Clipping Noise Cancellation Based on Compressed Sensing for Visible Light Communication

Presented by

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Contents

1 / Technical Background
2 / System Model
3 / Proposed Solutions
4 / Simulation Results
5 / Conclusions
Contents

1 / Technical Background
2 / System Model
3 / Proposed Solutions
4 / Simulation Results
5 / Conclusions
Technical Background

- Asymmetrically clipped optical OFDM (ACO-OFDM)
  - Hermitian symmetry (real-valued)
  - Only the odd subcarriers in the frequency domain are occupied (non-negative)

- Clipping noise
  - nonlinear transfer characteristics of LEDs
    - generate the self-interference
    - deteriorates the performance
Proposed scheme to reconstruct clipping noise

- compressed sensing
- Taking advantage of the time-domain sparsity of the clipping noise
- Using sparsity adaptive matching pursuit (SAMP) greedy algorithm
- partially aware support
- a coarse estimation of the clipping noise location

✓ improve the accuracy and robustness, complexity is also lower
Contents

1 / Technical Background
2 / System Model
3 / Proposed Solutions
4 / Simulation Results
5 / Conclusions
The transmitted symbol
\[ X = (0, X_1, 0, X_2, \ldots, X_{N/2-1}, 0, X_{N/2-1}^*, \ldots, 0, X_1^*) \]
\[ x_n = \sum_{k=0}^{N-1} X_k \exp \left( \frac{j2\pi kn}{N} \right) \]

The ACO-OFDM signal
\[ x_{ACO,n} = \begin{cases} x_n, & x_n \geq 0, \\ 0, & x_n < 0. \end{cases} \]
\[ X_k = 2X_{ACO,k} \]
The transmitter block diagram of the OFDM systems

- The clipped signal

\[
\tilde{x}_{ACO,n} = \begin{cases} 
    x_{ACO,n}, & |x_{ACO,n}| \leq A_{th}, \\
    A_{th}, & |x_{ACO,n}| > A_{th},
\end{cases}
\]

\[
\bar{x}_{ACO,n} = x_{ACO,n} + c_n
\]

\[
\bar{x}_{ACO,k} = X_{ACO,k} + C_k
\]
The proposed receiver block diagram of the OFDM systems

- The received symbol
  \[ Y_k = \overline{X}_{ACO,k} + Z_k = X_{ACO,k} + C_k + Z_k \]

- The initial decision
  \[ \hat{X}_k = \arg \min |2Y_k - s|, s \in \chi \]

- Compressed Sensing Model
  \[ Y - \frac{\hat{X}}{2} = X + C + Z - \frac{\hat{X}}{2} = C + (X - \frac{\hat{X}}{2} + Z) \]

- The final decision
  \[ \hat{X}_k = \arg \min |2(Y_k - \hat{C}_k) - s|, s \in \chi \]
## Contents

1. Technical Background
2. System Model
3. Proposed Solutions
4. Simulation Results
5. Conclusions
Proposed Solutions

**Compressed Sensing Model**

- Measurement vector
- Sensing matrix $\phi$
- Unknown vector $c$

\[
\hat{y}_{SC} = \Phi \cdot \hat{c}
\]

\[
Y - \frac{\hat{X}}{2} = C + \left( X - \frac{\hat{X}}{2} + Z \right) = C + \theta
\]

\[
\tilde{Y} = S(Y - \frac{\hat{X}}{2}) = SC + S\theta
\]

\[
= SFc + S\theta
\]

\[
= \Phi c + \eta
\]

- Selection matrix $S$

\[
K = \{k : |\theta_k|^2 < E\{|C_k|^2\}\}
\]

✓ select a series of reliable tones
Proposed Solutions

Compressed Sensing Model

\[ \hat{y} = SC c + S \theta = \Phi c + \eta \]

RIP (restricted isometry property)

\[ F_{k,n+\frac{N}{2}} = e^{-j \frac{2\pi}{N} k(n+\frac{N}{2})} = e^{-j \frac{2\pi}{N} kn} = F_{k,n} \]

\[ \Phi_{m,n} = -\Phi_{m,n+\frac{N}{2}} \]

RIP doesn’t hold

needs to be reconsidered
The Transformation of CS Problem

\[ \Phi = [A, -A], \quad c = [c_1; c_2] \]

\[ \tilde{Y} = \Phi c + \eta \Leftrightarrow \tilde{Y} = [A, -A] \cdot \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \eta = A\tilde{c} + \eta, \quad \tilde{c} = c_1 - c_2 \]

\[
\begin{cases}
c_{1,n} = 0, c_{2,n} = \tilde{c}, & \text{if } \tilde{c} > 0, \\
c_{1,n} = \tilde{c}, c_{2,n} = 0, & \text{if } \tilde{c} \leq 0.
\end{cases}
\]

\[ \tilde{Y} = SFc + S\theta = \Phi c + \eta \]

RIP

the clipping noise \( c \leq 0 \)
Proposed Solutions

- **Problem** \( \tilde{Y} = \Phi c + \eta \)

- **Solution**
  - CS method
  - clipping noise is variable and unknown

- **SAMP (sparsity adaptive matching pursuit)**
  - not require the sparsity level to be known

- partially aware support → PAS-SAMP
Proposed Solutions

- priori information

- partial support

\[ \Pi^{(0)} = \left\{ n \mid |y_n|^2 > \lambda_i \right\} \]

- Facilitate the CS recovery process
Proposed Solutions

Algorithm 1 PAS-SAMP: The Partially Aware Support Sparsity Adaptive Matching Pursuit for Clipping Noise Reconstruction

Inputs:
1) The partially aware support $\Pi^{(0)}$
2) Initial sparsity level $K^{(0)} = |\Pi^{(0)}|$
3) Measurement vector $\mathbf{y}$
4) Sensing matrix $\Phi$
5) Step size $\Delta s$

Initialization:
1: $\xi^{(0)}|_{\Pi^{(0)}} \leftarrow \Phi|_{\Pi^{(0)}} \mathbf{y}$
2: $r^{(0)} \leftarrow \mathbf{y} - \Phi \xi^{(0)}$
3: $T \leftarrow K^{(0)} + \Delta s$; $k \leftarrow 1$; $j \leftarrow 1$

Iterations:
4: repeat
5: $S_k \leftarrow \max(\Phi^H r^{(k-1)}, T - K^{(0)})$ {Preliminary test}
6: $C_k \leftarrow \Pi^{(k-1)} \cup S_k$ {Make candidate list}
7: $\Pi_k \leftarrow \max(\Phi^H \Pi_k \mathbf{y}, T)$ {Temporary final list}
8: $\xi^{(k)}|_{\Pi_k} \leftarrow \Phi^H \Pi_k \mathbf{y}$, $\xi^{(k)}|_{\Pi^c_k} \leftarrow 0$
9: $r \leftarrow \mathbf{y} - \Phi_{\Pi_k} \Phi^H_{\Pi_k} \mathbf{y}$ {Compute residue}
10: if $\|r\|_2 \geq \|r^{(k-1)}\|_2$ then
11: $j \leftarrow j + 1, T \leftarrow K^{(0)} + j \times \Delta s$ {Stage switching}
12: else
13: $\Pi^{(k)} \leftarrow \Pi_k, r^{(k)} \leftarrow r$
14: $k \leftarrow k + 1$ {Same stage, next iteration}
15: end if
16: until $\|r\|_2 < \varepsilon$

Output:
Recovered clipping noise vector $\xi$, s.t.
$\xi|_{\Pi_k} = \Phi^H_{\Pi_k} \mathbf{p}$, $\xi|_{\Pi^c_k} = 0$

- **The priori information**
  - initial support set

- **Complexity**
  - the testing sparsity level
  
  $T \leftarrow K^{(0)} + j \cdot \Delta s$ \quad $T \leftarrow j \cdot \Delta s$

- **Adaptivity**
Contents

1 / Technical Background
2 / System Model
3 / Proposed Solutions
4 / Simulation Results
5 / Conclusions
Simulation Results

- 16-QAM, N=256, A_{th}=1.5
- Sparse level K =10
- At the target BER=10^{-3}

- PAS-SAMP outperforms SAMP 0.2dB
- the gap to worst case is 1.5dB
Simulation Results

- 64-QAM, $N=1024$, $A_{th}=1.8$
- Sparse level $K=20$
- At the target $BER=10^{-3}$

- PAS-SAMP outperforms SAMP $0.3\, \text{dB}$
- The gap to worst case is $1.6\, \text{dB}$
Contents

1 / Technical Background
2 / System Model
3 / Proposed Solutions
4 / Simulation Results
5 / Conclusions
Conclusions

- Clipping noise cancellation for ACO-OFDM systems based on compressed sensing with partially aware support

- Apply CS to clipping noise cancellation in ACO-OFDM systems

- Solves the RIP problem that the sensing matrix for ACO-OFDM systems

- Improve the accuracy and robustness of the proposed scheme

- Computational complexity is lower


THANKS

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