Optimal Relay Selection Strategy for Joint Data and Energy Transfer in Wireless Systems

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Abstract

We study a relay selection problem in a two-hop amplify-and-forward (AF) enabled network for facilitating simultaneous Wireless Transmission of Information and Energy (Wi-TIE) to a destination able to perform both information processing and energy harvesting concurrently.

Time-Switching based Wi-TIE Receiver Architecture

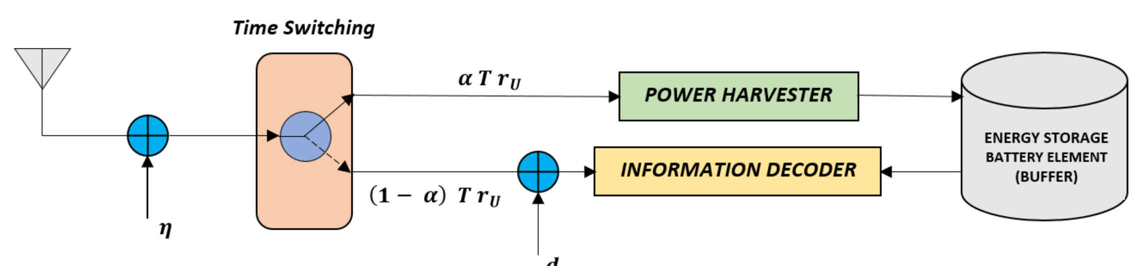

Figure 1. TS Receiver for Wi-TIE.

TS ratio is defined as: 'α', s.t. $0 \leq \alpha \leq 1$.

Power-Splitting based Wi-TIE Receiver Architecture

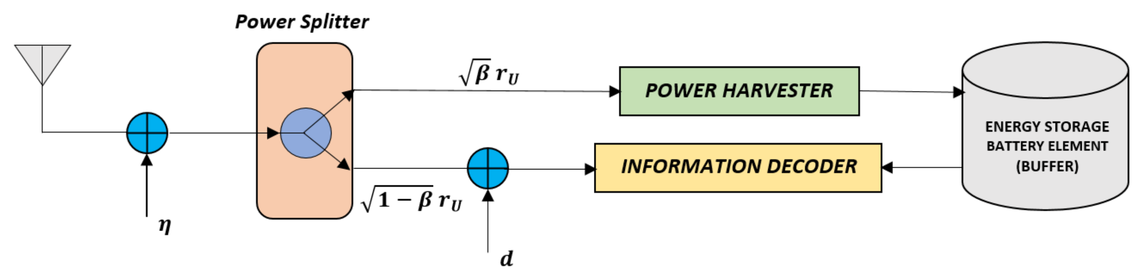

Figure 2. PS Receiver for Wi-TIE.

PS ratio is defined as: 'β', s.t. $0 \leq \beta \leq 1$.

System Model

We consider a cooperative wireless network with single source, L non-regenerative relays, and single destination, as shown in Fig. 3.

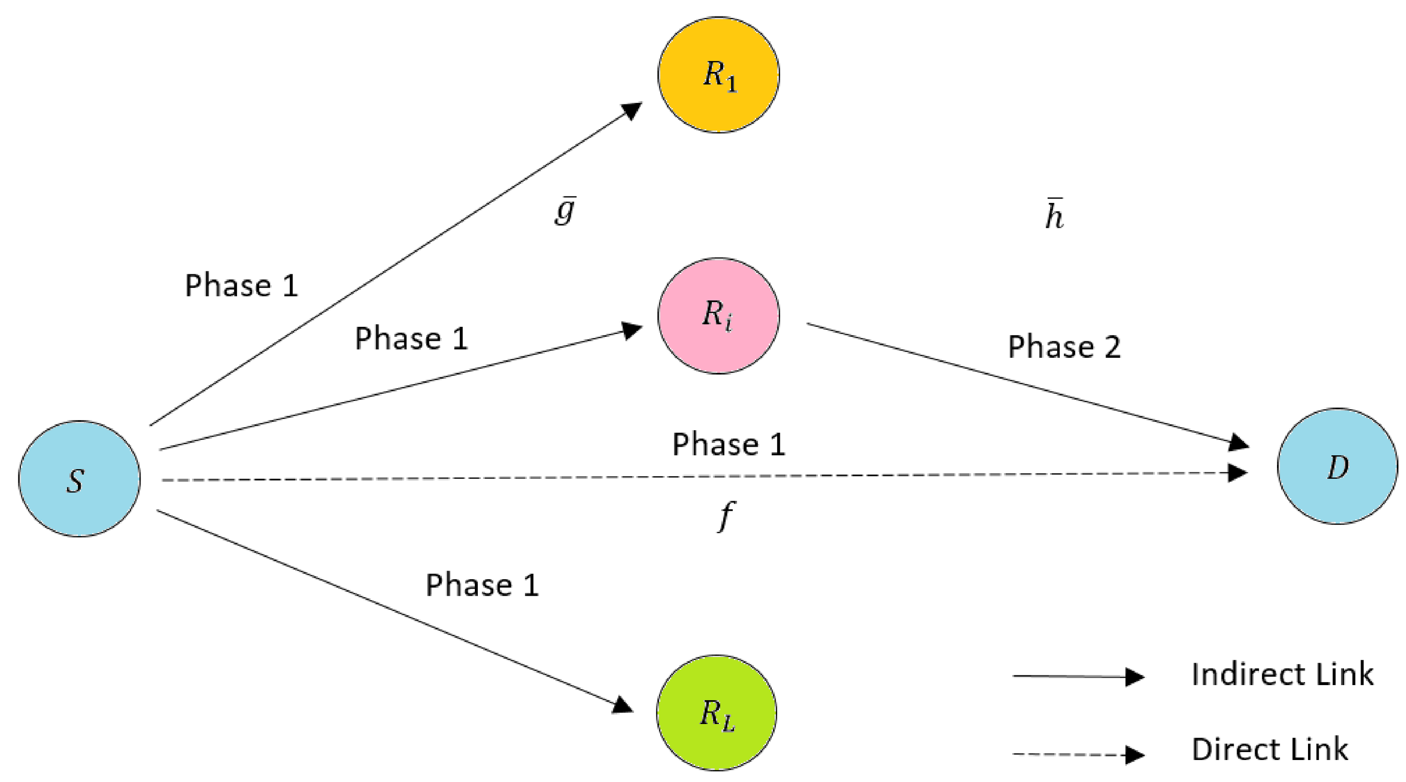

Figure 3. System Model.

Source communicates to the destination via two communication links s.t. overall transfer of data and power takes place in two phases which may or may not include the direct link.

Definitions

The signals received at the ith relay, and at the destination via the direct link (DL) can be respectively written as

$$r_i = \sqrt{P_T} g_i s + n_i, \text{ and } r_U^{(1)} = \sqrt{P_T} f s + \eta$$

DL: Signal-to-Noise (SNR) Ratio & Harvested Power (HP) Eqns

DL - SNR at D: TS and PS	DL - HP at D: TS and PS
$\gamma_{TS}^{(1)} = \frac{P_T\|f\|^2}{\sigma_\eta^2 + \sigma_d^2}$, and $\gamma_{PS}^{(1)} = \frac{(1-\beta)P_T\|f\|^2}{(1-\beta)\sigma_\eta^2 + \sigma_d^2}$	$P_{TS}^{(1)} = \zeta\alpha(P_T\|f\|^2 + \sigma_\eta^2)$ $P_{PS}^{(1)} = \zeta\beta(P_T\|f\|^2 + \sigma_\eta^2)$

Assuming $\widetilde{P}_R = \frac{P_{Max} - P_T}{P_T|g_i|^2 + \sigma_{n_i}^2}$, the signal received at the destination from the indirect link (IDL), when the ith relay is selected, is

$$r_U^{(2)} = w_i h_i r_i + \eta, \text{ with } 0 < |w_i|^2 \leq \widetilde{P}_R$$

IDL - SNR at D: TS and PS	IDL - HP at D: TS and PS
$\gamma_{TS}^{(2)} = \frac{\|w_i\|^2\|h_i\|^2\|g_i\|^2 P_T}{\|w_i\|^2\|h_i\|^2\sigma_{n_i}^2 + \sigma_\eta^2 + \sigma_d^2}$ $\gamma_{PS}^{(2)} = \frac{(1-\beta)\|w_i\|^2\|h_i\|^2\|g_i\|^2 P_T}{(1-\beta)(\|w_i\|^2\|h_i\|^2\sigma_{n_i}^2 + \sigma_\eta^2) + \sigma_d^2}$	$P_{TS}^{(2)} = \zeta\alpha(\|w_i\|^2\|h_i\|^2(P_T\|g_i\|^2 + \sigma_{n_i}^2) + \sigma_\eta^2)$ $P_{PS}^{(2)} = \zeta\beta(\|w_i\|^2\|h_i\|^2(P_T\|g_i\|^2 + \sigma_{n_i}^2) + \sigma_\eta^2)$

The overall equations for Rate and Harvested Power are

Overall User Rate : TS & PS	Overall HP at D: TS & PS
$R_U = \begin{cases} R_{TS} = \frac{1}{2}(1-\alpha)\log_2(1+\hat{\gamma}_{TS}) \\ R_{PS} = \frac{1}{2}\log_2(1+\hat{\gamma}_{PS}) \end{cases}$	$P_U = \begin{cases} P_{TS} = P_{TS}^{(1)} + P_{TS}^{(2)} \\ P_{PS} = P_{PS}^{(1)} + P_{PS}^{(2)} \end{cases}$

$\hat{\gamma}_{TS} = \gamma_{TS}^{(1)} + \gamma_{TS}^{(2)}$, and $\hat{\gamma}_{PS} = \gamma_{PS}^{(1)} + \gamma_{PS}^{(2)}$: Using the Maximum Ratio Combining (MRC)

References

[1] S. Gautam and P. Ubaidulla, "Relay Selection and Transceiver Design for Joint Wireless Information and Energy Transfer in Cooperative Networks," in IEEE Vehicular Technology Conference (VTC), Sydney, Australia, Jun. 2017.

[2] X. Zhou, R. Zhang, and C.K. Ho, "Wireless Information and Power Transfer: Architecture Design and Rate-Energy Tradeoff," IEEE Trans. Commun., vol. 61, no. 11, pp. 4754-4767, Nov. 2013.

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User Rate Maximization for Relay Selection

The relay selection optimization problem that maximizes the effective source-destination rate, while ensuring a minimum harvested power at the destination node can be represent as

$$\begin{aligned} (P1): \quad & \max_{i \in \mathcal{I}, \theta, \{w_i\}} \quad R_U \\ \text{subject to}: \quad & P_U \geq \kappa, \\ & 0 < |w_i|^2 \leq P_R, \\ & 0 \leq \theta \leq 1, \end{aligned}$$

where i is the relay index, $\mathcal{I} = \{1, 2, \cdots, L\}$ is the set of relay indices, $P_R \leq \widetilde{P}_R$, and κ is the minimum harvested power demand, $\theta = \{\alpha$: TS, or β: PS$\}$, respectively.

(P1): Non-Linear Mixed-Integer Programming Problem • Difficult to solve • Recast into pair of coupled optimization problems • Outer optimization : Relay Selection, and Inner Optimization : Splitting factors & Amplification coefficients.

By using the Lagrange Dual Method, we have

Solution of Inner Optimization without the DL

$$|w_i|^2 = P_R, \text{ and } \theta = \frac{\kappa(\zeta)^{-1}}{P_R|h_i|^2(P_T|g_i|^2 + \sigma_{n_i}^2) + \sigma_\eta^2}$$

Solution of Inner Optimization with the DL

$$|w_i|^2 = P_R, \text{ and } \theta = \frac{\kappa(\zeta)^{-1}}{P_T|f|^2 + P_R|h_i|^2(P_T|g_i|^2 + \sigma_{n_i}^2) + 2\sigma_\eta^2}$$

The solution of outer optimization yields the index of the selected relay, which can be expressed as $j^\star = \text{argmax}_{j \in \{1,2,\cdots,L\}} R_j^\star$, where $R_j^\star$ is the rate achieved by the jth relay.

Simulation Result

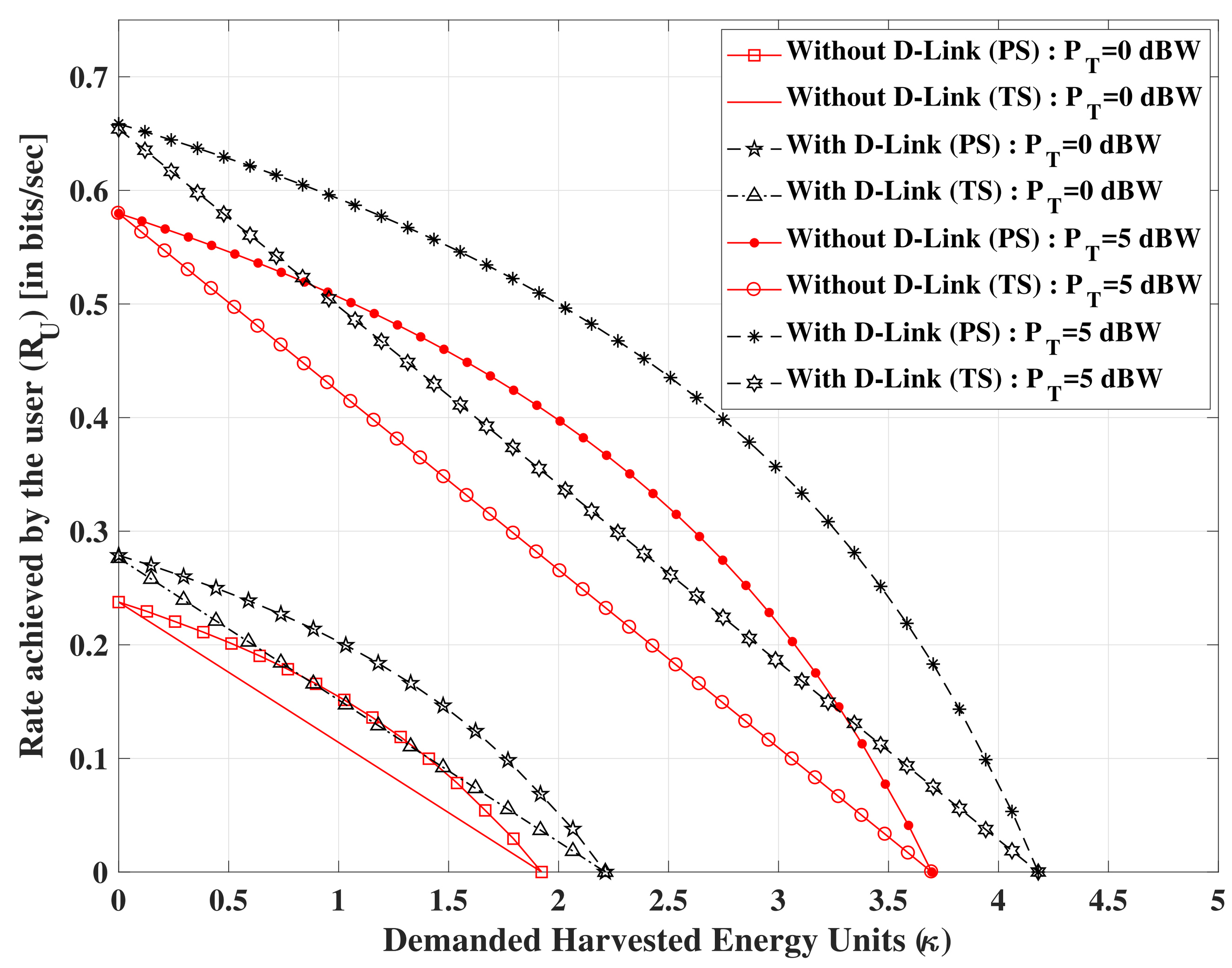

Figure 4. User rate (R_U) versus the demanded harvested power (κ) for different values of P_T considering P_R = 0 dBW, $\sigma_{n_i}^2 = \sigma_d^2$ = 0 dBW, σ_η^2 = -7 dBW, and $|f|$ = 0.3.

Conclusion

Combining both direct and relay-assisted links is beneficial for Wi-TIE in cooperative networks.

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