Multi-objective Resource Allocation Optimization for SWIPT in Small-cell Networks

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Outline

Motivation

- Internet of Things (IoT)
  - Battery replacement

    Energy harvesting solution

- 5G Networks are excellent opportunities for interconnecting IoTs
  - High network capacity
  - High coverage and available data rates
  - Long handset battery life

    Small cell deployment solution

- SWIPT in small cell networks

System Model

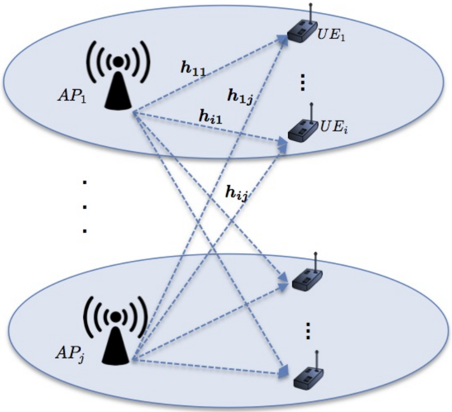


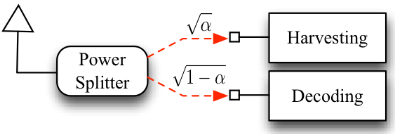
Figure : Multi-AP MISO SWIPT system

Received signal in the *i*th user

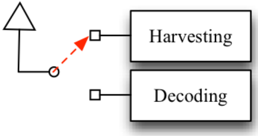
$$y_i = \sum_{j=1}^{N_{AP}} \boldsymbol{h}_{ij}^{H} \sum_{l=1}^{N_{UE}} \boldsymbol{x}_{lj} s_l + n_i$$

System Model

- Colocated Receiver Architecture
  - Ideal SWIPT: Not feasible
  - Power Splitting (PS):



  - Time Switching (TS):



System Model

Throughput (bits/sec/Hz) in the TS scheme

$$R_i^{TS}(\boldsymbol{X}, \alpha_i) = \alpha_i \log_2(1 + \frac{\sum_{j=1}^{N_{AP}} \text{trace}(\boldsymbol{H_{ij}X_{ij}})}{\sigma_i^2 + \sum_{j=1}^{N_{AP}} \sum_{l=1, l\neq i}^{N_{UE}} \text{trace}(\boldsymbol{H_{ij}X_{lj}})}),$$

Harvested Energy (Joule/sec) in the TS scheme

$$E_{h_i}^{TS}(\boldsymbol{X}, \alpha_i) = (1 - \alpha_i)\eta_i \sum_{j=1}^{N_{AP}} \sum_{l=1}^{N_{UE}} \text{trace}(\boldsymbol{H_{ij}X_{lj}}).$$

$$\boldsymbol{X_{ij}} = \boldsymbol{x_{ij}x_{ij}^H}, \boldsymbol{H_{ij}} = \boldsymbol{h_{ij}h_{ij}^H}$$

$$\boldsymbol{X_{ij}}, \boldsymbol{H_{ij}} \in \mathbb{C}^{N_{A_j} \times N_{A_j}}, \quad i \in \mathcal{N}_{UE}, j \in \mathcal{N}_{AP}.$$

Problem Formulation

- Multi-Objective Optimization (MOO)
  - $\boldsymbol{u}_i(\boldsymbol{X}, \alpha_i) = [R_i^{TS}(\boldsymbol{X}, \alpha_i), E_{h_i}^{TS}(\boldsymbol{X}, \alpha_i)]$.
- Problem Formulation

$$
\begin{aligned}
\underset{\boldsymbol{X}, \boldsymbol{\alpha}}{\text{Maximize}} \quad & \boldsymbol{u}(\boldsymbol{X}, \boldsymbol{\alpha}) \\
\text{subject to} \quad & (1) \sum_{j=1}^{N_{AP}} \sum_{l=1}^{N_{UE}} \text{trace}(\boldsymbol{X_{lj}}) \leq P_{max} \\
& (2) \boldsymbol{X_{lj}} \succeq 0, \text{Rank}(\boldsymbol{X_{lj}}) = 1, \ \forall l, j \\
& (3) \alpha_i \in [0, 1], \ \forall i.
\end{aligned}
$$

Problem Formulation

- SDR (Semidefinite Relaxation) technique
- Weighted Chebyshev scalarization

$$
\begin{aligned}
\underset{\boldsymbol{X},\boldsymbol{\alpha},\lambda}{\text{Maximize}} \quad & \lambda \\
\text{subject to} \quad & (1)\ \alpha_i R_i(\boldsymbol{X}) \geq \lambda v_i^{(1)},\ \forall i \\
& (2)\ (1-\alpha_i) E_i(\boldsymbol{X}) \geq \lambda v_i^{(2)},\ \forall i \\
& (3)\ \sum_{j=1}^{N_{AP}} \sum_{l=1}^{N_{UE}} \text{trace}(\boldsymbol{X_{lj}}) \leq P_{max} \\
& (4)\ \boldsymbol{X_{lj}} \succeq 0,\ \forall l, j \\
& (5)\ \alpha_i \in [0,1],\ \forall i.
\end{aligned}
$$

Problem Formulation

$$
\begin{aligned}
\underset{\substack{\boldsymbol{X},\alpha_i,\beta_i,R_i,E_i\\ I_i,\lambda,\ \forall i}}{\text{Maximize}} \quad & \lambda \\
\text{subject to} \quad & \text{(C1) } \alpha_i R_i \geq \lambda v_i^{(1)},\ \forall i \\
& \text{(C2) } \beta_i \eta_i E_i \geq \lambda v_i^{(2)},\ \forall i \\
& \text{(C3) } E_i = \sum_{j=1}^{N_{AP}} \sum_{l=1}^{N_{UE}} \text{trace}(\boldsymbol{H_{ij} X_{lj}}),\ \forall i \\
& \text{(C4) } I_i = \sum_{j=1}^{N_{AP}} \sum_{l=1, l\neq i}^{N_{UE}} \text{trace}(\boldsymbol{H_{ij} X_{lj}}),\ \forall i \\
& \text{(C5) } R_i = \log(E_i + \sigma_i^2) - \log(I_i + \sigma_i^2),\ \forall i \\
& \text{(C6) } \sum_{j=1}^{N_{AP}} \sum_{l=1}^{N_{UE}} \text{trace}(\boldsymbol{X_{lj}}) \leq P_{max} \\
& \text{(C7) } \boldsymbol{X_{lj}} \succeq 0,\ \forall l, j \\
& \text{(C8) } \alpha_i + \beta_i = 1,\ \forall i \\
& \text{(C9) } \alpha_i \in [0, 1],
\end{aligned}
$$

Algorithm

Initialization

Choose an initial point $\boldsymbol{I}_i^0$ inside the convex set defined by (C1)-(C4), (C6)-(C9), $\gamma \in \mathbb{R}$ and a given tolerance $\epsilon > 0$.

Convex-concave procedure (CCP)

For a given $\boldsymbol{I}_i^k$, solve the convex SDP below to obtain the solution $\hat{\boldsymbol{I}}_i(\boldsymbol{I}_i^k)$.

$$\begin{aligned} \underset{\substack{\boldsymbol{X},\alpha_i,\beta_i,R_i,E_i \\ I_i,\hat{\lambda},\ \forall i}}{\text{Maximize}} \quad & \hat{\lambda} \\ \text{subject to} \quad & \text{(C1)-(C4)} \\ & (\overline{\text{C5}})\ R_i \leq \log(E_i + \sigma_i^2) - \\ & (\log(I_i^k + \sigma_i^2) + \frac{1}{I_i^k + \sigma_i^2}(I_i - I_i^k)) \\ & \text{(C6)-(C9)} \end{aligned}$$

Termination criteria

If $\|\hat{\boldsymbol{I}}_i(\boldsymbol{I}_i^k) - \boldsymbol{I}_i^k\| \leqslant \epsilon$
then stop.

Otherwise set
$\boldsymbol{I}_i^k = \boldsymbol{I}_i^k + \gamma(\hat{\boldsymbol{I}}_i(\boldsymbol{I}_i^k) - \boldsymbol{I}_i^k)$.

Proposition 1

The optimal precoding matrices are rank-one.

$$\text{Rank}(\boldsymbol{X_{lj}}) = 1,$$
$$\boldsymbol{X_{ij}} = \boldsymbol{x_{ij}}\boldsymbol{x_{ij}^H} \quad \forall l, j$$

Proposition 2

CCP Algorithm converges to a *stationary point* of the original problem.

Numerical Results

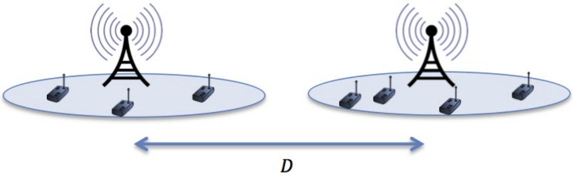


Figure : Simulation scheme

Parameters	Values	Parameters	Values
N_{AP}	2	Pathloss exponent	3
$N_{A_1} = N_{A_2}$	2	σ_i^2	-90 dBm
D	20 m	P_{max}	1 Watt
d_{min}/d_{max}	2/10 m	N_{UE}	2,4,6

Numerical Results

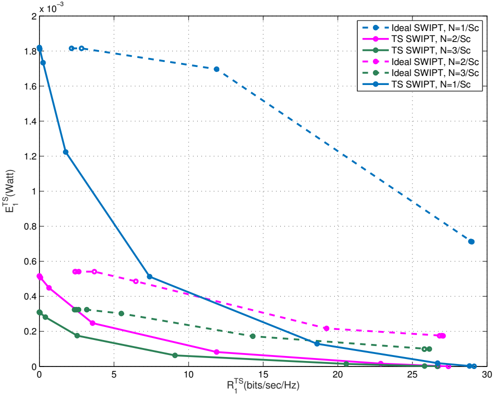
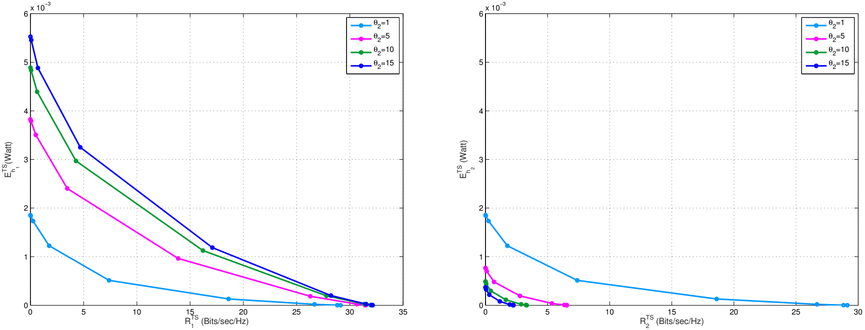


Figure : Pareto frontier of TS SWIPT and ideal SWIPT, $v_i^{(1)} = \theta_1, v_i^{(2)} = 1\ \forall i$

Numerical Results



(a) (b)

Figure : Pareto frontier of first and second TS SWIPT UEs with different priorities, $v_1^{(1)} = \theta_1\theta_2, v_1^{(2)} = \theta_2$ and $v_2^{(1)} = \theta_1, v_2^{(2)} = 1$

Numerical Results

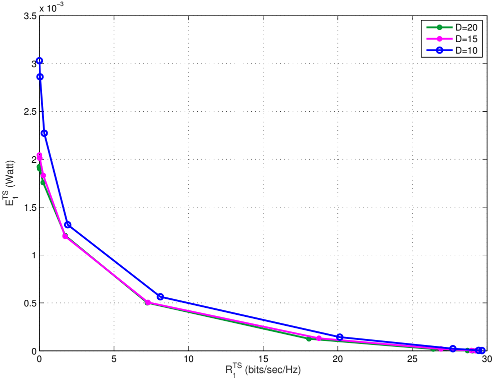


Figure : Pareto frontier of TS SWIPT for different AP distances

Conclusion

- Joint Transmit Precoding and Receiver Time Switching SWIPT Design was formulated as an MOO problem and solved using CCP Algorithm.
- Numerical results show that:
  - The loss due to TS SWIPT decreases with increasing the number of users.
  - Coordination between cells can be used to drastically increase the energy harvested of one user at the expense of the other user's performance.
  - Interference can be exploited to increase the amount of harvested energy while not degrading the data rate.

References

- R. Zhang and C. K. Ho, "MIMO broadcasting for simultaneous wireless information and power transfer," *IEEE Transactions on Wireless Communications*, vol. 12, no. 5, pp. 1989–2001, 2013.
- L. Liu, R. Zhang, and K.-C. Chua, "Wireless information transfer with opportunistic energy harvesting," *IEEE Transactions on Wireless Communications*, vol. 12, no. 1, pp. 288–300, 2013.
- D. W. K. Ng, E. S. Lo, and R. Schober, "Wireless information and power transfer: Energy efficiency optimization in ofdma systems," *IEEE Transactions on Wireless Communications*, vol. 12, no. 12, pp. 6352–6370, 2013.
- D. W. K. Ng, and R. Schober, "Resource allocation for coordinated multipoint networks with wireless information and power transfer,". *In IEEE Global Communications Conference*, pp. 4281-4287, December 2014.
- S. Leng, D. W. K. Ng, N. Zlatanov, and R. Schober, "Multi-objective beamforming for energy-efficient SWIPT systems," *IEEE International Conference on Communications (ICC)*, Kuala Lumpur, Malaysia, 22-27 May 2016.
- S. Leng, D. W. K. Ng, N. Zlatanov, and R. Schober, "Multi-objective resource allocation in full-duplex SWIPT systems," *arXiv preprint arXiv:1509.05959*, 2015.

Thank you for your attention!