Diverse Methods to Reduce Peak to Average Power Ratio (PAPR) in wireless communication: A review

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Abstract— **Multicarrier system like orthogonal frequency division multiplexing is considered to be a promising technique against the multipath fading channel for wireless communications. However, it faces the Peak-to-Average Power Ratio (PAPR) problem that is a major drawback of multi-carrier transmission system which leads to power inefficiency in RF section of the transmitter. Diverse methods, such as clipping, peak windowing, scrambling, and selected mapping, are used to reduce PAPR and improve transmission efficiency. Each technique has trade-offs in terms of complexity, efficiency, and impact on system performance. This paper discusses briefly the overview, drawbacks and comparison of diverse methods to reduce PAPR.**

Keywords— **PAPR, SLM, PTS, OFDM, TR.**

1. OVERVIEW

Peak-to-Average Power Ratio (PAPR) is the ratio of the peak power to the average power of a signal expressed in decibels (dB). It is particularly relevant in wireless communication systems like Orthogonal Frequency-Division Multiplexing, where signals can exhibit high peak values compared to their average power. It occurs due to the nature of signals in wireless communication systems. PAPR of generated OFDM symbols x(t) is calculated by dividing the upper instantaneous power to the average power and is given as:

$$\mathrm{PAPR}[x(t)] = \frac{P_{PEAK}}{P_{AVERAGE}} = 10\log_{10}\frac{\max[|X(n)|^2]}{E[|x_n|^2]}$$

P_{PEAK} symbolizes peak output power, $P_{AVERAGE}$ symbolizes average output power. E[·] symbolizes the probable value, x_n symbolizes the propagated OFDM symbols which are acquired with IFFT on modulated input symbols X_k [3].

In Orthogonal Frequency-Division Multiplexing, multiple sub-carriers are transmitted simultaneously, each carrying different data. These sub-carriers can sometimes align in phase, leading to constructive interference, which causes sudden spikes in signal amplitude. Since the peak power can be significantly higher than the average power, this results in a high PAPR. A high PAPR can lead to inefficiencies in power amplifiers, causing distortions and reducing overall system performance. The PAPR problem is more significant in the uplink because the efficiency of power amplifier is critical because a mobile terminal has a limited battery power. Various techniques, such as clipping, peak windowing, scrambling, and selected mapping, are used to reduce PAPR and improve transmission efficiency. Each technique has trade-offs in terms of complexity, efficiency, and impact on system performance. PAPR is especially important in modern cellular systems like %G and LTE, where OFDM is widely used. High PAPR can impair signal clarity and increase hardware costs especially important in satellite and radar systems. Devices like smartphones and Wi-Fi routers benefit from PAPR reduction to improve battery life and signal quality.

2. KEY REASONS FOR HIGH PAPR

- **Multicarrier Nature of Modern Wireless System (OFDM)**

  Modern Wireless systems use OFDM which transmits data over multiple closely spaced sub-carriers. When these subcarriers align in phase, their amplitudes add up, creating large instantaneous peaks. This is the fundamental cause of high PAPR

- **Random Input Data Sequences**

  The input data to OFDM is typically random. Certain sequences can cause all subcarriers to transmit at high amplitudes simultaneously, resulting in constructive interference and high peak power.

- **Signal Summation**

  The OFDM signal is a sum of many sinusoids. While the average power remains moderate due to destructive interference, the peak can be very high when all sinusoids align constructively.

- **Lack of Power Control Mechanisms**

  Without specific techniques to manage or shape the signal envelope, the natural output of OFDM tends to have high PAPR. This is especially problematic when no coding or mapping strategies are used to limit peak formation.

- **Nonlinear Amplifier Effects**

  High PAPR stresses power amplifiers, which are often nonlinear. This leads to in-band distortion (increased bit error rate) and out-of-band radiation (interference with adjacent channels).

High PAPR in modern wireless/ cellular systems is a natural outcome of combining multiple sub-carriers, especially when their phases align. This causes large peaks relative to the average signal power, leading to inefficiencies and distortion unless mitigated by methods like clipping, coding, or selective mapping.

3. CONSEQUENCES OF HIGH PAPR

- **Reduced Power Efficiency**:
  Amplifiers must operate with a large back-off to avoid distortion, reducing efficiency.
- **Signal Distortion**:
  Nonlinearities in amplifiers distort high-peak signals.
- **Costly Hardware**:
  Requires highly linear and expensive components to handle peak power.
- **Battery Drain**:
  In mobile devices, inefficient amplification leads to faster battery depletion.

4. DIVERSE METHODS TO REDUCE HIGH PAPR

Reducing Peak-to-Average Power Ratio (PAPR) is essential in multi-carrier systems like OFDM to improve power amplifier efficiency and reduce signal distortion. Here’s a breakdown of the most effective techniques used to mitigate PAPR:

4.1. Clipping and Windowing

Clipping is the simplest and most direct way to reduce PAPR. It limits the amplitude of the signal to a predefined threshold. Set a clipping level A. Any signal sample x(t) with magnitude greater than A is clipped:

Advantages:

- Easy to implement.
- Effective in reducing PAPR quickly.

Disadvantages:

- **In-band distortion:** Degrades Bit Error Rate (BER).
- **Out-of-band radiation:** Causes interference with adjacent channels.
- **Peak regrowth:** Filtering after clipping can regenerate peaks.

Windowing is often used in conjunction with clipping to suppress out-of-band radiation caused by clipping. After clipping, apply a window function (e.g., Hamming, Kaiser, Blackman) to the clipped signal. This smooths the transitions and reduces spectral leakage.

Advantages:

- Reduces out-of-band emissions.
- Improves spectral efficiency.

Disadvantages:

- May slightly reduce signal power.
- Doesn't eliminate in-band distortion from clipping.

4.2. Selected Mapping (SLM)

Selective Mapping (SLM) is a powerful technique used to reduce Peak-to-Average Power Ratio (PAPR) in multicarrier systems like OFDM. It works by generating multiple versions of the same signal and selecting the one with the lowest PAPR for transmission.

Methodology:

1. **Input Data Block**: Start with a block of input data symbols.
2. **Phase Rotation**: Multiply the data block by several different phase sequences (called phase vectors), each producing a unique version of the signal.
3. **IFFT Operation**: Apply Inverse Fast Fourier Transform (IFFT) to each version to generate time-domain signals.
4. **PAPR Calculation**: Compute the PAPR of each candidate signal.
5. **Selection**: Choose the signal with the lowest PAPR for transmission.

Advantages:

- **No distortion:** Unlike clipping, SLM doesn't alter the signal waveform
- **Flexible:** Works with any modulation scheme.
- **Effective:** Can significantly reduce PAPR depending on the number of phase sequences.

Disadvantages:

- **Computationally intensive:** Requires multiple IFFT operations.
- **Side information:** The receiver must know which phase sequence was used, which adds overhead.
- **Storage:** Needs memory to store multiple candidate signals.

4.3. Partial Transmit Sequence (PTS)

It works by dividing the signal into sub-blocks and optimizing their phase to minimize peak power without distorting the signal.

Methodology:

1. **Input Data Block**: Start with an OFDM symbol in the frequency domain.
2. **Sub-block Division**: Divide the symbol into V disjoint sub-blocks each of length N.

3. **Phase Rotation**: Multiply each sub-block by a phase factor (usually selected from a set like {±1, ±j}).
4. **Combination**: Combine the phase-rotated sub-blocks:
5. **IFFT Operation**: Apply IFFT to get the time-domain signal.
6. **PAPR Calculation**: Choose the set of phase factors that minimizes the PAPR.

Advantages:

- **No distortion**: Maintains signal integrity.
- **Flexible**: Works with any modulation scheme.
- **Effective**: Can achieve significant PAPR reduction.

Disadvantages

- **Computational complexity**: Requires multiple IFFT operations and phase optimization.
- **Side information**: Receiver must know the phase factors used.
- **Latency**: Optimization step can introduce delay.

4.4. Tone Reservation (TR):

Tone Reservation (TR) is a distortion less method used to reduce PAPR in OFDM systems. It works by reserving a small set of subcarriers (tones) specifically for peak cancellation, without affecting the data-carrying subcarriers. Most subcarriers carry user data however few subcarriers are left unused for data and instead optimized to generate a cancellation signal that reduces peaks in the time-domain OFDM signal.

Methodology:

1. **Identify high peaks** in the time-domain OFDM signal.
2. **Optimize reserved tones** to generate a cancellation signal that reduces these peaks.
3. **Add the cancellation signal** to the original OFDM signal.
4. **Transmit the modified signal**, which has lower PAPR.

Advantages:

- **No distortion**: Data tones remain untouched.
- **No side information**: Receiver doesn't need extra info to decode.
- **Flexible**: Can be adapted dynamically based on peak locations.

Disadvantages:

- **Reduced data rate**: Some subcarriers are sacrificed for peak cancellation.
- **Computational cost**: Requires solving an optimization problem.
- **Tone placement**: Choosing which tones to reserve affects performance.

Tone Reservation is especially useful in systems where maintaining signal integrity is critical, such as LTE, 5G, and satellite communications.

The comparison of these techniques is depicted in table 1.

Table 1: Comparison of PAPR Reduction Methods

Method	Distortion	Side Info needed	Complexity	PAPR Reduction	Data Rate Impact
Clipping	Yes	No	Low	Moderate	None
Peak Windowing	Yes	No	Low	Low to moderate	None
SLM	No	Yes	High (Multiple IFFTs)	High	None
PTS	No	Yes	High (Phase optimization)	High	None
TR	No	No	Moderate (Optimization)	Moderate to High	Slight (reserved tones)
Coding Techniques	No	No	Moderate to High	Moderate to High	Reduced (due to redundancy)
Companding	Yes (Nonlinear)	No	Low	Moderate	None

5. CONCLUSION

Reducing Peak-to-Average Power Ratio (PAPR) is essential for improving power amplifier efficiency, minimizing signal distortion, and enhancing overall system performance in OFDM-based communication systems. Each technique offers a unique trade-off between complexity, effectiveness, and signal integrity: Simple methods like clipping and companding are easy to implement but introduce distortion, which can degrade Bit Error Rate (BER).

Distortion-less techniques such as Selective Mapping (SLM), Partial Transmit Sequence (PTS), and Tone Reservation (TR) offer high PAPR reduction without compromising signal quality, though they require additional computational resources and side information.

Coding-based approaches and interleaving provide moderate PAPR reduction while enhancing error correction, but may reduce data rate. Scrambling and windowing are lightweight methods that can be used in conjunction with other techniques for incremental improvement.

Ultimately, the choice of method depends on system requirements such as complexity tolerance, spectral efficiency, hardware constraints, and performance goals.

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