

Decision Feedback Equalization for Filter Bank Multicarrier Systems

Abhishek B G, Dr. K Sreelakshmi, Desanna M

M.Tech Student, Department of Telecommunication, R. V. College of Engineering, Bengaluru, India

Professor, Department of Telecommunication, R. V. College of Engineering, Bengaluru, India

Sr. Research Staff, Department of Communication, Central Research Lab, Bharat Electronics, Bengaluru, India

ABSTRACT: The filter bank multicarrier (FBMC) transmission system is an enabling technology for the new concepts and, especially, cognitive radio and it results into an enhanced physical layer for conventional networks. In this paper, we present a decision feedback equalizer based on RLS (Recursive Least Square) and LMS (Least Mean Square) algorithms at the sub-channel level for FBMC systems using exponentially modulated filter banks. The input to the FBMC system is offset quadrature amplitude modulated (OQAM) input symbols. Simulation results exhibit that, in spite of its increased computational complexity, the FBMC/OQAM transmission technique provides better bit error rate performance.

KEYWORDS: Filter bank multicarrier systems, orthogonal quadrature amplitude modulated staggering, orthogonal quadrature amplitude modulated de-staggering, decision feedback equalizer, analysis filter bank, synthesis filter bank, Recursive Least Square, Least Mean Square.

I. INTRODUCTION

In the seventies, Multicarrier transmission techniques with digital filter banks were developed to perform the conversion between FDM (Frequency Division Multiplexing) and PCM (Pulse Code Modulation) systems. In the nineties, OFDM (Orthogonal Frequency Division Multiplexing) was preferred because of its simpler concept, less complexity and minimum latency.

Now, radio communications are moving in directions that make the objections to the filter bank approach unfounded and, in fact, make filter banks particularly attractive. First, in order to achieve quality of service (QoS) and high throughput, radio transmission is resorting to multi-antenna terminals (MIMO), which is a considerable increase in complexity. Second, communications are migrating to all-IP networks, which implies packet transmission and, therefore, minimum latency at the physical (PHY) layer is no longer crucial and the actual constraints are put on the upper layers. Scalability is a function that is being introduced and it is easily implemented with filter banks because of the independence of sub-channels. In addition, the new concepts such as cognitive radio and DASM (Dynamic Access Spectrum Management) require high resolution spectral analysis, a functionality in which filter banks superior over the discrete Fourier transform of OFDM.

Filter bank-based methods were the first multicarrier methods that were developed, prior to OFDM. The first proposal came from the author of [6], in the 1960s, who presented the conditions required for signaling a parallel set of pulse amplitude modulated (PAM) symbol sequences through a bank of overlapping vestigial side-band (VSB) modulated filters. A year later, author of [7], extended the idea and exhibited how the author [6]'s method could be modified for quadrature amplitude modulated (QAM) symbols transmission. Author [7] showed that a perfect reconstruction FBMC system can be implemented using a half-symbol space delay between the in-phase and the quadrature components of QAM symbols and by proper transmit and receive pulse-shapes in a multichannel QAM system while having the maximum spectral efficiency. In 1980s, author of [8], progressed more on FBMC and presented an efficient polyphase implementation for the author [7]'s method. The method proposed by author [7] is referred to as OFDM based on offset QAM. The half symbol shift between the in-phase and quadrature of each QAM symbol with respect to each other

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introduces an offset. We refer to this method as staggered modulated multitone (SMT), where the word staggered refers to the time staggering of in-phase and quadrature components in each QAM symbols. The first solution to the equalization problem in an FBMC/OQAM systems was presented by Author of [8]. An MMSE equalizer was proposed by the authors of [4][5], takes into account intersymbol interference (ISI), and intercarrier interference (ICI) coming from adjacent subchannels.

In this paper, we propose a modified decision feedback equalizer based on RLS (Recursive Least Square) and least mean square (LMS) algorithms, which operates efficiently at the subchannel level in order to reduce or eliminate inter symbol interference present in the FBMC/OQAM systems.

II. FBMC/OQAM SYSTEM STRUCTURE

The basic principle of filter bank multicarrier system is shown in Fig. 1 & Fig. 2. The transmitter contains a synthesis filter bank (SFB) and the receiver comprises an analysis filter bank (AFB).

A QAM modulated input symbols $c_k[l]$ are fed into OQAM Staggering block, shown in Fig. 3, where a symbol is symbol period ($T/2$) is applied to either the real part or the imaginary part of the QAM symbol. For two successive sub-channels, say k and $k+1$, the offset is applied to either the real part of the OQAM symbol in subchannel k , while it is applied to the imaginary part of the QAM symbol in sub-channel $k+1$.

An analysis filter bank (AFB) present in the FBMC receiver, divides the high rate received signal into M low rate subchannel signals again. Decision feedback equalizer (DFE) at each subchannel level is used to compensate for the intercarrier interference (ICI) and intersymbol interference (ISI) introduced by the frequency selective radio channel. The equalized symbols are then fed into OQAM de-staggering block, where the symbols are down-sampled by a factor of 2 and an offset is introduced as shown in Fig. 4.

A fundamental constraint for transmission of data is that the channel has to satisfy the Nyquist criterion in order to avoid intersymbol interference. Suppose T_{symbol} is symbol period and $f_{symbol}=1/T_{symbol}$ is symbol rate, the frequency response of the channel must be symmetrical about $f_{symbol}/2$. Hence, the prototype filter for the synthesis and analysis filter banks of the FBMC system has to be half-Nyquist, i.e., the square of frequency response of prototype filter has to satisfy the Nyquist criterion.

The filter length dependent multipliers are defined as,

$$\beta_{k,n} = (-1)^{kn} \exp\left(-j \frac{2\pi}{M} \left(\frac{L_p-1}{2}\right)\right) \quad (1)$$

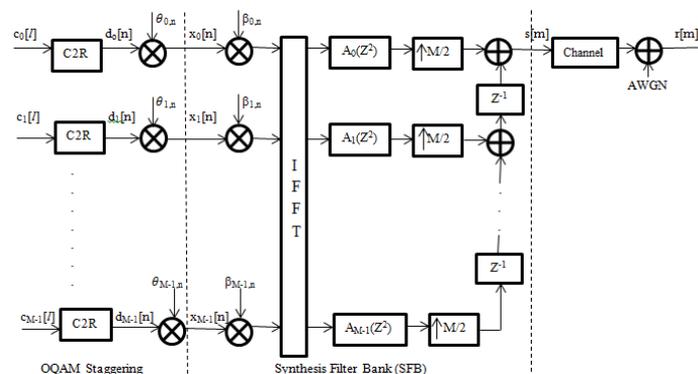


Fig. 1. FBMC/OQAM Transmitter

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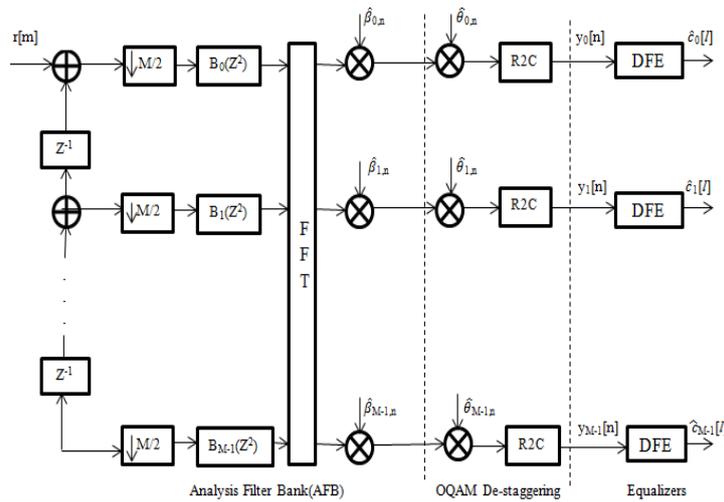


Fig. 2. FBMC/OQAM Receiver

The prototype filter used for the synthesis and analysis filter banks is defined as,

$$a_k[m] = p[k + mM] \quad (2)$$

$$b_k[m] = p[M - 1 - k + mM] \quad (3)$$

Where $p[m]$ is the prototype filter of length $L_p = KM$.

The output of an FBMC transmitter based on offset-QAM (OQAM) modulation is the discrete-time baseband signal, which can be expressed as,

$$s[m] = \sum_{k=M_u}^{\infty} d_{k,n} \theta_{k,n} \beta_{k,n} p\left(m - \frac{nM}{2}\right) e^{-j \frac{k}{M} (L_p - 1) \pi}$$

Where $\theta_{k,n} = j^{(k+n)}$
 $d_{k,n} = (-1)^{kn}$

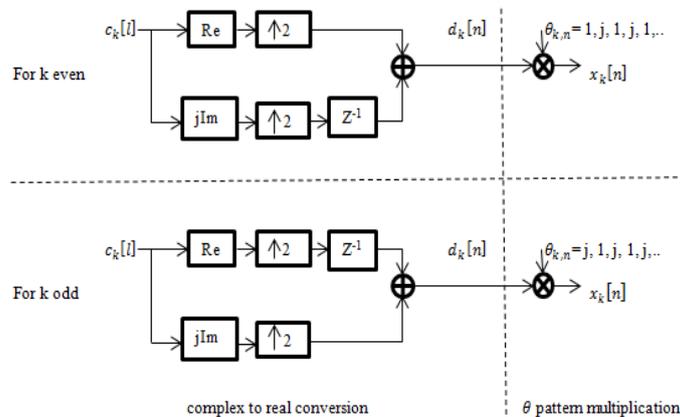


Fig. 3. OQAM Staggering

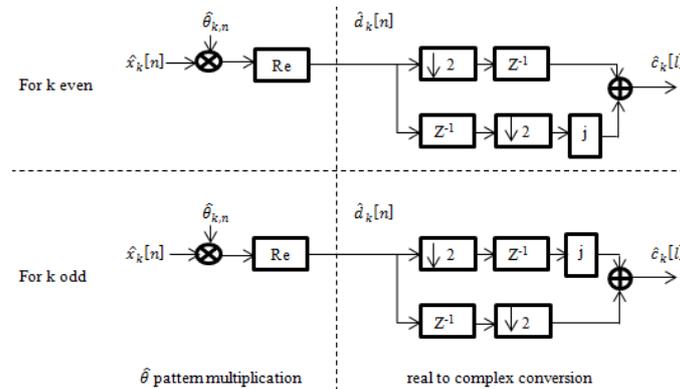


Fig. 4. OQAM De-staggering

M denotes the overall number of subchannels, also equal to IFFT/FFT length, M_u is the number of active subchannels, and $d_{k,n}$ represents the real-valued symbols at the k^{th} subchannel during the n^{th} symbol interval, modulated at rate $2/T$. The signaling interval is defined as the inverse of the subchannel spacing, i.e., $T = 1/\Delta f$. The symbols $d_{k,n}$ and $d_{k,n+1}$ carry the in-phase and quadrature components of the complex-valued symbol $c_{k,l}$ (of rate $1/T$) from a QAM-alphabet.

III. ADAPTIVE DECISION FEEDBACK EQUALIZER STRUCTURE

The per-subchannel Decision feedback equalizer (DFE) based on conventional LMS and RLS algorithms for FBMC system is shown in Fig. 5.

An FBMC/OQAM system where overlap of only immediate adjacent subchannel filters is considered, that means the nonadjacent subchannels interference is negligible. This is true only when polyphase length $K \geq 4$ and roll-off factor $\rho \geq 1$, which implies that the prototype filter with high attenuation level in the stop-band.

The RLS algorithm is used initially to set the weights in the first data block, and LMS thereafter, for speed purposes. The weights and weight inputs of the LMS equalizer is set to those of the RLS equalizer for future data blocks. The initial weights of LMS and RLS equalizers are set by using weight settings block.

Equalized output is defined as,

$$\hat{c}_k[l] = (\text{Updated weights}) \text{ circular convolution } (y_k[l]) \quad (5)$$

Where $y_k[l]$ is the input to the DFE.

The error is calculated as,

$$e_k[l] = d[l] - \hat{c}_k[l - 1] \quad (6)$$

The transmission of training sequence $d[l]$ before the data symbols guarantees the convergence of LMS algorithm, and hence the DFE equalizer operates in the training mode.

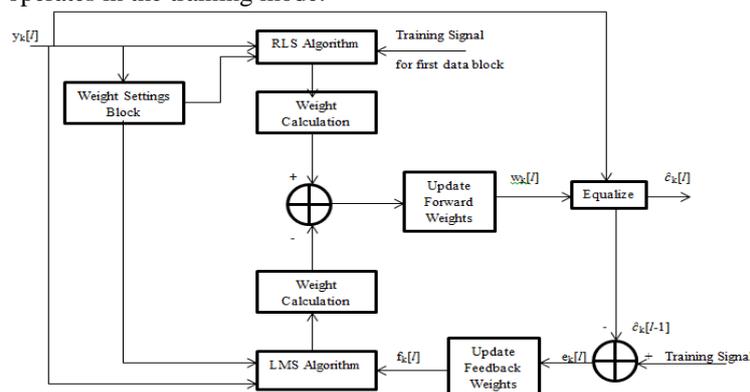


Fig. 5. Per-subchannel adaptive decision feedback equalizer for FBMC/ OQAM system

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The weights are updated as follows

$$w_k[l + 1] = w_k[l] + \Delta w_k[l] \quad (7)$$

$$\Delta w_k[l] = w_k[l] \pm \left(\frac{w_k[l] e_k[l]}{\hat{c}_k[l]} \right) \quad (8)$$

$$f_k[l + 1] = f_k[l] + \Delta f_k[l] \quad (9)$$

$$\Delta f_k[l] = f_k[l] \pm \left(\frac{f_k[l] e_k[l]}{\hat{c}_k[l-1]} \right) \quad (10)$$

Where $w_k[l]$ and $w_k[l + 1]$ are the current and updated weights of feedforward filter respectively. $f_k[l]$ and $f_k[l + 1]$ are the current and updated weights of feedback filter respectively.

IV. SIMULATION RESULTS

The simulated bit error rate performance of FBMC/OQAM system with per-subchannel DFE is shown in figure 6. We have considered 1024 and 256 subchannels and 1000 data symbols in each subchannel and rayleigh fading channel is considered.

In this design, we have employed a low pass FIR filter having polyphase length $K = 4$ and roll-off factor $\rho = 0.5$ as a prototype filter, since this kind of prototype filter is nearly Nyquist (nearly ISI free) and only immediately adjacent subchannels overlap significantly.

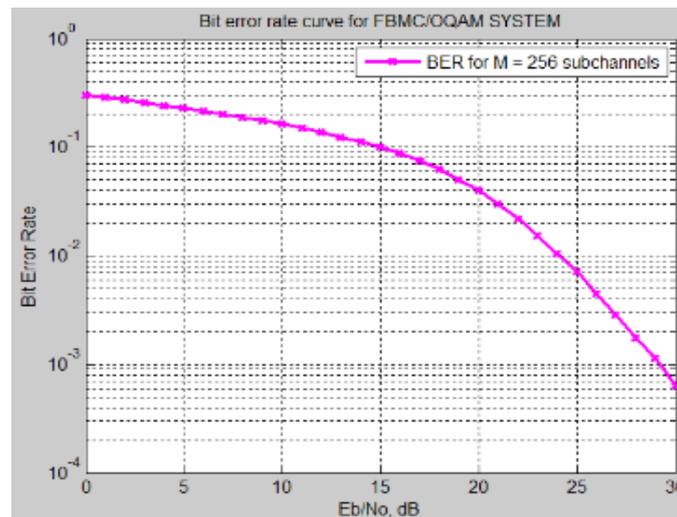


Fig. 6: BER curve for FBMC/OQAM system with M = 256

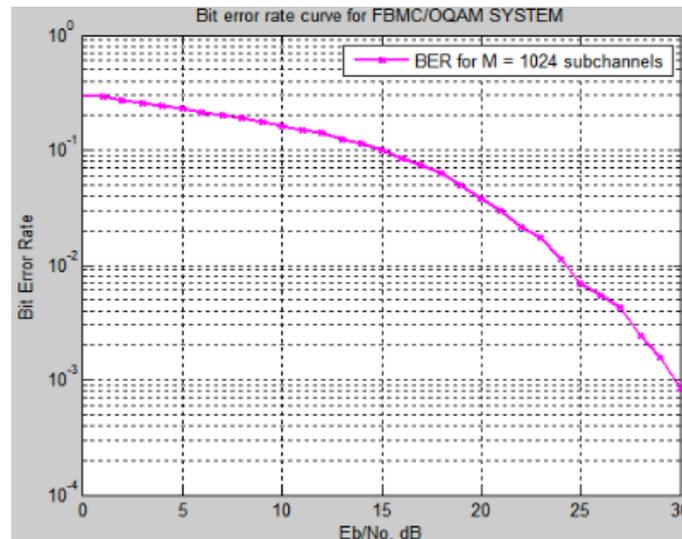


Fig. 7. BER curve for FBMC/OQAM system with M = 1024

V. CONCLUSION

In this paper we have examined the channel equalization problem in FBMC/OQAM systems. We have presented a decision feedback equalization based on RLS and LMS algorithms, which can be adjusted, depending on the requirements of FBMC/OQAM system. The DFE works as a fractionally spaced ($T/2$) equalizer in order to compensate ISI and ICI.

From the simulation results it is clear that the FBMC/OQAM system in presence of our proposed DFE operates effectively with large number of subchannels.

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