INTERFERENCE EXPLOITATION PRECODING FOR MULTI-LEVEL MODULATIONS

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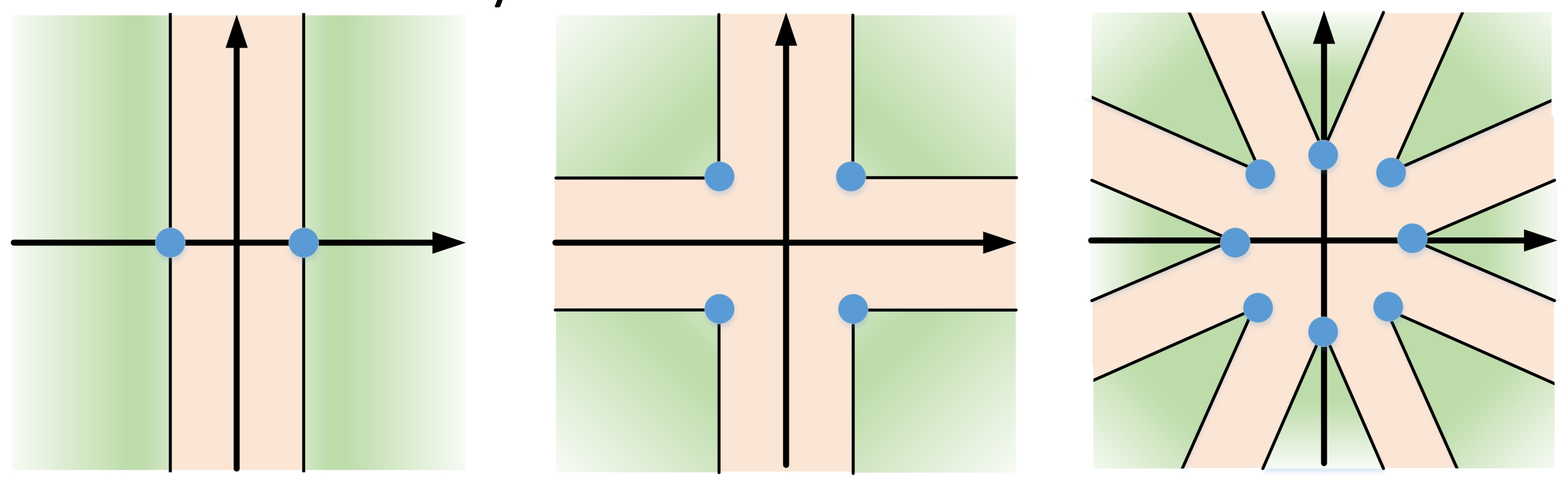
I. Principle of Constructive Interference

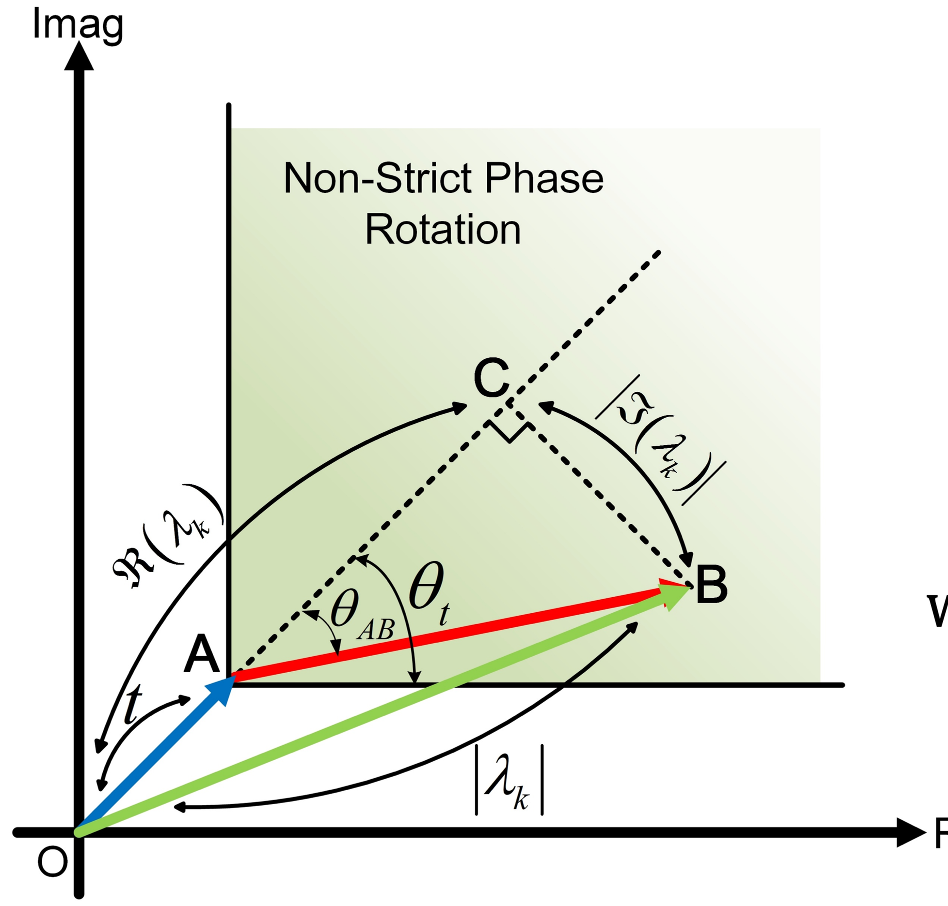
Definition: the interference that pushes the received signals away from detection thresholds



Symbol-level interference can be exploited to increase the received signal power and improve performance

II. Benchmarks: CI precoding for PSK

A typical MU-MISO downlink transmission: $r_k = \mathbf{h}_k\mathbf{W}\mathbf{s} + n_k$



max-min fair optimization:

$$\mathcal{P}_{CI}^{PSK}: \max_{\mathbf{W},t}\ t$$
$$s.t.\quad \mathbf{h}_k\mathbf{W}\mathbf{s} = \lambda_k s_k,\ \forall k \in \mathcal{K}$$
$$\left(\lambda_k^{\Re} - t\right)\tan\theta_t \geq \left|\lambda_k^{\Im}\right|,\ \forall k \in \mathcal{K}$$
$$\|\mathbf{W}\mathbf{s}\|_2^2 \leq p_0$$

$$\mathbf{W} = \frac{1}{K}\cdot\mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1} diag\left\{\sqrt{\frac{p_0}{\hat{\mathbf{u}}^T\hat{\mathbf{V}}^{-1}\hat{\mathbf{u}}}}\mathbf{F}^{-1}\tilde{\mathbf{V}}^{-1}\mathbf{u}\right\}\mathbf{s}\hat{\mathbf{s}}$$

$$\mathcal{P}_{\hat{\mathbf{u}}}^{PSK}: \min_{\hat{\mathbf{u}}}\ \hat{\mathbf{u}}^T\hat{\mathbf{V}}^{-1}\hat{\mathbf{u}}$$
$$s.t.\quad \mathbf{1}^T\hat{\mathbf{u}} = 1$$
$$\hat{u}_k \geq 0,\ \forall k \in \{1, 2, \cdots, 2K\}$$

QP over a simplex

[A] A. Li, and C. Masouros, 'Interference Exploitation Precoding Made Practical: Optimal Closed-Form Solutions for PSK Modulations', *IEEE Trans. Wireless Commun.*, vol. 17, no. 11, pp. 7661-7676, Nov. 2018.

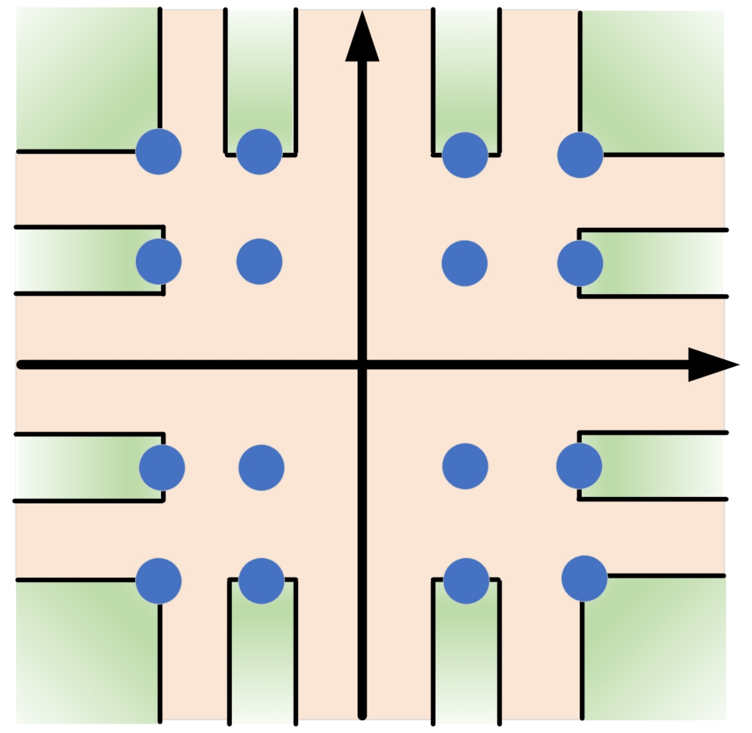
III. Adaptation of CI precoding to QAM

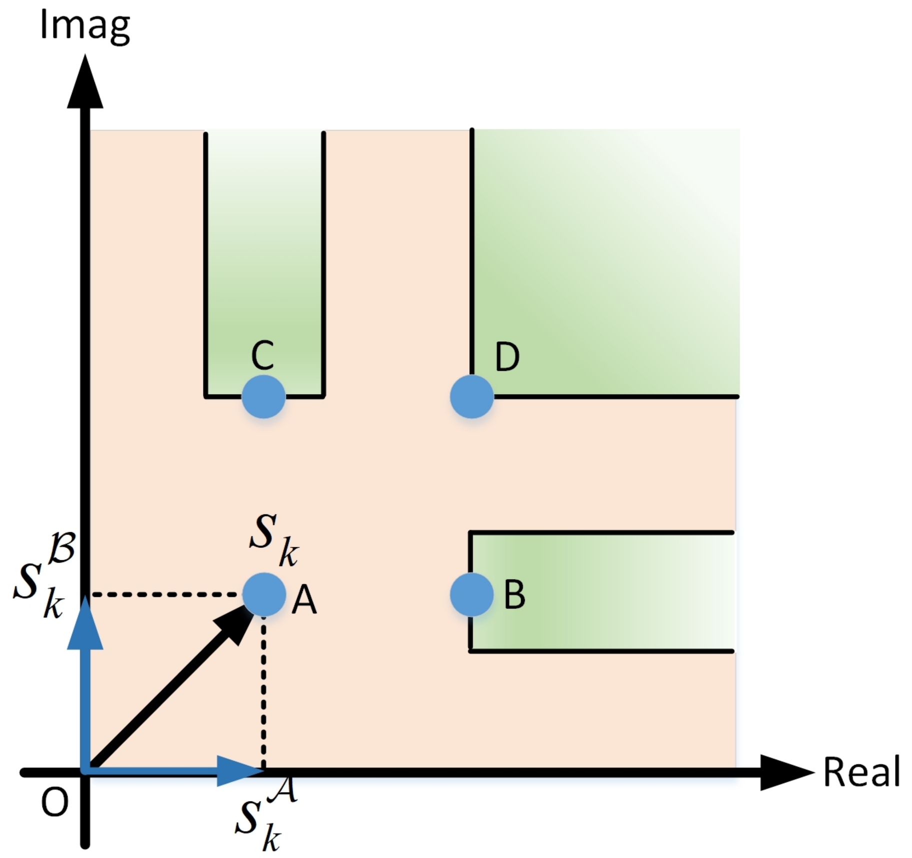
Modify CI metric to accommodate multi-level modulations

multi-level modulations

Outer constellation points: constructive + destructive

Inner constellation points: destructive





Phase-rotation CI metric is not applicable to QAM

Signal decomposition:

$$s_k = s_k^{\mathcal{A}} + s_k^{\mathcal{B}}$$
$$\mathbf{h}_k\mathbf{W}\mathbf{s} = \alpha_k^{\mathcal{A}} s_k^{\mathcal{A}} + \alpha_k^{\mathcal{B}} s_k^{\mathcal{B}}$$

Constructive interference criterion (QAM): $\alpha_k^{\mathcal{A}} > 0, \alpha_k^{\mathcal{B}} > 0$

max-min fair optimization

$$\mathcal{P}_{CI}^{QAM}: \max_{\mathbf{W},t}\ t$$
$$s.t.\quad \mathbf{h}_k^T\mathbf{W}\mathbf{s} = \mathbf{\Omega}_k^T\mathbf{s}_k,\ \forall k \in \mathcal{K}$$
$$t \leq \alpha_m^{\mathcal{O}},\ \forall \alpha_m^{\mathcal{O}} \in \mathcal{O}$$
$$t = \alpha_n^{\mathcal{I}},\ \forall \alpha_n^{\mathcal{I}} \in \mathcal{I}$$
$$\|\mathbf{W}\mathbf{s}\|_2^2 \leq p_0$$

standard minimization form

$$\mathcal{P}_{CI}^{QAM}: \min_{\mathbf{W},t}\ -t$$
$$s.t.\quad \mathbf{h}_k^T\sum_{i=1}^{K}\mathbf{w}_i s_i - \mathbf{\Omega}_k^T\mathbf{s}_k = 0,\ \forall k \in \mathcal{K}$$
$$t - \alpha_m^{\mathcal{O}} \leq 0,\ \forall \alpha_m^{\mathcal{O}} \in \mathcal{O}$$
$$t - \alpha_n^{\mathcal{I}} = 0,\ \forall \alpha_n^{\mathcal{I}} \in \mathcal{I}$$
$$\sum_{i=1}^{K} s_i^*\mathbf{w}_i^H\mathbf{w}_i s_i \leq \frac{p_0}{K}$$

$$\|\mathbf{W}\mathbf{s}\|_2^2 \leq p_0 \Rightarrow \sum_{i=1}^{K} s_i^*\mathbf{w}_i^H\mathbf{w}_i s_i \leq \frac{p_0}{K}$$

IV. Optimal Precoding Structure

Via KKT conditions, we can express $\mathbf{W}$ as a function of $\mathbf{\Omega}$:

$$\mathbf{W} = \frac{1}{K}\cdot\mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}\mathbf{U}diag\{\mathbf{\Omega}\}\mathbf{s}_{\mathbf{E}}\hat{\mathbf{s}}^T$$

Zero-forcing component — Pre-scaling — Symbol-level operation

an equivalent optimization on $\mathbf{\Omega}$:

$$\mathcal{P}_{CI}^{QAM}: \min_{\mathbf{\Omega},t}\ -t$$
$$s.t.\quad \mathbf{\Omega}^T\mathbf{V}\mathbf{\Omega} - p_0 = 0$$
$$t - \alpha_m^{\mathcal{O}} \leq 0,\ \forall \alpha_m^{\mathcal{O}} \in \mathcal{O}$$
$$t - \alpha_n^{\mathcal{I}} = 0,\ \forall \alpha_n^{\mathcal{I}} \in \mathcal{I}$$

dual problem

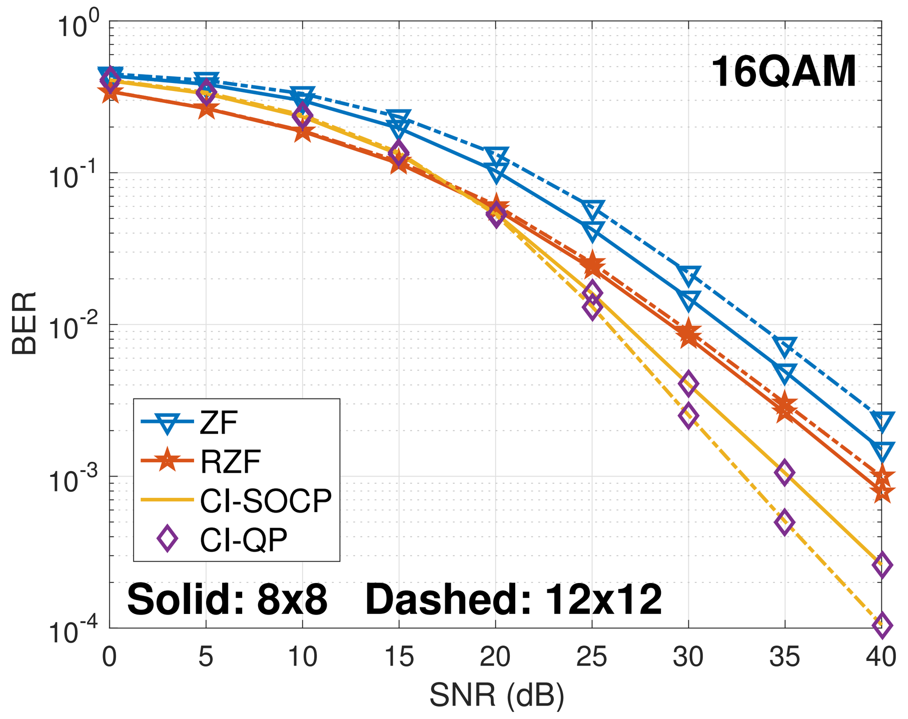
$$\mathcal{P}_{\mathbf{u}}^{QAM}: \min_{\mathbf{u}}\ \mathbf{u}^T\tilde{\mathbf{V}}^{-1}\mathbf{u}$$
$$s.t.\quad \mathbf{1}^T\mathbf{u} - 1 = 0$$
$$\mu_m \geq 0,\ \forall m \in \{1, 2, \cdots, card\{\mathcal{O}\}\}$$

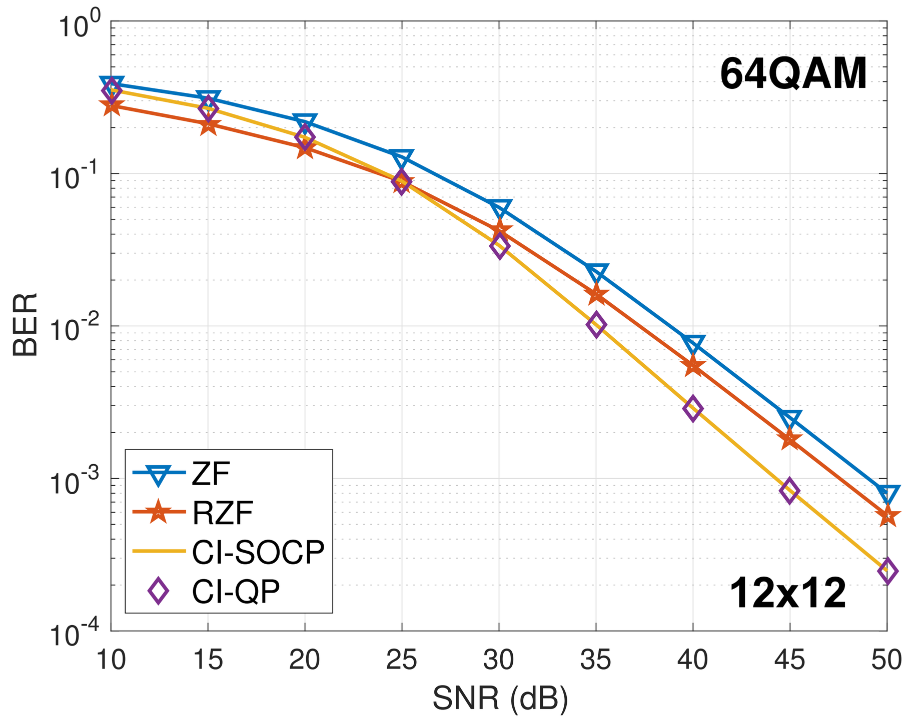
only part of $\mathbf{u}$ is constrained, not over a simplex

Final expression of $\mathbf{W}$ as a function of $\mathbf{u}$:

$$\mathbf{W} = \frac{1}{K}\cdot\mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}\mathbf{U}diag\left\{\sqrt{\frac{p_0}{\mathbf{u}^T\tilde{\mathbf{V}}^{-1}\mathbf{u}}}\mathbf{F}^{-1}\tilde{\mathbf{V}}^{-1}\mathbf{u}\right\}\mathbf{s}_{\mathbf{E}}\hat{\mathbf{s}}^T$$

V. Numerical Results





✓ CI Precoding achieves the best performance when SNR>20dB for 16QAM and when SNR>25dB for 64QAM.

✓ As opposed to conventional sense that CI precoding is mostly effective for PSK, CI precoding also achieves a significant performance gain for multi-level modulations.

Journal Version: A. Li, C. Masouros, Y. Li, B. Vucetic, and A. L. Swindlehurst, 'Interference Exploitation Precoding for Multi-Level Modulations: Closed-Form Solutions', *arXiv preprint*, available online: https://arxiv.org/abs/1811.03289.