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Optimized PTS-SLM Techniques for Reducing Signal Power Fluctuations in OFDM Systems Using BPSK and QPSK Modulation under AWGN and Fading Channels

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Abstract:

Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a prominent modulation scheme for wireless communications due to its efficiency in combating multipath fading and supporting high data rates. A major drawback of OFDM is the high variation between peak and average signal power, which leads to nonlinear distortion when passed through power amplifiers. This paper presents improved Partial Transmit Sequence (PTS) and Selected Mapping (SLM) techniques aimed at reducing signal power fluctuations while minimizing computational complexity. The proposed method achieves effective suppression of signal peaks without compromising system efficiency. Simulations conducted in MATLAB R2012 under various modulation schemes (BPSK, QPSK) and channel models (AWGN, fading) demonstrate that the proposed PTS technique offers superior performance in terms of peak power control compared to conventional SLM approaches, as verified by Complementary Cumulative Distribution Function (CCDF) analysis.

Keywords: OFDM, Signal Power Fluctuations, Partial Transmit Sequence (PTS), Selected Mapping (SLM), BPSK, QPSK, AWGN, Fading Channel, MATLAB, CCDF, Peak Signal Control.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has become a widely adopted modulation technique in modern wireless communication systems due to its high spectral efficiency, resilience to multipath fading, and robust performance in frequency-selective environments [1]. It has been successfully integrated into standards such as IEEE 802.11a/g/n (Wi-Fi), WiMAX (IEEE 802.16), LTE, Digital Video Broadcasting (DVB), and power line communication systems. Despite its numerous advantages, one of the critical limitations of OFDM is the **high variation between peak**

and average signal power levels, which can significantly degrade system performance when transmitted through nonlinear power amplifiers [2-4].

Several techniques have been proposed in literature to mitigate this problem, including Clipping, Tone Reservation (TR), Tone Injection (TI), Selected Mapping (SLM), and Partial Transmit Sequence (PTS) [1, 5-7]. Among these, **SLM and PTS are widely favored due to their effectiveness and compatibility with various OFDM system configurations**. However, both techniques come with their own trade-offs—SLM requires multiple phase sequence candidates and side information, whereas PTS is computationally intensive due to the multiple Inverse Fast Fourier Transform (IFFT) operations required [8].

This paper focuses on the design and evaluation of **optimized PTS techniques** that aim to reduce signal power fluctuations with minimal complexity. The proposed methods are evaluated using Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulation schemes under both **Additive White Gaussian Noise (AWGN)** and **fading channel** conditions. The Complementary Cumulative Distribution Function (CCDF) is used to assess performance improvements in terms of power variation suppression. All simulations are performed using **MATLAB R2012**, offering a reliable and reproducible analysis platform.

2. Motivation of PAPR Technology

Peak-to-Average Power Ratio (PAPR) reduction is critical in Orthogonal Frequency Division Multiplexing (OFDM) systems to enhance power efficiency and reduce non-linear distortion. Various techniques have been proposed to tackle this issue, with Partial Transmit Sequence (PTS) and its derivatives proving effective. Kumar et al. introduced a low-complexity PTS approach that utilizes correlation-based candidate selection for effective PAPR mitigation with reduced complexity [1]. Arora and Aggarwal proposed a modified PTS scheme with phase modulation that achieves better performance under AWGN conditions [2]. A novel technique combining signal scrambling with PTS was presented by Bala et al. to further suppress PAPR [3]. Hussain and Ali proposed a simplified Partial SLM scheme that maintains reduction performance while lowering computational cost [4]. Phale et al. improved PTS further by incorporating matrix phase multiplication, reducing the number of IFFT operations [5]. A significant advancement was made by Chen et al. through a cross-entropy-based algorithm that provided effective PAPR reduction with minimal computational overhead [6]. For MIMO-OFDM systems, Singh et al. introduced an enhanced PTS technique tailored for multiple-input multiple-output configurations [7]. Jiang and Wu provided a comprehensive survey on PAPR reduction strategies, highlighting the trade-offs between complexity and performance in various methods [8].

In comparative analysis, Rao and Chaitanya studied the effectiveness of PTS, SLM, and companding techniques in reducing PAPR [9], while Gokkul and Natarajan developed a hybrid scheme integrating clipping and interleaving with C-PTS to balance complexity and signal quality [10]. Benchmarking in OFDM performance for broadband wireless systems was provided by Ghosh et al. [11] and foundational principles were presented by Van Nee and Prasad [12]. Yang emphasized future potential via MIMO-OFDM-based interfaces [13], while Pauli and Meyr focused on optimizing cyclic prefix length [14]. Han and Lee reviewed multiple reduction methods including SLM, PTS, and companding [15]. Kumar and Singh proposed another simplified PTS-based method for real-time OFDM deployment [16]. Later, Arora and Singh explored phase factor modification for better efficiency [17], and Bala and Sharma assessed system-level PTS performance under varying conditions [18]. Hussain and Qureshi introduced another lightweight Partial SLM model at the ICCS conference [19], while Phale and Joshi refined the PTS method with fewer IFFT stages for faster computation [20]. The standard IEEE 802.16-2009 further reinforced these advancements in WiMAX systems [21]. Armstrong's method of repeated clipping with frequency-domain filtering remains influential in legacy systems [22]. Hara and Prasad provided historical context on multicarrier CDMA and its relation to OFDM [23], and Wang and Luo optimized iterative clipping and filtering techniques [24].

In parallel, emerging approaches such as Farid and Ahmed's low-complexity SLM for energy-efficient OFDM systems [25] and Kaiser's OFDM-CDM techniques [26] shaped evolving frameworks. Beyond classical techniques, novel integrations with hardware and IoT environments were explored. Patel focused on minimizing wiring harnesses using Internet of Vehicles (IoV) and ESP-32 modules [27], analyzed adaptive filtering in acoustic echo scenarios [28], and proposed wireless image quality improvement methods [29]. Genetic algorithms for smart antenna optimization were introduced by Yadav et al. [30]. Patidar et al. worked extensively on nanotechnology-enabled computing, starting with a QCA-based Toffoli gate [31], followed by quantum-dot fault modeling in arithmetic circuits [32], and an exploration of nanoelectronics in smart cities [33]. Their final contribution showcased an ultra-efficient Arithmetic Logic Unit (ALU) using QCA technology [34], highlighting how future PAPR reduction techniques may benefit from compact, high-performance nanodevices integrated into next-generation wireless systems.

3. Multicarrier OFDM System

OFDM is a special case of multicarrier system, in which a single data stream is transmitted over a number of lower-rate subcarriers. One of the main reasons to use OFDM is to increase robustness against frequency selective fading or narrowband interference. OFDM is used in many wireless applications today. Already it is used in different WLAN standards (e.g. HIPERLAN-2, IEEE 802.11a), Wireless Metropolitan Area Networks (WMAN), Digital Video Broadcasting (DVB), 3GPP-LTE, Asymmetric Digital Subscriber Line (ADSL) and power line communication [4].

In a classical parallel-data system, the total signal frequency band is divided into N non overlapping frequency sub-channels. Each sub-channel is modulated with a separate symbol, and then N sub-channels are multiplexed through FDM. It seems good to avoid spectral overlap of channels to eliminate inter channel interference [12]. Fig. 1 illustrates the difference between the conventional non overlapping multicarrier technique and the overlapping multicarrier modulation technique. By using the overlapping multicarrier modulation technique, we save almost 50% of bandwidth. To realize this technique, however, we need to reduce cross talk between SCs, which means that we want orthogonality between the different modulated carriers [16].

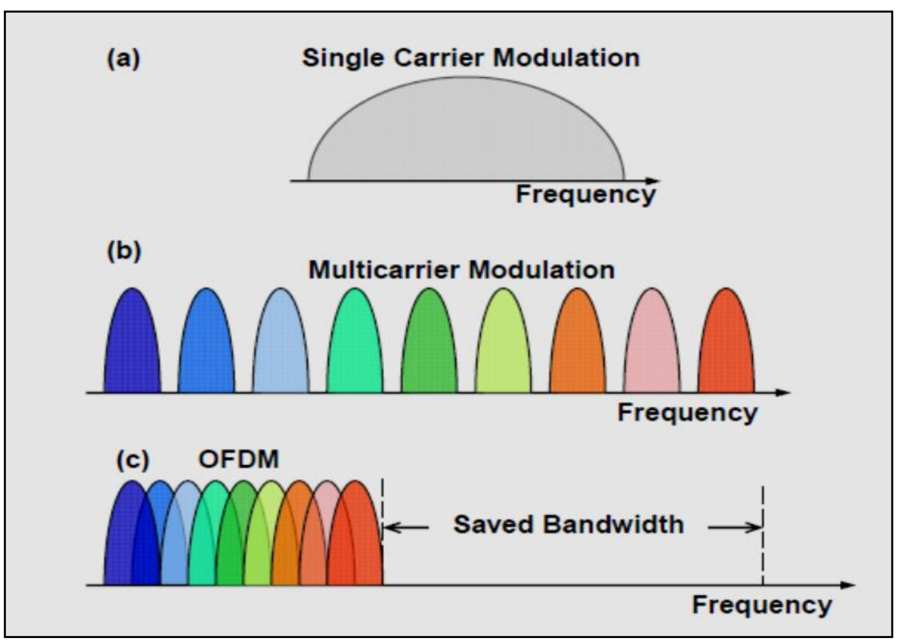

Fig. 1 Comparison of (a) Single Carrier Modulation, (b) General Frequency Division

A. *Cyclic-prefix in OFDM*

To deal with this problem and to make an OFDM signal truly insensitive to time dispersion of the radio channel, cyclic-prefix (CP) insertion is typically used. As illustrated in Fig. 2, cyclic-prefix insertion implies that the last part of the OFDM symbol is copied and appended at the beginning of the OFDM symbol.

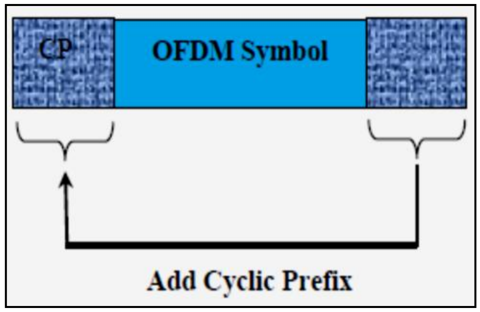

Fig. 2: Cyclic prefix insertion

Cyclic-prefix insertion is thus increases the length of the OFDM symbol duration from *T*S to *TS* + *T*CP, where *T*CP is the length of the cyclic prefix. As illustrated in Fig. 3, if the correlation at the receiver side is still carried out over a time interval *T*s, subcarrier orthogonality will be preserved in case of a time-dispersive channel, as long as the span of the time dispersion is shorter than the length of cyclic-prefix.

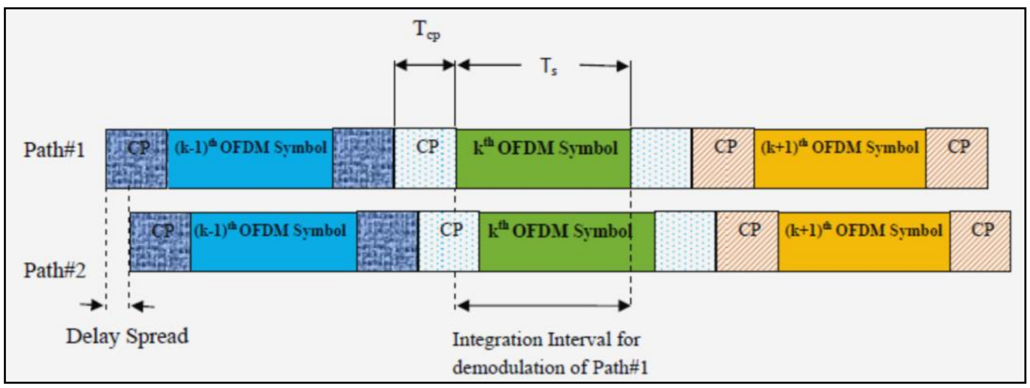

Fig. 3: Time dispersion and corresponding received signal using cyclic prefix insertion

At the receiver side, the corresponding samples are discarded before OFDM subcarrier demodulation i.e. before DFT processing. A cyclic-prefix insertion of *N*CP samples is beneficial, when an OFDM symbol x[n] is passed through dispersive channel (h[n]) with maximum delay spread of *N*CP +1 samples. Since CP values are repetition of the last (*N*CP) sample values of the symbol, it is equivalent to conversion of the linear convolution of x[n] and h[n] into circular convolution. Because of the circular convolution operation in time domain, the DFT of the received signal is a simple multiplication of the DFTs of x[n] and h[n], which makes it trivial to recover the transmitted symbol by a simple one tap equalizer.

4. Literature Survey

Table 1: Literature Survey for PTS

Author(s)	Year	Technique	Key Contribution	Results / Outcome
Er. Sanjeev Kumar et al.	Pre-2023	PTS with Correlation-based Search	Reduced computational complexity using correlation among candidate signals rather than exhaustive search	Achieved similar PAPR reduction with significantly reduced

				complexity (FFT=64, M-QAM used)
Misha Arora et al.	Pre-2023	PTS with Phase Modulation	Modified phase structure in PTS to enhance PAPR performance over AWGN channel	PAPR reduction from 8.8 dB to 7.8 dB
Manju Bala et al.	Pre-2023	PTS with Signal Scrambling	Focused on CCDF-based evaluation, simulated for N=256 and 512 subcarriers	Effective trade-off achieved among PAPR reduction, BER, and system complexity
Ibrahim M. Hussain et al.	Pre-2023	Partial SLM	Divided IFFT into blocks; reduced complexity and improved PAPR over traditional SLM	Achieved ~3 dB PAPR reduction at CCDF=10^-3
Vrushali P. Phale et al.	Pre-2023	Modified PTS (Matrix Phase Multiplication)	Reduced number of IFFT operations using point-wise phase multiplication	Complexity halved; slight degradation in PAPR reduction compared to C-PTS
Jung-Chieh Chen et al. (IEEE)	Pre-2023	Cross-Entropy Based PTS	Proposed stochastic method to replace exhaustive phase search	PAPR reduced from 10.67 dB to as low as 6.04 dB depending on iteration count
Er. Sukhjinder Singh et al.	Pre-2023	Improved PTS for MIMO-OFDM	Proposed PTS for MIMO; enhanced gain over traditional methods	3–5 dB reduction with V=12, 16, 32 subblocks for varying subcarriers
Tao Jiang et al. (IEEE)	Pre-2023	Survey of PAPR Techniques	Compared SLM, PTS, Companding, and Coding methods	Identified trade-offs and scenarios for optimal technique selection
K. Ram Mohan Rao et al.	Pre-2023	PTS, SLM, Companding	Comparative study of three scrambling/distortion methods	Companding outperformed both PTS and SLM in reducing PAPR
N. Annamalai Gokkul et al.	Pre-2023	Hybrid (C-PTS + Interleaving + Clipping)	Developed a hybrid method reducing extra IFFT operations; enhanced clipping efficiency	Outperformed C-PTS in PAPR reduction with lower complexity

5. Communication Channel

To estimate the system behavior possibly near to real world conditions, channel models are used for simulations in MATLAB. There are a number of models which simulate different aspects of the wireless transmission. The most known and used models are the-

- ✓ AWGN channel model,
- ✓ Rayleigh (Fading) channel model,
- ✓ Rician (Fading) channel model.

A. AWGN Channel

The AWGN channel model is a simple but basic concept for modeling channel effects on electromagnetic signals in communication systems. The simplest channel model in wireless commutations is the well-known Additive White Gaussian Noise (AWGN) model. The mathematical expression of the AWGN channel as follows in Fig. 4.

The AWGN channel adds white noise $n(t)$ to the signal $x(t)$:

$$y(t) = x(t) + n(t) \qquad (1)$$

The noise has a constant spectral density and the amplitudes are normal distributed with variance$\sigma^2 = N_0/2$. N0 is the single-sided noise spectral density. White Noise is existent in all communication systems independent of their propagation and induced by many sources like thermal noise in electronic circuits, terrestrial noise, and cosmic noise.

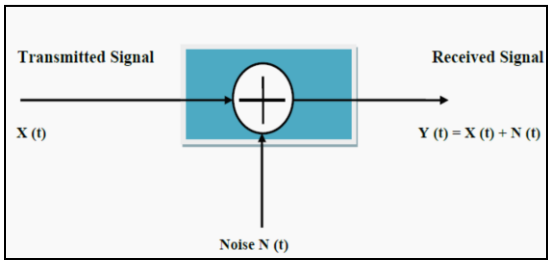

Fig. 4: AWGN channel

Hence the AWGN channel model is essential but not sufficient to model terrestrial propagation effects. The terrestrial propagation faces further effects like multipath, slow and deep fading, which can affect the channel severe. To consider these, other channel models have to be used additionally. The Rayleigh and the Rician channel model are common representatives of these and described below.

If the average received power is $P'[w]$ and the noise power spectral density is N_0 [W/Hz], the channel capacity is:

$$c_{awgn} = W \log_2 \left(1 + \frac{p'}{N_0 W}\right) \text{ Bit/Hz} \qquad (2)$$

Where $\frac{p'}{N_o W}$ is the received signal-to-noise ratio (SNR).

- When the SNR is large (SNR >> 0 dB), the capacity C≈ W $\log_2 \frac{p'}{N_o W}$ is logarithmic in power and approximately linear in bandwidth. This is called the bandwidth-limited regime.
- When the SNR is small (SNR << 0 dB), the capacity C≈ W $\log_2 e$ is linear in power but insensitive to bandwidth. This is known as power limited regime.

B. Fading channel

Multipath is the propagation phenomenon that results in radio signal reaching the receiver antennas via multiple propagation paths. There are many causes of multipath fading including atmospheric ducting, refraction, reflection from terrestrial objects such as buildings and mountains, etc. The most harmful fading channel is the Rayleigh fading model which was first introduced by Bell Lab in 1970s. It is a statistical model of the communication channel to represent the effects of a propagation environment on a radio signal. A statistical Rayleigh fading model is the simplest fading channel model. A Rayleigh fading channel is viewed as a model when a radio signal passes through communication channel that varies power of signal according to Rayleigh distribution [13].

Rayleigh fading model performs as reasonable channel model when there are many objects (such as building and mountain) in the propagation environment which causes scattering of the the radio signal before it arrives at the receiver.

Consider a transmitting and a receiving antenna, both above a plane surface such as a road Fig. 5. Where the horizontal distance between them is r, height of transmitting and receiving antenna is h_s and h_r respectively. There are two paths through wireless communication possible one is direct r_1 and another one.is indirect r_2.The indirect path is the one which reaches to the receiving antenna after the reflection from the ground. But direct path will always be shortest path of. communication.

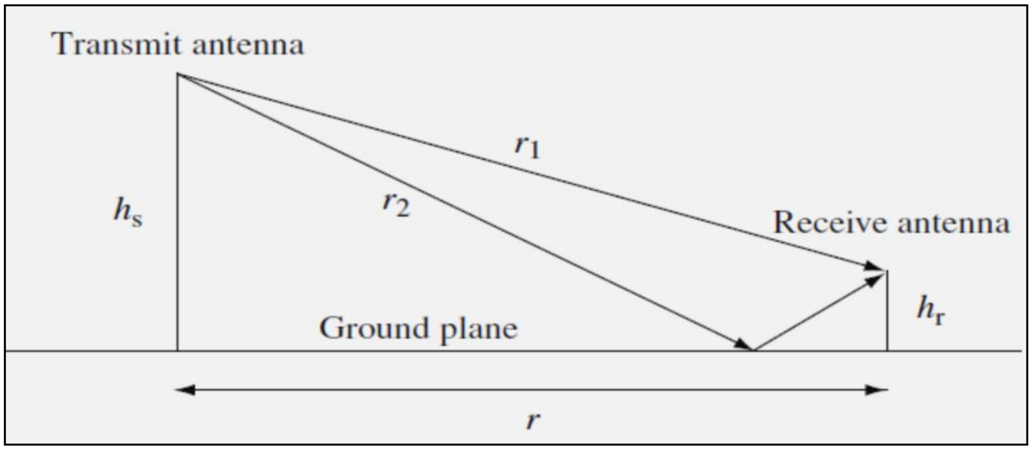

Fig. 5: Illustration of a direct path and a reflected path off a ground plane [4]

6. Simulation Result of PTS Technique with BPSK Modulation

The PAPR reduction performance is evaluated by the Cumulative Complementary Distributive Function (CCDF). In order to analyze the PAPR reduction performance of our proposed Partial Transmit Sequence technique (PTS), simulation has been performed. The simulation of our proposed technique has been carried out using MATLAB R2012a Computer Simulation was performed for the OFDM systems. The number of sub-carriers employed is 64. We have also chosen BPSK modulation technique for carrying out our analysis, OFDM symbols is equal to 512, IFFT is consider 128 and number of user is 8. The result is shown in Fig.6 input data for 8 users; Fig. 7 shows the input data with add noise after pass the noise channel and finely Fig.8 shows the performance of CCDF versus PAPR.

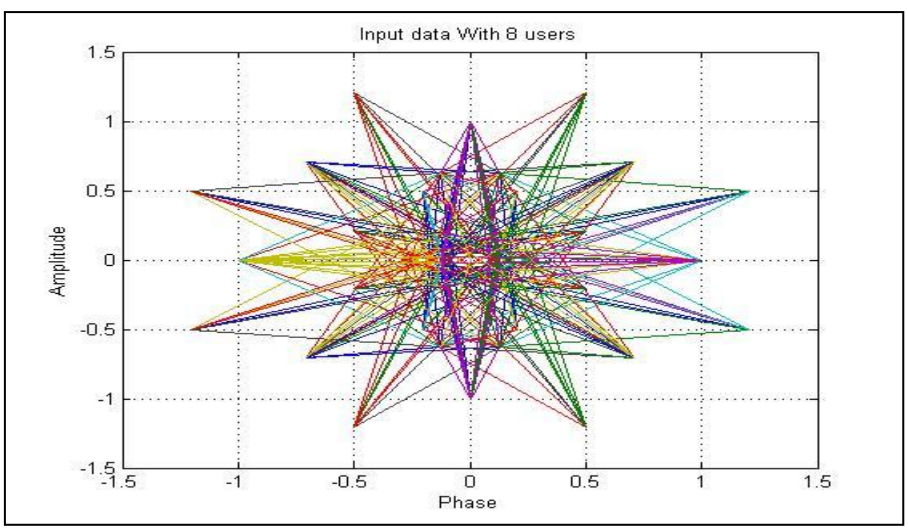

Fig. 6: PAPR BPSK with Rayleigh and AWGN input data with 8 users

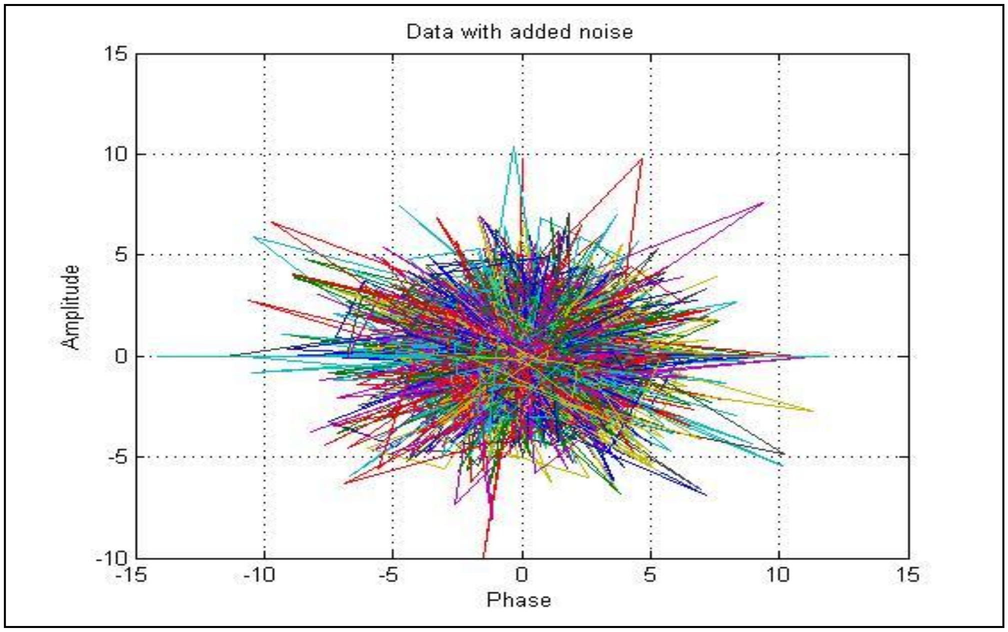

Fig. 7: PAPR BPSK with Rayleigh and AWGN input data with added noise

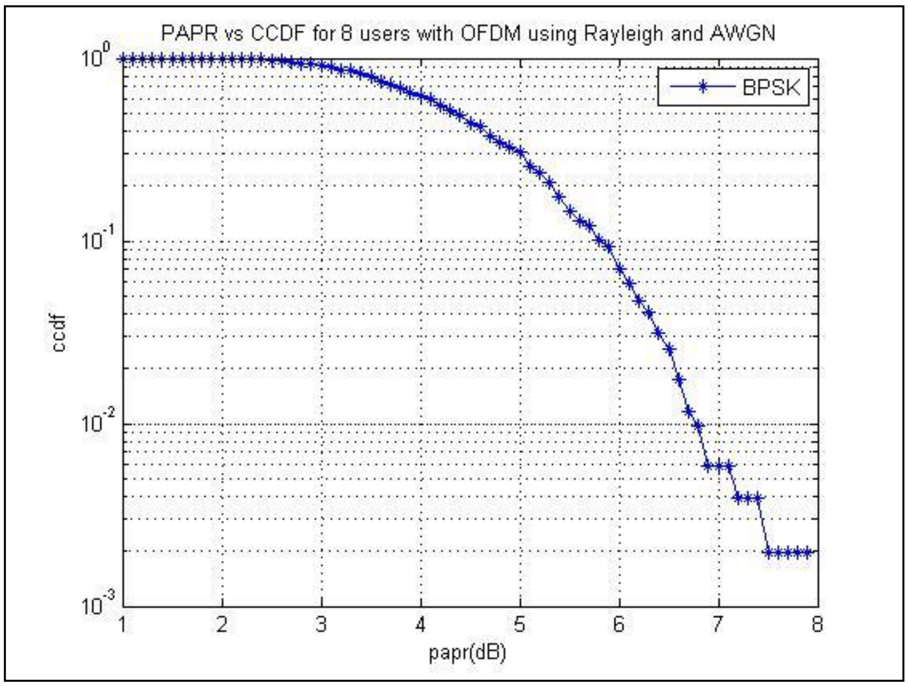

Fig.8: PAPR reduction performances with BPSK modulation

Table 2: Observation Result for PTS with BPSK

S. No	Used Parameter	CCDF (P_r)	PAPR
01	BPSK Modulation with Rayleigh and AWGN Channel	10^0	1.0dB
02		10^{-1}	5.9dB
03		10^{-2}	6.8dB

A. PTS Technique Result Analysis with BPSK

The Simulation results are carried out taking into account various simulation parameters like total number of Subcarriers, Number of sub-blocks, and Number of subcarriers allocated, Spreading factor, Communication Channel and type of modulation technique. The performance is draw between bit error rate (BER) versus signal to noise ratio (SNR) using New PTS technique and C-PTS technique. Fig. 9 the modulated OFDM signal and last draw the Curve between BER versus SNR.

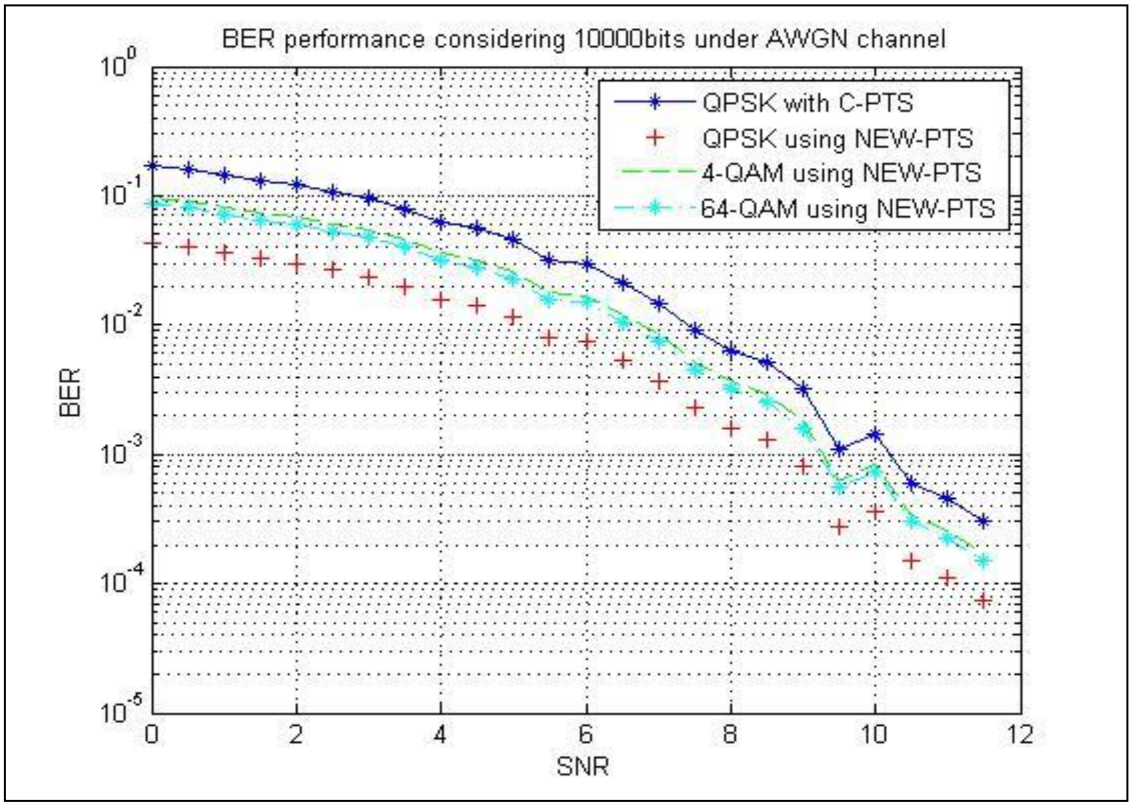

Fig.9: Performance of QPSK with C-PTS, QPSK, 4-QAM, 64-QAM

Table 3: Observation Result for SLM Techniques

S. No	Channel	Modulations	PAPR Technique	BER	SNR
01	AWGN	QPSK	C-PTS	10^{-3}	10.10dB
02		QPSK	New PTS	10^{-3}	9.00dB
03		4-QAM	New PTS	10^{-3}	9.20dB
04		64-QAM	New PTS	10^{-3}	9.22dB

B. Result Analysis

The Simulation results are carried out taking into account various simulation parameters like Total number of Subcarriers, Number of sub-blocks, Number of subcarriers allocated, Spreading factor, Roll-off factor, Type of modulation technique. The performance is draw between bit error rate versus signal to noise using New PTS technique and C-PTS technique. We observed that in BER 10^{-4} the (SNR is QPSK= 13.1dB and 16-QAM = 13dB). The SNR is increased by 0.1dB.

7. Conclusion

The focus of this investigate one of the problems that exist in OFDM wireless communication system high peak-average power ratio (PAPR) of OFDM signal, and discuss how to reduce it by different effective algorithms. The comprehensive research and comparison are put forward for a variety of currently promising PAPR reduction methods on the basis of extensive reading and studying of associated paper and literature in this research area. Among these different proposals, they were mainly focusing on the PTS technology and verify the theoretical analysis by observing the MATLAB2012a simulation results.

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