ACHIEVABLE RATE MAXIMIZATION BY PASSIVE INTELLIGENT MIRRORS

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Motivation

Background:

- Wireless devices increase exponentially;
- 1000 x higher data rates in future;
- Critical needs for green and energy-efficient solutions;

What is PIM (Passive Intelligent Mirrors)?

- Physical meta-surface composed of many small-unit reflectors;
- Each unit reflect a phase-shifted version of incoming electromagnetic wave;
- Significantly reducing energy consumptions, and super-easy deployment;

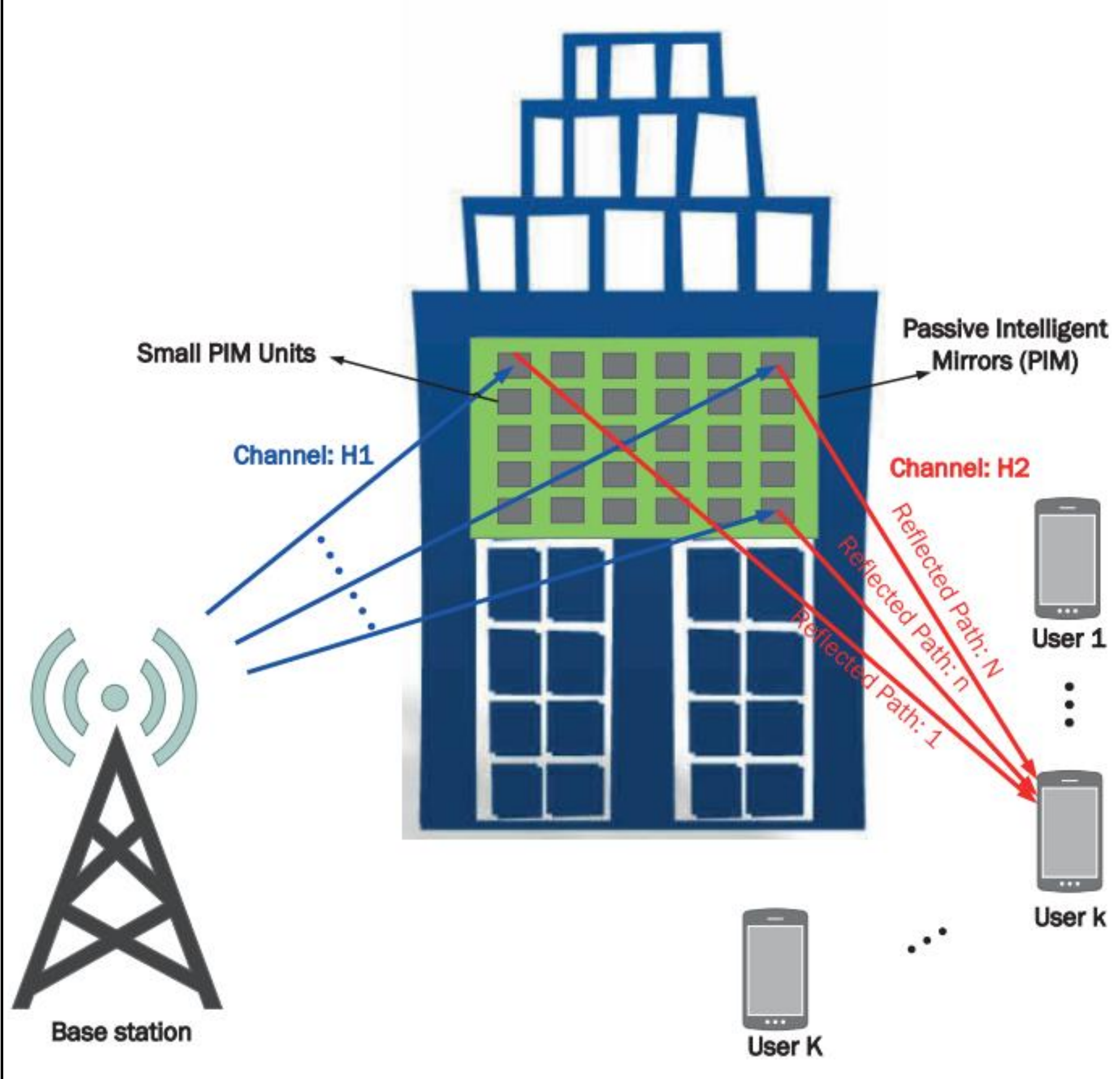
Key contributions:

- Formulated a sum-rate maximization problem for the outdoor MIMO system scenario equipped with PIM;
- Proposed MM-based method for addressing this non-convex;

System model

Outdoor scenario:

- multi-user MISO downlink communication system equipped with PIM



- A base station: M antennas
- K single-antenna users
- PIM: N reflecting units

Received signal at user k :

$$y_k = \mathbf{h}_{k,2}\boldsymbol{\Theta}\mathbf{H}_1\mathbf{x} + w_k,$$

$\mathbf{h}_{k,2} \in C^{1\times N}$: The channel between the PIM and user k

$\mathbf{H}_1 \in C^{N\times M}$: The channel Between the BS and PIM

$\Theta = diag[e^{j\theta_1},\ldots,e^{j\theta_N}]$: The PIM phase-shift matrix.

Problem formulation

Transmitted signal at BS: $\mathbf{x} = \sum_{k=1}^{K}\sqrt{p_k}\, g_k s_k$, g_k is beamforming vector;

Zero-forcing precoding: SINR at user k is simplified: $\gamma_k = \frac{p_k}{\delta^2}$

Objective: Optimize the transmit powers and the matrix Θ for system sum-rate maximization, under QoS constraints.

Non-convex optimization problem:

$$\max_{\boldsymbol{\Theta},\mathbf{P}} \sum_{k=1}^{K} \log_2\left(1+\frac{p_k}{\sigma^2}\right)$$

$$\text{s.t. } \log_2\left(1+\frac{p_k}{\sigma^2}\right) \geq R_{min,k} \ ,\forall\, k=1,\ldots,K$$

$$\mathrm{tr}((\mathbf{H}_2\boldsymbol{\Theta}\mathbf{H}_1)^{+}\mathbf{P}(\mathbf{H}_2\boldsymbol{\Theta}\mathbf{H}_1)^{+H}) \leq P_{max}$$

$$0 \leq \theta_i \leq 2\pi \ ,\forall\, i=1,\ldots,N$$

Proposed Algorithm

Alternating maximization: separately and iteratively optimize $\mathbf{P}$ and Θ.

1. Optimization with respect to Θ:

Change of variable:

$\Phi = diag[\phi_1,\ldots,\phi_1], \phi_i = e^{j\theta_i}$

$$\max_{\boldsymbol{\Phi}} \ 1$$

$$\text{s.t. } \mathrm{tr}((\mathbf{H}_2\boldsymbol{\Phi}\mathbf{H}_1)^{+}\mathbf{P}(\mathbf{H}_2\boldsymbol{\Phi}\mathbf{H}_1)^{+H}) \leq P_{max}$$

$$|\phi_i| = 1, \forall\, i=1,\ldots,N\ ,$$

Still non-convex

Solution by employing the ***majorization-minimization (MM)*** method:

$$\mathbf{c}_t = |\mathbf{A}^{\mathbf{H}}\mathbf{x}_\mathbf{t}|;\ c_t^{max} = \max(\mathbf{c}_t);\ \mathbf{M} = c_t^{max}\mathbf{A}\mathbf{A}^H;$$

$$\mathbf{L} = \mathbf{A}\left(\mathrm{diag}(\mathbf{c}_t) - N^2\mathbf{I}\right)\mathbf{A}^H;$$

$$\mathbf{y} = \frac{-(\mathbf{A}(\mathrm{diag}(\mathbf{c}_t)-c_t^{max}\mathbf{I}-N^2\mathbf{I})\mathbf{A}^H)}{c_t^{max}\mathbf{A}\mathbf{A}^H}\mathbf{x}_\mathbf{t};$$

$$\mathbf{x}_{t+1} = e^{j\arg(\mathbf{y})};\ t \leftarrow t+1;$$

Where $\mathbf{x} = \mathrm{vec}(\boldsymbol{\Phi}^{-1})$.

2. Optimization with respect to $\mathbf{P}$:

$$\max_{\mathbf{P}} \sum_{k=1}^{K} \log_2\left(1+\frac{p_k}{\sigma^2}\right)$$

$$\text{s.t. } p_k \geq \sigma^2(2^{R_{min,k}}-1)\ ,\forall\, k=1,\ldots,K$$

$$\mathrm{tr}((\mathbf{H}_2\boldsymbol{\Theta}\mathbf{H}_1)^{+}\mathbf{P}(\mathbf{H}_2\boldsymbol{\Theta}\mathbf{H}_1)^{+H}) \leq P_{max}$$

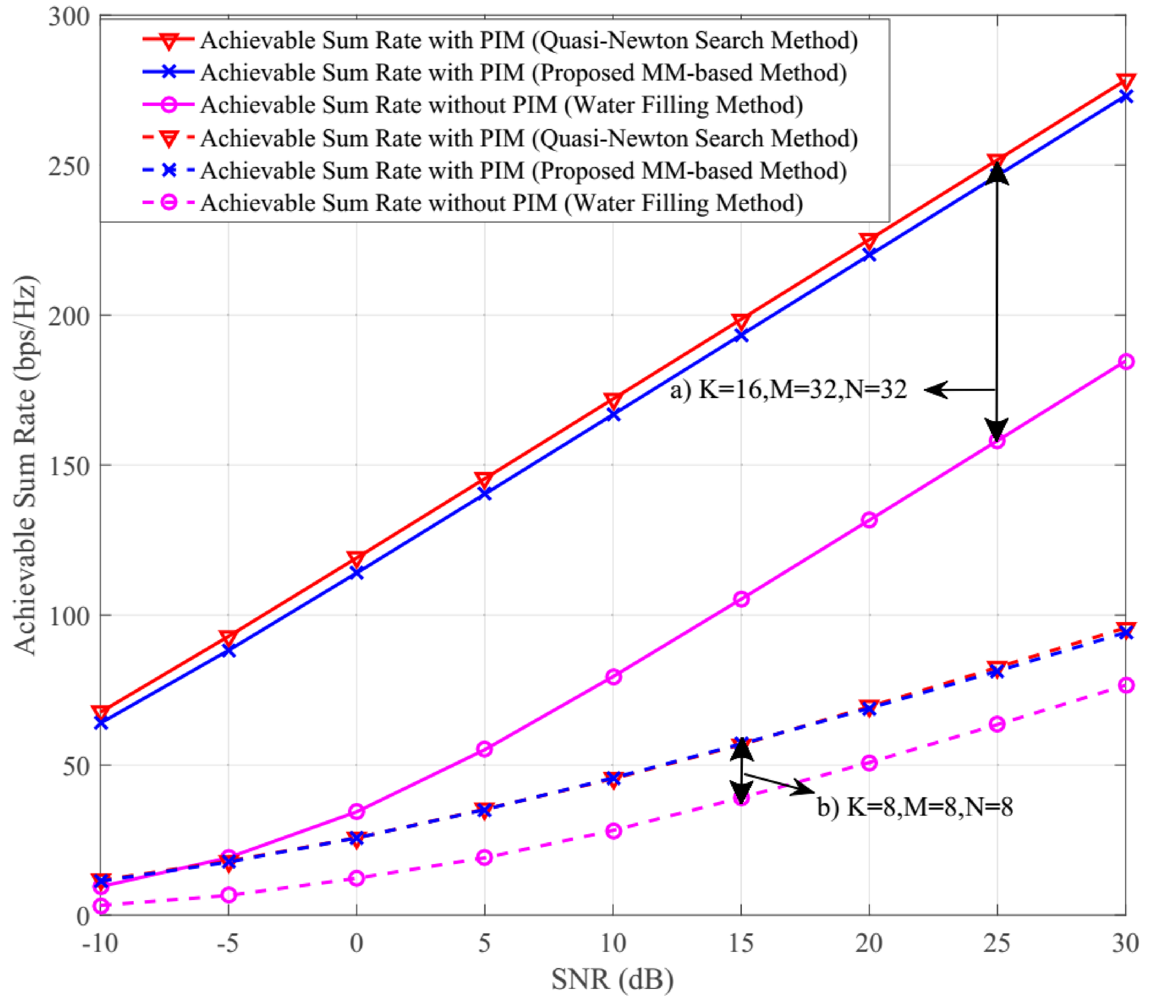
Convex, analyzing the Karush–Kuhn–Tucker (KKT) optimality conditions yields:

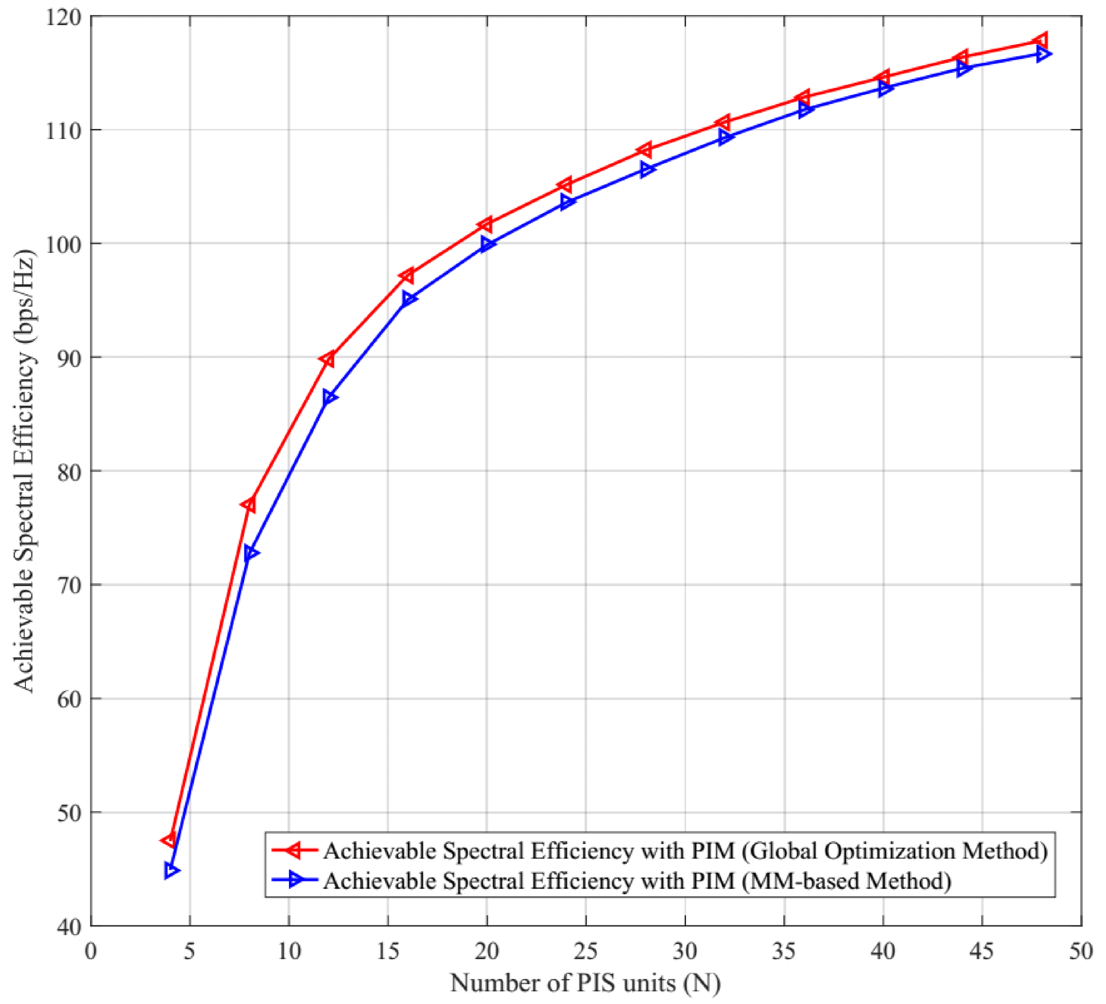
$$p_k = [\alpha\lambda_k - \sigma^2]^+ + \sigma^2(2^{R_{min,k}}-1)\lambda_k^{-1}$$

$$\alpha = \frac{1}{q}\left(P_{max} - \sum_{k=1}^{K}\sigma^2(2^{R_{min,k}}-1)\lambda_k^{-1} + \sigma^2\sum_{k=1}^{q}\lambda_k^{-1}\right)$$

Closed-form solution

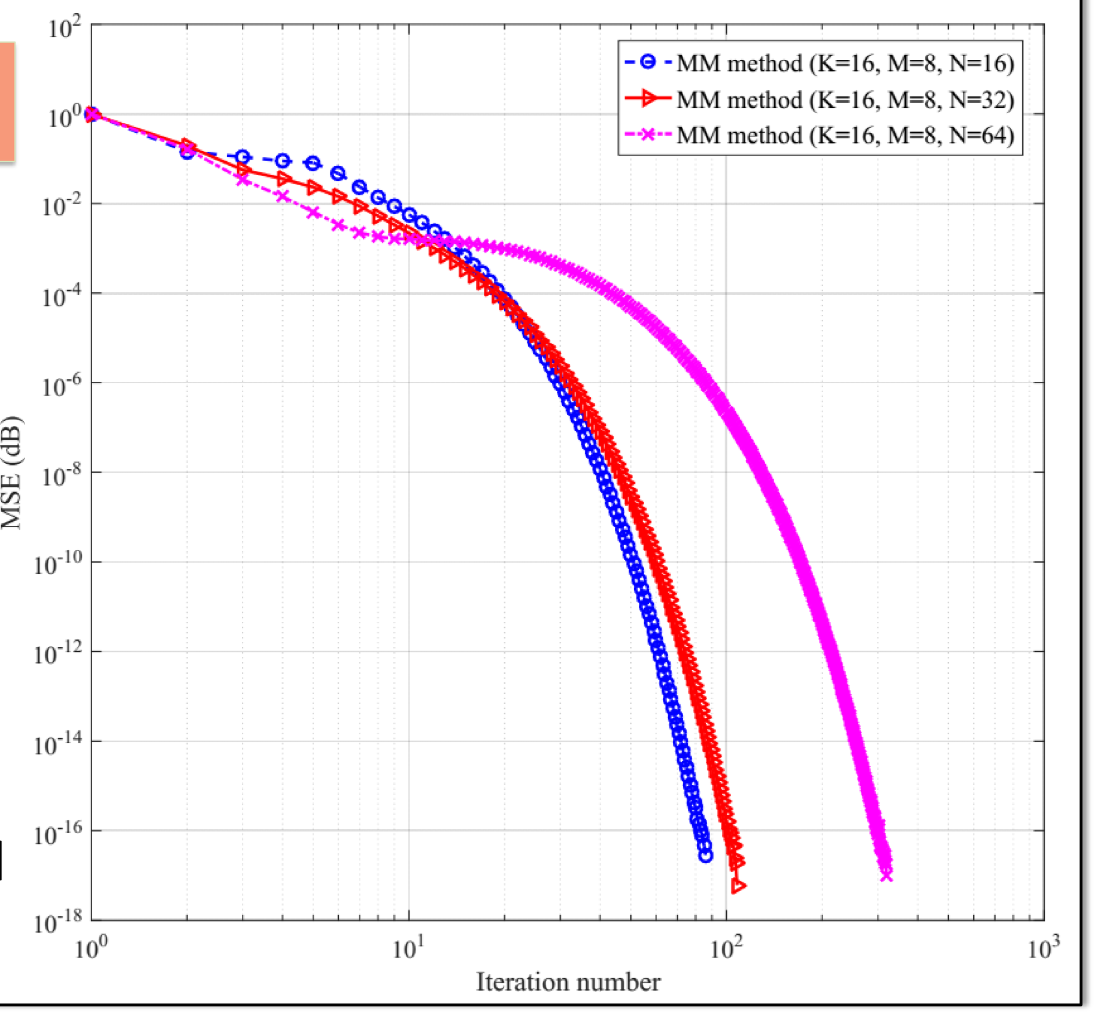
Numerical results





Results and Conclusions

- Employing the PIM increases the sum rate by more than 40%;
- Proposed algorithm is approximating the global optimal one;
- ➢ proposed Algorithm matches the sum spectral efficiency of optimal method;
- ➢ more PIM units the larger the sum spectral efficiency;
- ➢ And the increase saturates as PIM units grows;
- very limited complexity of the proposed MM-based method;



Reference

[1] A. Zappone, L. Sanguinetti, G. Bacci, E. Jorswieck, and M. Debbah, “Energy-efficient power control: A look at 5G wireless technologies,” IEEE Transactions on Signal Processing, vol. 64, no. 7, pp. 1668–1683, April 2016.

[2] L. Subrt and P. Pechac, “Controlling propagation environments using intelligent walls,” in 2012 6th European Conference on Antennas and Propagation (EUCAP), March 2012, pp. 1–5.