Reducing Peak-to-Average Power Ratio in 5G Systems through the Hybrid AGP-SLM Technique

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Abstract: - The imminent era of 5G mobile communication necessitates the exploration of novel modulation techniques as alternatives to the prevalent OFDM modulation technique. The pursuit of low Peak-to-Average Power Ratio (PAPR) has become a standard for 5G waveforms, aligning with the requirements of 5G and aiming to optimize power efficiency. Consequently, there is a compelling need to mitigate PAPR, making hybrid techniques an appealing choice due to their ability to harness the strengths of multiple methods without introducing spectrum side-lobes or compromising the bit error rate (BER) performance of the systems. This paper proposes a technique that combines selective mapping technique (SLM) and Active Constellation Extension (AGP) algorithms to achieve PAPR and BER reduction in OFDM systems. The proposed approach enhances PAPR reduction while concurrently maintaining BER performance, and it accomplishes this with reduced computational complexity when compared to conventional techniques.
Keywords: - Generalized Frequency Division Multiplexer (GFDM), Peak Average Peak Ratio (PAPR), Selective Mapping Technique (SLM), Active Constellation extension (AGP)

I. Introduction

To effectively assist the spectrum effective network slicing and different requirements of 5G, from the physical layer perspectives, one of the keys and fundamental problems over the prior system [1], which is the novel waveform strategy to allow the isolation and multiservice signal multiplexing. In addition, inherits the advantage of the OFDM models, like easily implement channel equalization or estimation and multiple antenna methods, there are two key characteristics that the novel waveform should withstand the complete design requirement of 5G: relaxed synchronization and low OOB Emission requirements. Initially, decrease guard band to a small value for attaining spectrum effective transmission. Besides, this feature also provides a basis to enable different kinds of services with many optimum frame structures coexisting in one baseband with negligible interference [2].

At the same time, relaxed synchronization might result in transceiver processing and simplified hardware/algorithm design. For instance, lower cost MTC devices mayn't have complex RF hardware/baseband synchronization algorithm; also, asynchronous communicating might be adapted in 5G for up linking communication to store the synchronization signaling overheads in mMTC scenario.

The key features discussed in the above are envisaged in association with the scenario mentioned below for 5G. They are bit pipe transmission. The prerequisite of these different scenarios might impact the selection of waveform. Along this line, to empower aforementioned qualities and to mention the downside of OFDM, different physical layer waveforms are studied for 5G networks. There are various classification of MCM candidate systems for 5G. The waveform is categorized into four major classes: Single Carrier based Waveform, OFDM based Waveform for Discrete Fourier Transform (DFT) Spread, OFDM reliant Waveform, and Non-Orthogonal Waveform [3, 4].

FOFDM is unique of the OFDM oriented competitor modulation for upcoming 5G framework. Nevertheless, each MCM has higher PAPR affects considerable drawbacks of this regulation, however, the broadcast signal is the superposition of distinct autonomous with symmetrical subcarrier. Less PAPR is fundamental waveform plan standard for the 5G waveform to be capable of satisfying the 5G prerequisite and to enhance efficacy of energy, hence PAPR must be reduced. It has gotten basic to use productive PAPR reduction method, but using single methodologies might lead to lower PAPR reduction, as well as it has certain shortcomings that could shake the performances of system limitations such as Bit Error Rate (BER) and spectral efficacy. Hence hybrid technique is believed to be the best selection since it exploits the drawbacks of both methods utilized in hybridization and would effectively reduce the PAPR without degrading BER routine or creating spectrum side-lobes of the framework [5].

II. GFDM System

Generalized Frequency Division Multiplexing (GFDM) is a novel modulation scheme that has garnered significant attention in the context of 5G systems. Unlike traditional Orthogonal Frequency Division Multiplexing (OFDM), GFDM introduces waveform shaping and a filter bank structure, providing increased flexibility, reduced out-of-band emissions, and improved spectral containment. This section explores the key characteristics of GFDM and its mathematical expressions relevant to 5G communication systems.

Key Features of GFDM:

1. **Flexibility in Time-Frequency Domain:** GFDM exhibits flexibility in both the time and frequency domains, allowing for tailored waveform designs to suit the requirements of diverse communication scenarios in 5G systems.
2. **Waveform Shaping:** GFDM employs shaped waveforms in both time and frequency domains. This shaping is achieved through pulse shaping, enabling improved spectral containment and reducing interference with adjacent frequency bands.
3. **Filter Bank Structure:** The fundamental building block of GFDM is a filter bank structure. This structure consists of overlapping subcarriers, each with its own filter. The use of filters enhances spectral efficiency and allows for efficient use of the available frequency spectrum.
4. **Reduced Out-of-Band Emissions:** By employing shaped waveforms and a filter bank structure, GFDM aims to minimize out-of-band emissions. This is crucial for coexistence with other systems and regulatory compliance.
5. **Adaptability to Different Services:** GFDM is designed to be adaptable to various communication services, making it a versatile choice for the diverse requirements of 5G networks, including enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC).

GFDM Signal Generation:

$$s(t) = \sum_{m=0}^{M-1}\sum_{n=-\infty}^{\infty} X_m[k]g(t-mT-nT_s)e^{j2\pi fk(t-mT-nT_s)}$$

Where:

- $s(t)$ is the GFDM signal in the time domain.
- $Xm[k]$ represents the data symbols on the k-th subcarrier of the m-th block.
- $g(t)$ is the prototype filter.
- T is the symbol duration.
- Ts is the sampling interval.
- fk is the center frequency of the k-th subcarrier.

Filter Bank Structure:

$$H_k(f) = \sum_{n=-\infty}^{\infty} G\left(f-\frac{n}{T_s}\right)e^{-j2\pi\frac{n}{T_s}kf}$$

Where:

- $H_k(f)$ is the frequency response of the k-th filter.
- $G(f)$ is the frequency response of the prototype filter.

Signal Demodulation:

$$\hat{X}_m[k] = \int_{-\infty}^{\infty} \int_{mT}^{(m+1)T} s(t) g^*(t - mT - nT_s) e^{-j2\pi f k(t - mT - nT_s)} dt$$

Where:

- $\hat{X}_m[k]$ is the demodulated symbol on the k-th subcarrier of the m-th block.
- $g^*(t)$ is the complex conjugate of the prototype filter.

GFDM represents a promising modulation scheme for 5G systems, offering enhanced flexibility and spectral efficiency. The mathematical expressions provided here offer insight into the signal generation, filter bank structure, and demodulation processes of GFDM, illustrating its adaptability to the diverse and demanding communication requirements of the 5G landscape.

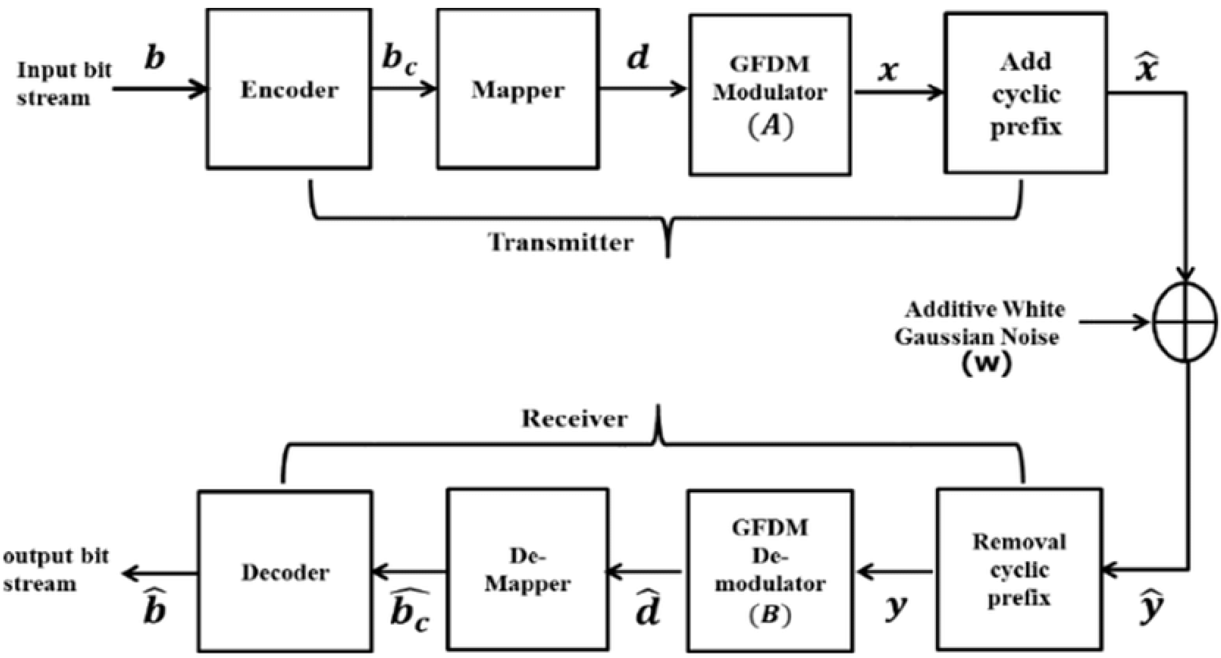

Fig. 1: GFDM Transmitter & Receiver System

III. Papr Reduction Techniques

In wireless communication systems, mitigating the Peak-to-Average Power Ratio (PAPR) is crucial to avoid power inefficiency and distortion in signal transmission. Several PAPR reduction schemes have been developed to address this challenge. This section provides a detailed exploration of various PAPR reduction techniques, each designed to enhance the efficiency and reliability of signal transmission.

1. Selected Mapping (SLM):

Selected Mapping is a widely used technique that involves generating multiple versions of the same signal with different phase sequences. The version with the lowest PAPR is selected for transmission. Mathematically, this can be expressed as:

$$x_m[n] = x[n]. e^{j\theta_m}$$

Where, $x_m[n]$ is the modified signal, $x[n]$ is the original signal, and θ_m is a random phase.

2. Partial Transmit Sequence (PTS):

PTS divides the signal into non-overlapping blocks, and different phase sequences are applied to each block. The combination with the lowest PAPR is selected. Mathematically, this is represented as:

$$x_{PTS}[n] = \sum_{i=0}^{N-1} x_i[n]$$

Where $x_i[n]$ is the signal with phase sequence i and N is the total number of phase sequences.

3. Clipping and Filtering:

Clipping involves limiting the amplitude of high peaks in the signal, followed by filtering to mitigate distortion. This technique can be expressed as:

$$x_{clipped}[n] = \begin{cases} x[n] & if\ |x[n]| \leq \alpha \\ \alpha e^{jarg(x[n])}, & if\ |x[n]| > \alpha \end{cases}$$

Where α is the clipping threshold

4. Tone Reservation (TR):

TR reserves specific tones in the signal to cancel or suppress high peaks. Mathematically, this can be described as:

$$x_{TR}[n] = x[n] + \beta r[n]$$

Where r[n] is the reserved signal and β is the scaling factor.

5. Active Constellation Extension (ACE):

ACE modifies the constellation points by adding extra points to the constellation diagram. This extension creates additional space for signal representation, reducing PAPR. Mathematically, this involves adjusting the signal constellation points.

6. Geometric Signal Constellation Techniques:

Various geometric shaping techniques optimize the signal constellation geometry to inherently reduce PAPR. This can involve altering the arrangement of constellation points in the complex plane.

7. Machine Learning (ML) based Approaches:

ML techniques, including deep learning, have been explored for adaptive PAPR reduction. These approaches adaptively learn and apply PAPR reduction strategies based on the specific characteristics of the communication channel.

8. Hybrid Techniques:

Hybrid approaches combine multiple PAPR reduction techniques to achieve enhanced performance. For example, combining SLM with Clipping and Filtering can provide a synergistic effect.

PAPR reduction schemes play a vital role in optimizing the efficiency and reliability of signal transmission in wireless communication systems. The choice of a specific technique depends on factors such as computational complexity, adaptability to channel conditions, and the specific requirements of the communication system. Researchers continue to explore and develop new approaches to address the challenges associated with PAPR reduction in diverse communication scenarios.

IV. Proposed Methodology

This approach consists of series connection of two conventional techniques. Both techniques perform in their strength like as PTS in PAPR and AGP in Complexity. Simultaneously the drawbacks of each other can be resolved.

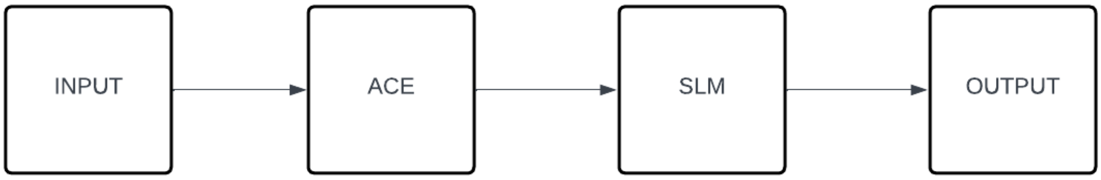

Fig. 2: Block diagram of Proposed Technique

Here, combination is little bit different i.e. half number of subcarriers are taken, as shown in Fig. 1, the switching between the AGP and PTS is based on peak of half symbol. The comparison of two half's decides that higher peak symbol move to AGP and vice versa.

Proposed algorithm:

Input:

- $x[n]$: Original time-domain signal.
- M: Number of ACE iterations.
- P: Number of SLM candidate signals.
- K: Number of selected signals in SLM.

Output:

- $x_{output}[n]$: Processed time-domain signal with reduced PAPR.

Steps:

1. **Initialize:**
- Set $x_{output}[n] = x[n]$ as the initial processed signal.

2. **ACE Processing:**
- For $m = 1\ to\ M$:
- Apply ACE to $x_{output}[n]$ to modify the constellation points and reduce PAPR.
- Calculate the PAPR of the ACE-processed signal.

3. **SLM Processing:**
- Generate P different versions of $x_{output}[n]$ using random phase sequences.
- For each version $p = 1\ to\ P$:
- Apply SLM to the p-th version to find K signals with the lowest PAPR.
- Calculate the PAPR of each processed signal.

4. **Select Best SLM Candidate:**
- Choose the candidate signal from the SLM iterations with the lowest PAPR.

5. **Final Signal Combination:**
- Combine the selected SLM signal with the ACE-processed signal.
- The final processed signal is given by:

$$x_{output}[n] = \alpha \cdot x_{ACE}[n] + \beta \cdot x_{SLM}[n]$$

where α and β are scaling factors, typically set to normalize the power.

6. **Output:**
- The final processed signal $x_{output}[n]$ is the output with reduced PAPR.

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Notes:

- The scaling factors α and β can be chosen based on the desired power normalization for the output signal.
- The ACE and SLM processes can be adapted based on the specific characteristics of the communication system and the waveform requirements.
- The number of ACE iterations (M), the number of SLM candidate signals (P), and the number of selected signals in SLM (K) are parameters that can be adjusted based on the system's needs and computational constraints.

This algorithm provides a systematic way to combine ACE and SLM techniques for PAPR reduction, leveraging the benefits of both methods in reducing peak power levels in the transmitted signal. Adjustments to the parameters and scaling factors can be made based on the specific requirements of the communication system.

Complexity: The focus of the proposed scheme is on computational complexity. SLM is dependent on number of sub block to search the optimum phase vectors, whereas AGP requires iterations to find optimal constellation [3, 4]. These activities raise the computation complexity of both algorithms correspondingly. Complexity involved in SLM scheme is much larger than AGP.
The proposed technique uses the serial combination of AGP and SLM.

Table 1: Hybrid PAPR reduction comparison

Techniques / Parameters	POCS-PTS	AGP-PTS	POCS-SLM	AGP-SLM
Distortion less	Y	Y	Y	Y
Power increase	N	N	N	N
Data rate loss	N	N	N	N
Complexity	Y	Y	Y	Y
BW expansion	Y	Y	Y	Y
BER degradation	N	N	N	N
Side information	Y	Y	Y	Y

V. Simulation Result

The computational complexity of conventional and proposed methods is summarized in Table 2. Though proposed technique shows more complexity among combinational techniques but it possess less PAPR among other reduction technique. From Table 1, in case of N=64, the proposed scheme offers an increment of 38% in complex multiplications as compared to SLM scheme and at the same time it only utili 46% more complex additions. Similarly, for N=256, it shows rise in complex multiplication and reduction in complex addition as 37% and 43% respectively.

Table 2: Complexity comparison of proposed method for WLAN and WiMAX

Standards	Methods / Parameters	SLM	PTS	AGP	PROPOSED (AGP-SLM)
802.11a (WLAN)	Complex Mult.	801	593	504	1304
	Complex Add.	1186	24307	1009	2195
802.16e (WiMAX)	Complex Mult.	3858	3058	2329	6187
	Complex Add.	6115	125360	4658	10773

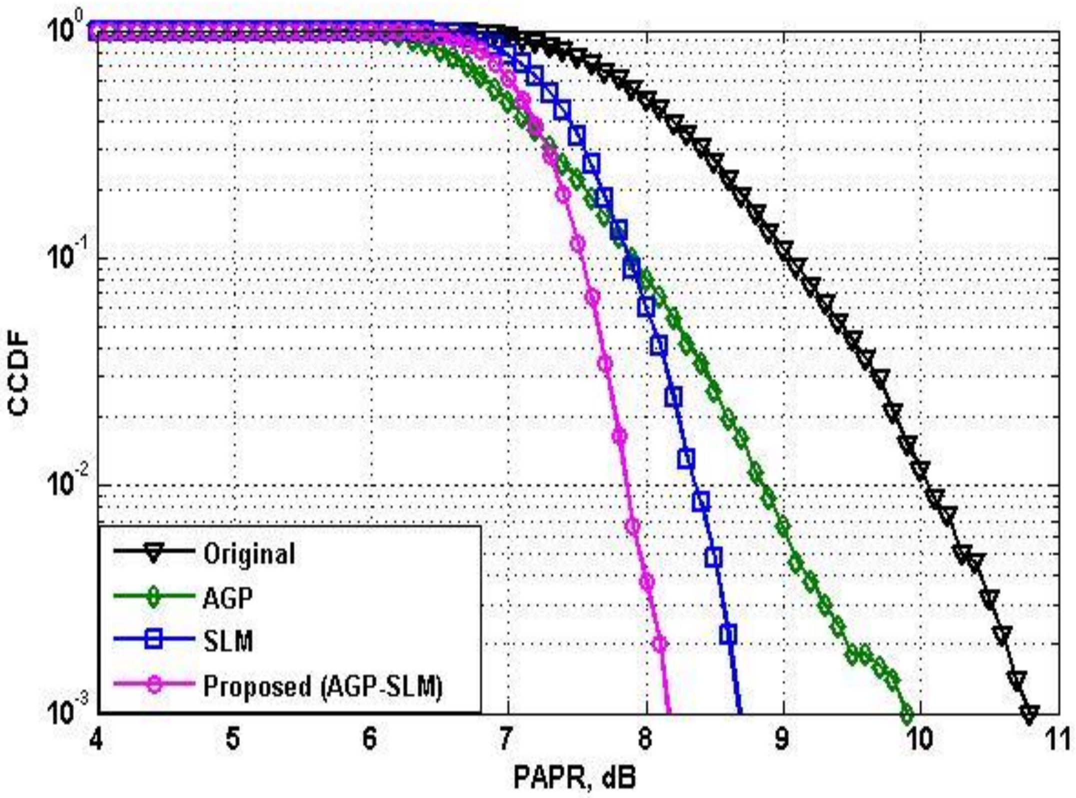

Fig. 3: PAPR comparison WLAN (N=64)

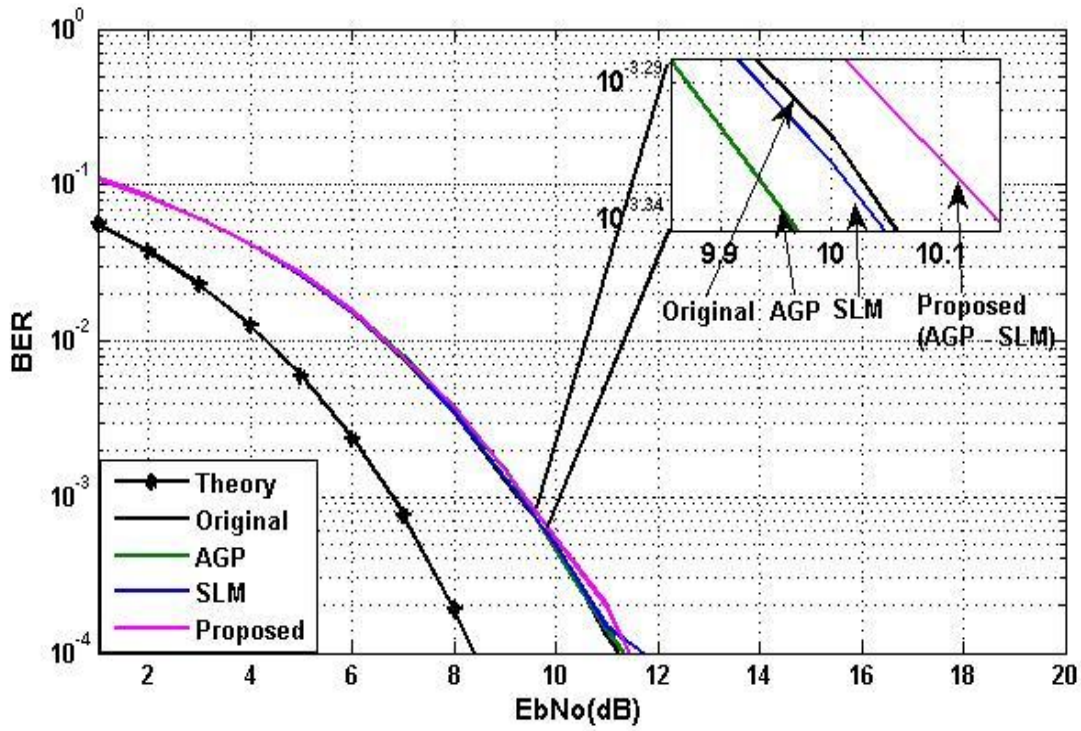

Fig 4: BER performance WLAN (N=64**)**

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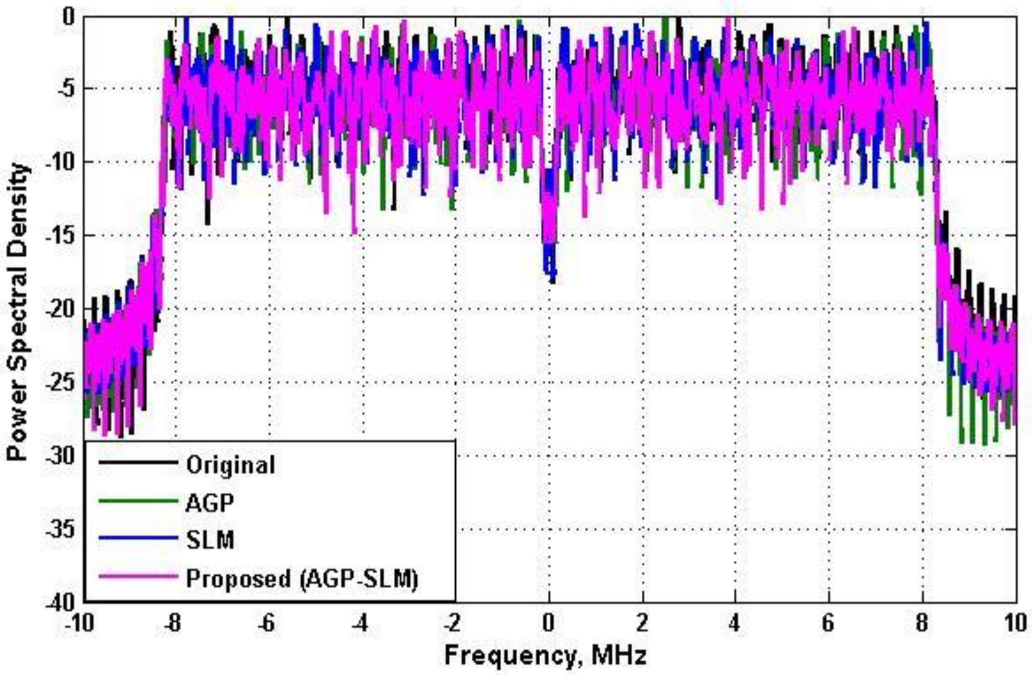

Fig 5: PSD performance WLAN (N=64)

VI. Conclusion

In this paper, various combinational techniques for PAPR reduction are presented. Out of which, the proposed scheme is a series combination of AGP and SLM method. The proposed scheme provides a good performance in PAPR reduction as well as in BER to conventional methods. Moreover, for large number of subcarrier, the PAPR further reduces and simultaneously BER improves. The proposed method reduces the PAPR significantly (0.7dB), maintains the BER performance.

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