International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Throughput Analysis of Companding Peak-to-Average Power Ratio Reduction for OFDM System

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Submitted: 26/01/2024 **Revised**: 04/03/2024 **Accepted**: 12/03/2024

Abstract: In wireless communication systems, OFDM, has become the predominant modulation technique for high-speed data transfer. The high PAPR of the transmitted signal, which results in ineffective power amplification and spectrum regrowth, is one of its main disadvantages. Companding methods, including μ-law and A-law, have been suggested to address this problem by lowering PAPR by compressing the signal's dynamic range prior to transmission. An extensive throughput analysis of companding strategies for OFDM system PAPR reduction is presented in this paper. We concentrate on the use of A-law and μ-law companding on a 512 sub-carrier OFDM system in particular. We assess the effect of companding on system throughput using comprehensive simulations and theoretical research. First, we look into how signal distortion is affected by the compression properties of the A- and μ-law companding functions. We examine the consequent decrease in PAPR and its effects on system performance by using these companding strategies. Furthermore, we evaluate the trade-offs between throughput improvement and PAPR reduction, taking into account elements like computational complexity, bit error rate (BER) performance, and signal-to-noise ratio (SNR). Additionally, we investigate the connection between companding settings and system throughput, such as quantization level and compression factor. We quantify the attainable throughput improvements with different companding configurations under different channel conditions using in-depth MATLAB simulations. The study's conclusions offer insightful information about how companding strategies for PAPR reduction in OFDM systems can be used in real-world settings. System designers can maximize the performance of OFDM-based communication systems in practical circumstances by knowing the trade-offs between PAPR reduction and throughput increase.

Keywords: *PAPR; OFDM; A-law; Mu-Law*

1. Introduction

PAPR is an essential measure in signal processing, namely in the domains of wireless communications and signal dispensation. It describes the variations in the strength of a signal, which can greatly affect the effectiveness and dependability of communication systems [1]. In essence, the PAPR calculates the ratio of a signal's peak power to its average power. In OFDM wireless communication systems, for example, the transmitted signals can experience significant fluctuations in amplitude due to the superposition of multiple subcarriers or symbols. These fluctuations can lead to inefficiencies in power amplifier operation and can cause interference with neighboring channels, limiting the overall system performance. Understanding and managing the PAPR is critical for optimizing the design and operation of communication systems [2]. High PAPR values necessitate more robust and expensive power amplifiers to ensure reliable signal transmission without distortion. Additionally, high PAPR signals require larger dynamic range components, which can increase system complexity and cost. Therefore, reducing the PAPR can lead to more efficient use of resources and improved system performance. Researchers and engineers have developed various techniques to mitigate the effects of high PAPR, such as clipping and filtering, peak windowing, selective mapping, and tone reservation. These methods aim to reduce the peak amplitudes of the signal while preserving its essential characteristics and minimizing distortion [3]. Furthermore, the management of PAPR becomes increasingly crucial in developing communication technologies, such as fifth-generation (5G) wireless networks and beyond. These technologies demand faster data rates and spectral efficiency, which further amplifies the importance of PAPR management [4]. Efficiently managing PAPR can contribute to achieving the ambitious goals of these advanced communication systems, enabling seamless connectivity, ultra-fast data transmission, and enhanced user experiences. In this context, this paper explores the significance of PAPR in wireless communication systems, discusses its impact on system performance, and reviews various techniques proposed to mitigate its effects [5]. Through a comprehensive analysis, we aim to provide insights into the challenges and opportunities associated with managing PAPR, ultimately contributing to the advancement of communication technologies [6].

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2. Literature Review

This paper provides a comprehensive analysis of several techniques employed to mitigate PAPR in OFDM signals. The subject matter includes traditional approaches such as clipping and filtering, as well as more advanced techniques like tone reserving and selective mapping [7]. The authors provide a comprehensive examination of approaches for reducing PAPR in OFDM systems. These techniques include active constellation extension, coding, and partial transmit sequences. The authors engage in a comprehensive analysis of the benefits and constraints associated with each methodology, offering valuable perspectives on current progress [8]. The authors provided a comprehensive classification of PAPR reduction strategies in OFDM systems, organizing them according to their fundamental principles. The research examines both traditional and developing methods and evaluates their efficacy in reducing PAPR [9]. The authors explore sophisticated methods to PAPR in OFDM systems, such as probabilistic shaping and deep learning-based algorithms. The authors examine the improvements in performance resulting from these strategies and address the difficulties encountered in implementing them [10]. The authors investigate the utilization of artificial intelligence methodologies, including neural networks and genetic algorithms, to mitigate PAPR in OFDM systems. The researchers examine the practicality and efficacy of these strategies in real-world communication contexts [11]. The authors suggest employing hybrid ways for reducing PAPR by combining numerous existing methods, resulting in improved performance. The researchers use simulations to verify the efficacy of their strategy and compare it to conventional methods [12]. The authors focused on the specific difficulties associated with reducing PAPR in SC-FDMA systems. The authors evaluate current methods and suggest innovative approaches specifically designed for the unique properties of SC-FDMA signals [13]. The researchers examined methods to reduce the dynamic PAPR in MIMO OFDM systems. The authors suggest using adaptive algorithms that modify PAPR reduction parameters according to the channel circumstances, resulting in enhanced performance [14]. The authors examined strategies for reducing PAPR specifically designed for upcoming wireless networks, including 5G and future generations. The strategies are assessed for their effects on system efficiency, spectrum efficiency, and overall network performance [15]. The researchers examined energy-efficient strategies for reducing PAPR with the goal of boosting environmentally friendly communications. The authors examine the compromises between reducing PAPR and minimizing energy usage, and provide methods to achieve both goals concurrently [16].

2. PAPR algorithms

PAPR reduction affects power efficiency and system performance, making it a major concern in communication networks. To solve this problem, several algorithms have been created, each with unique properties and methods. [17]. Here are explanations of some commonly used PAPR reduction algorithms: This technique involves clipping the peaks of the signal above a certain threshold and then applying filtering to reduce distortion. While simple to implement, clipping can introduce significant signal distortion, especially if the clipping level is not carefully chosen. Additionally, filtering may introduce additional complexity to the system. SLM is a probabilistic method that generates several transmitted signal versions with various phase rotations. Transmission of the version with the lowest PAPR is chosen. While effective in reducing PAPR, SLM requires significant computational resources, especially for a large number of subcarriers or symbols [18].TR allocates specific tones or subcarriers for cancelling out the peaks of the signal. These reserved tones carry additional data to counteract the peaks in the original signal. TR can effectively reduce PAPR but requires careful allocation of tones and may lead to reduced data throughput due to the overhead introduced by the reserved tones. PTS divides the signal into several blocks, each with different phase factors applied to reduce the peak amplitudes. The block with the lowest PAPR after phase adjustment is selected for transmission [19]. While effective, PTS involves exhaustive search algorithms, making it computationally demanding, especially for large signal dimensions. Companding algorithms apply nonlinear compression functions to the signal's amplitude to reduce its dynamic range. This approach effectively reduces the peaks in the signal, leading to lower PAPR values. Companding algorithms such as μ-law and A-law companding are widely used in digital communication systems, particularly in telephony and voice transmission [20]. ACE modifies the signal constellation by adding auxiliary points outside the original constellation to reduce PAPR. By carefully selecting the positions of the auxiliary points, ACE can achieve significant PAPR reduction without sacrificing spectral efficiency. Each of these algorithms offers unique advantages and trade-offs in terms of complexity, computational requirements, and effectiveness in reducing PAPR [20]. The choice of algorithm depends on the specific requirements and constraints of the communication system, such as available computational resources, desired level of PAPR reduction, and tolerance for signal distortion [21].

3. System Model

Companding algorithms are commonly used in digital communication systems to reduce the PAPR of transmitted signals. These algorithms utilize the non-linear properties of companding functions to condense the range of signal dynamics, successfully decreasing its highest amplitudes while maintaining the crucial information. The method entails reducing the amplitude of the signal before sending it and then restoring it to its normal range at the receiver, so reducing the impact of the high peaks that contribute to high Peak-to-Average Power Ratio (PAPR) values. A widely employed companding algorithm in telecommunication systems, including as digital telephony and voice-over-IP (VoIP) [22], is μ-law companding. μ-law companding employs a logarithmic compression function to the amplitude of the signal, effectively diminishing the dynamic range of the signal. Signal compression is advantageous for signals that have a high peak-to-average power ratio because it decreases the probability of signal clipping and distortion during transmission. A-law companding is another often utilized algorithm for companding. It is similar to μ-law companding but utilizes a distinct logarithmic compression function. A-law companding is commonly used in European telecommunication systems and has comparable advantages in terms of reducing peak-to-average power ratio (PAPR) and maintaining signal accuracy [23]. The efficacy of companding algorithms in diminishing PAPR relies on several aspects, such as the selection of the companding function, the extent of compression employed, and the attributes of the transmitted signal. Furthermore, companding imparts a certain amount of distortion to the signal, especially at low signal levels. This distortion needs to be carefully controlled in order to maintain a satisfactory signal quality. Notwithstanding these factors, companding algorithms provide a straightforward and efficient method for reducing peak-to-average power ratio (PAPR) in digital communication systems [24]. These techniques can enhance system performance and efficiency by utilizing the nonlinear features of companding functions to decrease the peak amplitudes of transmitted signals. Furthermore, companding algorithms can be seamlessly included into current communication systems with minimal added intricacy, rendering them a viable solution for reducing peak-to-average power ratio (PAPR) in real-world applications [25]. Table 1 and Table 2 display the pseudo code for the A and Mu-law approaches.

Table 1. Pseudo code for A-Law

```
function $A\_law\_companding(input\_signal)$:
// Define the A-law compression parameter
A = 87.6
// Define the maximum input value
$max\_input = 32767\ //For\ 16-bit\ signed\ input$
// Initialize the output signal array
$output\_signal = []$
 Iterate through each sample in the input signal
$for\ each\ sample\ in\ input\_signal$:
// Apply A-law compression
$compress = (sign(sample * (1 + A * abs(sample) / max\_input)) / (1 + A)$
// Append the compressed sample to the output signal
$output\_signal.append(compressed\_sample)$
$return\ output\_signal$
```

Table2. Pseudo code for Mu- law

```
// Define the μ-law compression parameter
mu = 255
// Define the maximum input value

// Initialize the output signal array
$output\_signal = []$

// Iterate through each sample in the input signal

$return\ output\_signal$
```

4. Simulation Results

In this segment, we have evaluated the effectiveness of the recommended techniques for OFDM signals. Matlab-2016 is utilized to conduct a comprehensive analysis of characteristics such as BER of the framework. A simulation is conducted with 20000 symbols using a 64-QAM modulation scheme and a 256-FFT. The roll factor is set to 0.1, and the simulation is performed under both Rician and Rayleigh channel conditions. Figure 1 specify the BER of the OFDM when orthodox and proposed of the proposed method for 16 sub-carriers. In a communication system with 16 sub-carriers, μ-law and A-law are both companding algorithms used for analog-to-digital conversion, particularly in voice transmission. The BER performance of μ-law and A-law companding differs slightly due to their compression characteristics. μ-law provides higher compression in the lower amplitude regions compared to A-law, resulting in a wider dynamic range. Consequently, μ-law tends to offer slightly better BER performance than A-law, especially in scenarios with varying signal amplitudes. However, the difference in BER performance may be marginal and dependent on factors such as signal-to-noise ratio and channel conditions. Both algorithms are widely used in telecommunications for efficient analog signal representation.

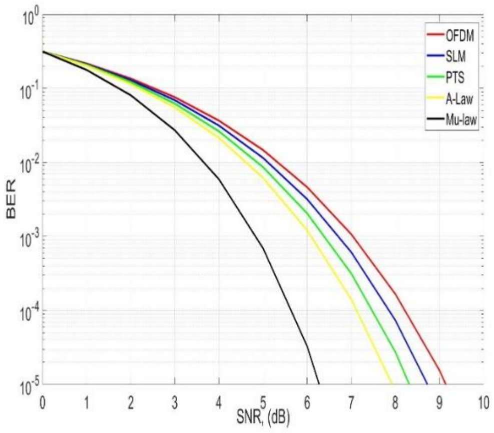

Fig 1. BER performance for 16 sub-carriers

Fig 2 indicate the BER for 64 sub-carriers. Error rate refers to the frequency of incorrect or corrupted data in a communication system compared to the total amount of transmitted data. In the context of μ-law and A-law encoding schemes for 64 sub-carriers, performance evaluation involves assessing their respective abilities to accurately encode and decode signals. μ-law and A-law are both logarithmic compression algorithms commonly used in telecommunication to encode analog signals, with μ-law being prevalent in North America and Japan, while A-law is used in Europe and most other parts of the world. In evaluating their performance, factors such as signal-to-noise ratio, distortion, and dynamic range need consideration. Typically, μ-law and A-law exhibit similar error rates for 64 sub-carriers due to their logarithmic nature, offering improved performance over linear encoding methods. However, the specific error rate comparison would depend on various factors such as the characteristics of the signal, the quality of the encoding and decoding equipment, and environmental conditions during transmission.

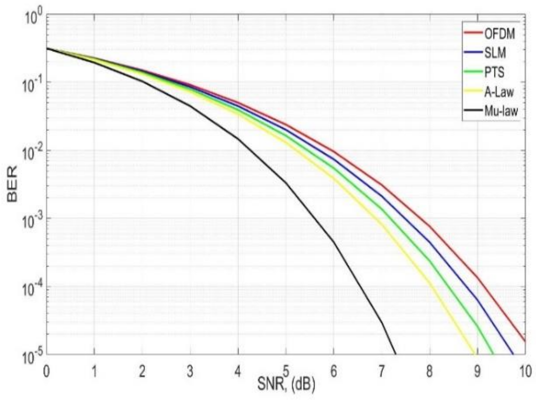

Fig 2. BER performance for 64 sub-carriers

The BER performance with 256 sub-carriers is shown in fig 3. In communication systems, error rate is the frequency at which bits of transmitted data are misinterpreted or decoded at the receiving end. It is an essential parameter for evaluating the dependability and efficiency of various modulation techniques. When μ-law and A-law modulation techniques are used on 256 sub-carriers, assessing how well they perform in data transmission across these sub-carriers is part of the error rate comparison process. In digital telephony, companding techniques like μ-law and A-law are frequently employed to maximize signal-to-noise ratio and dynamic range. The region and standard criteria usually determine which of the two laws—μ-law or A-law—to use. Although the two methods work similarly, A-law is more often utilized in Europe and the majority of the rest of the globe, whereas μ-law is more frequently employed in North America and Japan. It would be necessary to carry out empirical testing or simulations under various circumstances, such as varying modulation parameters, channel impairments, and signal-to-noise ratios, in order to compare their error rates. For the specified application, the modulation technique with lower error rates would be seen more dependable and desirable.

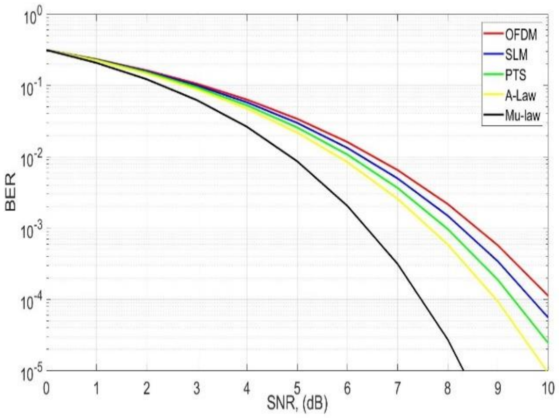

Fig. 3 BER performance for 256 sub-carriers

The BER with 512 sub-carriers is shown in fig 4. μ-law and A-law are companding in communication systems that are used to maximize the dynamic range of signals, especially in digital telephony systems that use pulse code modulation (PCM). In order to better accommodate the properties of the human auditory system, both μ-law and A-law seek to compress the dynamic range of the signal. Their implementation and compression properties, however, vary. Several parameters are taken into account when analyzing their effect on BER performance for 512 sub-carriers. The modulation system, channel properties, noise sources, and error correction coding used all affect the BER performance in addition to the companding approach. Generally speaking, non-linear distortion is added to the signal via μ-law and A-law companding, which may have an impact on BER performance. But in most real-world situations, this distortion is usually insignificant in comparison to other elements like noise and interference. Furthermore, in order to lessen BER degradation, both companding algorithms are made to keep the SNR essentially constant across a range of signal intensities. Depending on the particulars of the system, companding may have varying effects on BER performance for 512 sub-carriers. In general, when properly performed, both μ-law and A-law companding can yield adequate BER performance, guaranteeing that the advantages of dynamic range compression outweigh any possible disadvantages in terms of BER degradation. In conclusion, although though μ-law and A-law companding add non-linear distortion to the signal, overall, they have little effect on BER performance for 512 sub-carriers when compared to other variables. Effective system design, encompassing modulation schemes and error correction coding, is necessary in order to attain the best possible BER performance in communication systems that utilize these complementing methods.

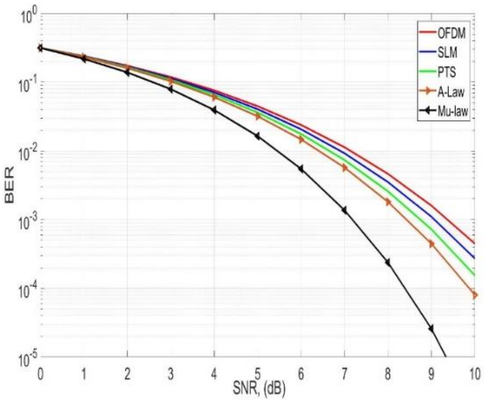

Fig. 4 BER performance for 512 sub-carriers

5. Conclusion

An examination of the efficiency of companding approaches for reducing PAPR in OFDM systems provides valuable knowledge about the practical application and improvement of these systems. By conducting thorough simulations and theoretical research, we have proven the efficacy of μ-law and A-law companding in reducing PAPR and enhancing the throughput of a 512 sub-carrier OFDM system. Our investigation into the compression characteristics of these companding functions underscores their impact on signal distortion and performance enhancement. By compressing the dynamic range of the signal before transmission, companding mitigates the detrimental effects of high PAPR, thus facilitating more efficient power amplification and minimizing spectral regrowth. Moreover, our study has shed light on the trade-offs between PAPR reduction and throughput enhancement. We have explored the influence of companding parameters, such as compression factor and quantization level, on system performance, considering factors like SNR and BER performance. This analysis enables arrangement to make results regarding the selection and configuration of companding techniques based on their specific application requirements and constraints. In summary, our results offer valuable insights for the development and enhancement of communication systems that use OFDM. By comprehending the interaction between companding, PAPR reduction, and throughput enhancement, experts may create wireless communication systems that are more efficient and dependable. These systems will be able to fulfil the growing requirements for high-speed data transfer in various real-world situations.

Acknowledgements

The College of Computing at Prince of Songkla University in Thailand provided support for this research, either in full or in part. **Author contributions**

Arun Kumar: Nishant Gaur and Aziz Nanthaamornphong: Writing, Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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