Joint Energy Beamforming and Optimization for Intelligent Reflecting Surface Enhanced Communications

Yuze Zou 1, Shimin Gong 2, Jing Xu 1, Wenqing Cheng 1, Dinh Thai Hoang 3 and Dusit Niyato 4

1 School of Electronic Information & Communications, Huazhong Univ. of Science & Technology, China
2 School of Intelligent Systems Engineering, Sun Yat-sen University, China
3 School of Electrical and Data Engineering, University of Technology Sydney, Australia
4 School of Computer Science and Engineering, Nanyang Technological University, Singapore
Outline

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- System Model
- Two-stage Approximation Algorithm
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Introduction
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IRS element
Introduction

IRS element

Power Splitting

Energy Harvesting

Information Receiver

Phase-Shifter

Reflected Signal

\( \rho_n \)

\( \theta_n \)
System Model

- Channel Enhancement

\[ \hat{g} = g + H \Theta f \]

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

\[ \gamma = \| \hat{g}^H w \|^2 / \sigma^2 \]
System Model

Access Point (AP) — Active beamforming — Information exchange — Active beamforming — User

H

Intelligent Reflecting Surface (IRS)

IRS Micro-controller

Energy Storage

f

Passive beamforming

g
System Model

- Self-sustainable IRS

**Incident Signal at element $n$**

$$x_n = H_n^H w$$

**Harvested Energy**

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

**Energy Budget**

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

\[
\max_{w, \theta, \rho} \| (g + H\Theta f)^H w \|^2
\]

s. t. \( \|w\|^2 \leq \bar{\rho} \)

\[
\eta \sum_{n=1}^{N} (1 - \rho_n^2) \|H_n^H w\|^2 \geq N\mu
\]
Two-stage Approximation Algorithm

- Simplification and reformulation

\[
\begin{align*}
\max_{w, \theta, \rho} & \quad \left\| (g + \bar{\rho} H\Theta f)^H w \right\|^2 \\
\text{s. t.} & \quad \|w\|^2 \leq \bar{\rho} \\
& \quad \eta(1 - \bar{\rho}^2)\|H^Hw\|^2 \geq N\mu
\end{align*}
\]

Identical PS ratio

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

\[H\Theta f = \Delta g\]
Two-stage Approximation Algorithm

- 1st Stage: Bisection

Algorithm 1 1st Stage: Bisection search

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

2) while $\Delta_U - \Delta_L > \epsilon$:
   - $\Delta_M = (\Delta_U + \Delta_L)/2$
   - if $\Delta_M$ 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: $\Delta^*$
Two-stage Approximation Algorithm

- 2\textsuperscript{nd} Stage: Successive Convex Approx.

\[
\max_{W,\rho} \left( 1 + \bar{\rho} \Delta^* \right)^2 \text{Tr}(GW)
\]

s.t. \( \text{Tr}(W) \leq \bar{\rho} \)

\[
\eta (1 - \bar{\rho}^2) \text{Tr}(\hat{H}W) \geq N \mu
\]

\( \text{Tr}(\cdot) \): Trace of matrix

G = gg^H, \( \hat{H} = HH^H \)
Two-stage Approximation Algorithm

2nd Stage: Successive Convex Approx.

\[
\gamma^{(k)} \triangleq \max_{W,z} \left[ (u^{(k)} + v^{(k)})^2 + 2(u^{(k)} + v^{(k)})u - u^{(k)} + v - v^{(k)} - (u - v)^2 \right]/4,
\]

s.t. \( \text{Tr}(W) \leq \bar{p} \), \( \sqrt{N\mu \eta}/\eta \) \[
\begin{bmatrix}
1 - z & \sqrt{N\mu \eta} \\
\sqrt{N\mu \eta} & \text{Tr}(\hat{H}W)
\end{bmatrix} \succeq 0,
\]

\[
u \leq 2t^{(k)}(t - t^{(k)}) + \left[ t^{(k)} \right]^2,
\]

\[
t \leq 1 + \Delta^* \sqrt{z},
\]

\[
v \leq \text{Tr}(GW),
\]
Two-stage Approximation Algorithm

- 2nd Stage: Successive Convex Approx.

Algorithm 2 2nd stage: Successive Convex Approx.

With given $\Delta^*$ solved in the 1st stage, $\epsilon \leftarrow 10^{-5}$
Initialize $(\mathbf{W}, \tilde{\rho})$ randomly that is feasible for problem (8)
Set $t^0 \leftarrow 1 + \Delta^* \tilde{\rho}$, $u^0 \leftarrow (t^0)^2$, $v^0 \leftarrow \text{Tr}(\mathbf{GW})$

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!

Email: zouyuze@hust.edu.cn