Joint Optimization of Wireless Power Transfer and Collaborative Beamforming for Relay Communications

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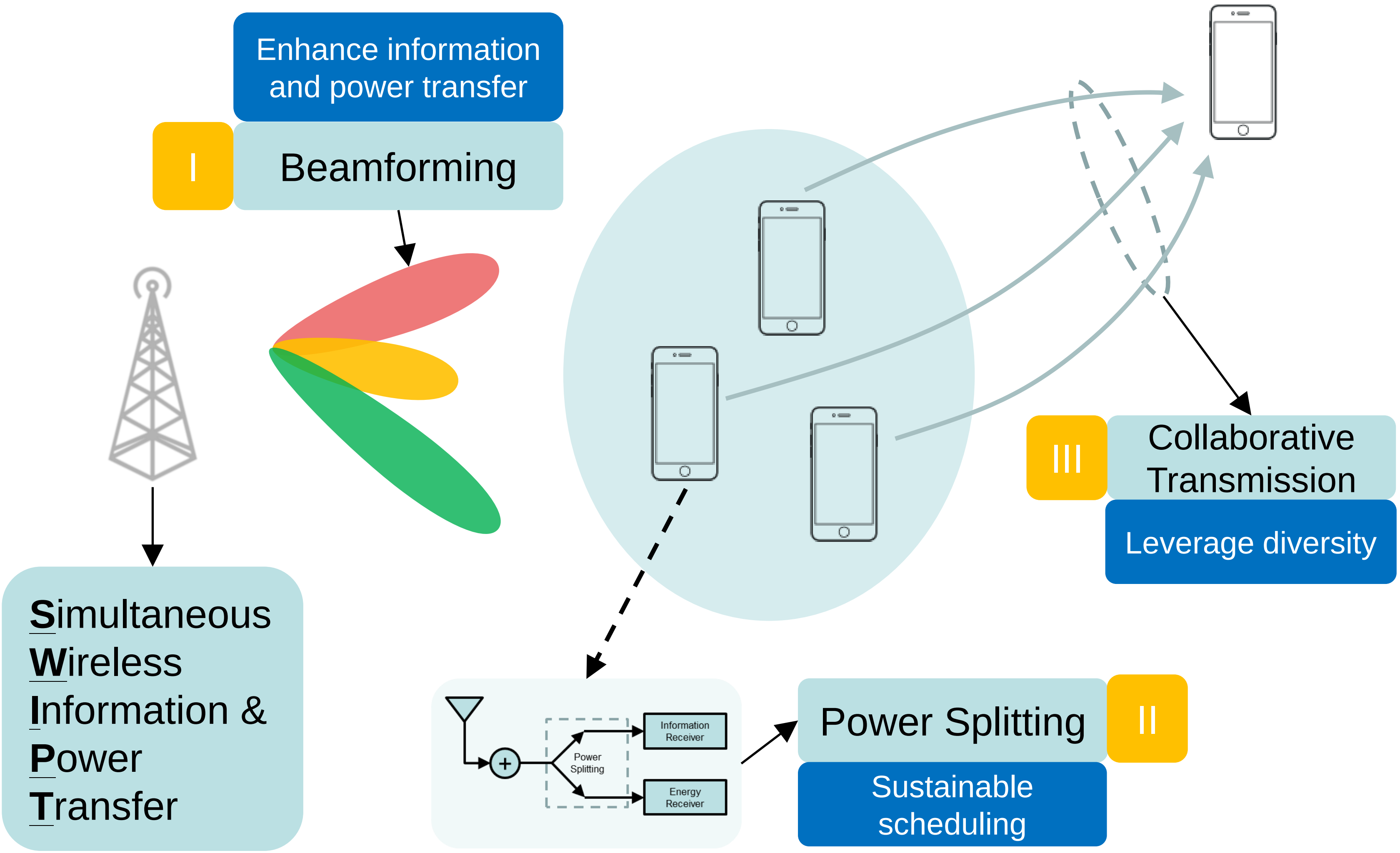
Outline

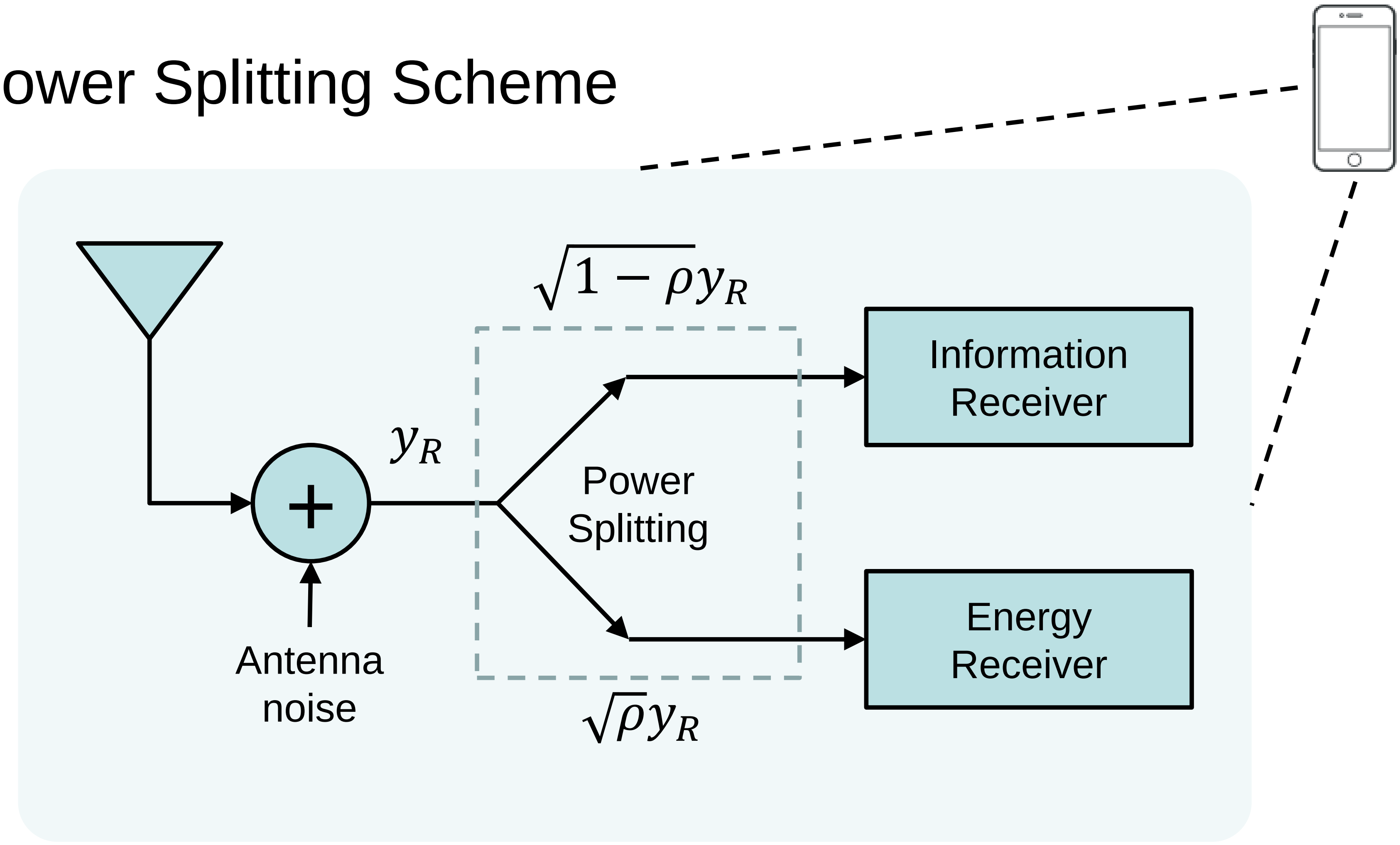
- Introduction
- System Model
- Robust Multi-Relay Transmission
- Numerical Results

Introduction

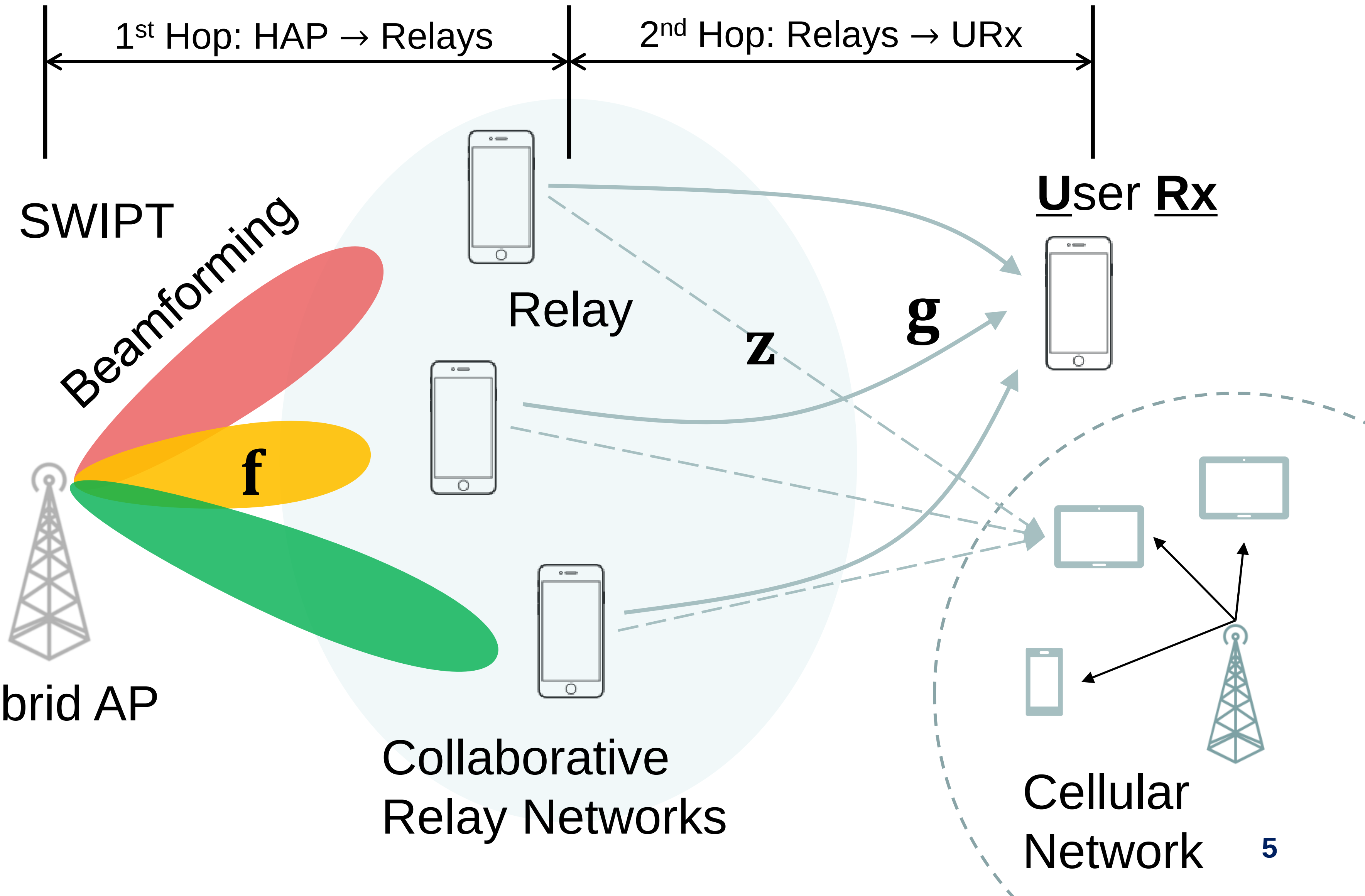


Introduction

Power Splitting Scheme

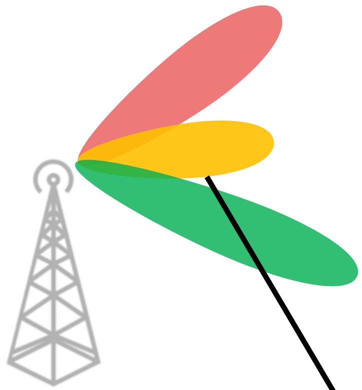


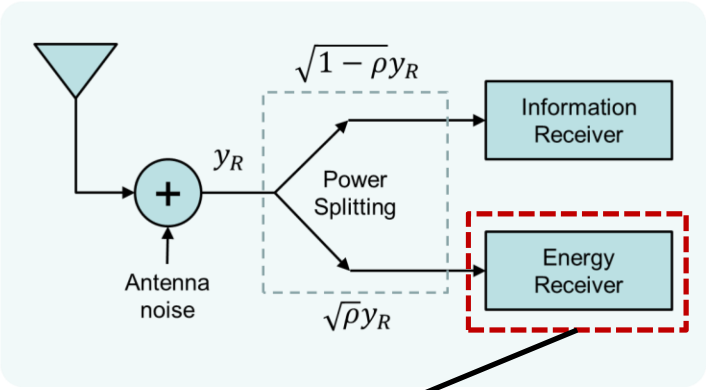
System Model



System Model

- Energy Beamforming and Harvesting





$$(y_R)_n = \sqrt{p_t}\mathbf{f}_n^H \mathbf{w} s + \sigma_n \qquad p_n \le \eta \rho_n p_t \mathbf{f}_n^H \mathbf{W} \mathbf{f}_n$$

$\mathbf{w}$, Beamforming Vector

p_t, HAP Transmit Power

s, HAP Transmit Symbol

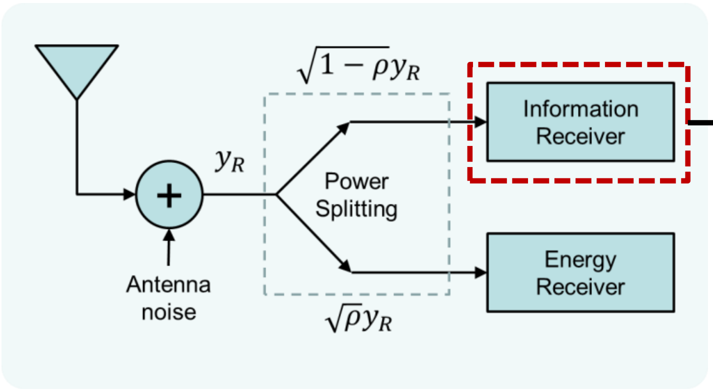
$\mathbf{W} = \mathbf{w}\mathbf{w}^H$, Beamforming Matrix

η, Energy Harvesting Efficiency

ρ_n, Power Splitting Ratio

System Model

- Relays' Transmit Control



Amplify-and-Forward

$$\sqrt{(1-\rho_n)p_t\mathbf{f}_n^H\mathbf{w}s+\sigma_n}$$

$$x_n=\sqrt{\frac{p_n}{N_0+(1-\rho_n)p_t\mathbf{f}_n^H\mathbf{W}\mathbf{f}_n}}$$

Amplify Coefficient

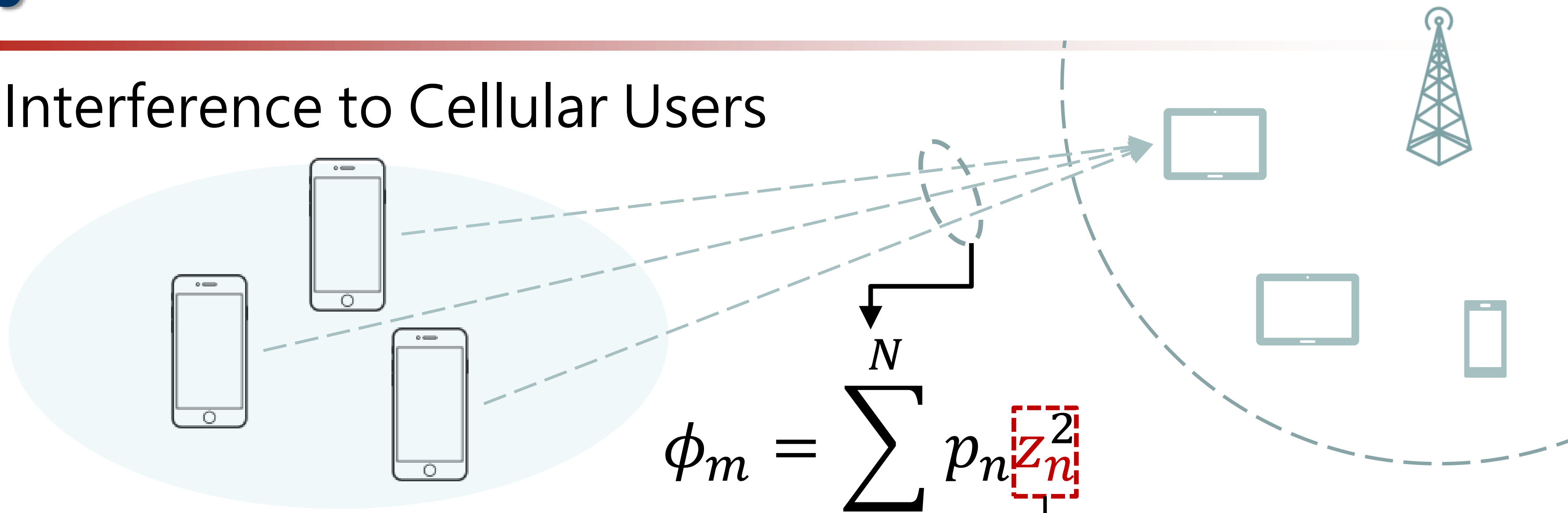
URx Reception

$$u=\sum_{n=1}^{N}\left(x_n\sqrt{(1-\rho_n)p_t}\mathbf{f}_n^H\mathbf{w}g_ns\right)+\sum_{n=1}^{N}(x_n\sigma_ng_n)+v_d$$

Signal ⟷ Noise ⟷

System Model

- Interference to Cellular Users



$$\phi_m = \sum_{n=1}^{N} p_n z_n^2$$

Channel Uncertainty

$$\mathbb{P}_{\mathbf{z}} \in \mathcal{P}(\mathbf{u}_{\mathbf{z}}, \mathbf{S}_{\mathbf{z}})$$

$\mathbf{u}_{\mathbf{z}}$, First Order Moment

$\mathbf{S}_{\mathbf{z}}$, Second Order Moment

Robust Interference Constraint

$$\max_{\mathbb{P} \in \mathcal{P}_{\mathbf{z}}} \mathbb{P}(\phi_m \geq \bar{\phi}) \leq \zeta$$

Robust Multi-Relay Transmission

$$\max_{\rho_n, \mathbf{w}, p_n} \; r = \log\left(1 + \frac{|(\mathbf{x} \circ \mathbf{y})^H \mathbf{g}|^2}{1 + \mathbf{x}^T \mathrm{D}(\mathbf{g} \circ \mathbf{g})\mathbf{x}}\right)$$

Highly Coupled

URx Throughput Maximization

$$\text{s.t.} \quad 0 \le p_n \le \eta p_t \rho_n \mathbf{f}_n^H \mathbf{W} \mathbf{f}_n$$

Energy Constraint

$$\max_{\mathbb{P} \in \mathcal{P}_{\mathbf{z}}} \mathbb{P}(\phi_m \ge \bar{\phi}) \le \zeta$$

Interference Constraint

Non-Convex

$$\mathbf{Tr}(\mathbf{W}) \le 1, \mathbf{W} \succcurlyeq 0, \text{and } 0 \le \rho_n \le 1$$

$\circ$, Hadamard Product

$\mathrm{D}(\mathbf{x})$, Diagonal matrix with the diagonal given by the vector $\mathbf{x}$

$\mathbf{y} = [y_1, \cdots, y_N]^T, y_n \triangleq \sqrt{(1-\rho_n)p_t}\mathbf{f}_n^H \mathbf{w} g_n$

Robust Multi-Relay Transmission

$$\gamma = \frac{|(\mathbf{x}\circ\mathbf{y})^H\mathbf{g}|^2}{1+\mathbf{x}^T\mathrm{D}(\mathbf{g}\circ\mathbf{g})\mathbf{x}} \le \frac{\mathbf{x}^T\mathrm{D}(\mathbf{g}\circ\mathbf{g})\mathbf{x}}{1+\mathbf{x}^T\mathrm{D}(\mathbf{g}\circ\mathbf{g})\mathbf{x}} \times (\mathbf{y}^T\mathbf{y})$$

Cauchy-Schwarz Inequality

$$= \frac{X}{1+X}Y$$

$$\exists c \neq 0, \mathrm{s.t.}\ \mathbf{y} = c\mathbf{x}\circ\mathbf{g}$$

Equivalence Condition

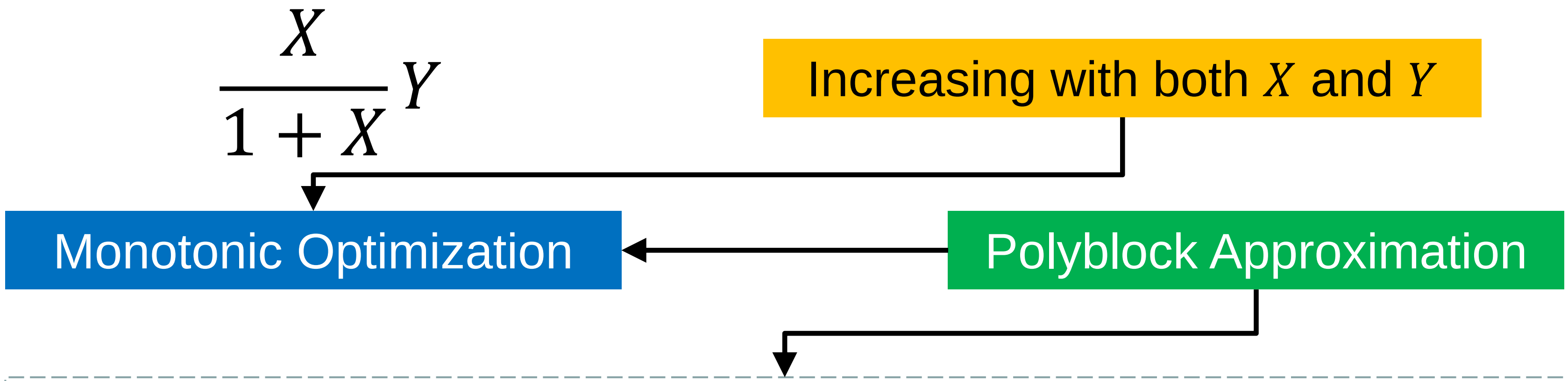
$$\max \log(1+\gamma)$$

Lower Bounded by

$$\max \frac{X}{1+X}Y$$

$$\mathrm{s.t.}\ \mathbf{y} = c\mathbf{x}\circ\mathbf{g}, c \neq 0$$

Robust Multi-Relay Transmission



1. Initialize $V_0 = [X_0, Y_0], V = [V_0], P_0 = \text{Rectangle}([0,0], V_0), k = 0,$
   $r^U = \frac{X_0}{X_0+1} Y_0, r^L = 0$
2. WHILE $(r^U - r^L \geq \epsilon)$
3. $k \leftarrow k + 1$
4. Select $V_k = \arg\max \frac{V_j(1)}{V_j(1)+1} V_j(2)$, $r^U = \frac{V_k(1) V_k(2)}{V_k(1)+1}$
5. Project V_k onto the *edge* of *Feasible Region* as $O_k, r^L = \frac{O_k(1) O_k(2)}{O_k(1)+1}$
6. Crop $P_k = P_{k-1} \backslash \text{Rectangle}(O_k, V_k)$
7. Update V according to O_k
8. END WHILE

Robust Multi-Relay Transmission

Projection

Bisection

$$|\mathbf{y}|^2 \geq q_k Y_k,$$

$$\mathbf{x}^T \mathrm{D}(\mathbf{g} \circ \mathbf{g})\mathbf{x} \geq q_k X_k,$$

$$\max_{\mathbb{P} \in \mathcal{P}_{\mathbf{z}}} \mathbb{P}(\phi_m \geq \bar{\phi}) \leq \zeta,$$

$$cx \circ g = y,$$

$$\eta \rho_n p_t \mathbf{f}_n^H \mathbf{W} \mathbf{f}_n \geq p_n.$$

Convex SDP

$$\max \sum_{n=1}^{N} s_n$$

$$\text{s.t.}\ p_n \leq \eta p_t \mathbf{f}_n^H \bar{\mathbf{W}} \mathbf{f}_n,$$

$$s_n \leq p_t \mathbf{f}_n^H (\mathbf{W} - \bar{\mathbf{W}}) \mathbf{f}_n,$$

$$\begin{bmatrix} c^2 p_n g_n^2 - s_n & s_n \\ s_n & 1 \end{bmatrix} \succcurlyeq 0,$$

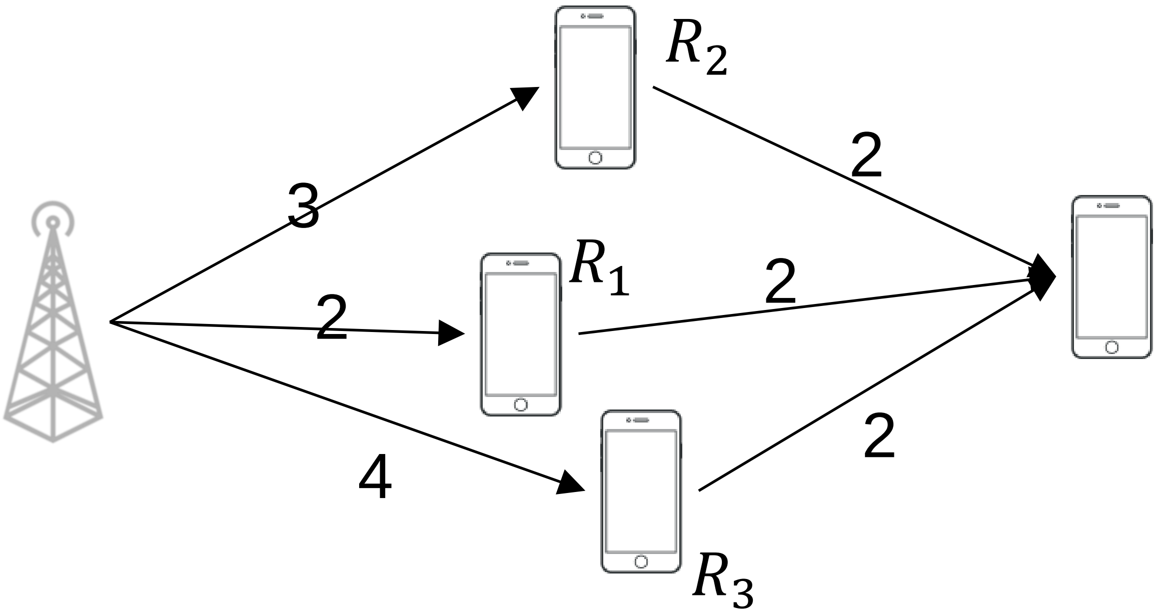
$$\mathbf{M} \succcurlyeq \begin{bmatrix} \mathrm{D}(\mathbf{p}) & 0 \\ 0 & \nu - \bar{\phi} \end{bmatrix},$$

$$\mathbf{Tr}(\mathbf{\Sigma_z M}) \leq \nu\zeta, M \succcurlyeq 0, \nu \geq 0,$$

$$\mathbf{Tr}(\mathbf{W}) \leq 1, \mathbf{Tr}(\bar{\mathbf{W}}) \leq 1.$$

$^*s_n = y_n^2, \rho_n = \mathbf{f}_n^H \bar{\mathbf{W}} \mathbf{f}_n / \mathbf{f}_n^H \mathbf{W} \mathbf{f}_n$

Numerical Results



Path Loss: $L = 25 + 20\log_{10}(d)$

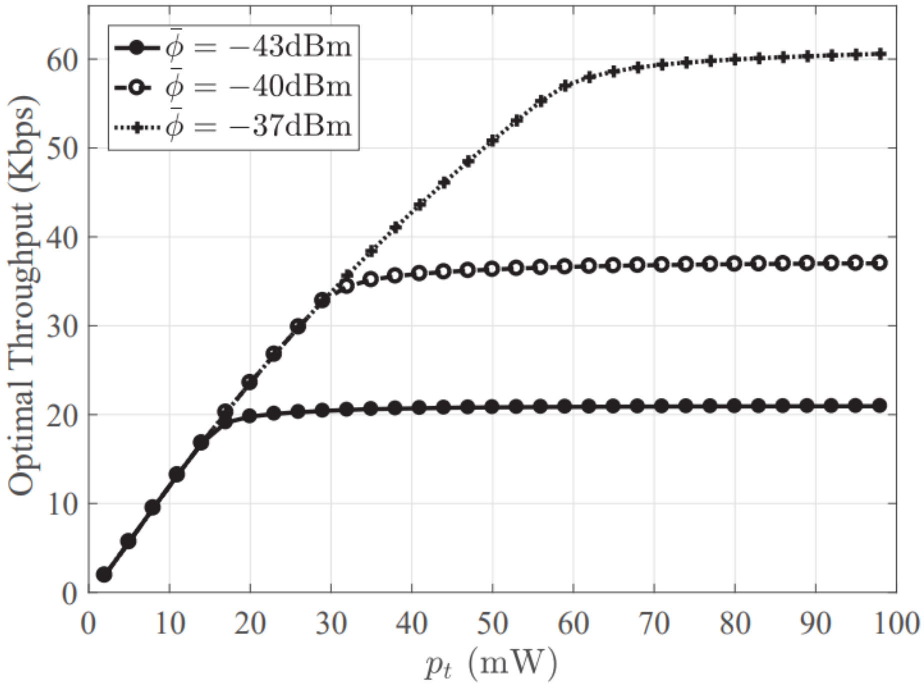
Noise Power: -90 dBm

Bandwidth: 100 kHz

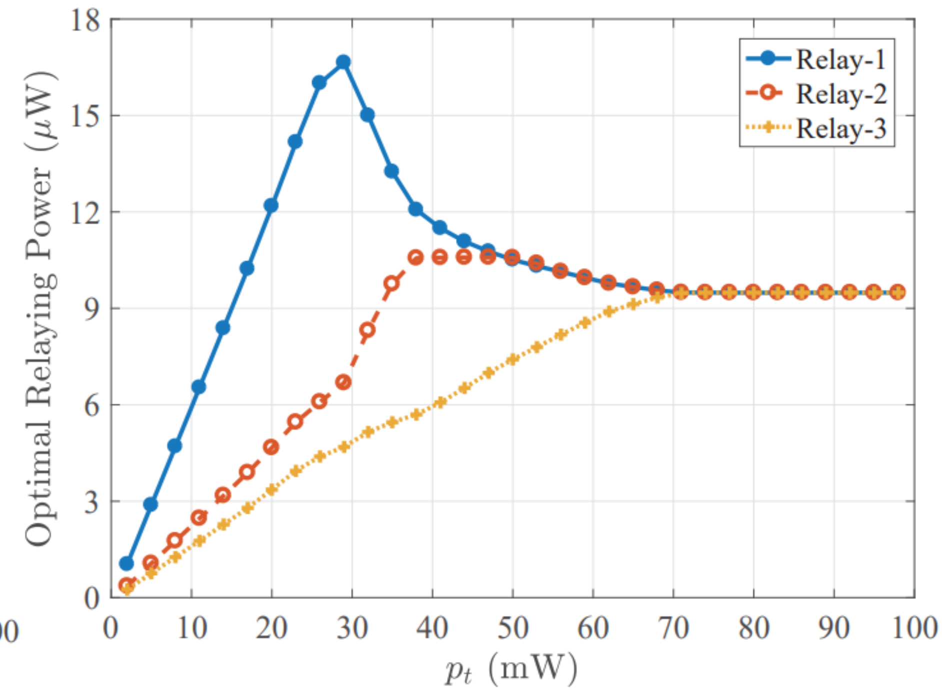
Energy harvesting efficient: $\eta = 0.5$

HAP Transmit Power:
$p_t \in [10, 100]$ mW

Numerical Results



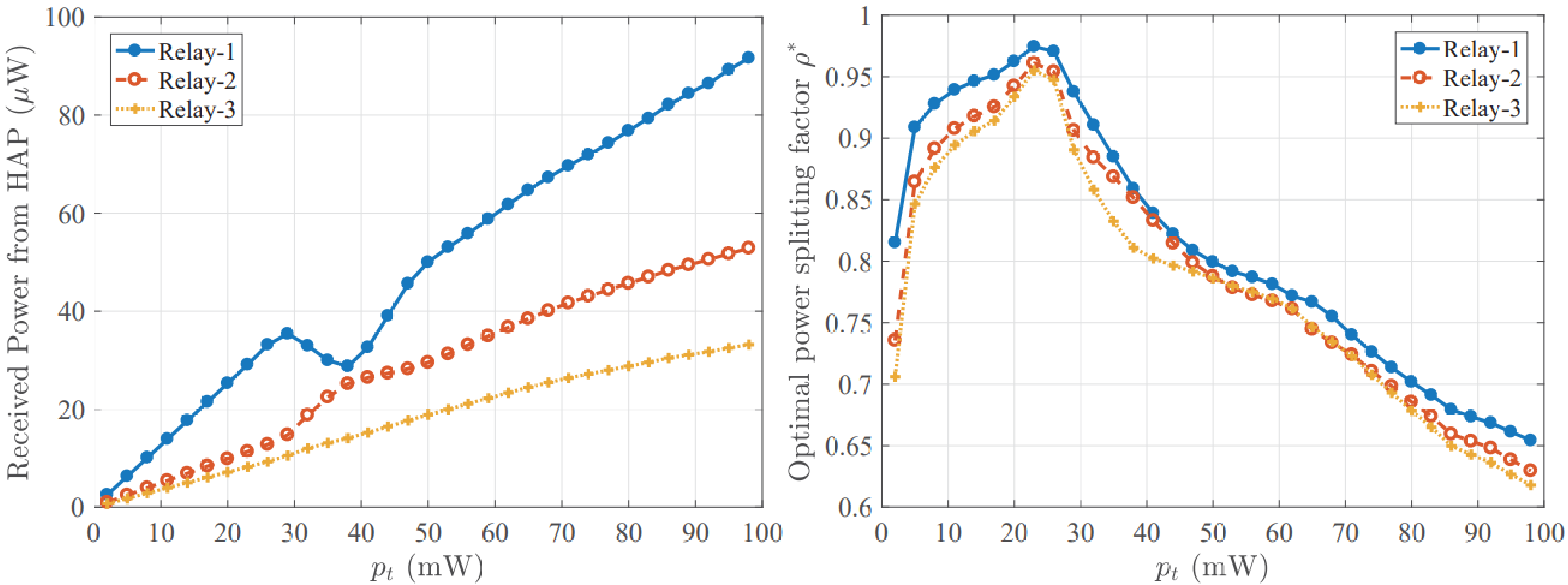
(a) Optimal throughput



(b) Optimal relay power.

Throughput and Relays' Transmit Power limited by
Cellular Users' Interference Constraint

Numerical Results



(a) Received power from HAP **(b)** Optimal PS ratio

HAP's beamforming and Relays' PS ratio Optimization

Conclusions

- **Pros: Jointly Optimizing Power Transfer and Relay Strategy**
  - ✓ We formulate a throughput maximization problem that jointly optimizes the relay strategy (PS ratio and transmit power) and the beamforming of HAP.
  - ✓ A lower bounded SDP reformulation is deduced via monotonic optimization.
  - ✓ Near optimal result is found via Polyblock iteration algorithm according to numerical results.

- **Cons:**
  - ✓ No direct link considered

Questions & Answers

Thank you !