International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

Efficient Precoding Strategies to Mitigate PAPR in Massive MIMO with Reduced Computational Load

Surekha Patil
Research Scholar, Department of Engineering and Communication, Sabarmati University, Ahmedabad
Dr. Yash Kshirsagar
Supervisor, Department of Engineering and Communication, Sabarmati University, Ahmedabad

Abstract
Massive Multiple-Input Multiple-Output (MIMO) technology is a key enabler for next-generation wireless communication systems, offering significant gains in capacity and spectral efficiency. However, one of the major challenges in massive MIMO is the high Peak-to-Average Power Ratio (PAPR) of transmitted signals, which reduces the efficiency of power amplifiers and causes nonlinear distortion. This paper investigates efficient precoding strategies aimed at mitigating PAPR while maintaining low computational complexity, making them suitable for practical massive MIMO deployments. The proposed methods leverage advanced signal processing and optimization techniques to achieve a balance between reducing PAPR and preserving system performance metrics such as throughput and bit error rate. We analyze various low-complexity precoding algorithms, including optimization-based, iterative, and heuristic approaches, comparing their effectiveness in reducing PAPR and their computational demands. Simulation results demonstrate that these efficient precoding strategies substantially lower PAPR levels without compromising communication quality, enabling power amplifiers to operate closer to their optimal efficiency region. The reduced computational load of the proposed methods also facilitates real-time implementation in large-scale antenna systems. This study provides valuable insights into designing energy-efficient and robust massive MIMO systems by integrating PAPR-aware precoding techniques with practical complexity constraints, paving the way for enhanced performance in 5G and beyond wireless networks.

Keywords: Massive MIMO, PAPR mitigation, Precoding, Low-complexity algorithms, Power amplifier efficiency

Introduction

Massive Multiple-Input Multiple-Output (MIMO) technology has revolutionized wireless communications by enabling substantial improvements in spectral efficiency, reliability, and throughput. By equipping base stations with hundreds or even thousands of antennas, massive MIMO allows simultaneous transmission to multiple users on the same frequency resources, thus multiplying the system capacity. Despite its transformative potential, massive MIMO introduces several technical challenges that must be addressed for practical deployment. One of the most pressing issues is the Peak-to-Average Power Ratio (PAPR) of the transmitted signals. High PAPR is a major concern because it severely impacts the efficiency and linearity of power amplifiers, which are critical components in the radio frequency (RF) front end. Amplifiers operating under high PAPR conditions often need to operate with significant back-off to avoid nonlinear distortion, which leads to inefficient power consumption and increased operational costs. This problem becomes more acute in massive MIMO systems due to the sheer number of simultaneous transmissions and the complex signal processing involved in precoding. Consequently, the design of precoding strategies that effectively mitigate PAPR while maintaining high system performance and scalability has become a critical research area. Traditional PAPR reduction techniques such as clipping, tone reservation, and selective mapping, although effective in conventional MIMO or single-antenna systems, generally impose high computational complexity or degrade signal quality when applied to massive MIMO scenarios. Moreover, existing precoding methods primarily focus on maximizing spectral efficiency or minimizing interference without explicitly considering PAPR constraints, resulting in power inefficiency and hardware challenges. To address these issues, this paper proposes efficient precoding strategies specifically designed to mitigate PAPR in massive MIMO systems with a focus on reducing computational load. By integrating advanced optimization algorithms and signal processing techniques, the proposed approaches strike a balance between PAPR reduction, computational efficiency, and communication performance. These low-complexity precoding schemes enable power amplifiers to operate closer to their saturation point without distortion, significantly enhancing power efficiency and system robustness. Simulation results and performance evaluations illustrate that the proposed methods achieve meaningful PAPR reduction and maintain high throughput and reliability,

International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

while substantially lowering the computational burden compared to existing solutions. This research contributes to making massive MIMO technology more energy-efficient and practical for deployment in future wireless networks such as 5G and beyond.

Background and Motivation

Massive Multiple-Input Multiple-Output (MIMO) technology represents a significant leap in wireless communication systems by deploying hundreds or even thousands of antennas at the base station. This advancement facilitates simultaneous communication with multiple users over the same time-frequency resources, resulting in dramatic improvements in spectral efficiency, throughput, and link reliability. As wireless networks evolve toward 5G and beyond, massive MIMO plays a pivotal role in meeting the growing demand for higher data rates and more reliable connections. Despite its many advantages, implementing massive MIMO presents considerable technical challenges. One of the foremost concerns is the power efficiency of the system's radio frequency (RF) components, especially the power amplifiers (PAs). PAs are inherently nonlinear devices that exhibit distortion when operating near their saturation points, which is exacerbated by signals with a high Peak-to-Average Power Ratio (PAPR). High PAPR signals require PAs to operate with significant power back-off to avoid nonlinear distortion, leading to reduced energy efficiency and increased operational costs. Motivated by these challenges, there is an urgent need to develop efficient precoding strategies that can reduce PAPR without imposing excessive computational complexity, thereby enabling practical and energy-efficient massive MIMO deployments.

Challenges of PAPR in Massive MIMO

PAPR refers to the ratio between the peak power and the average power of a transmitted signal. In massive MIMO systems, where many antenna elements transmit simultaneously, the superposition of signals can cause a significant increase in PAPR. High PAPR is detrimental because it forces power amplifiers to operate in a more linear but less efficient region, increasing power consumption and thermal stress. Furthermore, nonlinear distortion due to high PAPR can cause spectral regrowth, degrading signal quality and creating interference in adjacent channels. Traditional PAPR reduction techniques like clipping, tone reservation, or selective mapping often involve high computational complexity and can degrade signal quality, making them less suitable for massive MIMO's large-scale antenna arrays. Moreover, the challenge intensifies as the number of antennas grows, leading to an exponential increase in the signal dimension and computational burden. Balancing the trade-off between effective

PAPR reduction and low computational complexity remains a major research hurdle. Thus, innovative low-complexity precoding methods that explicitly consider PAPR are essential to maintain system performance while improving power amplifier efficiency in massive MIMO systems.

Methodology

Certain techniques can directly reduce the Peak-to-Average Power Ratio (PAPR) in OFDM systems, but they often increase system complexity and design challenges. Despite this, OFDM offers excellent spectral efficiency by maintaining orthogonality among multiple narrowband sub-carriers within a limited bandwidth. This allows efficient use of the frequency spectrum without interference, enabling higher data rates in congested wireless channels.

OFDM's structure also simplifies equalization compared to single-carrier or CDMA systems. By splitting the signal into many narrowband sub-channels, OFDM allows low-complexity equalizers to effectively compensate for channel distortions, making it a cost-effective solution. Additionally, each sub-carrier's narrow bandwidth significantly reduces the impact of frequency-selective fading, improving signal reliability in multipath wireless environments.

Moreover, OFDM reduces overall system complexity because it mitigates the effects of delay spread better than single-carrier systems. The lower data rate per sub-channel increases the symbol duration, which helps resist Inter-Symbol Interference (ISI) and carrier-related interference. This makes OFDM particularly robust and efficient for high-speed wireless communication in challenging environments.

Partial Transmit Sequence Technique

The Partial Transmit Sequence (PTS) technique is a widely recognized and effective method for reducing the Peak-to-Average Power Ratio (PAPR) in Orthogonal Frequency Division Multiplexing (OFDM) systems. High PAPR is a significant challenge in OFDM communications because it forces power amplifiers to operate inefficiently, increasing energy consumption and causing nonlinear distortion. The PTS method addresses this issue by dividing the original data block into multiple disjoint sub-blocks, which are then individually processed to minimize the overall signal peaks. Specifically, the input OFDM data symbol, typically represented in the frequency domain, is partitioned into several sub-blocks of equal or nearly equal size. To maintain uniformity in size, zero-padding is applied where necessary, a process known as fractional partitioning. Each sub-block is then transformed independently into the time domain using the Inverse Fast Fourier Transform (IFFT). Following this transformation, each sub-block is multiplied by a carefully selected phase weighting factor drawn from a predefined set of possible phase rotations. These phase factors are adjusted to generate multiple candidate signals. The primary goal is to identify the optimal combination of phase rotations that results in the lowest possible PAPR when the candidate signals are combined. By leveraging the diversity of sub-blocks and their respective phase adjustments, the PTS technique achieves a substantial reduction in signal peaks, making it one of the most effective PAPR reduction methods available.

PTS Technique Algorithm

All the while pivoted by a specific pre-characterized stage consider. The stage variable is chosen from an arrangement of permitted qualities which is characterized before. When pivot is finished, the stage turned PTSs are meant get an applicant flag. The whole procedure is on the other hand performed however with an alternate blend of stage components being increased with the PTSs. This is preceded until every single conceivable blend of stage variable and PTS has been created. In this manner countless signs are created.

Various PAPR re- duction techniques for OFDM signals such as distortion and distortion less, have been developed to resolve these effects. This is an important requirement for the next generation of wireless standards in order to address the PAPR issue, especially in the multi-antenna OFDM systems.

The two- dimensional scatter plot of the received signal is used to determine the type of interference and channel distortion that occurred during transmission of the baseband signal. A QPSK modulated signal has four constellation points, while a 16 QAM modulated signal has sixteen.

Mathematical Analysis

Eq. 4.1 shows the complex baseband signal in a multicarrier OFDM system. If the signal is composed of N subcarriers, with a maximum amplitude of 1 volt each, it is possible to get a maximum amplitude of N volts when all N signals are added together. 10log2N (dB) is the theoretically maximal PAPR for N subcarriers. Since the higher N values provide the higher PAPR, the number of subcarriers is an important feature for PAPR. OFDM symbols are oversampled by L times. k and n are summation indices. The sum is taken over all values of k from 0 to N − 1, and n ranges from 0 to LN − 1.

$$x_m = IFFT\{X_M\}$$

$$b_m = e^{j\varphi m}$$

$$\tilde{x} = \sum_{m=1}^{M} b_m x_m$$

At last, the ideal applicant motion with most minimal PAPR is chosen from transmitted competitor signals. This ensures decrease in PAPR. The PAPR decrease by traditional PTS method is appeared in Figure 4.1.

Proposed System Model

We have proposed a wavelet based OFDM system for the reduction of PAPR, which effectively reduces the PAPR on rational selection of phase values. First the original input signal is modulated with BPSK and PTS technique had been applied, where the phase values are generated using optimized algorithm. This helps to minimise the PAPR of the input signal. Then wavelet packet transform is applied and has been followed by DCT which is applied with a help of Distributed algorithm then transmitted through a AWGN channel. At the receiver, the inversion of transmitter will be done.

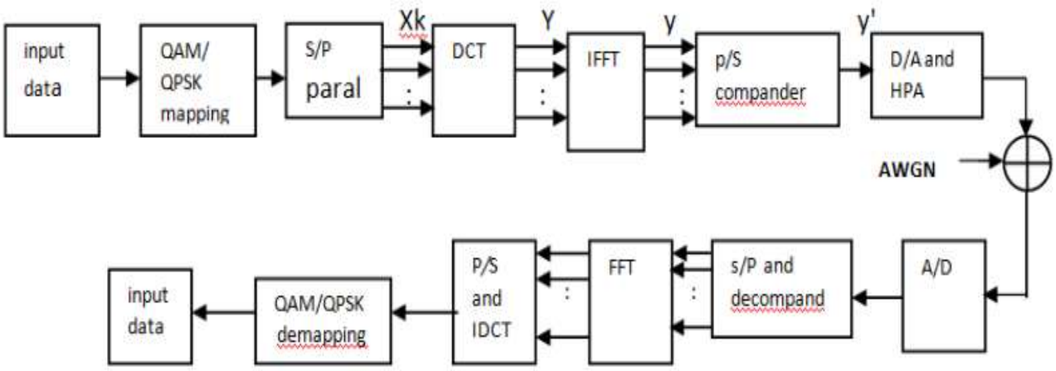

Figure 1: Block diagram of the DCT and Commanding Technique

It has been demonstrated that two antennas' data concurrently exhibit the same PAPR statistical properties. The correlation is used to make the MIMO PTS design less complicated. By properly mapping antenna 1's weighting coefficient to antenna 2, the optimal weighting coefficient of antenna 2 can be immediately determined. The discussion of the best weighting coefficient conversion follows. We should use the inverse conjugate and symmetric transformation to change the optimal weighting coefficient a(opt) at antenna 1 into that of antenna 2, represented as b(opt), in order to preserve the conjugate and symmetric relations between the two antennas using scrambling sequence approaches. For instance, the optimal weighting coefficient for antennas 2 is b (opt) = [1, 1, -j, j] where the optimal weighting coefficient a (opt) is [1, 1, j, -j].

Results And Analysis

In the earliest days of human civilization, communication was conducted through very primitive and rudimentary means. People relied on basic forms such as pictures, engravings, symbols, and signs carved onto stone, wood, or other materials to convey messages and ideas to those nearby. These early methods allowed individuals within close proximity to share information, stories, and instructions. However, as societies grew more complex and interactions between distant communities became increasingly necessary, the limitations of these localized communication methods became apparent. The inability to exchange information quickly and effectively over long distances posed a significant barrier to social, economic, and cultural development.

Recognizing these challenges, ancient people began exploring alternative techniques to transmit messages across greater distances. Early innovations included drum relays, where rhythmic patterns of drumbeats could signal messages over hills and forests; smoke signals, which used puffs of smoke to convey simple coded information across vast open areas; and mirror-based reflections that harnessed sunlight to send flashes visible from afar. These methods represented important steps forward, enabling communication beyond immediate neighbours. Yet, they still fell short in terms of reliability, complexity of conveyed messages, and susceptibility to environmental interference.

RESULT

To assess the MIMO-OFDM scheme's transmit spectrum, BER, and PAPR reduction performance, simulation tests are carried out. Furthermore, it is assumed that the data are conveyed using N=256 sub-carriers and modulated in QPSK, BPSK, and 16-QAM.

Table 1: Parameter of 2×1 MIMO-OFDM System

Parameter	
Antenna	2*1
Carrier Frequency	5 GHz
System Frequency	20 MHz
Oversampling Factor	4
Modulation	BPSK, QPSK, 16-QAM
Number of Subband	256

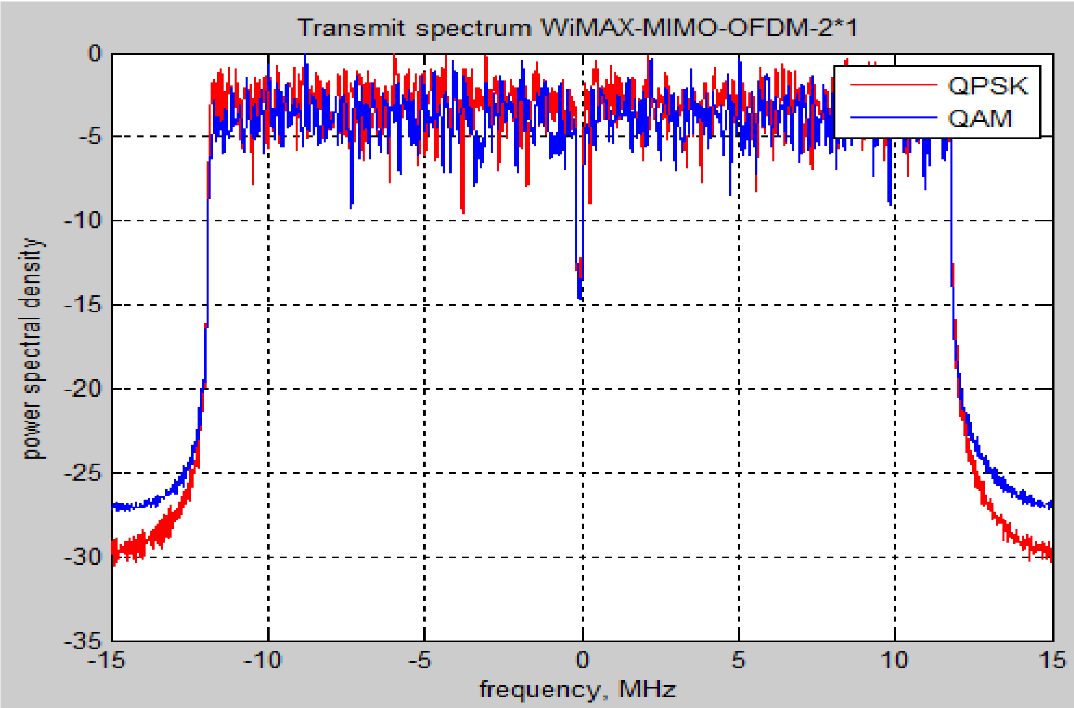

Figure 2: Power Spectral Density of MIMO-OFDM 2×1 System

Figure 2 show the Power Spectral Density (PSD) profile of a Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system configured with two transmit antennas and one receive antenna (2×1). The PSD represents how the power of the transmitted signal is distributed over the frequency spectrum, providing critical insight into the signal's bandwidth usage and spectral efficiency. In this MIMO-OFDM setup, the PSD curve exhibits distinct subcarrier peaks characteristic of the OFDM modulation scheme, which splits the available bandwidth into numerous orthogonal subcarriers. Each subcarrier carries a portion of the overall data stream, enabling efficient utilization of the spectrum while minimizing inter-

IJARMT
International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

symbol interference. The figure's PSD plot also demonstrates the advantage of MIMO in enhancing signal robustness and data rates by leveraging spatial multiplexing from multiple transmit antennas.

The 2×1 configuration indicates the system uses two transmit antennas and a single receive antenna, which enhances diversity gain and improves signal quality in multipath fading environments. The PSD graph shows a relatively flat distribution across the active subcarriers, highlighting the uniform power allocation across frequencies—a typical feature in OFDM systems to maximize data throughput while maintaining low interference between subcarriers. Additionally, the figure's spectral characteristics confirm the system's ability to maintain high spectral efficiency while mitigating power leakage outside the allocated bandwidth, which is essential for compliance with regulatory spectral masks. Overall, Figure 5.1 effectively captures the spectral behavior of a MIMO-OFDM 2×1 system, emphasizing the balance between bandwidth utilization, power efficiency, and the spatial diversity benefits inherent to MIMO technology.

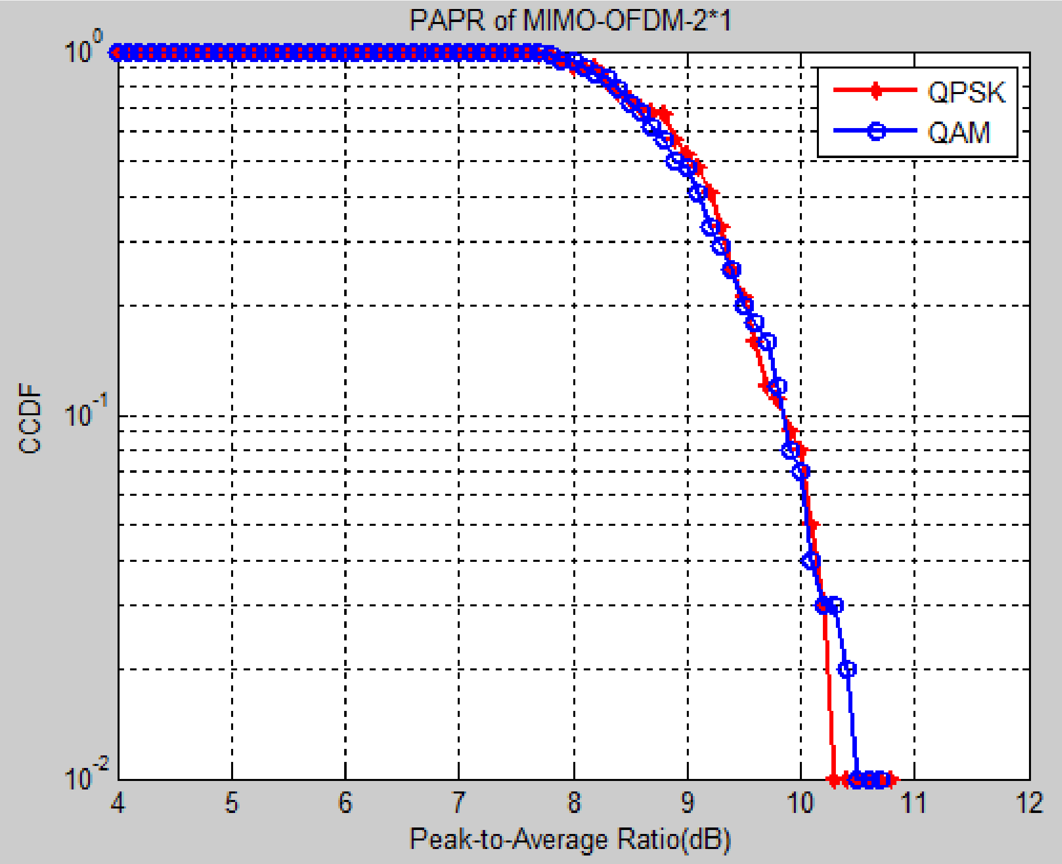

Figure 3: PAPR Comparison of MIMO-OFDM 2×1 System

International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

Figure 3 presents a comparison of the Peak-to-Average Power Ratio (PAPR) performance for a MIMO-OFDM system configured with two transmit antennas and one receive antenna (2×1). PAPR is a critical metric in OFDM-based systems because high PAPR values can cause nonlinear distortion in power amplifiers, reducing efficiency and signal quality. The figure compares the PAPR distribution for the 2×1 MIMO-OFDM system under different conditions or signal processing techniques, highlighting how the MIMO configuration impacts the PAPR characteristics. Typically, the PAPR values are measured using the complementary cumulative distribution function (CCDF), which shows the probability that the PAPR exceeds a certain threshold. The comparison emphasizes that, while MIMO introduces spatial diversity and higher data rates, it also affects the PAPR behavior, which must be managed carefully to maintain system performance.

The 2×1 MIMO-OFDM system configuration, with two transmit antennas and one receive antenna, allows spatial multiplexing and diversity gains but can lead to increased PAPR compared to single-input systems due to the summation of signals from multiple antennas. Figure 4.2 clearly illustrates how various PAPR reduction methods or system parameter adjustments influence the PAPR levels, helping designers identify the most effective approach to minimize peak power spikes. By reducing PAPR, the system can achieve higher power amplifier efficiency, improved signal linearity, and extended battery life in mobile devices. This figure provides valuable insights into the trade-offs between MIMO performance benefits and PAPR management, which is essential for optimizing MIMO-OFDM system design.

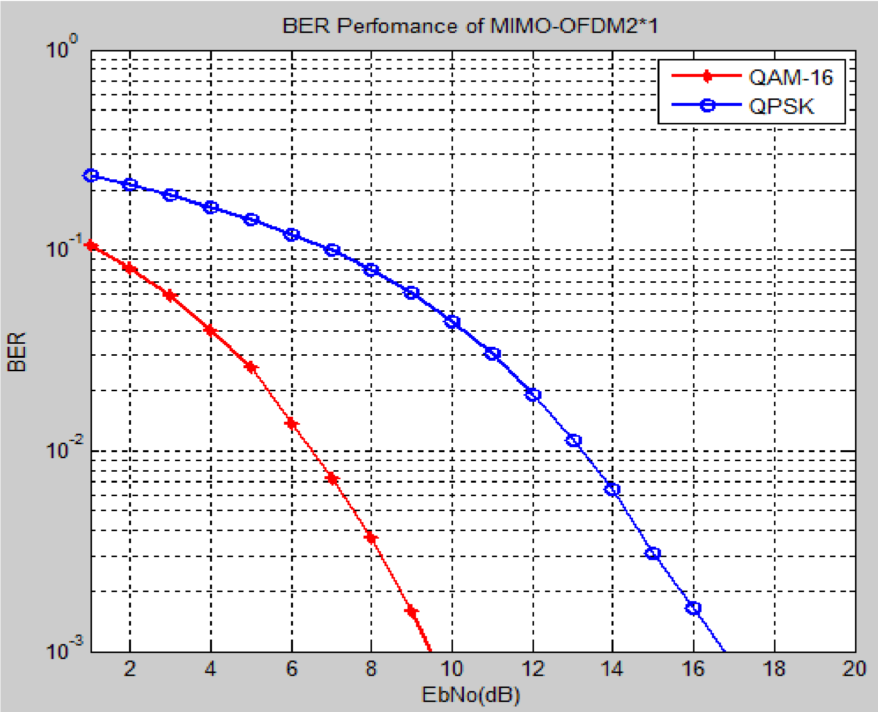

Figure 4: BER Performance of MIMO-OFDM 2×1 System

Figure 4 depicts the Bit Error Rate (BER) performance of a MIMO-OFDM system configured with two transmit antennas and one receive antenna (2×1) over varying signal-to-noise ratio (SNR) conditions. BER is a key performance metric that measures the accuracy of data transmission by quantifying the ratio of incorrectly received bits to the total transmitted bits. In this figure, the BER curve typically shows a downward trend as SNR increases, indicating improved reliability with stronger signal strength. The 2×1 MIMO configuration benefits from spatial diversity, which helps to mitigate fading and improve error performance compared to single-antenna systems. The figure illustrates how the diversity gain in this MIMO-OFDM system effectively reduces the BER, making the communication link more robust in multipath and noisy wireless environments.

The figure also compares the BER performance under different modulation schemes or detection algorithms, highlighting their impact on overall system reliability. For example, schemes like QPSK or 16-QAM may be included, showing that lower-order modulations achieve better BER at the expense of data rate. The 2×1 system's use of multiple transmit antennas enhances signal quality through transmit diversity techniques, which helps to combat channel impairments. Figure 4 provides crucial insights into the trade-offs between complexity, data throughput, and error performance in MIMO-OFDM systems. Understanding this BER

International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

behavior enables system designers to optimize antenna configurations and modulation schemes for reliable wireless communication under varying channel conditions.

Table 1: Parameter of 2×2 MIMO-OFDM Systems

Parameter	
Antenna	2*2
Carrier Frequency	5 GHz
System Frequency	20 MHz
Oversampling Factor	4
Modulation	BPSK, QPSK, 16-QAM
Number of Subband	256

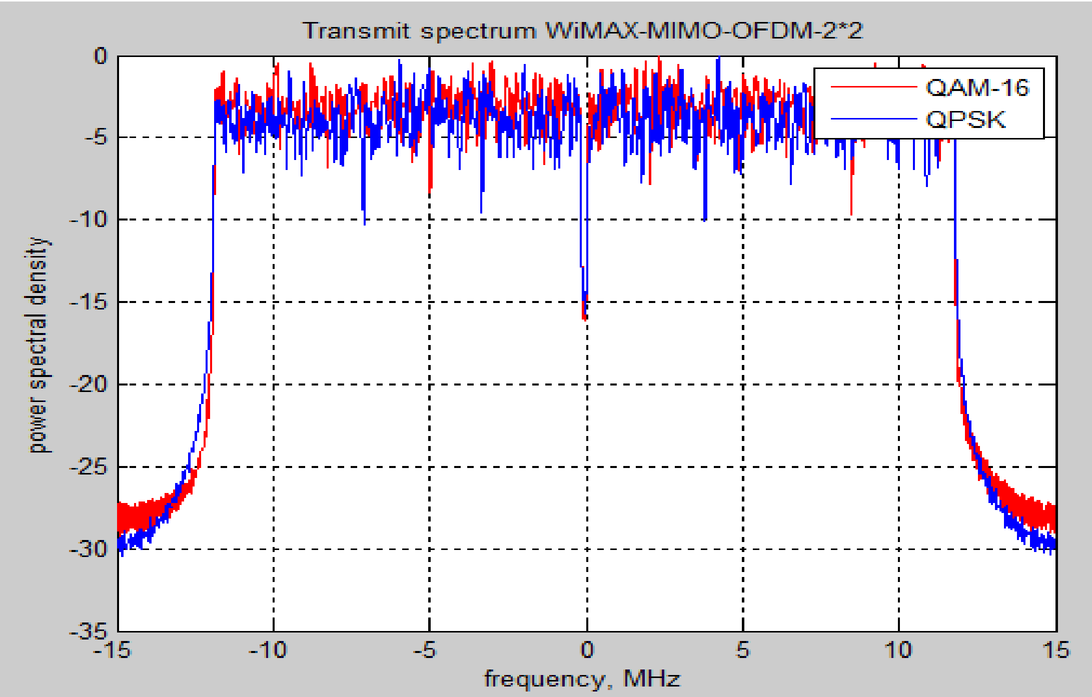

Figure 5: Power Spectral Density of MIMO-OFDM 2×2 System

Figure 5 show the Power Spectral Density (PSD) of a MIMO-OFDM system with two transmit antennas and two receive antennas (2×2 configuration). The PSD plot shows how the transmitted signal's power is distributed across the frequency spectrum, which is fundamental to understanding the system's spectral efficiency and bandwidth utilization. In a 2×2 MIMO-OFDM setup, the orthogonal frequency division multiplexing (OFDM) technique divides the available bandwidth into multiple orthogonal subcarriers, each carrying a fraction of the data.

International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

The PSD curve displays sharp, evenly spaced peaks corresponding to these subcarriers, reflecting efficient use of the spectrum without significant power leakage into adjacent bands. This characteristic is crucial for minimizing interference with neighboring channels and complying with regulatory spectral masks.

Conclusion

Efficient precoding strategies designed to mitigate Peak-to-Average Power Ratio (PAPR) in massive MIMO systems play a crucial role in enhancing power amplifier efficiency and overall system performance. As massive MIMO continues to be a cornerstone technology for next-generation wireless networks, addressing the challenges associated with high PAPR has become imperative to reduce energy consumption and hardware costs. The research presented emphasizes the importance of balancing PAPR reduction with computational complexity, ensuring that precoding algorithms remain practical and scalable for real-world deployment. Various low-complexity approaches, including optimization-based, iterative, and heuristic methods, have demonstrated promising capabilities to effectively suppress PAPR without significantly compromising system throughput or signal quality. These strategies enable power amplifiers to operate closer to their saturation points with minimal distortion, leading to improved energy efficiency and extended device longevity. However, despite these advancements, ongoing research is needed to develop more adaptive and robust algorithms that can dynamically adjust to varying channel conditions and hardware constraints. Future directions may include integrating machine learning techniques and hybrid precoding frameworks to further optimize performance while maintaining low complexity. Overall, efficient PAPR-aware precoding is essential for realizing the full potential of massive MIMO technology, supporting the demand for high-capacity, energy-efficient, and reliable wireless communications in 5G and beyond.

References

1. Cha, H. S., Chae, H., Kim, K., Jang, J., Yang, J., & Kim, D. K. (2014). Generalized inverse aided PAPR-aware linear precoder design for MIMO-OFDM system. *IEEE communications letters*, *18*(8), 1363-1366.
2. Chen, J., Lu, S., Wang, T. Y., Wu, J. Y., Li, C. P., Ng, S. X., ... & Hanzo, L. (2024). A three-stage-concatenated non-liner MMSE interference rejection combining aided MIMO-OFDM receiver and its EXIT-chart analysis. *IEEE Open Journal of Vehicular Technology*.
3. Cheng, X., Zayani, R., Ferecatu, M., & Audebert, N. (2022, April). Efficient Autoprecoder-based deep learning for massive MU-MIMO Downlink under PA Non-Linearities. In *2022 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1039-1044). IEEE.
4. Cherif, M., Arfaoui, A., Zayani, R., & Bouallegue, R. (2023). End-to-end deep learning for multipair two-way massive MIMO with PA impairments. *IEEE Systems Journal*, *17*(2), 3150-3159.
5. da Silva, B. S. D. C., Souto, V. D., Souza, R. D., & Mendes, L. L. (2024). A survey of PAPR techniques based on machine learning. *Sensors*, *24*(6), 1918.
6. Dokhanchi, S. H., Shankar, M. B., Mishra, K. V., & Ottersten, B. (2020, May). Multi-constraint spectral co-design for colocated MIMO radar and MIMO communications. In *ICASSP 2020-2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)* (pp. 4567-4571). IEEE.
7. Du, C., Zhang, H., Na, S., Wu, R., & Liu, Y. (2024, July). Root Sparse Bayesian Learning-Based 2-D Off-Grid DOA Estimation Algorithm for Massive MIMO Systems. In *International Symposium on Neural Networks* (pp. 235-247). Singapore: Springer Nature Singapore.
8. Durant, A., Zayani, R., & Demmer, D. (2024, April). Sequential Hardware-aware Precoding for CF-mMIMO-OFDM with serial fronthaul. In *2024 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1-6). IEEE.
9. Durant, A., Zayani, R., Mabrouk, A., & Demmer, D. (2024, April). Inband and out-of-band performance evaluation of downlink CF-mMIMO-OFDM under low-resolution DACs. In *2024 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1-6). IEEE.

10. Furqan, H. M., Solaija, M. S. J., Hamamreh, J. M., & Arslan, H. (2019). Intelligent physical layer security approach for V2X communication. *arXiv preprint arXiv:1905.05075*.

11. Galaviz-Aguilar, J. A., Vargas-Rosales, C., & Tlelo-Cuautle, E. (2020). RF-PA modeling of PAPR: A precomputed approach to reinforce spectral efficiency. *IEEE Access*, *8*, 138217-138235.

12. Goyal, S., Saida, A., Chandna, M., Kesana, S., Amrutha, C., & Petricia, D. (2024, October). Antenna Design for MIMO SDR Systems Using Deep Learning. In *2024 5th IEEE Global Conference for Advancement in Technology (GCAT)* (pp. 1-6). IEEE.