

PAPR Reduction in FBMC-OQAM Signals with Half Complexity of Trellis-based SLM

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Abstract— The filter Bank Multicarrier (FBMC) modulation with offset-QAM (OQAM) has attracted attention as a major candidate for future wireless communication systems which has several advantages. A disadvantage of FBMC-OQAM is high peak-to-average power ratio (PAPR). To overcome this problem, the trellis-based SLM [1] technique is employed and achieved a much better PAPR reduction performance. However, The Trellis-based algorithm has also the intrinsic disadvantage of high computational complexity, to decreasing the complexity will make the system more desirable. This paper proposes the half-complexity algorithm for trellis-based SLM scheme which achieves lower computational complexity when compared to trellis-based SLM scheme with small degradation of PAPR reduction performance. From various simulation results, the proposed algorithm shows less computational complexity about 50% compared to the trellis-based algorithm with similar PAPR reduction performance.

Keywords— FBMC-OQAM, PAPR, SLM, Trellis-based SLM and Half Complexity Trellis-based SLM.

I. INTRODUCTION

Filter Bank Multi-Carrier with Offset Quadrature Amplitude Modulation (FBMC-OQAM) has been involved in the next generation of wireless communications systems. The FBMC modulation does not require CP extension and shows higher robustness to residual frequency offsets than CP-OFDM by taking advantage of the spectral containment of its modulation prototypes filters. The further drawback of OFDM and FBMC-OQAM is the large peak in the time domain signal. The high PAPR leads the fatal degradation of FBMC-OQAM performance in the nonlinear power amplifier.

There are various kinds of technique have been introduced to overcome the problem of high PAPR for the FBMC-OQAM system, such as selected Mapping (SLM), Partial Transmit Sequence (PTS) and so on. However, if compared FBMC-OQAM signals to OFDM signals. The FBMC-OQAM signal has the adjacent data block overlap with one another. The conventional PAPR reduction techniques cannot be employed to FBMC-OQAM system. We have to consider the past symbols of FBMC-OQAM signal when the optimum PAPR reduction is calculated on the current symbol. The Dispersive SLM have been employed to reduce PAPR of FBMC-OQAM

signals with consideration of past symbols. At the current symbol, the determined optimum of phase pattern for conventional scheme is not efficient for dispersive SLM scheme [1]. Moreover, the trellis-based algorithm is obtained the better optimum path of phase pattern when compared to the conventional determination of phase pattern.

The high computational complexity can be problematic. The computational complexity of trellis-based SLM scheme [2] depends on M number of stages and U^2 number of possible paths. The possible paths were calculated by each symbol that is not necessary. To overcome this problem, we propose a half-complexity algorithm for trellis-based SLM to reduce PAPR of FBMC-OQAM signals.

II. SYSTEM MODEL

There are different structures of filter bank multicarrier that are presented, such as Cosine Modulated Multitone (CMT) [3], Filtered Multitone (FMT) [4], FBMC-OQAM [5]. However, the FBMC-OQAM method is the most attractive filter bank multicarrier structure because it achieves maximum transmission rate. Furthermore, Offset QAM (OQAM) is introduced the process which shifts a half symbol space during quadrature and phase components of quadrature amplitude modulated (QAM) symbols.

The structure of FBMC-OQAM transmitter system is shown in figure 1, which is consisted of OQAM pre-processing and synthesis filter bank (SFB).

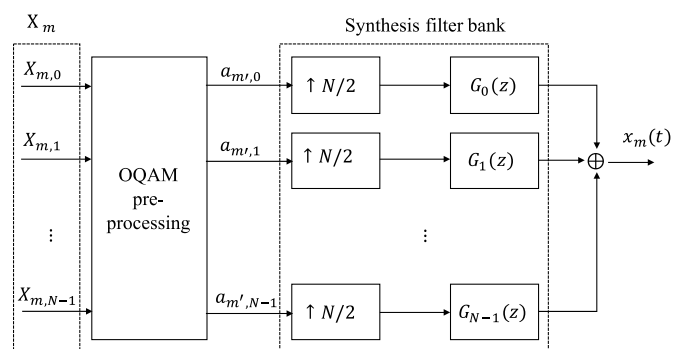


Figure 1. The structure of FBMC-OQAM transmitter system.

The OQAM pre-processing stage is placed at the FBMC-OQAM transmitter side, as figure 2 is placed a diagram of OQAM pre-processing structure which is separated operation into two parts

The first operation, to convert from complex to real by separating the real part and the imaginary part of QAM complex symbol. The real part and the imaginary part are separated into two new symbols which are $a_{m,n}$ and $a_{m+1,n}$ respectively. It can be transmitted at the rate $1/T$ where T is signalling period $T = 1/\Delta f$, Δf is subcarrier spacing. The even and odd subcarriers for complex-to-real conversion have totally different form as shown in the following equation.

$$m' = \begin{cases} 2m & m' \text{ is even} \\ 2m+1 & m' \text{ is odd} \end{cases} \quad (1)$$

$$a_{m',n} = \begin{cases} (1-\rho).R_m^n + \rho.I_m^n & m' \text{ is even} \\ \rho.R_m^n + (1-\rho).I_m^n & m' \text{ is odd} \end{cases} \quad (2)$$

Where m is a sample index at OQAM preprocessing input and m' is a sample index at OQAM preprocessing output. The OQAM pre-processing can efficiently increase the sample rate by two times.

The second operation, to retain the orthogonality of symbols, θ_m has been multiplied at this stage.

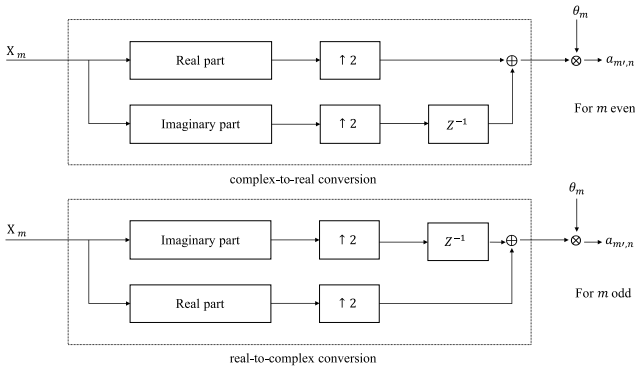


Figure 2. The diagram of OQAM pre-processing structure.

At the transmitter of FBMC-OQAM system, the synthesis filter bank is generated by N upsamplers and N Synthesis filters. $a_{m',n}$ is upsampled with $N/2$ and filtering by synthesis filter $G_n(z)$ and then every sub-channels are summation which obtain the result to be $x_m(t)$. The high spectral efficiency can be remained by prototype filter $p(n)$ [6]. Therefore, n^{th} synthesis filter $g(n)$ can be expressed as the following equation.

$$g_k(n) = p(n) \exp(j \frac{2\pi k}{N} (m - \frac{L_p-1}{2})) \quad (3)$$

Where $n = 0, 1, \dots, L_p - 1$, N is a number of subcarrier and L_p is length of prototype filter, $L_p = km - 1$ where k is overlapping factor.

III. PAPR REDUCTION BY USING SLM SCHEME

The following part of this paper moves on the description in greater detail of the PAPR reduction scheme, such as conventional SLM, Dispersive SLM, Trellis-based SLM and the final section will illustrate how the proposed scheme works.

The PAPR performance of FBMC signal at an interval T can be expressed by the following equation.

$$PAPR_{s(t)} = \frac{\max_{0 \leq t \leq T} |s(t)|^2}{\frac{1}{T} \int_0^T |s(t)|^2 dt} \quad (4)$$

A. Conventional SLM algorithm

SLM is an attractive technique of PAPR reduction because it is simple and effective. In Conventional SLM, phase rotation is generated N groups and being multiplied with input symbol. The remained input symbol would be multiplied with the different U which also obtain the different PAPR. The least PAPR signal is selected to be transmitted. Figure 3 shown the block diagram of conventional SLM algorithm.

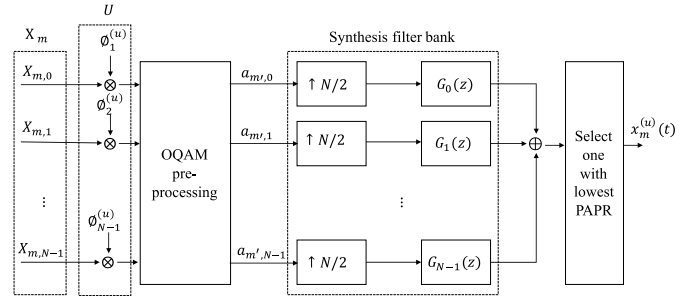


Figure 3. The diagram of conventional SLM algorithm.

The Conventional SLM achieves high efficiency in OFDM system because the symbols have no overlapping. On the other hand, In FBMC-OQAM system, there are some overlapping at the beside symbols which causes the regeneration of high PAPR.

B. Dispersive SLM algorithm

The Dispersive SLM technique is similar to Conventional SLM technique. The number of different U are multiplied by input symbol. $X_m^{(u)}$ is the results and then selected symbol $a_{m',n}^{(u)}$ with the least PAPR from $X_m^{(u)}$.

In FBMC signal, the current symbols have overlapping with previous symbols, this is different between Dispersive SLM and Conventional SLM, which causes the calculated PAPR performance. Therefore, In the Dispersive SLM scheme, before calculate and achieve the least PAPR of $a_{m',n}^{(u)}$ symbol, we would summation symbol $a_{m',n}^{(u)}$ with symbol the $a_{m',n}^{(u_{min})}$. In previous symbol at the overlapping site and then calculate $a_{m',n}^{(u_{min})}$ from $X_m^{(u)}$ at the current symbol.

Mathematically $\tilde{s}_{m',n}(t)$ can be written as (5).

$$\tilde{s}_{m',n}(t) = \underbrace{\sum_{m'=0}^{2M-1} \sum_{n=0}^{N-1} a_{m',n}^{(u_{min}^p)} h(t-m'T/2) e^{j\frac{2\pi}{T}nt} e^{j\phi_{m',n}}}_{\text{overlappings pass symbols}} + \underbrace{\sum_{m'=2m}^{2M-1} \sum_{n=0}^{N-1} a_{m',n}^{(u)} h(t-m'T/2) e^{j\frac{2\pi}{T}nt} e^{j\phi_{m',n}}}_{\text{current symbol}} \quad (5)$$

Where $a_{m',n}^{(u_{min})}$ is the selected symbol that achieves the least PAPR from previous symbol.

C. Trellis-based SLM algorithm

The Dispersive SLM is mentioned in the previous section, consider the PAPR performance in FBMC-OQAM system, which achieves less PAPR reduction performance when compared to the conventional SLM scheme.

The trellis-based SLM algorithm is introduced to overcome the problem, based on symbol-by-symbol optimization. The

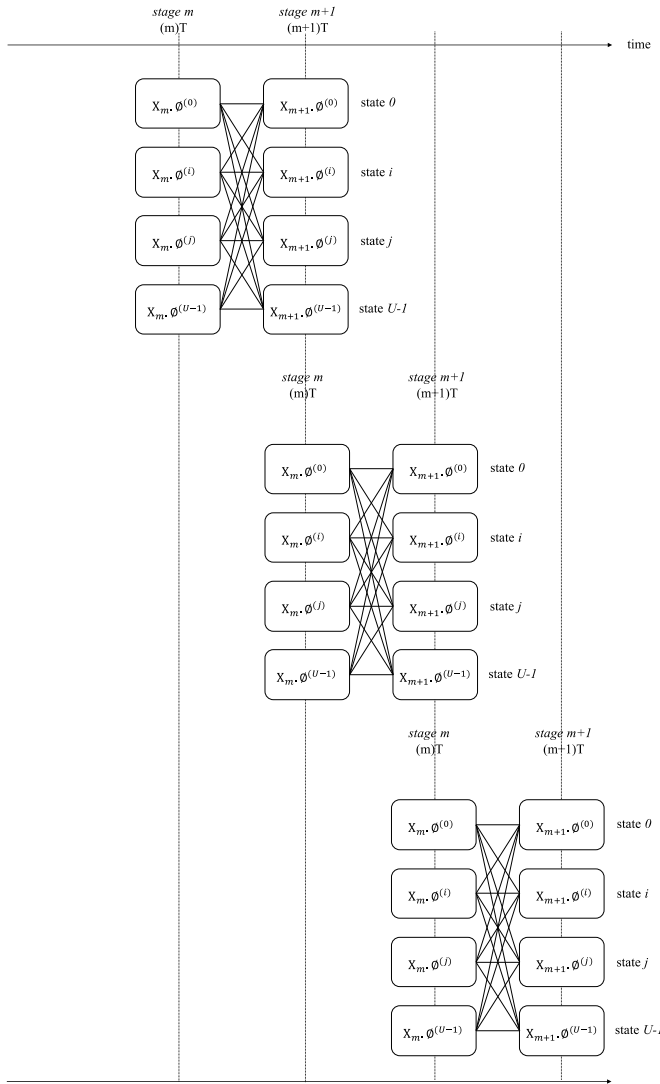


Figure 4. The diagram of trellis-based SLM algorithm.

main idea comes out that the high PAPR at current symbol has got an effect from the next symbol suddenly. In the Trellis-based SLM, we would find $\phi^{(u)}$ which is the optimal set of M different phase rotation vectors that gives the best PAPR with best path of phase pattern in the advanced symbols.

$$\Phi = \{\phi^{(u_{min}^0)}, \phi^{(u_{min}^1)}, \phi^{(u_{min}^2)}, \dots, \phi^{(u_{min}^{M-1})}\} \quad (6)$$

By $\{u_{min}^0, u_{min}^1, \dots, u_{min}^{M-1}\}$ is the selected phase rotation vectors of M input symbol which is transmitted as side information to the receiver. Figure 4 depicts the process of finding the best path as the trellis which achieve the least PAPR.

The best path of the trellis-based SLM scheme is finding multiplicative vectors, as shown in the equation (7).

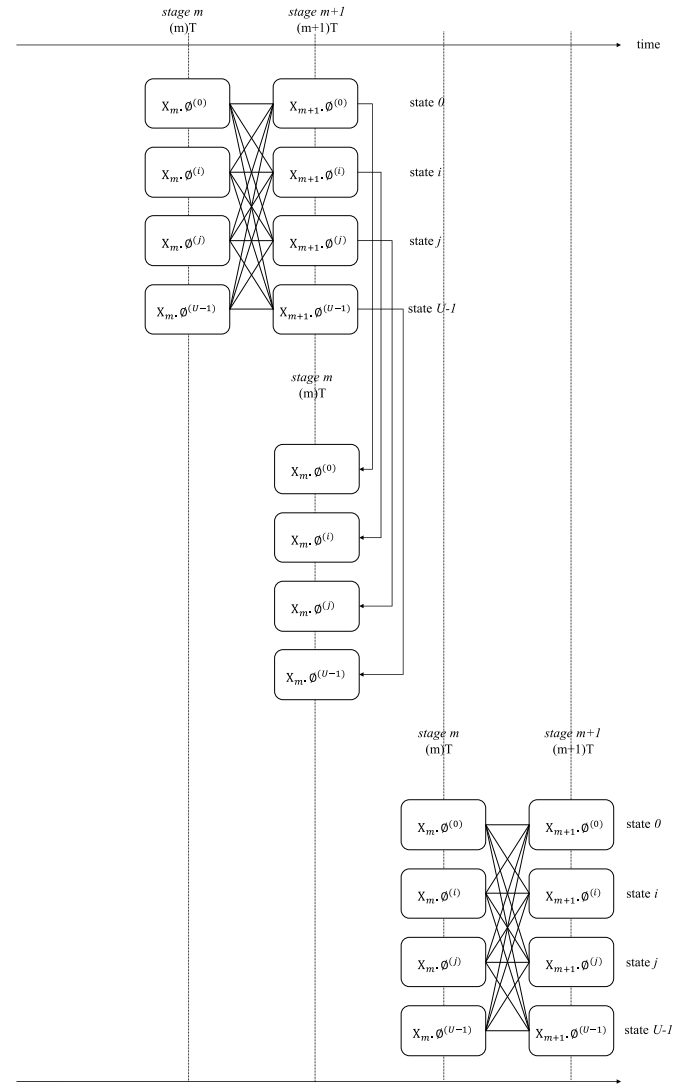


Figure 5. The diagram of the proposed method.

$$\begin{aligned}
x_m^{(u)}(t) &= \sum_{m'=2m}^{2m+1} \sum_{n=0}^{N-1} a_{m',n}^{(u)} h(t - \frac{m'T}{2}) e^{j\frac{2\pi}{T}nt} e^{j\phi_{m',n}} \\
x_{m+1}^{(v)}(t) &= \sum_{m'=2m+2}^{2m+3} \sum_{n=0}^{N-1} a_{m',n}^{(v)} h(t - \frac{m'T}{2}) e^{j\frac{2\pi}{T}nt} e^{j\phi_{m',n}} \\
x_{m,m+1}^{(u,v)}(t) &= x_m^{(u)}(t - T) + x_{m+1}^{(v)}(t), 0 \leq u, v \leq U - 1
\end{aligned} \tag{7}$$

For $0 < m < M - 1$, m^{th} stage in the trellis-based SLM is all m^{th} FBMC-OQAM symbols which is generated from the modulation of the input symbol vector X_m signals. At each stage, it will employ U different states, representing the rotated FBMC-OQAM symbols. In every i -th trellis stage, an operation is rotated by phase rotation vector in every two stages, the possible number of path is U^2 paths.

The joint FBMC-OQAM modulation of m^{th} rotated input symbol vectors X_m and $(m + 1)^{th}$ rotated input symbol vectors X_{m+1} is represented in the trellis by the path $\zeta_{(m \rightarrow m+1)}^{(u,u')}$ between u^{th} state in m^{th} stage and v^{th} state in $(m + 1)^{th}$ stage where $\Rightarrow$ represents a transition between two successive stages. All detail of the trellis-based SLM algorithm is described in [2].

D. Proposal of half complexity of TSLM algorithm

This paper proposes a scheme to improve the computation complexity of trellis-based SLM algorithm which is mentioned in the previous section. The proposed scheme could solve the serious drawback of trellis-based SLM scheme which is high computational complexity. The proposed scheme is named Half Complexity of Trellis-based SLM algorithm.

The trellis-based algorithm is applied to $m^{even(th)}$ symbols and $m^{even+1(th)}$ symbols. The optimum path determination of phase pattern for each $m^{even(th)}$ symbols can get the phase pattern both $m^{even(th)}$ and $m^{odd(th)}$ symbols. The $m^{odd(th)}$ symbols can be used as the optimum phase pattern in the next symbol, which have not need to take the trellis-base at the $m^{odd(th)}$ symbols as conventional trellis-based SLM scheme. The half-complexity algorithm for trellis-based SLM could solve the high computational complexity problem with reducing PAPR.

TABLE 1. COMPUTATIONAL COMPLEXITY OF EACH SCHEME

Algorithm	Complexity
Conventional SLM	MU
Dispersive SLM	MU
Trellis-based SLM	$(M - 1)U^2$
Proposed algorithm for SLM	$(M/2)U^2$

IV. PERFORMANCE EVALUATION

This section shows all simulation parameters in the table 2 which are employed for PAPR performance verification by computer simulation.

TABLE 2. SIMULATION PARAMETERS

Schemes	FBMC-OQAM
Modulation	16 OQAM
Demodulation	Coherent
Allocated bandwidth	5MHz
Number of FFT points (N)	2048
Number of sub-carriers (M)	512
Number of discrete phases (W)	4
Overlapping factor (K)	4
Number of Phase Pattern (U)	16
Prototype filter	Phydyas Filter

Figure 6, reveals the CCDF evaluation results for the proposed scheme compared to Conventional FBMC, Conventional SLM, Dispersive SLM and Trellis scheme when modulation technique is 16 OQAM, phase pattern (U) is 16 and number of subcarriers is 512. The graph shows that The PAPR reduction performance of the proposed scheme can achieve the PAPR reduction performance nearly the trellis scheme with 50% reducing of computational complexity when the number of M symbols is large. Approximately half of the computational complexity of proposed scheme is reduced. From the figure 6, it is clearly shown that the PAPR reduction performance of the proposed scheme is better than Dispersive SLM scheme.

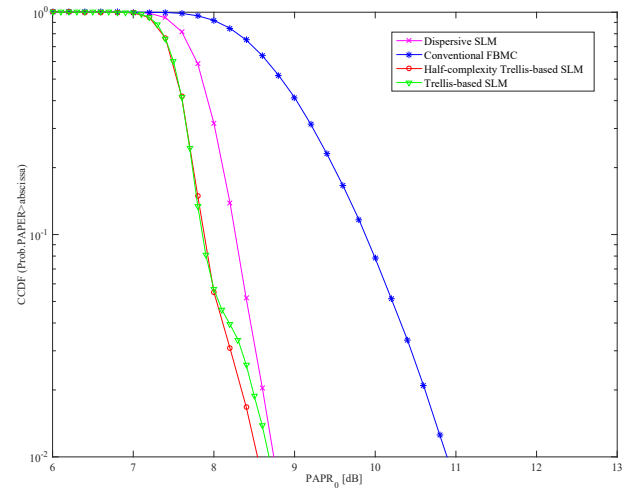


Figure 6. Comparison PAPR performance between conventional and proposed scheme for FBMC signal.

V. CONCLUSIONS

In this paper proposes the scheme that could reduce computational complexity for conventional Trellis-based SLM, which must be applied different phase rotation vectors to every two symbols m^{th} and $m + 1^{th}$ for getting the best phase to optimize the least PAPR of each symbol. The feature of proposed scheme is applied trellis-based algorithm between $m^{even(th)}$ symbols and $m^{even+1(th)}$ symbols, which have not need to take the trellis-based at the $m^{odd(th)}$ symbols as conventional trellis-based SLM scheme. However, the PAPR performance of proposed method is similar to conventional Trellis-based SLM with 50% reducing of computational complexity.

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