Optimal Simultaneous Wireless Information and Power Transfer with Low-Complexity Receivers

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Motivation

✓ In today’s widely used devices and internet-of-things (IoT) applications, such as wearables, and sensor networks, energy harvesting (EH) can be seen as the final challenge to true mobility.
✓ Harvesting energy from sources using radio frequency signals in communication applications, termed as wireless power transfer (WPT), has received much attention during the last years.
✓ Simultaneous wireless information and power transfer (SWIPT) system with an integrated energy and information receiver, with the advantage of low complexity and energy cost.

Contribution

➢ A tractable expression of the achievable rate of the integrated receiver.
➢ Definition of the joint harvested energy-rate outage probability, which is calculated for a point-to-point and multicasting system.
➢ Minimization of the joint harvested energy-rate outage probability, by optimizing the power-splitting (PS) ratio.

System Model

The equivalent discrete-time memoryless channel is modeled as

\[ Y = |h|^2 PX + Z, \]

or (channel output) = (path loss) x (channel gain) x (average transmit power) x (channel input) + (equivalent processing noise)

➢ channel input:

➢ equivalent processing noise caused by the rectifier and the analog-to-digital converter (ADC):

\[ Z \sim N\left(0, \sigma_{\text{rec}}^2 + \frac{\sigma_{\text{adc}}^2}{(1 - \rho)^2}\right) \quad \text{PS factor} \]

Two systems:

point-to-point communication

dowlink multicasting, the base station transmits the same information to N users, simultaneously.

Harvested Energy-Rate Trade-off

➢ Harvested energy:

\[ Q = \rho \mathbb{E}[|h|^2 P] \]

conversion efficiency

➢ Achievable rate:

\[ R = \frac{1}{2} \log_2 \left( 1 + \frac{\rho^2 (|h|^2 P)^2}{2\pi^2}\right) \]

\[ \sigma = \sigma_{\text{rec}}^2 + \frac{\sigma_{\text{adc}}^2}{(1 - \rho)^2}. \]

There is no exact expression for the capacity, the proposed one is a lower bound.

Harvested Energy-Rate Region

Joint Harvested Energy-Rate Outage Probability

Definition:

\[ P_o = \Pr \left( Q \leq \rho \Theta \cup R \leq \frac{R}{\Gamma} \right). \]

energy threshold  rate threshold.

It is proved that the joint harvested energy-rate outage probability for the point-to-point system is given by

\[ P_o = 1 - e^{-\min \left\{ \frac{\rho B}{\Gamma^2}, \frac{1}{\rho^2} \sqrt{\frac{2\rho^2}{\pi \rho^2} \left( \frac{2\pi^2 - 1}{A} \right)} \right\}}. \]

The optimal value of \( \rho \in [0, 1] \) is given by the solution of

\[ \rho^4 - 2\rho^3 + \left(1 + \frac{\sigma_{\text{ADC}}^2}{\sigma_{\text{rec}}^2} \frac{A^2}{2\pi^2 \sigma_{\text{rec}}^2 B^2}\right) \rho^2 + \frac{2A^2}{\sigma_{\text{rec}}^2 B^2} = 0, \]

where \( A = \frac{\rho}{\Gamma^2} \) and \( B = \sqrt{\frac{2\rho}{\pi \rho^2} \left( \frac{2\pi^2 - 1}{A} \right)} \).

Results

Conclusions

• A tractable expression for the achievable rate is provided.
• The joint harvested energy-rate outage probability is defined, calculated in closed-form expressions for a point-to-point and a multicasting system and minimized by optimizing the PS factor.
• The proposed theoretical framework facilitates the investigation of performance of the integrated receiver and opens the road for future research on this topic.