Receiver-based Recovery of Clipped OFDM Signals for PAPR Reduction:
A Bayesian Approach

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Motivation

Bayesian Clipping Recovery

Reliable Carriers as Measurements

Prior Information about clipping

Multiple Antenna Receivers

Multiple User System

Clipped OFDM and Channel Estimation
Content

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Clipped OFDM and Channel Estimation
OFDM

- OFDM is a multi-carrier modulation scheme that uses orthogonal carriers.
- Main Advantages include
  - Robustness against multi-path fading.
  - High data rate.
  - Easy single tap equalization.
- The main disadvantage is **High PAPR!** [1]
High PAPR

\[ \begin{bmatrix} 1011 \\ 1001 \\ \vdots \\ 1101 \end{bmatrix} \begin{bmatrix} 3 + 2j \\ 4 + 3j \\ \vdots \\ 2 - 3j \end{bmatrix} \]

A mixture of Sinusoids

\[ \begin{bmatrix} 1010 \cdots 101 \end{bmatrix} \]

Incoming data stream → S/P → QAM → IDFT → high PAPR Signal

- **Transmitter based schemes**
  - coding, partial transmit sequence (PTS), selected mapping (SLM), interleaving, tone reservation (TR), tone injection (TI) and active constellation extension (ACE).
  - Transmitter-based techniques are complex.
Clipping

- We follow a clipping scheme
- Clip signal above a prespecified threshold $\gamma$

$$x_p(i) = \begin{cases} \gamma e^{j\angle x(i)} & \text{if } |x(i)| > \gamma \\ x(i) & \text{otherwise} \end{cases}$$

- $x_p(i) = x(i) + c(i)$

QAM $\begin{bmatrix} 3 + 2j \\ 0 \\ \vdots \\ 2 - 3j \end{bmatrix}$

- Implications:
  - Clipping signal is sparse!
  - Pilot contamination.
  - Inter-user Interference.
Content

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Bayesian Sparse Signal Recovery

Implications of Sparsity

- Signal can be reconstructed using sparse signal recovery methods.
- Few Measurements will be required.

Why Bayesian Recovery?\(^a\)

- Low Complexity.
- Signal statistics are not required.
- Agnostic to distribution.
- Noise statistics are utilized.

\(^a\)By Bayesian recovery, we refer to the utilized SABMP scheme [2].
Content

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Clipped OFDM and Channel Estimation
Reserved tones reduce bandwidth efficiency.

Some data carriers (called Reliable tones) can be used as measurements.

**Question**

How to select the tones which are most likely to be in their correct decision region?

- Calculate the metric \[ R = \frac{\Pr(\lfloor \hat{X}(i) \rfloor = X(i))}{\Pr(\lfloor \hat{X}(i) \rfloor \neq X(i))} \]

\[ \lfloor \cdot \rfloor \] denotes hard decision.
Content

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Clipped OFDM and Channel Estimation
Phase and Likelihood

- Clipping operation does not affect the phase.

- Phase of the clipping signal can be retrieved from the received clipped signal.
- This helps in increasing the measurements.

- Probability of a clipping element is high, if received signal is closer to threshold.
- Find the dominant support faster and accurately.
Simulation Results

Simulation Parameters:
- Subcarriers: 512
- QAM Order: 64
- Reliable Carriers: 128
- Clipping Ratio: 1.61

Simulated BER vs. $E_b/N_0$ for different methods:
- No Est
- SABMP
- WPA-SABMP
- PA-FBMP
- WPAL
- Oracle-LS

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Clipped OFDM and Channel Estimation
Same clipping on all antennas

- Multiple receiver antennas provide more measurements for clipping reconstruction.
- Use measurements from all antennas together to improve clipping mitigation [4].

\[
\begin{bmatrix}
\tilde{y}_1 \\
\tilde{y}_2 \\
\vdots \\
\tilde{y}_L
\end{bmatrix} =
\begin{bmatrix}
\tilde{\Phi}_1 \\
\tilde{\Phi}_2 \\
\vdots \\
\tilde{\Phi}_L
\end{bmatrix}
\begin{bmatrix}
c \\
\tilde{Z}_1 \\
\tilde{Z}_2 \\
\vdots \\
\tilde{Z}_L
\end{bmatrix},
\]

Distortion Estimation

- Distortion Cancellation
- Distortion Cancellation

MRC Combiner

Sparse Bayesian Clipping Recovery
Simulation Results

Simulation Parameters:

- Subcarriers: 512
- QAM Order: 64
- Reliable Carriers: 77
- Eb/N0: 27 dB
- Antennas: 2
Content

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Clipped OFDM and Channel Estimation
OFDMA System

Orthogonal Channel Allocation

Challenge → Distortions Overlap in Frequency Domain

Two Stage Recovery

- Initially reconstruct jointly.
- Form decoupled systems.
- Perform individual reconstruction.

Sparse Bayesian Clipping Recovery
Simulation Results

Simulation Parameters:

- Subcarriers: 512
- Users: 2
- QAM Order: 64
- Reserved Tones: 75
- Clipping Ratio: 1.61
Content

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Clipped OFDM and Channel Estimation
Contaminated Pilots

Solutions

- Increase pilots.
- Data Aided pilot Estimation.

Proposed

- Estimate Corrupted Pilots.
- Use estimated and data aided pilots together.
Results

-40 -35 -30 -25 -20 -15
10 15 20 25 30

≈ 7.2dB

Simulation Parameters:
- Subcarriers: 256
- QAM Order: 64
- Pilot Tones: 16
- Reliable Tones: 16
- Clipping Ratio: 1.73

Simulation Parameters:

- Subcarriers: 256
- QAM Order: 64
- Pilot Tones: 16
- Reliable Tones: 16
- Clipping Ratio: 1.73


For more information...

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▶ For details and relevant papers:  
http://faculty.kfupm.edu.sa/ee/naffouri/publications.html

THANK YOU!