Clipping Noise Cancellation Based on Compressed Sensing for Visible Light Communication

Presented by

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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

Technical Background

■ 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

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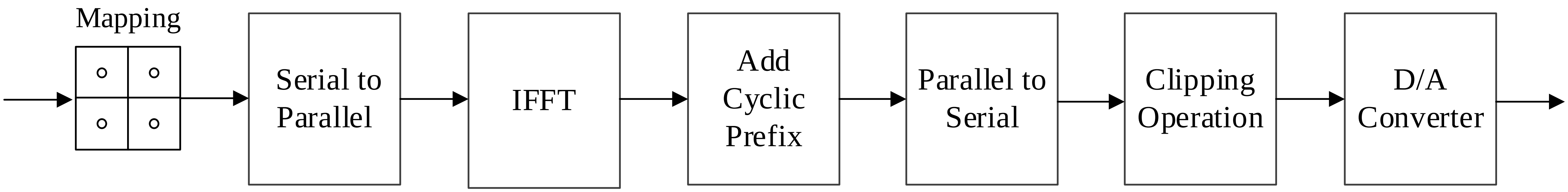
System Model

■ The transmitter block diagram of the OFDM systems



- The transmitted symbol

$$X = (0, X_1, 0, X_2, \cdots X_{N/2-1}, 0, X^*_{N/2-1}, \cdots, 0, X^*_1)$$

$$x_n = \sum_{k=0}^{N-1} X_k \exp\left(\frac{j2\pi kn}{N}\right)$$

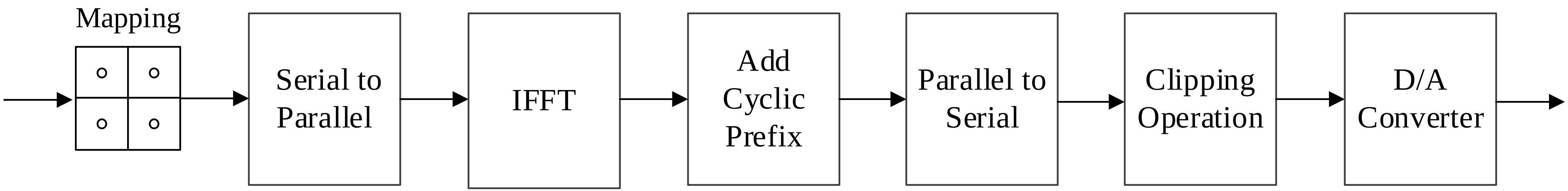
- The ACO-OFDM signal

$$x_{ACO,n} = \begin{cases} x_n, & x_n \geq 0, \\ 0, & x_n < 0. \end{cases}$$

$$X_k = 2X_{ACO,k}$$

System Model

■ The transmitter block diagram of the OFDM systems

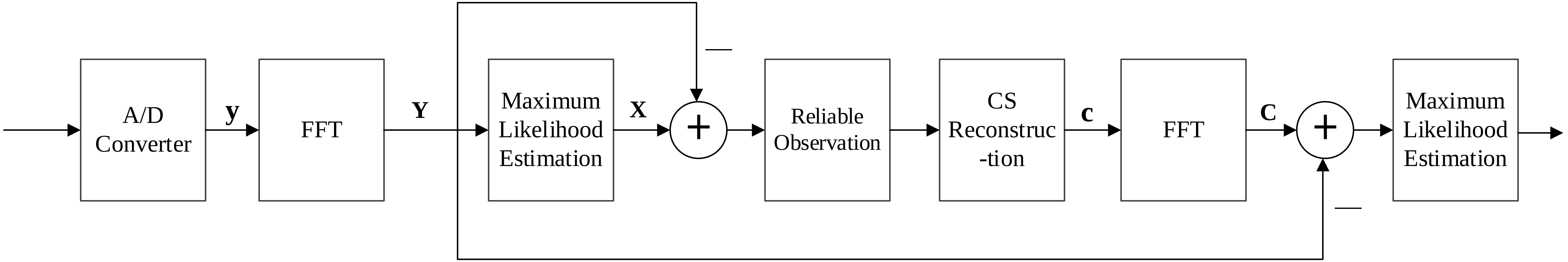


- The clipped signal

$$\bar{x}_{ACO,n} = \begin{cases} x_{ACO,n}, & |x_{ACO,n}| \leq A_{th}, \\ A_{th}, & |x_{ACO,n}| > A_{th}, \end{cases} \qquad \bar{x}_{ACO,n} = x_{ACO,n} + c_n \qquad \bar{X}_{ACO,k} = X_{ACO,k} + C_k$$

System Model

■ **The proposed receiver block diagram of the OFDM systems**



- The received symbol

$$Y_k = \bar{X}_{ACO,k} + Z_k = X_{ACO,k} + \boxed{C_k} + Z_k$$

- The initial decision

$$\hat{X}_k = \arg\min \left|2Y_k - s\right|, s \in \chi$$

- Compressed Sensing Model

$$Y - \frac{\hat{X}}{2} = X + C + Z - \frac{\hat{X}}{2} = C + \boxed{\left(X - \frac{\hat{X}}{2}\right.} + Z)$$

- The final decision

$$\hat{X}_k = \arg\min \left|2(Y_k - \hat{C}_k) - s\right|, s \in \chi$$

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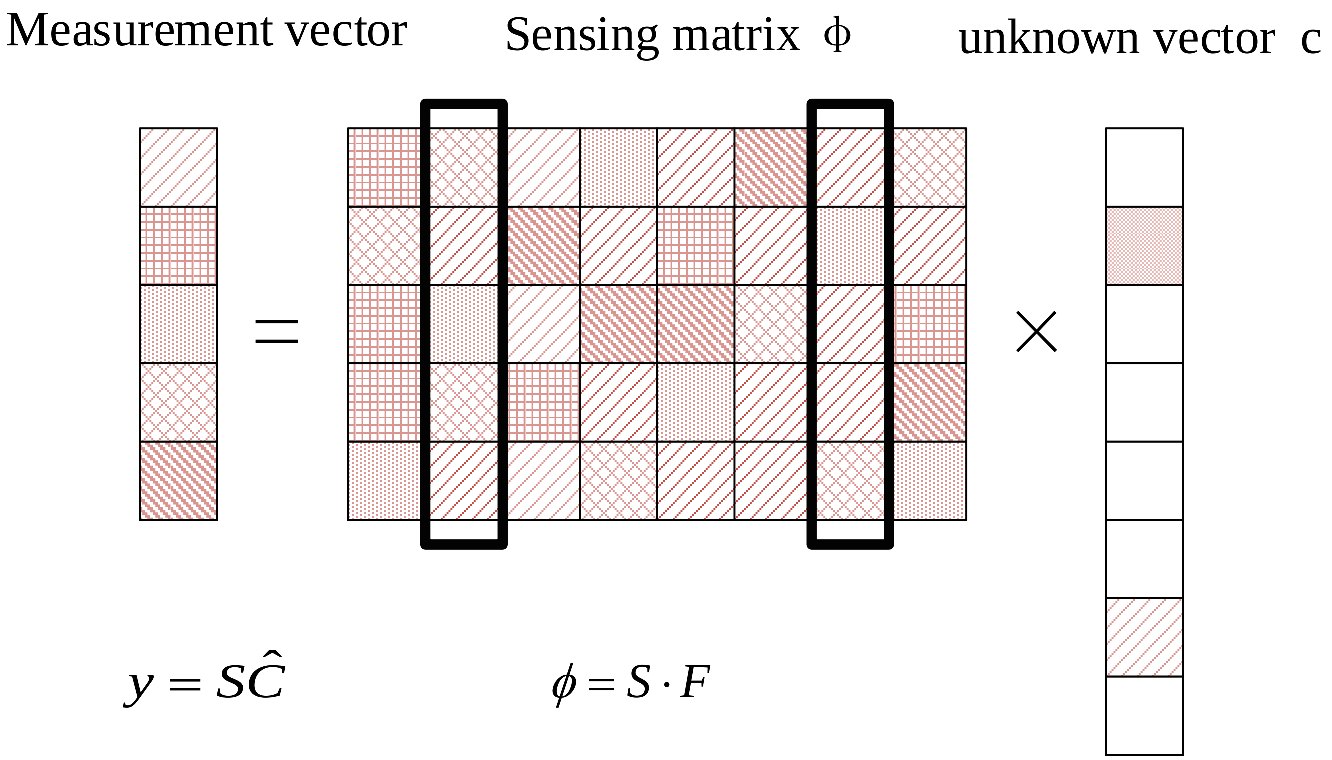
Proposed Solutions

■ Compressed Sensing Model

$$Y-\frac{\hat{X}}{2}=C+(X-\frac{\hat{X}}{2}+Z)=C+\theta$$



$y=S\hat{C}$ $\phi=S\cdot F$

$$\begin{aligned}\tilde{Y}&=S(Y-\hat{X}/2)=SC+S\theta\\&=SFc+S\theta\\&=\Phi c+\eta\end{aligned}$$

- Selection matrix S

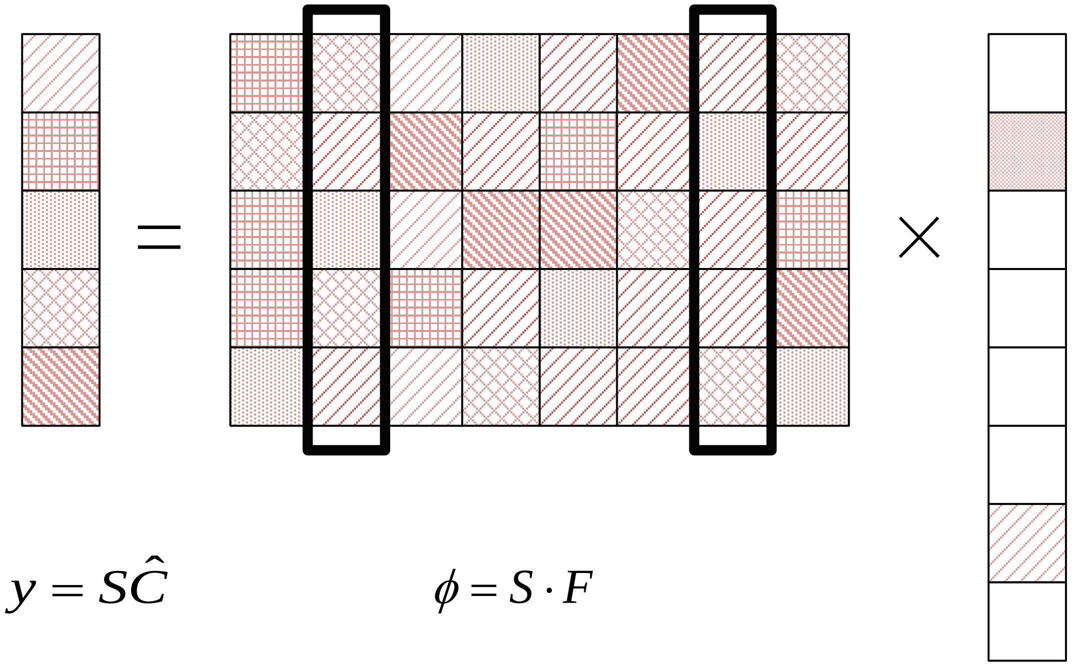
$$\mathcal{K}=\{k:|\theta_k|^2<E\{|C_k|^2\}\}$$

✓ select a series of reliable tones

Proposed Solutions

- **Compressed Sensing Model**

Measurement vector　　Sensing matrix ϕ　　unknown vector c



$y = S\hat{C}$　　$\phi = S \cdot F$

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

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 !

Proposed Solutions

- **The Transformation of CS Problem**

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

RIP

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

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

$$\begin{cases} c_{1,n} = 0, c_{2,n} = \tilde{c}, \text{ if } \tilde{c} > 0, \\ c_{1,n} = \tilde{c}, c_{2,n} = 0, \text{ if } \tilde{c} \le 0. \end{cases}$$

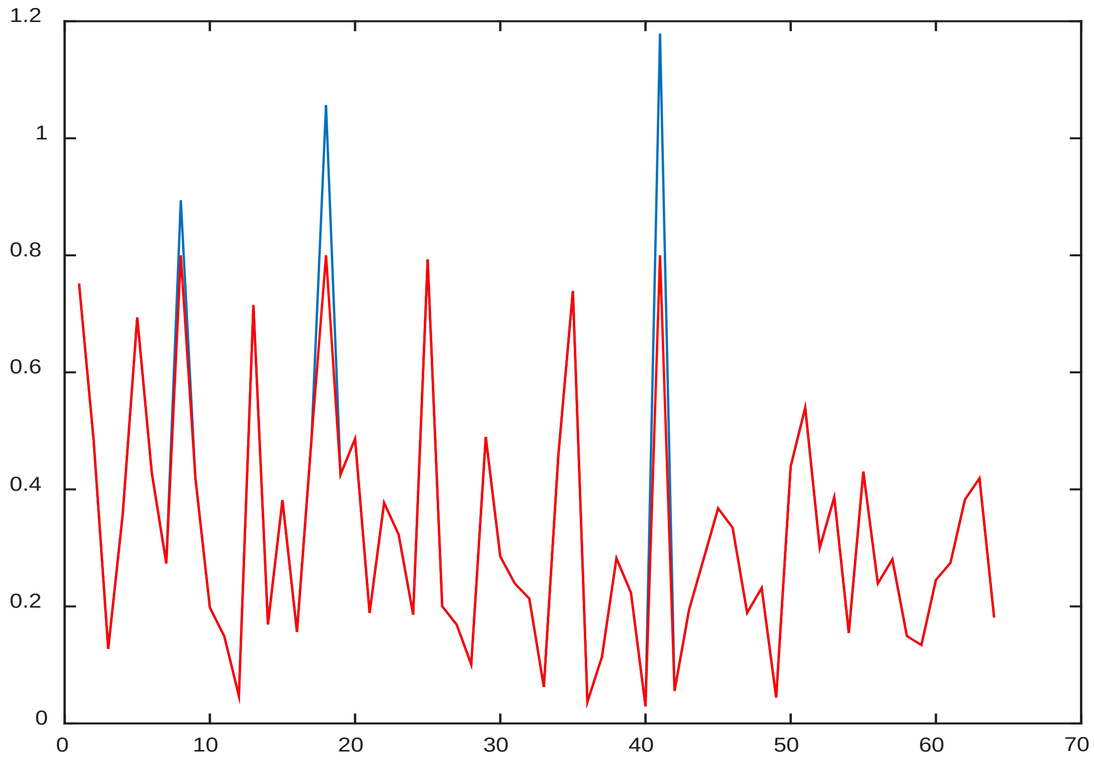
⇐ the clipping noise $c \le 0$

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

$$\Pi^{(0)} = \left\{ n \mid |y_n|^2 > \lambda_t \right\}$$

- 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 $\mathbf{\Phi}$
5) Step size Δs.

Initialization:

$\boldsymbol{\xi}^{(0)}\big|_{\Pi^{(0)}} \leftarrow \mathbf{\Phi}^{\dagger}_{\Pi^{(0)}}\mathbf{y}$

$\mathbf{r}^{(0)} \leftarrow \mathbf{y} - \mathbf{\Phi}\boldsymbol{\xi}^{(0)}$

$T \leftarrow K^{(0)} + \Delta s;\quad k \leftarrow 1;\quad j \leftarrow 1$

Iterations:

repeat

  $S_k \leftarrow \max(\mathbf{\Phi}^H \mathbf{r}^{(k-1)}, T - K^{(0)})$ {Preliminary test}

  $C_k \leftarrow \Pi^{(k-1)} \cup S_k$ {Make candidate list}

  $\Pi_t \leftarrow \max(\mathbf{\Phi}^{\dagger}_{C_k}\mathbf{y}, T)$ {Temporary final list}

  $\boldsymbol{\xi}^{(k)}\big|_{\Pi_t} \leftarrow \mathbf{\Phi}^{\dagger}_{\Pi_t}\mathbf{y},\ \boldsymbol{\xi}^{(k)}\big|_{\Pi_t^c} \leftarrow \mathbf{0}$

  $\mathbf{r} \leftarrow \mathbf{y} - \mathbf{\Phi}_{\Pi_t}\mathbf{\Phi}^{\dagger}_{\Pi_t}\mathbf{y}$ {Compute residue}

  if $\|\mathbf{r}\|_2 \geq \left\|\mathbf{r}^{(k-1)}\right\|_2$ **then**

    $j \leftarrow j+1, T \leftarrow K_I^{(0)} + j \times \Delta s$ {Stage switching}

  else

    $\Pi^{(k)} \leftarrow \Pi_t, \mathbf{r}^{(k)} \leftarrow \mathbf{r},$

    $k \leftarrow k+1$ {Same stage, next iteration}

  end if

until $\|\mathbf{r}\|_2 < \varepsilon$

Output:

Recovered clipping noise vector $\boldsymbol{\xi}$, s.t.

$\boldsymbol{\xi}_i|_{\Pi_t} = \mathbf{\Phi}^{\dagger}_{\Pi_t}\tilde{\mathbf{p}},\ \boldsymbol{\xi}|_{\Pi_t^c} = \mathbf{0}$

- **The priori information**
  - ✓ initial support set
- **Complexity**
  - ✓ the testing sparsity level

$$T \leftarrow K^{(0)} + j \cdot \Delta s \quad \Leftarrow \quad T \leftarrow j \cdot \Delta s$$

- **Adaptivity**

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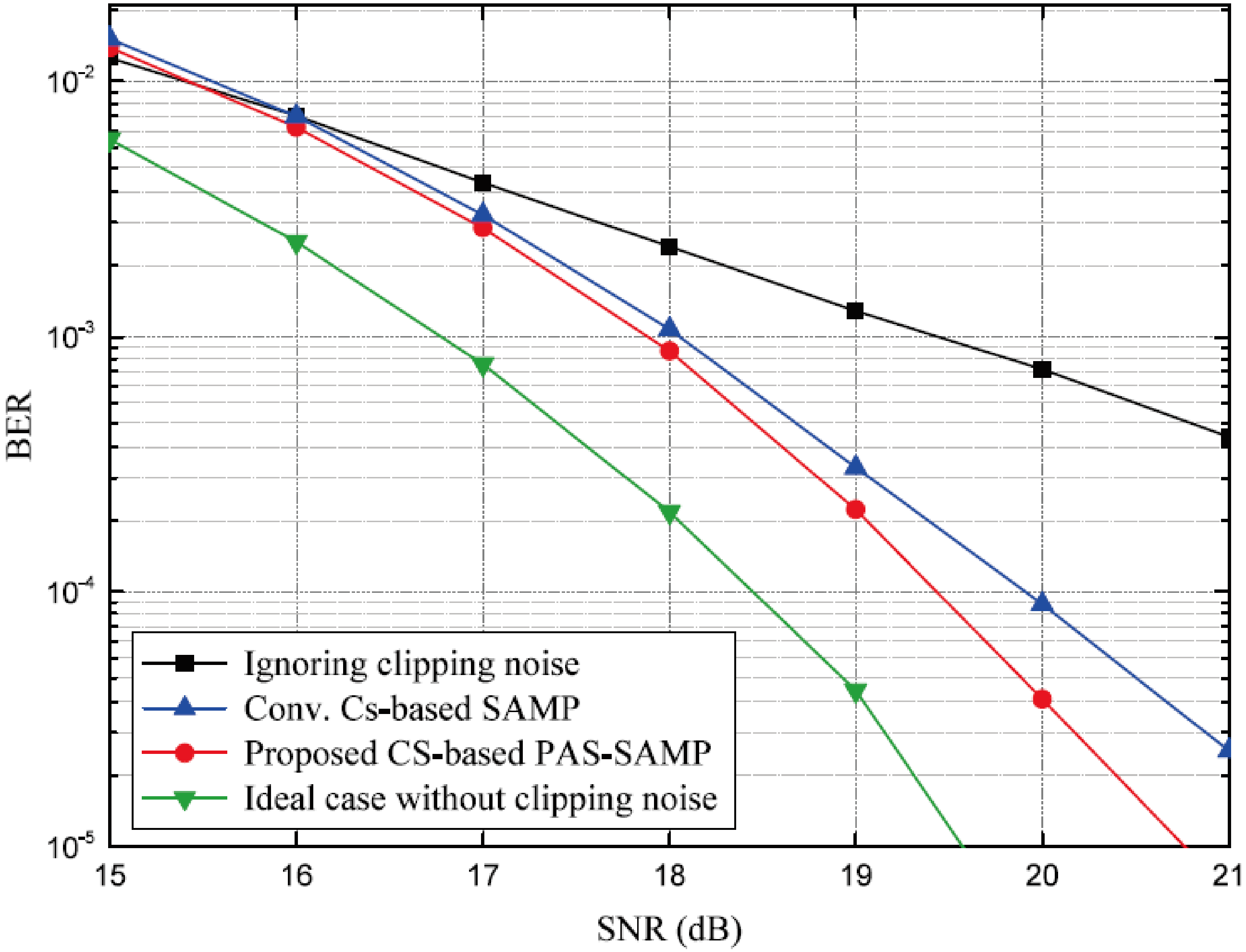
Simulation Results

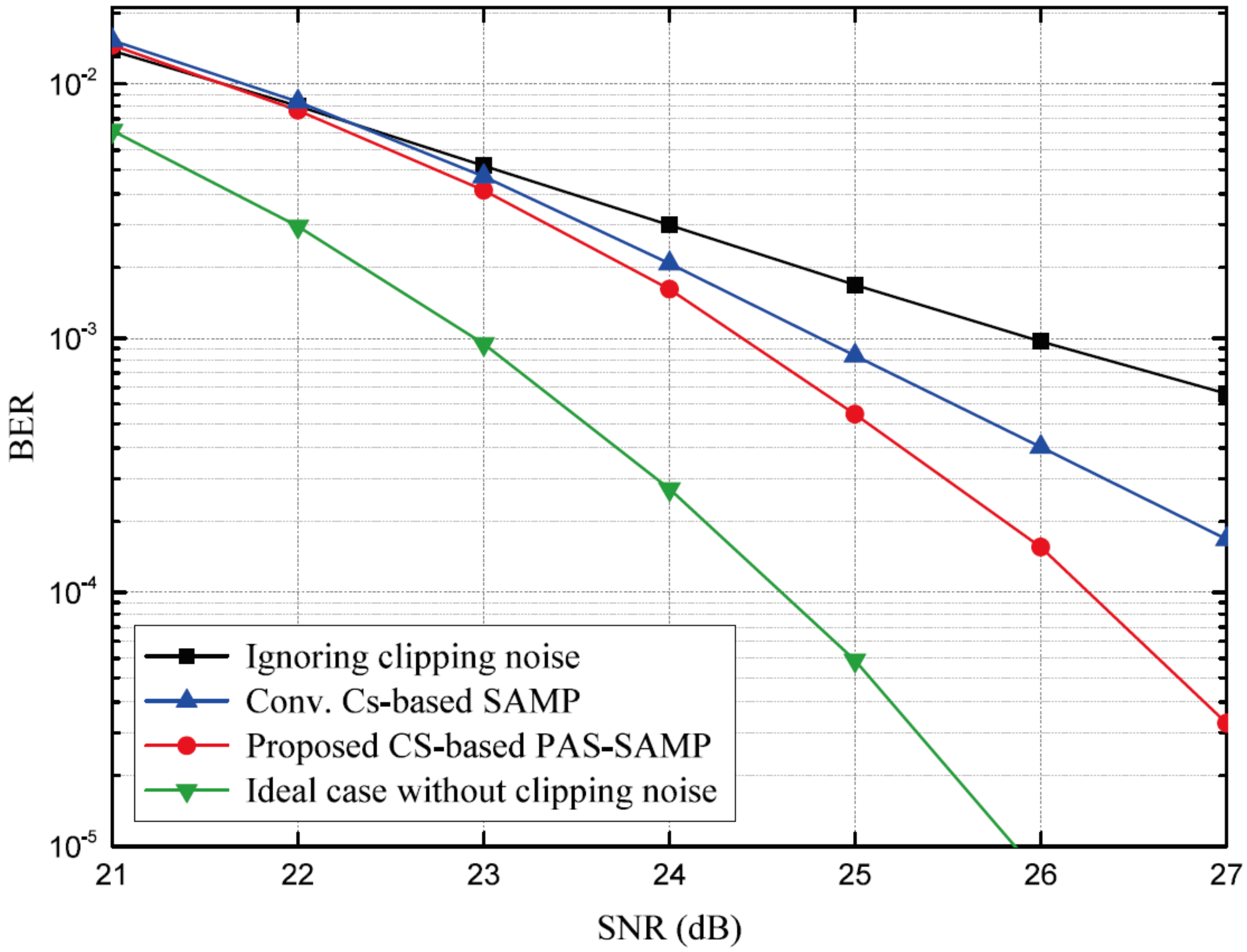


- 16-QAM , N=256 , A_{th}=1.5
- Sparse level K =10
- At the target BER=10^{-3}

✓ 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 0.3dB
- ✓ the gap to worst case is 1.6dB

Contents

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

References

1. E. B. Al-Safadi and T. Y. Al-Naffouri. Peak reduction and clipping mitigation in OFDM by augmented compressive sensing. IEEE Trans. Signal Process., 60(7):3834–3839, July 2012.
2. J. Armstrong. OFDM for optical communications. J. Lightw. Technol., 27(3):189–204, Feb. 2009.
3. J. Armstrong and A. J. Lowery. Power efficient optical OFDM. Electron. Lett., 42(6):370–372, Mar. 2006.
4. S. Arnon. Visible Light Communications. Cambridge University Press, 2015.
5. E. J. Candes, J. K. Romberg, and T. Tao. Stable signal recovery from incomplete and inaccurate measurements. Commun. Pure Appl. Math, 59(8):1207–1223, Aug. 2006.
6. E. J. Candes and T. Tao. Near-optimal signal recovery from random projections: Universal encoding strategies? IEEE Trans. Inf. Theory, 52(12):5406–5425, Dec.
7. H. Chen and A. M. Haimovich. Iterative estimation and cancellation of clipping noise for OFDM signals. IEEE Comm. Lett., 7(7):305–307, July 2003.
8. J. Dang, Z. Zhang, and L. Wu. A novel receiver for ACO-OFDM in visible light communication. IEEE Commun. Lett., 17(12):2320–2323, Dec. 2013.
9. S. Dimitrov, S. Sinanovic, and H. Haas. Clipping noise in OFDM-based optical wireless communication systems. IEEE Trans. Commun., 60(4):1072–1081, Apr. 2012.
10. W. Ding, Y. Lu, F. Yang, W. Dai, P. Li, S. Liu, and J. Song. Spectrally efficient CSI acquisition for power line communications: A Bayesian compressive sensing perspective. IEEE Journal on Selected Areas in Communications, 34(7):2022–2032, 2016.
11. W. Ding, F. Yang, C. Pan, L. Dai, and J. Song. Compressive sensing based channel estimation for OFDM systems under long delay channels. IEEE Trans. Broadcast., 60(2):313–321, June 2014.
12. S. D. Dissanayake, K. Panta, and J. Armstrong. A novel technique to simultaneously transmit ACO-OFDM and DCO-OFDM in IM/DD systems. In Proc. IEEE GLOBECOM Workshops, Dec. 2011.
13. T. T. Do, L. Gan, N. Nguyen, and T. D. Tran. Sparsity adaptive matching pursuit for practical compressed sensing. In Asilomar Conf. on Signals, Systems, and Computers, Oct. 2008.

References (cont’ d)

14. D. L. Donoho. Compressed sensing. IEEE Trans. Inf. Theory, 52(4):1289–1306, Apr. 2006.
15. H. Elgala, R. Mesleh, and H. Haas. Non-linearity effects predistortion in optical OFDM wireless transmission using LEDs. International Journal of Ultra Wideband Communications and Systems, 1(2):143–150, Aug. 2009.
16. A. Jovicic, J. Li, and T. Richardson. Visible light communication: opportunities, challenges and the path to market. IEEE Commun. Mag., 51(12):26–32, Dec. 2013.
17. D. Kim and G. L. Stuber. Clipping noise mitigation for OFDM by decision-aided reconstruction. IEEE Comm. Lett., 3(1):4–6, Jan. 1999.
18. K. H. Kim, H. Park, J. S. No, and H. C. D. Shin. Clipping noise cancelation for OFDM systems using reliable observations based on compressed sensing. IEEE Trans. Broadcast., 61(1):111–118, Mar. 2015.
19. S. Liu, F. Yang, W. Ding, and J. Song. Double kill: Compressive-sensing-based narrow-band interference and impulsive noise mitigation for vehicular communications. IEEE Trans. Veh. Technol., 65(7):5099–5109, July 2016.
20. S. Liu, F. Yang, and J. Song. Narrowband interference cancelation based on priori aided compressive sensing for DTMB systems. IEEE Trans. Broadcast., 61(1):66–74, Mar. 2015.
21. S. Liu, F. Yang, C. Zhang, and J. Song. Narrowband interference mitigation based on compressive sensing for OFDM systems. IEICE Trans. Funda., E98-A(3), Mar. 2015.
22. M. Peng, Y. Li, Z. Zhao, and C. Wang. System architecture and key technologies for 5G heterogeneous cloud radio access networks. IEEE Network, 29(2):6–14, Mar. 2015.
23. F. Yang, J. Gao, and S. Liu. Novel visible light communication approach based on hybrid OOK and ACO-OFDM. IEEE Photon. Technol.

THANKS

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