International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 3, March - 2014

Peak To Average Power Ratio Reduction and Inter Symbol Interference Cancellation of FBMC-OQAM Signals

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***Abstract*— Nowadays the signals with Filter Bank Multi Carrier Offset Quadrature Amplitude Modulation (FBMC-OQAM) is used widely for multicarrier transmissions. It has got several advantages like increased data rate, low out of band radiation etc. when compared with Orthogonal Frequency Division Multiplexing (OFDM). Like OFDM the major disadvantage with FBMC-OQAM is the high Peak-to-Average Power Ratio (PAPR). The PAPR reduction methods of OFDM cannot be used for FBMC-OQAM signals. Because the FBMC-OQAM signals has an overlapping structure. A modified Partial Transmit Sequence (PTS) method is used with Multi-Block Joint Optimization (MBJO) to reduce the PAPR of FBMC-OQAM signals. This method jointly optimizes multiple data blocks by using the overlapping structure of the FBMC-OQAM signals. Theoretical study and simulations show that this provides PAPR reduction in the FBMC-OQAM signals. Another drawback of FBMC signals is the presence of the inherent Inter Symbol Interference (ISI). When the FBMC-OQAM signals are transmitted, the received signals are corrupted by interference which makes the detection difficult. Here the receiver is with a simple tentative detector and a main detector. Matlab simulations show that in the proposed method, the ISI cancellation is optimum.**

Index Terms*—PAPR, ISI, FBMC, OQAM, Partial Transmit Sequence, ML

I.INTRODUCTION

Orthogonal Frequency Division (OFDM) is widely used for high bit rate digital transmissions. It has got wide acceptance due to its features like high spectral efficiency and immunity against multipath fading. The Cyclic Prefix (CP) used in OFDM protects from time dispersion but it does not guarantee frequency dispersion. Frequency dispersion causes loss of orthogonality between subcarriers which results in error. Also CP-OFDM spectrum has large side lobe levels due to rectangular pulse shaping filters. Design of pulse shaping filters was the solution to overcome the drawbacks of OFDM. Filter Bank Multi Carrier (FBMC) uses pulse shaping filters it does not use CP.In FBMC, every subcarrier is modulated with Offset Quadrature Amplitude Modulation (OQAM). In OQAM the real and imaginary samples are transmitted with a shift of half the symbol period between them.

But like the OFDM systems, the FBMC-OQAM system also has a major disadvantage of high Peak-to-Average Power Ratio (PAPR) of the transmitted signal. Although OFDM and FBMC-OQAM have similarities the PAPR reduction methods used for OFDM cannot be directly used for FBMC-OQAM signals due to its overlapping structure. Several methods are available for PAPR reduction of OFDM signals like clipping, Partial Transmit Sequence (PTS), Selective Mapping (SM), Active Constellation Extension (ACE), Tone Reservation (TR) etc. For the PAPR reduction of FBMC-OQAM signals an advanced PTS scheme called Multi Block Joint Optimization Partial Transmit Sequence (MBJO-PTS) is used. Data blocks are optimized independently in PTS scheme where as in MBJO-PTS data blocks are jointly optimized using its overlapping structure.

In OQAM symbols there is a shift of half the symbol period between the in-phase and quadrature components of QAM symbols, which results in a baud-rate spacing between adjacent subcarrier channels and helps to recover the information symbol free of Inter Symbol Interference (ISI). Thus, in OQAM the orthogonality conditions are considered only in the real field. And the data at the receiver side is carried either by the real or imaginary components and the other parts of the symbols constitute the interference terms. The data is always orthogonal to the interference term but the interference causes several problems when FBMC is combined with Multiple Input Multiple Output (MIMO) techniques.

At the receiver the Spatial Data Multiplexing (SDM) is considered, where N_t symbol streams are simultaneously transmitted over N_t transmitter antennas which increases the data rate. This transmitted symbol streams are received by N_r receiver antennas. Linear equalizations techniques such as Zero Forcing (ZF) or Minimum Mean Square Error (MMSE) can be used with FBMC symbol reception. The Maximum Likelihood (ML) detection can offer a diversity order equal to the number of the receiver antennas. But ML cannot be directly applied with FBMC due to the presence of the intrinsic inter symbol interference. In this paper the receiver is designed to cancel the effects of ISI. MMSE equalizer which is a simple tentative detector is first used to cancel the ISI and then the symbols are fed to the ML detector.

II. FBMC-OQAM SIGNALS AND PAPR REDUCTION

In the FBMC-OQAM system offset QAM symbols are transmitted instead of QAM symbols. The orthogonality is maintained with pulse shaping filters other than rectangular ones. The time offset is introduced to the imaginary part of the QAM symbols in one of the carriers, and to the real part on the other one. FBMC-OQAM signal model consists of complex input, filters and adders and summed output as shown in Figure 1. The complex input symbol at the transmitter of the FBMC-OQAM system, is

$$x_m^n = a_m^n + jb_m^n, 0 \le n \le N-1, 0 \le m \le M-1 \qquad (1)$$

where a_m^n is the real part of the symbol and b_m^n is the imaginary part of the complex symbol on the nth subcarrier. There are N subcarriers and the mth symbols on all N subcarriers form a data block $x_m = [x_m^0, \ldots\ldots, x_m^{N-1}]^T$. The symbol period or data block period is T and the difference between real and imaginary components of the symbols in time domain is T/2.

Fig.1. FBMC-OQAM signal model

The OQAM symbols are passed through a bank of transmission filters. It is then modulated with N subcarrier modulators with carrier frequencies spaced 1/T apart. The FBMC-OQAM modulated signal of M data blocks is

$$\tilde{x}(t) = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} x_m^n(t)$$

$$= \sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left[a_m^n h(t-mT) + jb_m^n h(t-mT-\frac{T}{2})\right]e^{jn\varphi_t} \qquad (2)$$

where $x_m^n(t)$ is the time domain signal of x_m^n, $h(t)$ is the impulse response of the prototype filter and $\varphi_t = \frac{2\pi t}{T} + \frac{\pi}{2}$.

$h(t)$ is assumed to has a finite length T_h in time domain. In FBMC-OQAM systems the impulse response of prototype filters has longer time duration than T. So the signals in adjacent data blocks overlap each other and form an overlapping structure.

The PAPR reduction schemes existing so far can only be applied to discrete-time signals. To get the PAPR of the signal, $\tilde{x}(t)$ is sampled with sampling period T/K, where $K = LN$ and L the over-sampling factor. The sampled version of $x_m^n(t)$ is written as

$$x_m^n[k] = \left(a_m^n h[k-mK] + jb_m^n h\left[k-mK-\frac{K}{2}\right]\right)e^{jn\left(\frac{2\pi k}{K}+\frac{\pi}{2}\right)}$$

(3)

PAPR of the rth segment of the FBMC-OQAM signal is

$$PAPR_r = \frac{P_r}{E_{0\le k\le (M+A)\times K-1}[|\tilde{x}[k]|^2]}, 0 \le r \le M+A-1$$

(4)

where P_r denote the peak power of the rth segment and

$$P_r = \max_{rK \le k \le (r+1)\times K-1} |\tilde{x}[k]|^2, 0 \le r \le M+A-1 \qquad (5)$$

The conventional PTS scheme is designed for OFDM systems, where the adjacent data blocks do not overlap as in OQAM systems. In conventional PTS scheme phase factor vectors for each data block is optimized independently. But the PAPR of the FBMC-OQAM signal is affected by adjacent data block due to its overlapping structure and the conventional PTS scheme cannot be directly used with FBMC-OQAM signals. So conventional PTS is modified with Multi Block Joint Optimization (MBJO) technique which reduces the PAPR.

III. MBJO-PTS SCHEME FOR THE PAPR REDUCTION OF FBMC-OQAM SIGNALS

Multiple consecutive FBMC-OQAM data blocks are jointly optimized to obtain the reduced PAPR as shown in figure 2.

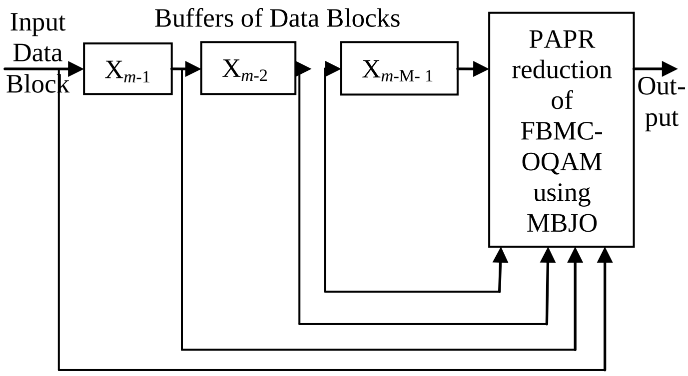

Fig.2. Multi-block Joint Optimization for the PAPR Reduction of FBMC-OQAM Signals

A number of data blocks are buffered and optimized. A penalty function $f(P_r)$ is defined. This penalty function represents the penalties like signal distortion, performance loss etc. The aim is to minimize the summed penalty of the signal of all M data blocks. This is done by jointly optimizing the phase factor vectors of M data blocks, i.e.,

$$\min_{\beta_0,\beta_1,\ldots,\beta_{M-1}} \sum_{r=0}^{M+A-1} f(P_r)$$

Subject to $\beta_m^v \in \{e^{j\frac{2\pi i}{w}}, i = 0,1,\ldots,W-1\},$

$$v = 1,2,\ldots,V, m = 0,1,\ldots,M-1 \quad (6)$$

As the penalty function $f(P_r)$ is an increasing function of P_r, the optimization problem becomes

$$\min_{\beta_r} P_r, 0 \le r \le M-1,$$

Subject to $\beta_r^v \in \{e^{j\frac{2\pi i}{w}}, i = 0,1,\ldots,W-1\},$ (7)

$$v = 1,2,\ldots,V, \mathrm{r} = 0,1,\ldots,M-1$$

This shows that the proposed MBJO optimization is only meaningful when the signals of different data blocks overlap. In Offset Quadrature Amplitude Modulation the signals of different data blocks overlap and multi block joint optimization is possible and effective and gives good result. One of the major features of MBJO is the overlapping data blocks.

A dynamic programming algorithm is used to solve the optimization problem without exhaustive search. Dynamic Programming (DP) is an optimization technique of solving complex problems by breaking them down into simpler steps. It is applicable to problems which exhibit the characteristics of overlapping subproblems and optimal substructure. The DP algorithm can find the optimal solution for with low computational complexity.

IV. INTERFERENCE ESTIMATION AND CANCELLATION

The transmitted signal travels through the channel which adds noise to the signal. Also Inter symbol Interference is high when the signal reaches the receiver. So the receiver should be capable of identifying and cancelling the interference effect and thus reduce the Bit Error Ratio (BER). Here the receiver consists of a primary or tentative detector and the main detector. Interference estimation and cancellation is done by this receiver. The tentative detector produce tentative decisions and main detector considers that the channel is free of interference.

The basic receiver scheme is showed in Figure 3. The incoming signal is fed to both the tentative detector and a delay block. The signal from the tentative detector is passed to the interference estimator. The signal from the interference estimator and delay block are added or subtracted and fed to the main detector. From the diagram it is clear that the output from the main detector can be fed back to the interference estimator block and the process can be repeated several times.

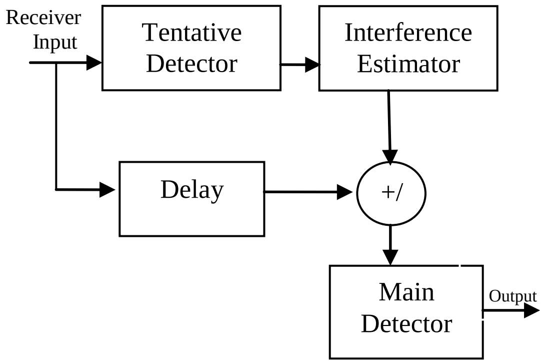

Fig. 3. Receiver scheme with ISI cancellation using tentative decisions

In this case, a receiver with iterative interference cancellation is obtained. A receiver scheme based on interference estimation and cancellation is proposed. The challenge in ISI estimation and cancellation is the error propagation through iterations. In different reference papers, it is showed that a necessary condition to avoid the error propagation through iterations is to hold the ISI power under a certain threshold. The interference cancellation technique becomes effective only when the ISI power is small and less than a certain amount. But this threshold amount of ISI power depends on the Signal-to-Noise Ratio (SNR) and it is not trivial to obtain a closed form of the ISI power threshold. Another problem is that, sometimes the threshold value lowers with the increase in SNR. At high SNR it is difficult to remove the ISI effects completely. The interference in FBMC is inherent or it does not depend on the noise variance or SNR. The ISI power in FBMC is constant for all the values of SNR.

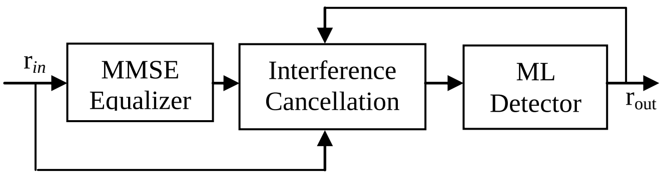

Fig. 4. Block scheme of the Rec-ML receiver

The error propagation appears from a certain amount of SNR when the ISI power threshold falls below the inherent interference power. Therefore, the interference cancellation is effective only when the SNR is less than a certain threshold amount for which the ISI power threshold is equal to the FBMC inherent interference power. If the inherent FBMC interference is decreased, then the value of SNR increases. An FBMC configuration is proposed to reduce the inherent interference power and to increase the SNR limit from which the error propagation is triggered. An MMSE equalizer is used as the tentative detector and a maximum likelihood detector is used as the main detector. The MMSE equalizer provides tentative estimations of the data vectors and based on these tentative estimations, the interference canceller calculates an estimation of the interference vector and then its contribution is removed from the received vector and then the

ML detection is done. Fig. 4 shows the blocks of the proposed Recursive-ML receiver.

VI. SIMULATION RESULTS

The simulation results of the proposed FBMC-OQAM scheme compared to OFDM is given. The system performance is assessed in terms of Complementary Cumulative Distribution Function(CCDF) as a function of the Peak to Average Power Ratio (PAPR). Extensive simulations are conducted to investigate the PAPR reduction performance. The number of the subcarriers N to be taken is set to 64 and 4 QAM modulation is adopted for the FBMC-OQAM system and the OFDM system for comparison. The time duration of the prototype filter impulse response is about four times of T, where T is the symbol period. The filter is obtained using the frequency sampling technique. FBMC-OQAM and OFDM signals with 256 data blocks (i.e., $M = 256$) are employed in the simulations. Generated the OFDM symbols using MATLAB code and the Partial Transmit Sequence is applied to the generated OFDM symbols. Then PTS is applied to the FBMC OQAM signals and compared with the conventional OFDM signals. MBJO-PTS is applied to the FBMC- OQAM signals and this gives a better PAPR reduction.

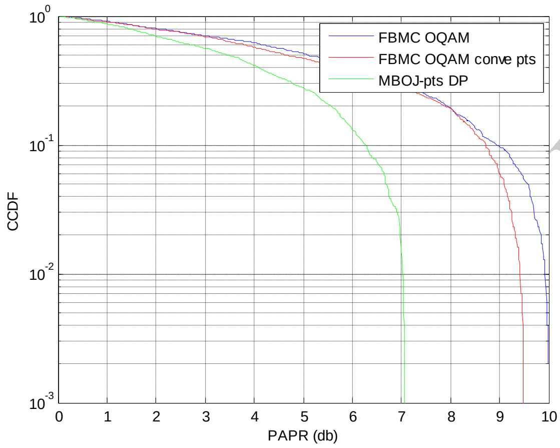

Fig. 5. CCDFs of the FBMC-OQAM signal with the conventional PTS scheme.and MBJO scheme

Fig. 6 shows the BER performance of the proposed FBMC-OQAM with the MMSE equalizer, which is the tentative detector. Also given the performance obtained using the Rec-ML for different values of iterations and compare them. It is clear that the increasing the number of iterations or Rec-ML improves the BER performance, and the performance converge after 5 iterations or there is practically no improvement beyond 5 iterations. Hence, the Rec-ML performs correctly with 5 iterations.

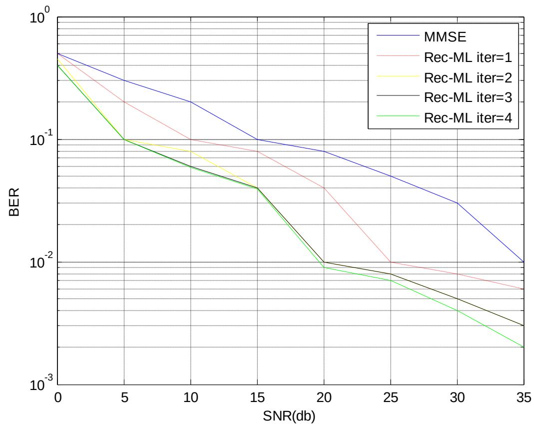

Fig. 6. Performance of Rec-ML receiver with FBMC-OQAM system

VII. CONCLUSION

In this paper, a method is proposed to optimize multiple consecutive FBMC-OQAM data blocks for the PAPR reduction in FBMC-OQAM systems. Moreover, I employ the Multi-Block Joint Optimization idea to improve the conventional PTS scheme and developed the MBJO-PTS scheme. Conducted simulations showed that an FBMC-OQAM system with the proposed MBJO-PTS scheme employing the DP algorithm is able to perform better in PAPR reduction than the OFDM system with the conventional PTS scheme, by exploiting the overlapping structure of the FBMCOQAM signal. Also shown that the ISI cancellation is effective only under some strict condition, which is that the ISI must be sufficiently small and less than a certain threshold. So I considered the association of the ML detection with the FBMC/MIMO system. The presence of the inherent interference due to the FBMC modulation obstructs the implementation of the ML detection directly. To overcome this situation, a receiver scheme based on interference estimation and cancellation is proposed. It is shown by simulations that the performance of the proposed system converges to the optimum after 5 iterations.

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