

Peak-to-Average Power Ratio Reduction in FBMC Using SLM and PTS Techniques



Arun Kumar and Manisha Gupta

Abstract Orthogonal frequency division multiplexing (OFDM) is the advanced transmission scheme utilized in 4G. Nevertheless, it has several shortcomings like guard band, peak-to-average power ratio (PAPR), high power consumption, incapable to accommodate various other devices (an IOT application). Hence, OFDM cannot be considered in 5G due to the several disadvantages mentioned above. Filter bank multi-carrier (FBMC) is believed to be one of the most promising technologies which can be used in 5G. FBMC and OFDM are multi-carrier system. It is obvious that it agonizes from PAPR which hamper the efficiency of the system. The conventional peak reduction methods utilized in OFDM cannot be used in FBMC due to the overlapping structure of FBMC. In this work, a novel selective mapping (SLM) and partial transmit sequence (PTS) PAPR reduction technique is suggested for FBMC. The proposed techniques are implemented by using an elementary successive optimization technique that upsurge the PAPR performance and ensure the design difficulty is taken low. PAPR and bit error rate (BER) parameters are analyzed and simulated for the proposed and conventional PAPR reduction techniques. The simulation results show that the SLM and PTS accomplished an excellent PAPR reduction up to 2.8 and 4.8 dB as compared to other peak power minimization techniques.

Keywords FBMC · PAPR · SLM · PTS · Clipping

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1 Background

In the year 1895, Marconi invented radio which was used to transmit the signal from one place to another place without the use of wires for which he got the noble prize in the year 1909. Graham Bell and Charles Sumner Trainers invented telephone in the year 1980 which was the beginning of telecommunication era. The first commercial phone was designed and implemented in Bell Lab, USA in 1946. Analog frequency transmission scheme and high-power transmitter were used in early mobile which limit the coverage up to 50 km due to which very few customers get the service with lots of constraint of spectrum. In order to achieve an efficient bandwidth, cellular model was introduced by Bell Lab which utilized the technique called frequency reuse to achieve an efficient bandwidth and power consumption was also reduced. The first-generation mobile phone also known as 1G was consisting of analog system accessing frequency division multiple access (FDMA) technique. Sensitive to interference, requirement of high power, and its analog technique were few disadvantages of 1G mobile. One of the main reasons for failure of analog mobile was usage of different standards by different countries which were incompatible. To overcome the issues of 1G, second-generation (2G) mobile were introduced which used digital technology. Better spectrum utilization due to accessing of advanced modulation technique, high capacity, introduction of SMS, improved handoff, and good signaling were few advantages of 2G. Among several, most popular 2G mobile phone was GSM (Global system for mobile communication). Due to rising demands from the industry and subscribers like high data rate lead to development of third-generation (3G) mobile communication system. In 3G, CDMA is used as a modulation technique, where multiple users share the same channel with different codes [1]. Hence, CDMA is considered as one of the secured communication. ISI, cross talk, and high power consumption are the disadvantages in CDMA due to which OFDM is considered in fourth-generation mobile communication system (4G). In the year 1971, Weinstein and Ebert introduced a new multi-carrier technique whose set of modulator and demodulator was replaced by using a discrete Fourier transform (DFT). OFDM as a radio technique is widely used for high data rate wireless communication system due to its better utilization of the spectrum and immune to fading of signals [2]. For instance, in OFDM, CP (Cyclic Prefix) is inserted between two symbols to eliminate inter-symbol interference (ISI). However, CP results in wastage of bandwidth. OFDM cannot be considered adequate for this purpose due to the abovementioned disadvantages. Hence, next-generation mobile communication is commonly known as 5G will need a new and improved technological core. A new modulation technique, such as FBMC, is being explored and experimented upon in hopes that one of them may become a conceivable option for 5G wireless communication.

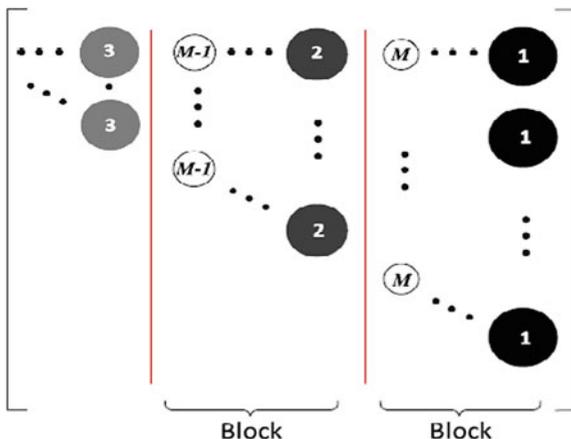
1.1 Introduction

FBMC is the most probable modulation techniques that have been able to exhibit not similar but better performance than OFDM. It does not insert a CP between the symbols, meaning the availability of extra bandwidth. It is an advanced version of OFDM, which uses a set of filters at both the transmitter and receiving end to provide better communication with more prudent bandwidth utilization [3]. OFDM as a radio technique is widely applied for high data rate wireless communication system due to its better utilization of the spectrum and immune to fading of signals. Contrariwise, it has the shortcoming of PAPR and spectral transmission in the wireless environment. Combined with the multiple inputs and multiple outputs (MIMO), MIMO-OFDM plays a significant role in enhancing the capacity and data rate by reducing a multipath and co-channel interference. MIMO-OFDM includes a large number of antennas at the transmitter and receiver. Hence, it receives the signals from the transmitter through different paths. However, high power consumption and implementation cost are the major disadvantage of MIMO-OFDM [4]. High-speed data transfer networks are the primary requirement for technology enhanced digital world for improvement of services and hence the lives of a human being. To cater the need of large amount of data at higher speed for real-time applications, next-generation communication systems should be developed. The next-generation wireless networks known as fifth-generation mobile communication (5G) must be able to address the capacity constraints and the existing challenges associated with current communication systems such as network link reliability, coverage and latency, and energy efficiency. Nevertheless, the principle of OFDM and FBMC is the same as both are multi-carrier techniques [5]. In multi-carrier methods, the subsequent result is the assemblage of numerous subcarriers that leads to a situation where peak power increases in the system [6]. Hence, the operation of the amplifier utilized in FBMC and OFDM system gets reduced. The peak power reduction techniques utilized in OFDM cannot be considered in proposed FBMC due to their intersecting structure [7, 8]. Therefore, in that respect is a requirement to study PAPR minimization methods for FBMC arrangement [9, 10]. The work presents the implementation of a novel PTS and SLM peak power reduction techniques for FBMC system. BER, PAPR measurements were simulated and examined.

2 Conventional SLM

One of the disadvantages of SLM detection is long latency which occurs due to the serial processing of the signals [11–15]. In this work, SLM detection scheme is implemented with parallel processing that scales the latency and complexity. One of the constraint point of this proposed scheme is to detect M transmit signal under N stages. The proposed method finds rank of $X^{\wedge}(k)$ to determine channels order. The second step is to calculated rank $T^{\wedge}(k)$ after QR disintegration and QR rearrange-

Fig. 1 Proposed channel ranking from an $M \times T$ matrix [24]



ment. The ranking method of channel is indicated by Fig. 1. The power rank of each column is given by the number of circles which are allocated likewise to all blocks [16–20]. The numbers of blocks are arranged in downward direction starting from the right-hand side. The circle of black, white, and gray indicates the comparative power. The power of black circle is greater than white and gray. In the next step, the triangular matrix $T^{\wedge}(k)$ is converted into staircase matrix. This is achieved by eliminating the $T^{\wedge}(k)$ by using Gauss-Jordan elimination method [21–23]. The parallel detection determines the step of staircase matrix. In the other word, staircase matrix step depends on the number of blocks: For example, when four and two blocks are used then $T^{\wedge}(k)$ is given in Figs. 2 and 3 which are independent of each other. In this case, A_n is the nth block.

By utilizing $T^{\wedge}(k)$, the parallel detection is achieved to detect the transmitted signal. The RGB circles are initially detected simultaneously. Hence, the latency of the suggested method is decreased by $1/N_a$ times as comparing to conventional SLM method. Second, the diversity rate of the proposed technique is also decreased by the same order. Hence, the latency and diversity are independent of each other. The gain

Fig. 2 Modified T matrix as a four block T^{\wedge} [21]

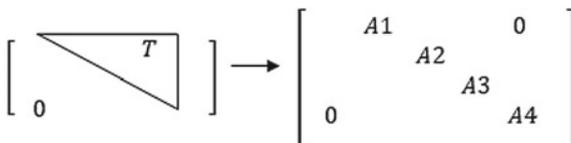
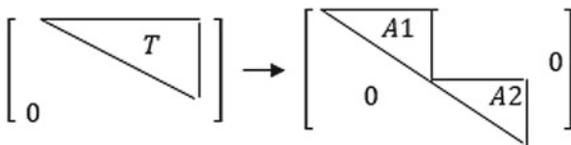


Fig. 3 Modified T matrix as a two block T^{\wedge} [25]



of the system can be enhanced slightly by increasing the diversity order. Therefore, it is not desirable to select extreme diversity order. Hence, in this proposed method, its diversity order is taken as four to obtain the optimum latency [26]. For example, we select two blocks in 4×4 MIMO. The rank of $T^\wedge(k)$ is given as

$$\begin{bmatrix} T_{1,\text{rank}(4)}(k)T_{1,\text{rank}(1)}(k)T_{1,\text{rank}(3)}(k)T_{1,\text{rank}(2)}(k) \\ T_{2,\text{rank}(4)}(k)T_{2,\text{rank}(1)}(k)T_{2,\text{rank}(3)}(k)T_{2,\text{rank}(2)}(k) \\ T_{3,\text{rank}(4)}(k)T_{3,\text{rank}(1)}(k)T_{3,\text{rank}(3)}(k)T_{3,\text{rank}(2)}(k) \\ T_{4,\text{rank}(4)}(k)T_{4,\text{rank}(1)}(k)T_{4,\text{rank}(3)}(k)T_{4,\text{rank}(2)}(k) \end{bmatrix} \quad (1)$$

Therefore, $Y(k)$ is given as

$$\begin{bmatrix} Y_4(K) \\ Y_1(K) \\ Y_2(K) \\ Y_3(K) \end{bmatrix} = \begin{bmatrix} T_{11}(k) & T_{12}(k) & T_{13}(k) & T_{14}(k) \\ 0 & T_{22}(k) & T_{23}(k) & T_{24}(k) \\ 0 & 0 & T_{33}(k) & T_{34}(k) \\ 0 & 0 & 0 & T_{44}(k) \end{bmatrix} \begin{bmatrix} X_4(K) \\ X_1(K) \\ X_2(K) \\ X_3(K) \end{bmatrix} \quad (2)$$

Hence, $T_{13}(k)$ and $T_{23}(k)$ are eradicated we select the third row. After $T_{14}(k)$ and $T_{24}(k)$ are eradicated by the fourth row $Y^\wedge(k)$ is given as

$$\begin{bmatrix} Y_4^\wedge(K) \\ Y_1^\wedge(K) \\ Y_2^\wedge(K) \\ Y_3^\wedge(K) \end{bmatrix} = \begin{bmatrix} T_{11}(k) & T_{12}(k) & 0 & 0 \\ 0 & T_{22}(k) & 0 & 0 \\ 0 & 0 & T_{33}(k) & T_{34}(k) \\ 0 & 0 & 0 & T_{44}(k) \end{bmatrix} \begin{bmatrix} X_4(K) \\ X_1(K) \\ X_2(K) \\ X_3(K) \end{bmatrix} \quad (3)$$

where $V^\wedge(k)$ is the permuted $Y(k)$.

Hence, by using Eq. (3) the detection of $X_4(K)$, $X_1(K)$, $X_2(K)$ and $X_3(K)$ are independently functioned as

$$\begin{bmatrix} Y_4^\wedge(K) \\ Y_1^\wedge(K) \end{bmatrix} = \begin{bmatrix} T_{11}(k) & T_{12}(k) \\ 0 & T_{22}(k) \end{bmatrix} \begin{bmatrix} X_4(K) \\ X_1(K) \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} Y_3^\wedge(K) \\ Y_2^\wedge(K) \end{bmatrix} = \begin{bmatrix} T_{33}(k) & T_{34}(k) \\ 0 & T_{44}(k) \end{bmatrix} \begin{bmatrix} X_2(K) \\ X_3(K) \end{bmatrix} \quad (5)$$

Hence, the signal $X_4(K)$, $X_1(K)$, $X_2(K)$, and $X_3(K)$ are detected simultaneously in two step, and in this way the latency and multiplication complexity of the projected scheme is drastically decrease [27, 28]. The past and present studies are given in Table 1.

Table 1 PAPR reduction techniques with outcomes

References	Technique	System model	PAPR (%)
[29]	PTS	OFDM	4.1
[30]	STR and TI	OFDM	6
[31]	Hybrid clipping	OFDM	8, 4
[32]	Circular fourier transformation	4-QAM WPT-OFDM, FFT-OFDM	7.05 and 4.95
[33]	Chiken swarm optimization	Coherent Optical-OFDM	5.5
[34]	Hybrid and filtering	QPSK-OFDM	6.3 and 7.3
[35]	Double hybrid, A. hybrid	OFDM	6.569, 5.8 and 5.3
[36]	I.Noise, clipping, and μ Law	OFDM	3.8, 6.6 and 10.2
[37]	Improved SLM for PAPR reduction	OFDM	2.6
[38]	Hybrid, M-Hybrid	FBMC	6 and 7
[39]	DCT-Precoding, WHT-Precoding, and MU-Law commanding	FBMC	3.5 and 13.4
[40]	ACE, TRACE, and TR reduction method	FBMC	4, 4.2 and 7
[41]	Clipping and filtering	FBMC	7 and 6.3
[42]	TSLM and MBJO-PTS	FBMC	8.2 and 7.4
[43]	SLM and W-SLM	FBMC	8 and 7.5
[44]	Tone injection, companding	FBMC	10.5 and 3.7

3 Single Carrier Versus Multi-carrier Modulation

In single carrier systems, a guard band must be placed between each carrier bandwidth to provide a space where an adjacent carrier signal can be attenuated to prevent data loss. But this is wastage of costly bandwidth only. Also, in a multipath propagation environment, a shorter symbol period drives toward greater possibility ISI. The OFDM, a multi-carrier system, is well capable of addressing these problems of a single carrier system. Available channel is divided into several narrowband sub-channels which experience almost flat-fading making equalization very simple. Orthogonality of subcarriers allows them to overlap each other without interference which results in saving of bandwidth which is a constraint for wireless communication. Also, symbols acquiring long symbol duration undergo serial to parallel conversion which eliminates the ISI and increases the data rates significantly. Disadvantage of the single carrier system is when we increase the number of users than the overall quality of service decrease. Inter-symbol interference and huge power

consumption create a big problem in single carrier system. For a high-frequency communication, multi-carrier modulation techniques are more efficient [45].

3.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM has been recently proposed in many advanced techniques. Also, several precise methods of OFDM have been suggested for cognitive radio (Cr) systems [46, 47]. A subsection of subcarriers is allotted to each and every user. To overcome inter-carrier interference (ICI), synchronization between the subcarriers signals need to be achieved at the receiver input. Bearing on this point, OFDM fits in downlink, where OFDM signals are transmitted from the identical terminal. Hence, synchronization can be easily carried out the equivalent Doppler frequency change at each receiver. On the other hand, in the uplink of an OFDM system, synchronization between subcarrier signals is difficult to attain. Further, digital algorithm steps have to be added to reduce interference among the subcarrier from diverse ends. Additional digital algorithm steps increase the complexity in OFDM receiver [48]. The problem is increasing in Cr system where both license and non-license users communicate autonomously and might be centered on different rules. This problem can be overcome by using a filtering technique that separates the license and non-license user signals. OFDM with filters introduce large side lobes which result in an outflow of signal powers between the groups of different users, making it unsuitable. The side lobes of OFDM with filters are improved by proposed methods. However, the performance of the proposed solutions is limited. For instance, in OFDM, CP (Cyclic Prefix) is introduced between two symbols to eliminate inter-symbol interference (ISI). Normally, ISI occurs when channel bandwidth is more than the coherence bandwidth and noise is greater than received signal. However, use of CP in OFDM resulted in wastage of bandwidth [49]. OFDM is recognized to be sensitive to the fast deviation of communication channels. The poor frequency bandwidth of the sub-carrier signals in OFDM is the main root of difficulties that bound the applicability of OFDM system. The above difficulties can be overcome by going through filters that synthesize/investigate the subcarrier signals had trivial side lobes. A motivating, but apparently not extensively implicit, point is that the first multi-carrier technique designed before the creation of OFDM used lot of filters for the examination and synthesis of multi-carrier techniques. These filters can be followed out with low side lobes and consider to be perfect modulation scheme to Cr and multiple access schemes as well as broadband signal spread over unprotected wires. FBMC has diverted a great heap of attention every bit one of the alternates to OFDM, which also occupy an important role in the cognitive radio application [50]. Consequently, several peak power minimization techniques are explored for advanced modulation technique. One of the most challenging issues in a wireless communication system is to increase the capability of the system. In this work, the channel capacity of FBMC and OFDM integrated with Cr is discussed and described. The result reveals that the capacity and gain of FBMC are better than OFDM [50]. In [51] Greedy suboptimal

algorithm based FBMC cognitive radio performance is discussed and analyzed. The primary objective of the proposed study was to efficiently apply the bandwidth without causing any hindrance. The mathematical results of BER and SNR were analyzed to reveal that performance of the FBMC was better than OFDM. In [52] the performance of QAM-FBMC and O-QAM FBMC and the effect of time offset (TO) and carrier frequency offset (CFO) is analyzed and computed. The production of the study reveals that the effect of ISI is greater for O-QAM FBMC because it includes two different filters whose orthogonality criteria are not met. QAM-FBMC utilizes two types of filters whose orthogonality criteria are not satisfied which results in severe ISI. In [21], FBMC is designed to execute a simple synchronization to access the fragmented spectrum, which also cuts the physical channel signaling of the scheme. Additionally, the performance and capacity of OFDM and FBMC are analyzed and compared. Result reveals that FBMC performs better than OFDM. In [53], a new radio wave technique called QAM-FBMC is introduced which overcomes the disadvantage of CP-OFDM. FBMC does not use CP due to which 10–12% efficiency in bandwidth is achieved, but interference due to non-orthogonal filter degrades the BER performance. The work introduced a decision feedback equalization scheme to overcome the interference problem. Outcome also reveals that the proposed radio wave scheme is superior to conventional OFDM system. The transmitter and receiver of OFDM are shown in Fig. 4.

The combination of OFDM with MIMO systems gives tremendous results. It improves the performance of the system significantly. A very compact description of MIMO-OFDM system is mentioned here. The MIMO channel can be given as

$$\begin{aligned} \bar{z}(t) = & H(0)\bar{s}(t) + H(1)\bar{s}(t - 1) + H(2)s(t - 2) + \dots\dots\dots \\ & + H(L - 1)\bar{s}(t - L + 1) + n^-(t) \end{aligned} \tag{6}$$

where

$s^-(t) = Tx$ vector at time(t)

$\bar{s}(t - 1) = Tx$ vector at time($t - 1$)

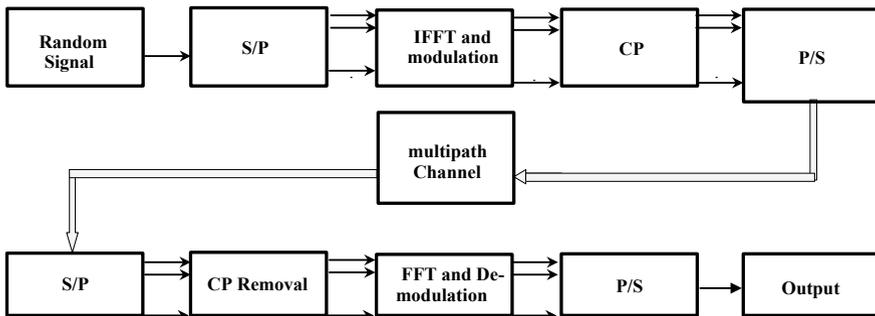


Fig. 4 Block diagram of OFDM transmitter and receiver

$H(L)$ = channel matrix corresponding to tap L . ($N \times M$ matrix);
and $n^-(t)$ = noise

For flat-fading system, the MIMO channel is given as

$$\begin{aligned} z^-(0) &= \bar{H}(0)s^-(0) \\ z^-(1) &= \bar{H}(1)s^-(1) \\ &\vdots \\ z^-(N-1) &= \bar{H}(N-1)s^-(N-1) \end{aligned} \quad (7)$$

In general,

$$\bar{z}(k) = \bar{H}(k)s^-(k) \quad (8)$$

where

$\bar{z}(k)$ = $R \times 1$ receive vector corresponding to subcarrier (k)

$\bar{H}(k)$ = flat fading channel matrix corresponding to the subcarrier (K)

$\bar{s}(k)$ = $T \times 1$ transmit vector corresponding to subcarrier (k).

3.2 Filter Bank Multi-carrier Modulation (FBMC)

FBMC is designed by using a PHYDAS filter at the transmitter and receiver of the system. The filter length is L ($L = K * N$). Haijian et al. (2010) discussed and described the channel capacity of FBMC and OFDM integrated with cognitive radio. Result reveals that the capacity and gain of OFDM are better than FBMC [54]. Won-suk et al. (2014) evaluates the performance of QAM-FBMC and O-QAM FBMC and the effect of time offset (TO) and carrier frequency offset (CFO) is analyzed and computed. The output of the work reveals that the effect of ISI is greater for O-QAM FBMC because it includes two different filters whose orthogonality criteria are not satisfied. QAM-FBMC utilizes two types of filters whose orthogonality criteria are not satisfied which results in severe ISI. Overall, an outcome of the work reveals that QAM-FBMC performance is better for CFO but sensitive to TO as compared to O-QAM-FBMC [55]. Greedy suboptimal algorithm based FBMC cognitive radio performance is discussed and analyzed in this work. The main aim of the proposed work was to efficiently utilize the bandwidth without causing any interference. The numerical results of BER and SNR were analyzed to reveal the performance of the proposed system [56]. Increasing amount of data traffic, capacity, and limited bandwidth is the major challenges in the present scenario. It is also estimated that by the next 4 years, data consumption will increase by 20–30% and presently there are no technologies to support this. Hence, there is an urgency to find a new radio and efficient bandwidth utilization techniques. In this regard, FBMC, a new transmission technique, is the most promising technique for next-generation wireless communi-

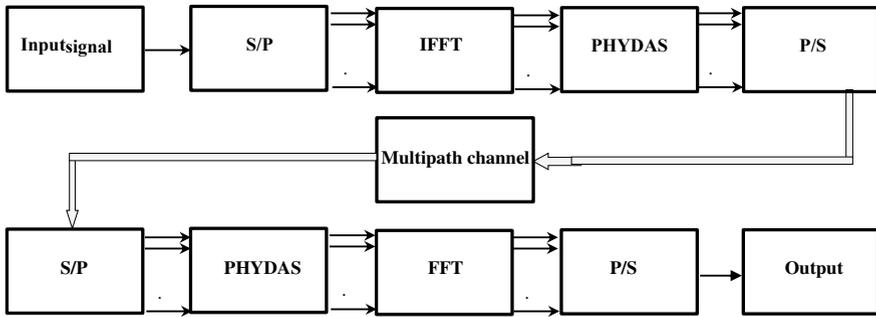


Fig. 5 FBMC block diagram

cation. It includes filters in the transmitter and receiver which motivate to discard the use of OFDM where more than 10% of bandwidth is wasted due to insertion of CP. Additionally, CR better utilizes the unused spectrum by allocating it to needy users. In this work, different spectrum sensing techniques are discussed and described for FBMC and OFDM system. In this work, FBMC is designed to perform a simple synchronization to access the fragmented spectrum, which also reduces the physical channel signaling of the system. Additionally, the performance and capacity of OFDM and FBMC are analyzed and compared [57]. Presently, CP-OFDM is one of the most popular radio techniques used in 4G, WLAN, etc. The performance of OFDM is severely affected by synchronous heterogeneous network environment. A proposed work described a new radio wave technique called QAM-FBMC which overcomes the disadvantage of CP-OFDM. FBMC does not use CP due to which 10–12% efficiency in bandwidth is achieved, but interference due to non-orthogonal filter results in interference which degrade the performance of the system. The work introduced a decision feedback equalization scheme to overcome the interference problem as mentioned above. Outcome also reveals that the proposed radio wave scheme is superior to conventional FBMC system. OFDM-CDMA is designed with multiplexed space-time block codes (STBC) which results in high-spectral transmission efficiency and it also enhanced the performance of space/frequency diversity gain of frequency fading channels. The proposed work is also inexpensive due to the use of less numbers of receiver antennas as compared to transmitter antennas [58]. The structure of FBMC is shown in Fig. 5.

3.3 PAPR in FBMC

FBMC has an overlapping nature and due to this nature we cannot openly apply it to PAPR reduction technique to FBMC. The PAPR for FBMC in time duration can be written as [59]

$$PAPR(x(t))dB = 10 \log_{10} \frac{\max_{mT \leq t \leq (m+1)T} |x(t)|^2}{E[|x(t)|^2]} \quad (9)$$

$i = 0, 1 \dots M + q - 1$, and $E[\cdot]$ called the expectation.

3.4 PHYDAS Filter

The analytical model of PHYDAS filter in time domain is given by following equation:

$$\begin{cases} \left(1 + 2 \sum_{k=1}^{L-1} a_k \cos 2\pi \frac{kt}{Lt}\right) & -LT \leq t \leq \frac{Lt}{2} \\ else & 0 \end{cases} \quad (10)$$

where L is the length of filter and K is the overlapping factor. Stop band performance of PHYDAS filter is excellent for infinite symbols. The design complexity of filter is directly proportional to the length of filter. The impulse and magnitude response of PHYDAS filter are shown below: The impulse response of PHYDAS is not compact which will make it more prone to noise and frequency fading channel, whereas in frequency domain, its response is more compact which make it insensitive to noise and frequency fading channel [60].

3.5 PAPR Reduction Techniques for OFDM

It has several weaknesses, such as CP some part of the system band width is lost, and BER performance is also decreased. The conventional PAPR minimization techniques mentioned cannot be utilized in the FBMC system because of its different structure as compared to OFDM [59].

3.5.1 Conventional Partial Transmit Sequence (PTS)

It represents several signal methods. In this technique, the input signal is segregated into several blocks. These block of signals are converted into time-domain PTS. This shift can be accomplished with the help of IFFT. The output signals are autonomously switched by phase aspects to minimize the peak power [61].

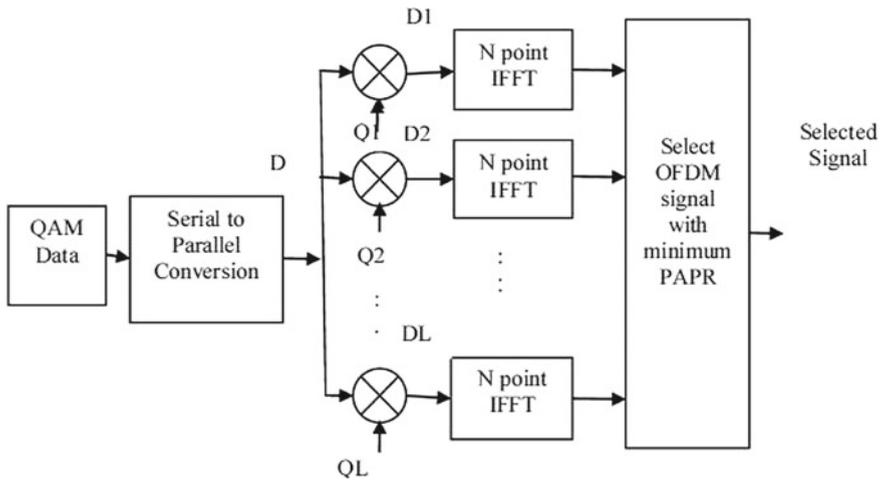


Fig. 6 Selected mapping OFDM system

3.5.2 Conventional Selected Mapping (SLM)

In this scheme, the signal is convolved with each phase series made. And accordingly, arrangements which transfer the identical data are made. From these data's, the reduced PAPR signal is identified for communication [62]. The structure of SLM is indicated in Fig. 6.

3.5.3 Conventional Tone Rejection (TR)

In this method, the peak power is reduced by adding the time-domain signal and orthogonal signal. The main motive is to encompass the constellation and therefore to form the similar signal equivalent to numerous likely constellation [44]. The structure of TR is indicated in Fig. 7.

3.5.4 Conventional Clipping

It is one of the popular peak minimization techniques for OFDM. It is implemented usually at the transmitting part of the system. The introduction of noise is one of the drawbacks of this technique. Table 2 indicates the evaluation of different PAPR reduction techniques.

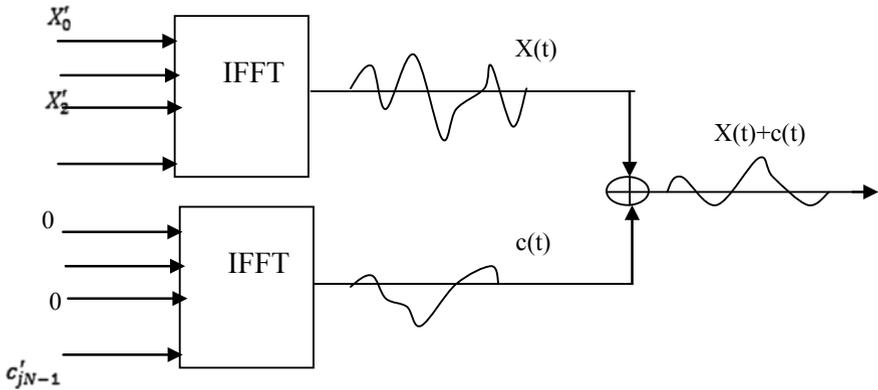


Fig. 7 Block diagram for TR

Table 2 Evaluation of PAPR minimization schemes

PAPR techniques	Advantage	Disadvantage	Operation prerequisite
Block coding	Low noise	High power and loss of data rate	Transmitter: advanced coding require Receiver: advanced coding require
PTS	Low noise and low power	Loss data rate	Transmitter: IDFTs operation require Receiver: information estimation is require
Clipping and filtering	No loss of data rate	High noise	Transmitter: clipping Receiver: no clipping
TR	Simple to implement	High noise, high power, and loss of data	

3.5.5 Signal-to-Noise Ratio (SNR)

How much quantity of information will be carried out by a communication channel is decided by the channel bandwidth and the extent of the noise in the channel. The typical measure of amount of noise present in a system is denoted by SNR. It is expressed mathematically as

$$SNR = P_s/P_n \tag{11}$$

3.5.6 Bit Error Rate (BER)

In digital communication, bits are changed because of interferences, noise added by the channel, error of synchronization, and any other distortions. The number of changed bits received at receiver end is known as bit error. For example, let us consider a sequence of transmitted bits as 1 1 0 0 1 0 1 0 0 1 and the sequence of received bits as 0 1 0 0 1 1 10 0 1. The number of bits changed is 2. Therefore, bit error is 2. The BER is calculated as 2 altered bits divided by total transmitted bits (10 bits), resulting as 0.2 or 20%.

4 Proposed Partial Transmit Sequence

The structure of P-PTS is shown in Fig. 8. The input signal is modulated and converted into parallel form. The signals are divided into numbers of block followed by a precoder and IFFT. Finally, the signals are optimized and summed to generate the reduced PAPR signal. Let the FBMC input signal is given by

$$Y = [Y_1, Y_2, \dots, Y_N]^T \tag{12}$$

$$y(a) = \sum_{i=0}^{v-1} X_i e^{\frac{j2\pi ft}{T}} a_v \tag{13}$$

$$= \sum_{i=0}^{v-1} X_i e^{\frac{j2\pi it}{T}} a_v \sum_{m=0}^{v-1} P_{i,n} y_n \tag{14}$$

$$y(a) = a_v \sum_{m=0}^{v-1} y_n \left(\sum_{i=0}^{v-1} P_{i,n} e^{\frac{j2\pi it}{T}} \right) \tag{15}$$

The PAPR of PTS is given by

$$PAPR \leq \frac{1}{N} \left(\sum_{m=0}^{v-1} y_n \left| p_{i,n} e^{\frac{j2\pi it}{T}} a_v \right. \right) * \left(\sum_{m=0}^{v-1} y_n \left| p_{i,n} e^{\frac{j2\pi it}{T}} a_v \right. \right) \tag{16}$$

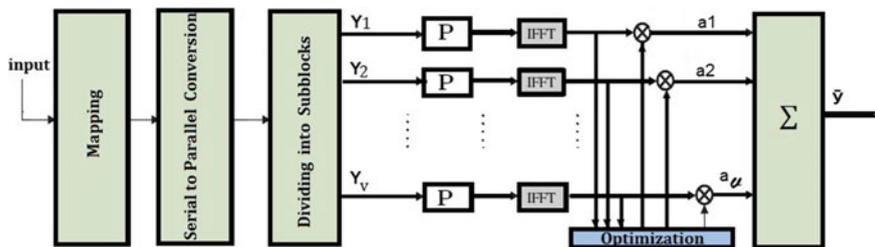


Fig. 8 Proposed modified PTS technique

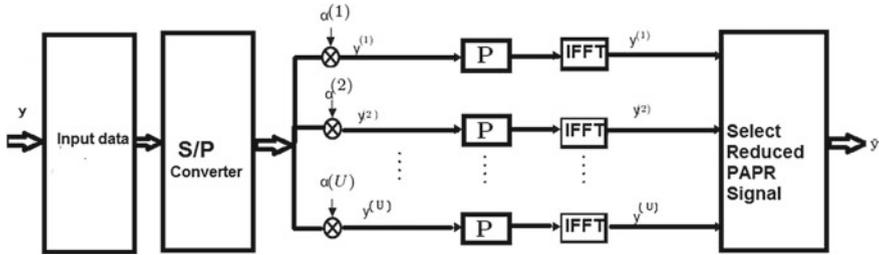


Fig. 9 Proposed SLM technique

4.1 Proposed SLM Technique

The structure of SLM technique is given in Fig. 9. The block of same data is generated by multiplying an FBMC signal with phase factor U . The different FBMC signals are accompanied by precoder and modulator. The structure of minimum PAPR is selected. The multiplication of FBMC input signals and U is given by

$$Y^u = y_{0\alpha_0}, y_{1\alpha_1}, \dots, y_{N-1\alpha_{N-1}} \tag{17}$$

where $U = 1, 2, \dots, U-1$

The precoder output is given by

$$X_m^u = \sum_{k=0}^{N-1} P_{n,k} Y_k^u \tag{18}$$

Taking IFFT of the above equation:

$$y_k^u(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} Y_n^u e^{j2\pi n\Delta f_i} \tag{19}$$

5 Results and Discussion

In this work, PAPR reduction schemes will be applied for FBMC. This effect in reduction of power and step-up in capacity. This study will provide fruitful outcomes for further research and analysis regarding next-generation communication systems. Matlab-2014 is used as a designing tool. The simulation parameters are indicated in Table 3.

The performance of conventional and proposed peak power reduction methods is given in Fig. 10. Original PAPR signal is 10 dB at CCDF of 10^{-5} . For CCDF of 10^{-5} , the PAPR of the Clipping, TR, Conventional PTS, and Conventional SLM is 9, 9, 7, 5.9 dB. For proposed PTS and SLM, the PAPR is reduced to 3.8 and 2.9 dB.

Table 3 Simulation parameters

S.no	Parameters
1.	Input symbols: 2048
2.	N = 64
3.	64-QAM
4.	FBMC system
5.	PHYDAS filter Roll of factor = 1 Overlapped symbols = 2

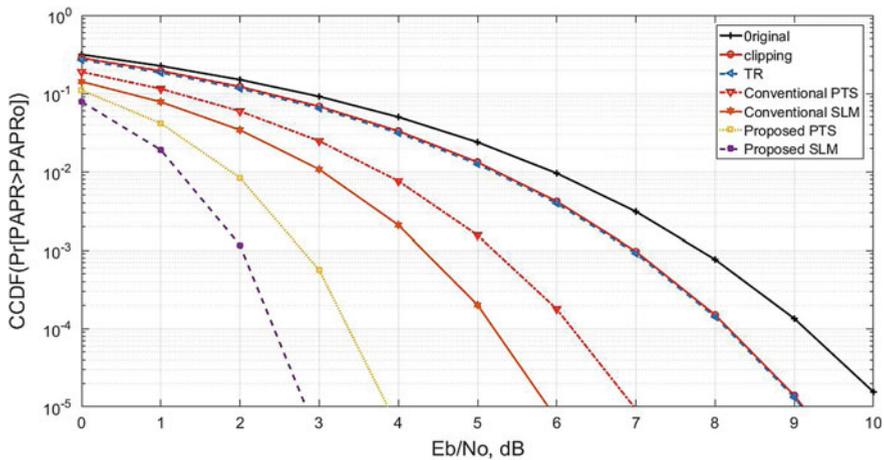


Fig. 10 Conventional and proposed PAPR techniques

Table 4 PAPR values of PAPR reduction techniques

PAPR > PAPR ₀	Original FBMC signal	Clipping	TR	Conventional PTS	Conventional SLM	Proposed PTS	Proposed SLM
10 ⁻⁵	9.5 dB	9.2 dB	9.3 dB	7 dB	5.3 dB	3.4 dB	2.7 dB

The results reveal that the proposed PTS and SLM method perform better than the conventional PAPR reduction techniques. It can be also observed that the proposed SLM technique achieved 1 dB gain as compared to proposed PTS technique. The PAPR values of different PAPR reduction techniques are given in Table 4.

Figure 11 shows the performance of PAPR reduction technique for $U = 4$ and $U = 8$. It can be seen that SLM ($U = 4$) achieved 2 dB gain as compared to the original signal. PTS ($U = 4$) achieved a gain of 2.2 dB as compared to SLM ($U = 4$). SLM ($U = 8$) achieved a 2 dB gain than PTS ($U = 8$). The value of SLM and PTS for different values of U is given in Table 5.

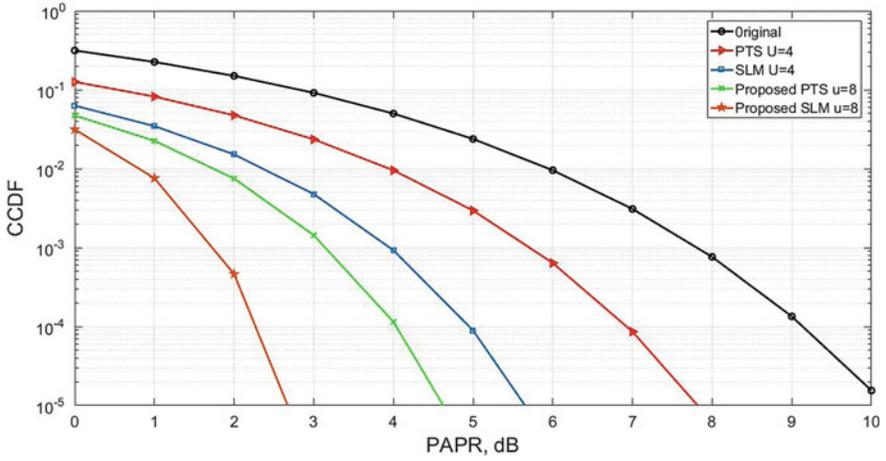


Fig. 11 SLM and PTS for U

Table 5 PAPR values for SLM and PTS for different values of U

PAPR > PAPR _o	Original FBMC signal	PTS(U = 4)	SLM (U = 4)	PTS (U = 8)	SLM (U = 8)
10 ⁻⁵	10 dB	7.9 dB	5.5 dB	4.6 dB	2.7 dB

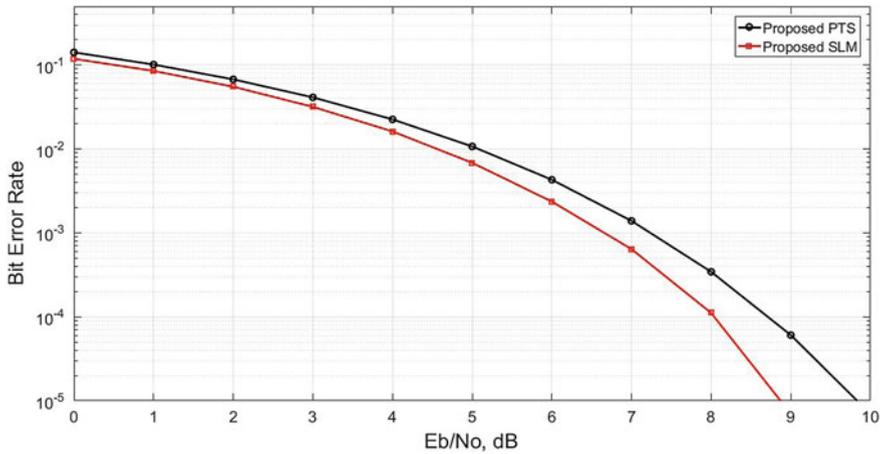


Fig. 12 BER performance of SLM and PTS

Figure 12 shows a BER performance of PTS and SLM PAPR reduction techniques. The output shows that the SLM is superior to PTS.

6 Conclusion

Though this study focused on FBMC in current and forthcoming communication systems, the significance and desired structures of OFDM system cannot be ignored. The purpose is to highlight the point that OFDM, though extensively implemented in the current engineering, is not the best techniques in several next-generation communication systems, more often than not in cognitive radio networks and multiple accesses where FBMC is considered to be more promising. We have proposed a FBMC which do not use CP results in utilization of bandwidth as compared to OFDM (11% of bandwidth is lost). In the proposed study, novel peak reduction methods are implemented, namely, SLM and PTS, respectively. The conventional and proposed PAPR techniques are compared. It was observed that peak power can be cut by using TR, SLM, and conventional PTS for OFDM system. But when we utilized these PAPR reduction techniques in FBMC, the performance of the system degrades because of the overlying arrangement of FBMC. The simulated results indicate that the proposed SLM and PTS techniques performance is better than the conventional PAPR reduction techniques. Further, the efficiency of proposed PTS and SLM is also equated for $U = 4$ and 8 and the simulated results indicate that the proposed SLM gives better result than PTS for $U = 4$ and 8 .

6.1 Future Scope of the Proposed Work

- Orthogonal Issue: Due to the structure and internal distortion, FBMC loses its orthogonality because of waveform overlapping nature in time domain.
- Packet Transmission: The performance of FBMC is excellent for short-range packet transmission but it is unsuitable for long-range packet transmission. Transmitting the information to a long range results in loss of orthogonality between the subcarriers.
- Hardware implementation of FBMC-OQAM P-PTS technique.
- Computational complexity reduction.
- The proposed PAPR reduction techniques of FBMC can be used with MIMO
- Minimum latency.
- Complexity: The use of banks of filter at the transmitter and receiver results in the complexity in the designing of FBMC structure. Further, the use of PAR reduction techniques also adds the complexity design.

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