IEEE Wireless Communications Networking Conference

Joint Energy Beamforming and Optimization for Intelligent Reflecting Surface Enhanced Communications

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Outline

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- **System Model**
- **Two-stage Approximation Algorithm**
- **Numerical Results**

Introduction

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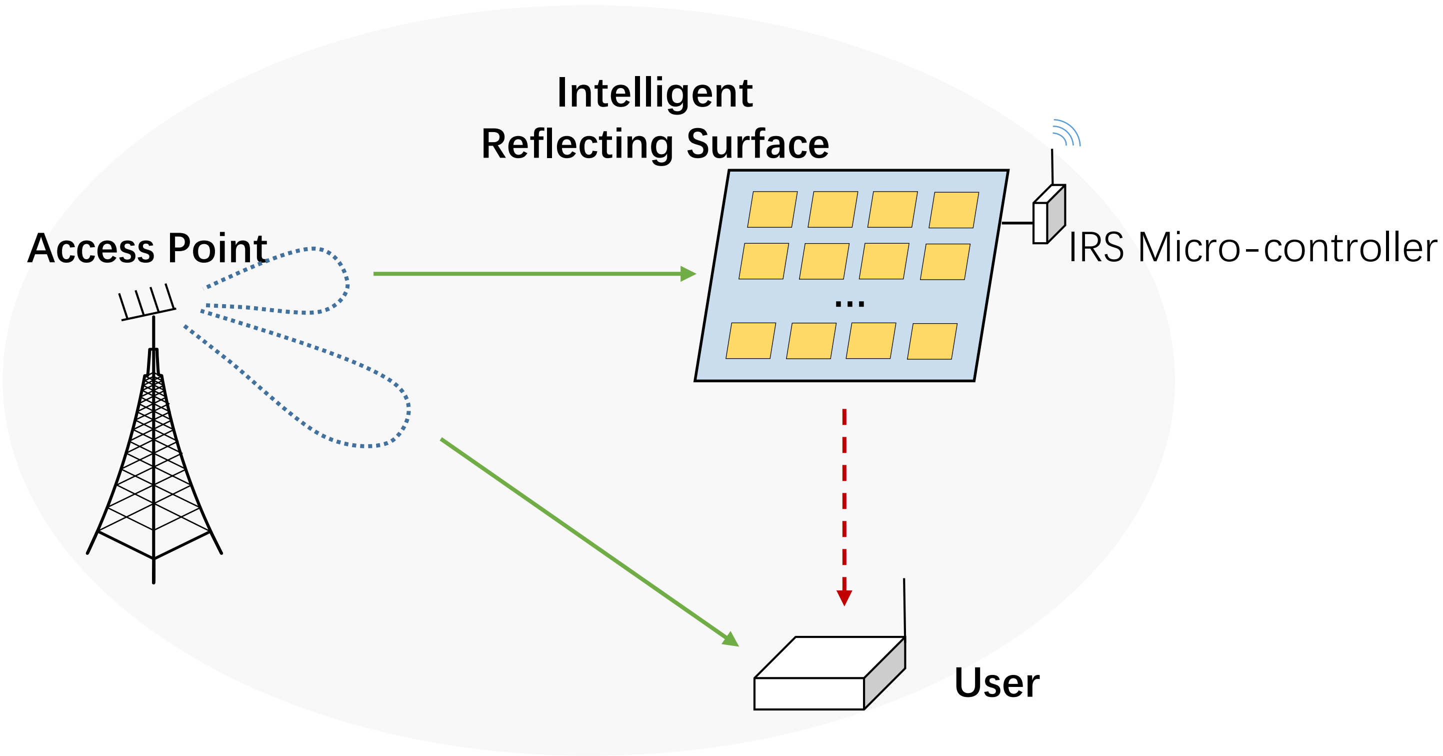
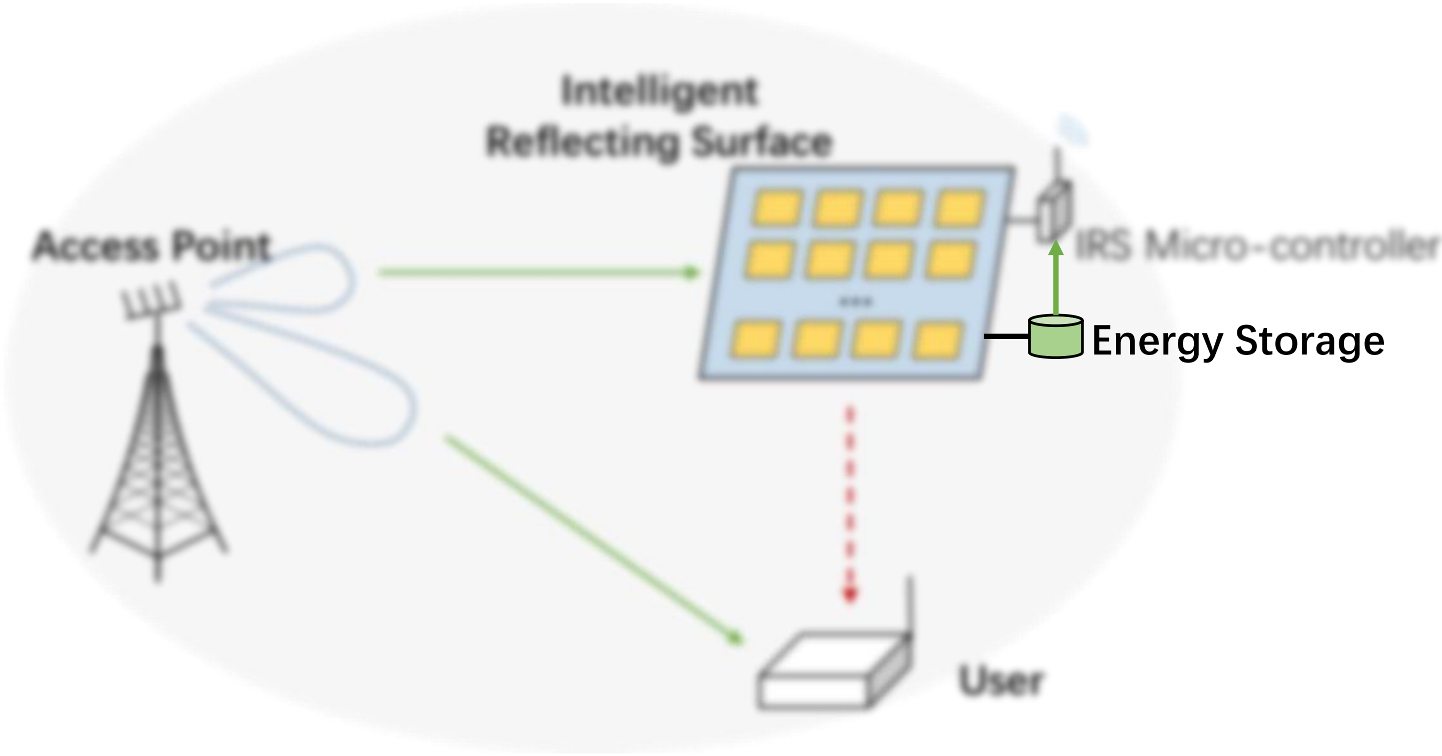


Introduction



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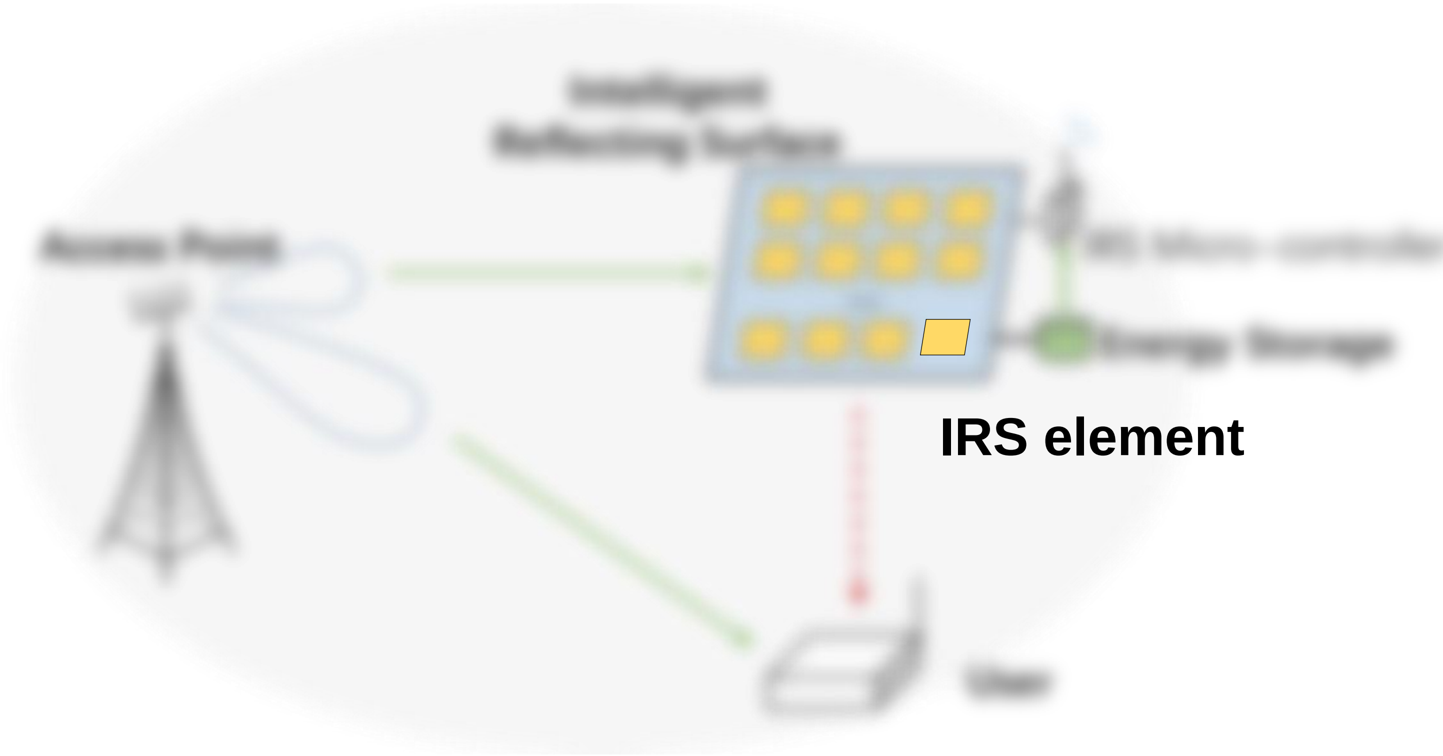

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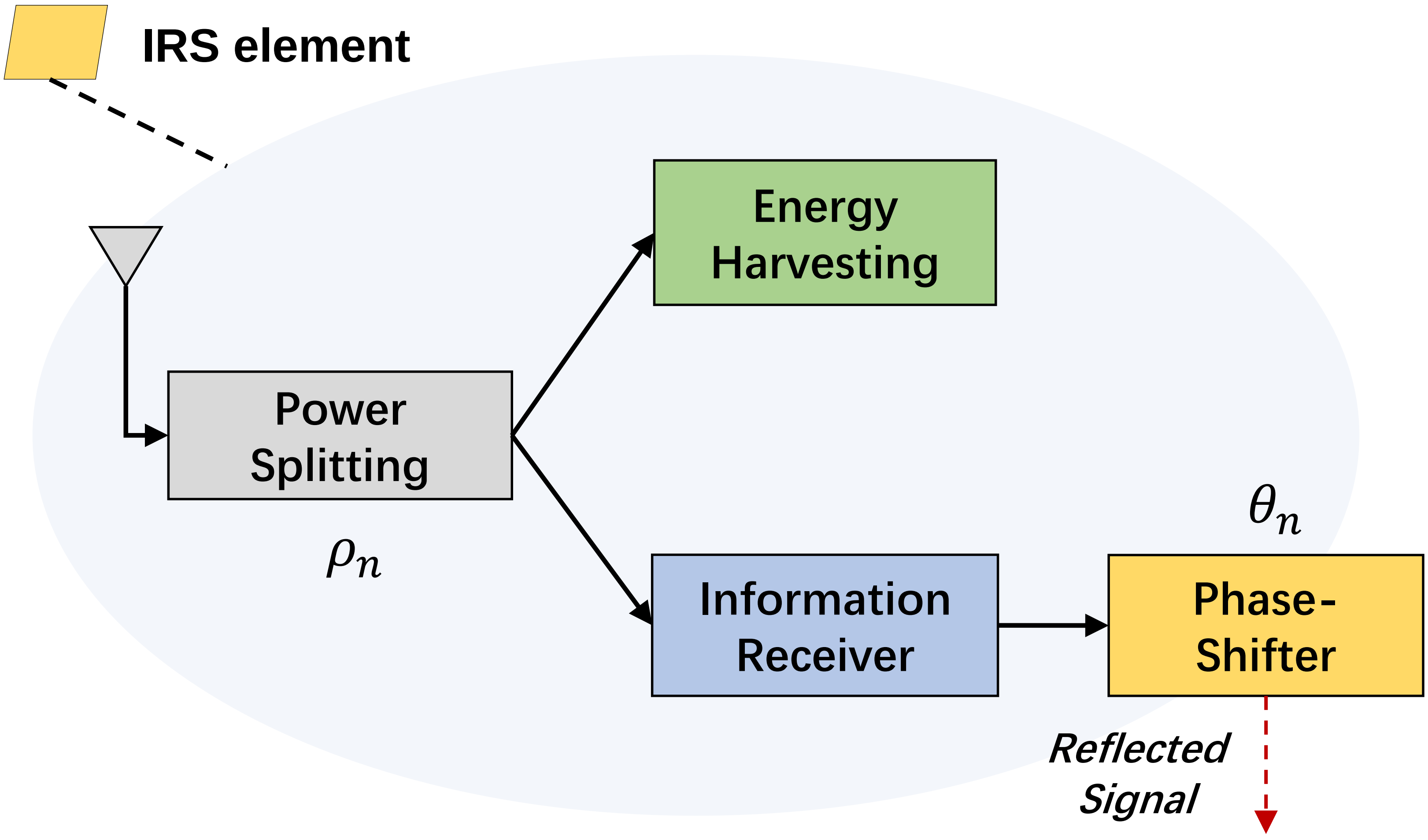


System Model

- Channel Enhancement

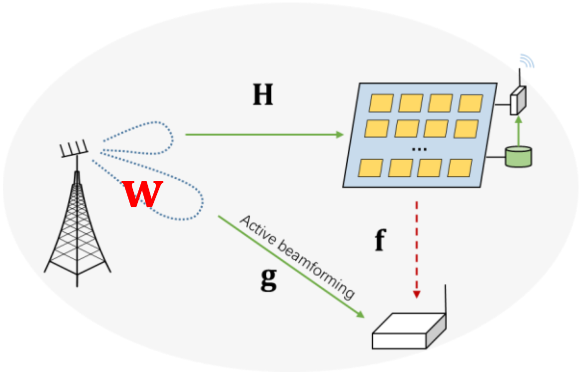
Enhanced Channel

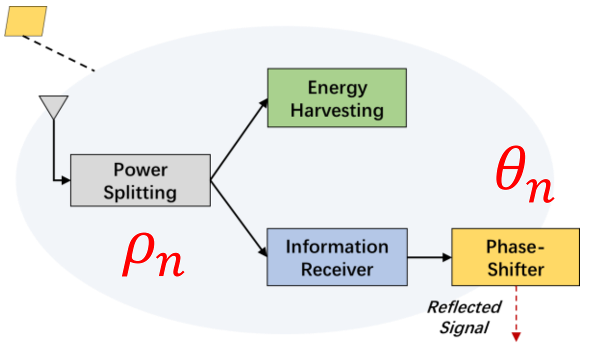
$$\hat{\mathbf{g}} = \mathbf{g} + \mathbf{H}\boldsymbol{\Theta}\mathbf{f}$$

$$\boldsymbol{\Theta} = \begin{bmatrix} \rho_1 e^{j\theta_1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_N e^{j\theta_N} \end{bmatrix}$$

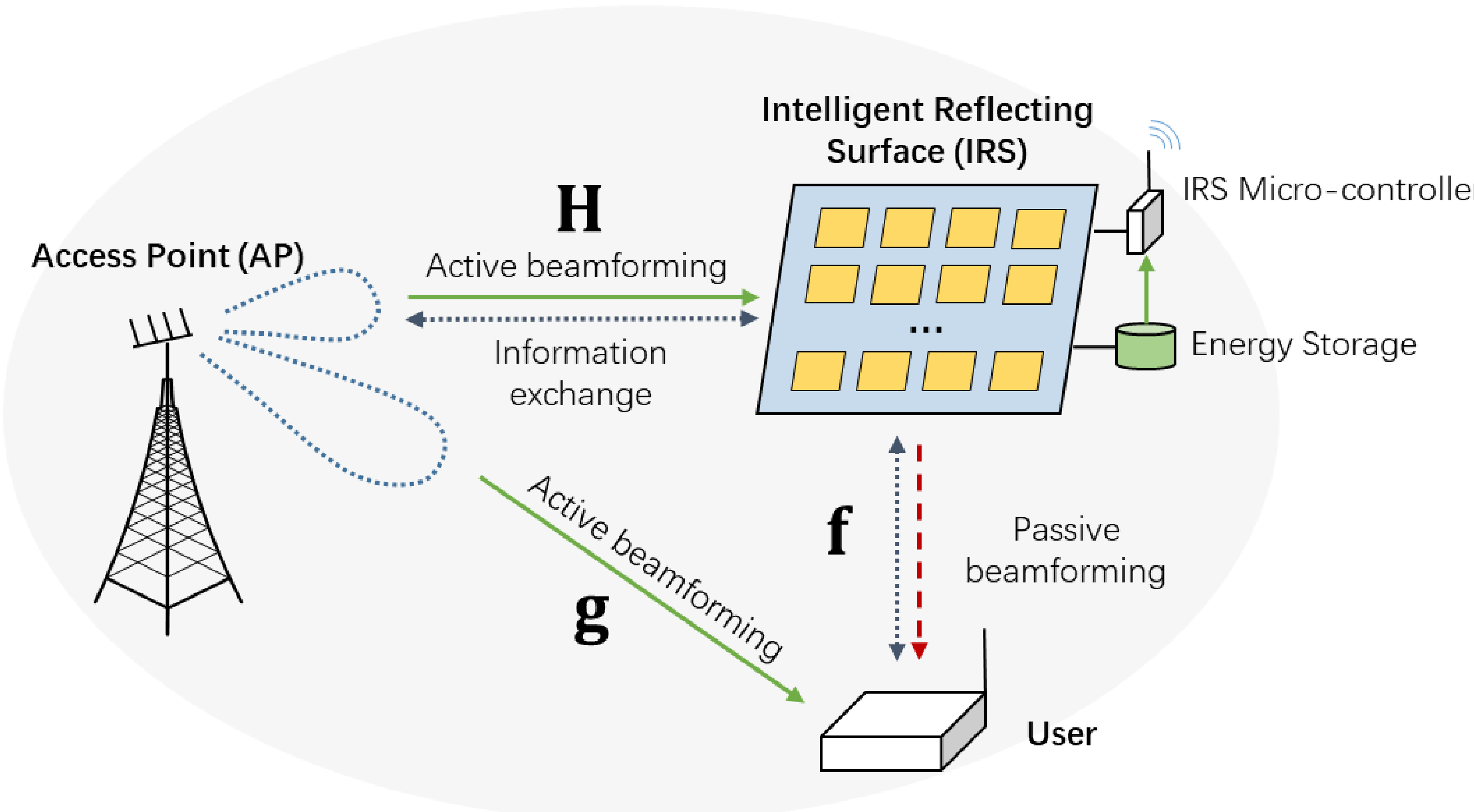
Enhanced SNR

$$\gamma = \|\hat{\mathbf{g}}^H \mathbf{w}\|^2 / \sigma^2$$





System Model



System Model

- Self-sustainable IRS

Incident Signal at element $\boldsymbol{n}$

$$x_n = \mathbf{H}_n^H \mathbf{w}$$

Harvested Energy

$$\eta \sum_{n=1}^{N} (1 - \rho_n^2) ||\mathbf{H}_n^H \mathbf{w}||^2$$

Energy Budget

$$\eta \sum_{n=1}^{N} (1 - \rho_n^2) ||\mathbf{H}_n^H \mathbf{w}||^2 \geq N\mu$$

System Model

Non-Convex | Highly Coupled

$$\max_{\mathbf{w},\boldsymbol{\theta},\boldsymbol{\rho}} \ ||(\mathbf{g} + \mathbf{H\Theta f})^H \mathbf{w}||^2$$

User SNR Maximization

$$\mathrm{s.t.} \ ||\mathbf{w}||^2 \leq \bar{p}$$

Power Constraint

$$\eta \sum_{n=1}^{N} (1 - \rho_n^2)||\mathbf{H}_n^H \mathbf{w}||^2 \geq N\mu$$

Energy Constraint

Two-stage Approximation Algorithm

- Simplification and reformulation

$$\max_{\mathbf{w},\boldsymbol{\theta},\boldsymbol{\rho}} \left\| \left(\mathbf{g} + \bar{\rho}\mathbf{H}\widehat{\boldsymbol{\Theta}}\mathbf{f}\right)^H \mathbf{w} \right\|^2$$

$$\text{s.t. } \|\mathbf{w}\|^2 \leq \bar{p}$$

$$\eta(1-\bar{\rho}^2)\|\mathbf{H}^H\mathbf{w}\|^2 \geq N\mu$$

Identical PS ratio

Proposition 1. [*Necessary cond.]* AP-IRS-user link aligns with the direct link, i.e., AP- user link

$$\mathbf{H}\widehat{\boldsymbol{\Theta}}\mathbf{f} = \Delta\mathbf{g}$$

Two-stage Approximation Algorithm

- 1st Stage: Bisection

Algorithm 1 1^{st} **Stage: Bisection search**

1) Initialize with feasible upper boundary of Δ, i.e., $\Delta_{\max}$ and $\Delta_L \leftarrow 0$, $\Delta_U \leftarrow \Delta_{\max}$, $\epsilon \leftarrow 10^{-5}$

2) **while** $\Delta_U - \Delta_L > \epsilon$:

    $\Delta_M = (\Delta_U + \Delta_L)/2$

    if Δ_M such that (6) is solvable **then**

        $\Delta_L \leftarrow \Delta_M$, $\Delta^* \leftarrow \Delta_M$

    else

        $\Delta_U \leftarrow \Delta_M$

    end if

  end while

3) **Output:** Δ^*

Two-stage Approximation Algorithm

- 2^{nd} Stage: Successive Convex Approx.

Non-Convex

$$\max_{\mathbf{W},\bar{\rho}} \ (1+\bar{\rho}\Delta^*)^2 \mathbf{Tr}(\mathbf{GW})$$

$$\text{s.t.} \ \mathbf{Tr}(\mathbf{W}) \leq \bar{p}$$

$$\eta(1-\bar{\rho}^2)\mathbf{Tr}\left(\widehat{\mathbf{H}}\mathbf{W}\right) \geq N\mu$$

$\mathbf{Tr}(\cdot)$: Trace of matrix

$\mathbf{G} = \mathbf{g}\mathbf{g}^H$, $\widehat{\mathbf{H}} = \mathbf{H}\mathbf{H}^H$

Successive Convex Approx.

Two-stage Approximation Algorithm

IEEE WCNC

- 2nd Stage: Successive Convex Approx.

$$\gamma^{(k)} \triangleq \max_{\mathbf{W},z} \; [(u^{(k)}+v^{(k)})^2 + 2(u^{(k)}+v^{(k)})(u - u^{(k)} + v - v^{(k)}) - (u-v)^2]/4, \tag{11a}$$

$$\text{s.t.} \quad \mathrm{Tr}(\mathbf{W}) \le \bar{p}, \tag{11b}$$

$$\begin{bmatrix} 1-z & \sqrt{\frac{N\mu}{\eta}} \\ \sqrt{\frac{N\mu}{\eta}} & \mathrm{Tr}(\hat{\mathbf{H}}\mathbf{W}) \end{bmatrix} \succeq 0, \tag{11c}$$

$$u \le 2t^{(k)}(t - t^{(k)}) + \left[t^{(k)}\right]^2, \tag{11d}$$

$$t \le 1 + \Delta^* \sqrt{z}, \tag{11e}$$

$$v \le \mathrm{Tr}(\mathbf{G}\mathbf{W}), \tag{11f}$$

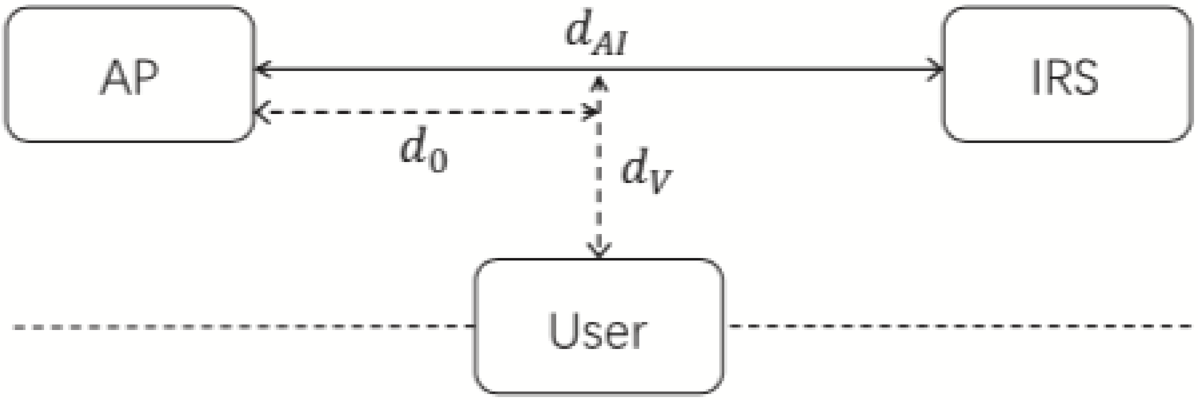
Two-stage Approximation Algorithm

- 2^{nd} Stage: Successive Convex Approx.

Algorithm 2 **2^{nd} stage: Successive Convex Approx.**

With given Δ^* solved in the 1^{st} stage, $\epsilon \leftarrow 10^{-5}$
Initialize $(\mathbf{W}, \bar{\rho})$ randomly that is feasible for problem (8)
Set $t^0 \leftarrow 1 + \Delta^* \bar{\rho}$, $u^0 \leftarrow (t^0)^2$, $v^0 \leftarrow \mathrm{Tr}(\mathbf{GW})$
while $\gamma^{(k)} - \gamma^{(k-1)} \geq \epsilon$
  $\gamma^{(k)} \leftarrow \gamma^{(k-1)}$, $k \leftarrow k + 1$
  $t^{(k)} \leftarrow t^{(k-1)}$, $u^{(k)} \leftarrow u^{(k-1)}$, $v^{(k)} \leftarrow v^{(k-1)}$
  Update $(\mathbf{W}, z, \gamma^{(k)}, t^{(k)}, u^{(k)}, v^{(k)})$ by solving (11)
end while

Numerical Results



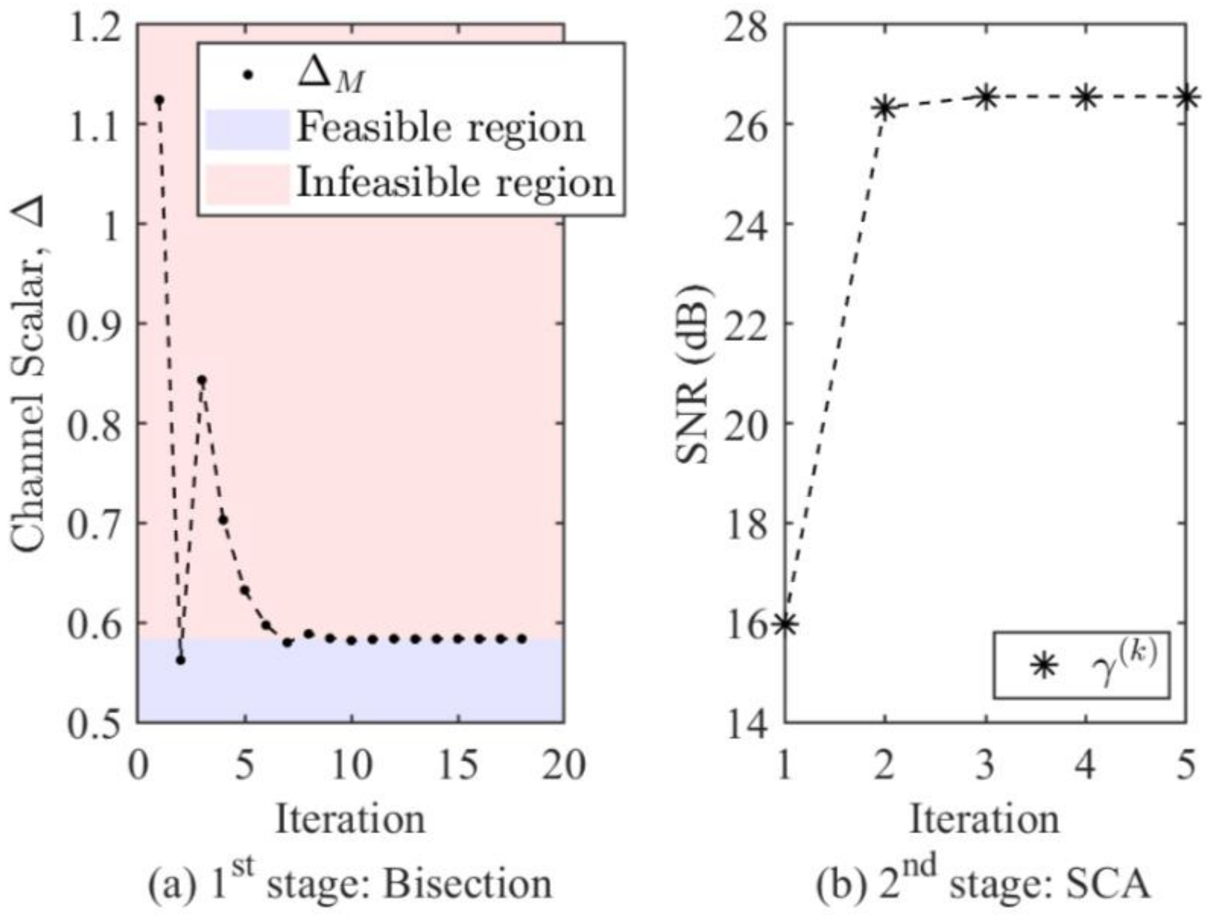
Path Loss: $L = 30 + 20\log_{10}(d)$

$M = 10, N = 80$

Energy harvesting efficient: $\eta = 0.8$

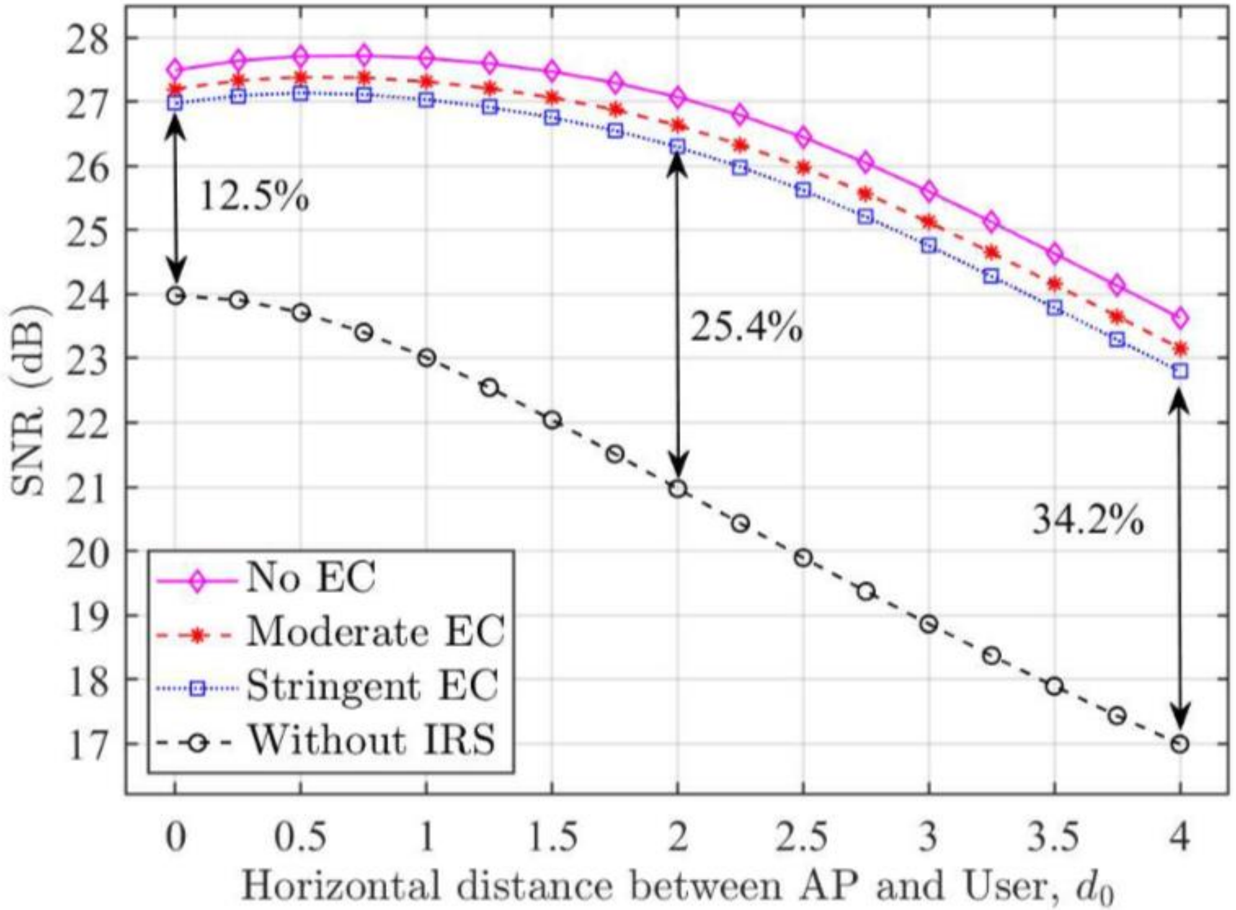
HAP Transmit Power:
$\bar{p} = 5$ dBm

Numerical Results



Verification of the two-stage algorithm convergence

Numerical Results



IRS-enhanced SNR against direct link quality under different IRS power consumption coefficients

Conclusions

- ✓ We formulate a throughput maximization problem that jointly we investigate the optimization of downlink SNR of the wireless powered intelligent reflecting surface-enhanced MISO system.
- ✓ To tackle the non-convexity, we propose a two-stage approximation algorithm by exploiting the structure of the problem.
- ✓ The extensive numerical results show that the influence of IRS power consumption on SNR improvement, and the feasibility of solving the IRS phase-shift independently by bisection algorithm with low complexity is also proved.

Questions & Answers

Thank you !

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