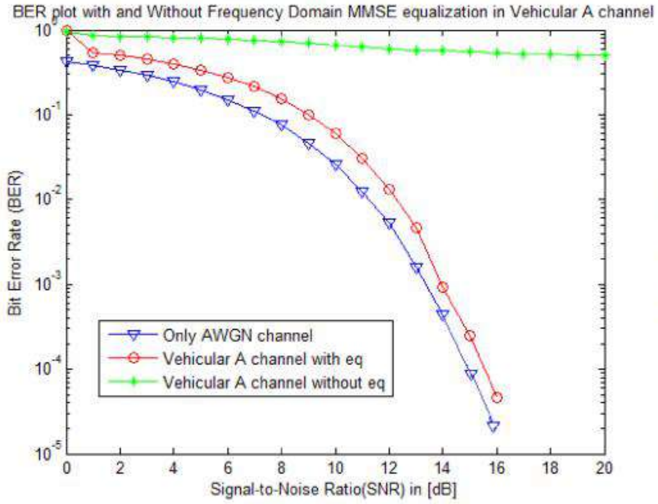

Figure 5: BER plot in Vehicular A channel

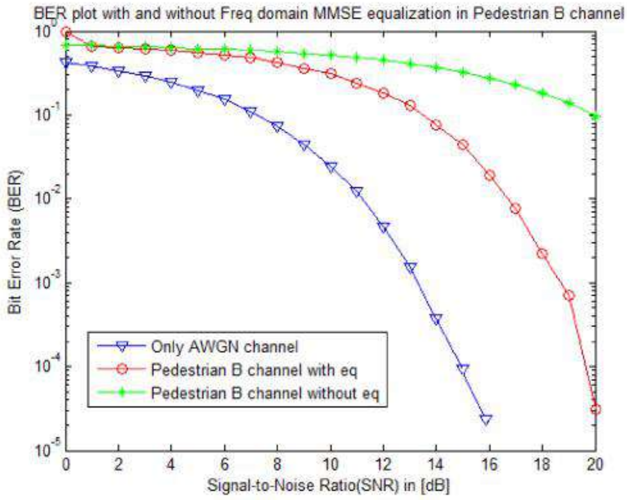

Figure 6: BER plot in Pedestrian B channel

BER performance of FBMC-OQAM system with and without Frequency Domain MMSE one-tap equalization in vehicular A and pedestrian B channel are shown in Figure 5 and Figure 6 respectively. It can be seen that the proposed equalization in FBMC-OQAM system gives very good BER performance for the system in Frequency selective channels also. Without equalizer the entire received bits are erroneous and are not recoverable. By the use of the proposed equalizer, BER can be reduced significantly. The system with only AWGN channel has a BER rate of about 10^{-5} at an SNR of 16 dB. With Frequency domain MMSE one tap equalizer, BER of the system is 0.5×10^{-5} at 16 dB SNR in Vehicular A channel and 0.5×10^{-5} at 20 dB SNR in Pedestrian B channel.

6. Conclusion

Multicarrier modulation (MCM) techniques have gained a lot of attraction in the modern communication world. In this paper a Filter Bank based Multi Carrier system with Offset Quadrature Amplitude Modulation (FBMC-OQAM system) is developed using exponential modulation of a single prototype filter. BER performance of the FBMC-OQAM system in AWGN channel and in Vehicular A and Pedestrian B channel with and without equalizer were studied. In fading channels, BER performance can be significantly improved by using the proposed Frequency domain MMSE one-tap equalizer.

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