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Optimal Resource Allocation and Relay Selection for Self-Sustainable Relaying Networks

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***Abstract*—In this paper, we consider a wireless co-operative network involving two transceiver nodes whose communication is aided by energy-constrained two-way relay nodes. Each relay node employs a non-regenerative relaying protocol. The transceiver nodes can simultaneously transmit information and energy and the relay nodes harvest the energy from the received signal and use the harvested energy to amplify and retransmit the signal to the destination. The relay nodes implement power-splitting (PS) scheme to apportion the received signal power to the information processing and the energy harvesting units. We address the problem of sum-rate maximization under constraints on total transmit power and harvested energy. We propose an optimal resource allocation and relay selection scheme as well as a reduced-complexity sub-optimal scheme. The performance of the proposed solutions are illustrated by numerical simulations.**

I. INTRODUCTION

The operational period of current energy-constrained wireless sensor networks are often limited due to the finite energy storage capacity. In order to ensure uninterrupted operation, we have to go for either periodic recharging or replacement of the battery. It may be impractical to do so periodically in an operational environment with physical and economical constraints. To prolong the lifespan of the energy-constrained nodes, one solution could be to harvest ambient energy such as solar, wind, vibrations, etc. But these are not reliable sources as they depend on factors which are beyond human control. Radio-frequency (RF) signals are capable of carrying both information and energy at the same time, so harvesting energy from RF signals that are used for communication is promising in circumventing the need for constant recharging or replacement of batteries [1], [2].

There has been a growth in research activity involving simultaneous wireless information and power transfer (SWIPT) [3]. Recent advances have shown the fundamental trade-off between achievable rate and power transferred [4], [5]. SWIPT provides an additional advantage of harvesting energy from RF signals constantly to communicate over large distances. The conventional receiver architectures have focused mainly on increasing the information transmission rate. With the incorporation of SWIPT, the receivers can harvest energy and process information simultaneously from the received signals without draining any additional time or frequency resource. Two of the receiver architectures proposed to support SWIPT are time-sharing (TS) and power-splitting (PS) schemes [6], [7], [8]. In TS, the receiver harvests energy for a fraction of transmission block and then decodes information for the remaining fraction. In PS, a fraction of the received signal is used for energy harvesting and the rest for information decoding. Relaying is a well-known technique in wireless co-operative communication to enhance communication range and diversity. Regenerative and non-regenerative are two popular relaying protocols. Amplify-and-forward (AF) is non-regenerative whereas decode-and-forward (DF) is regenerative [9]. TS-based relaying (TSR) and PS-based relaying (PSR) can be employed in the cooperative systems [10]. A TS-based two-way relaying is studied in [11]. Two-way relaying has better spectral efficiency compared to one-way relaying.

In this paper, we consider a wireless co-operative network consisting of a pair of transceiver nodes and two-way relay employing PSR scheme. The two-way relay aids the information exchange between the transceiver nodes and these nodes in turn transfer the power required by the relay. In other words, the relay node is not required to expend its own energy to assist the transceiver nodes. The energy harvested at the relay will be constantly used to amplify and re-transmit the signal. In this context, we address the problem of optimal resource allocation and relay selection to maximize the rate of communication between the transceiver nodes. We propose an optimal and a suboptimal scheme for power allocation along with energy harvesting and optimal relay selection. Even though the corresponding optimization problem is a mixed-integer programming problem, we propose a two-step process that results in closed-form solutions to the original problems. Furthermore, the analysis of the equivalent optimization problem is simplified by utilizing high SINR approximation of the instantaneous sum-rate. Effectively, the power is allocated on the basis of solutions obtained using the Karush-Kuhn-Tucker conditions in the optimal scheme. On the other hand, the sub-optimal scheme employs equal power allocation. Appreciable performance improvements are realised in the case of optimal scheme in comparison to sub-optimal scheme.

II. SYSTEM MODEL

A wireless co-operative network consisting of two transceiver nodes, T_1 and T_2 and a set of two-way relay is considered. The transceivers communicate with each other via a relay node selected from a set of L relay nodes. All the nodes are equipped with single antenna.

The communication takes place between the transceiver nodes over two time slots. In the first slot, the transmission of signal takes place at both transceiver nodes. The transmitted signals are then received by the relay. Let $x_1 \in \mathbb{C}$ and $x_2 \in \mathbb{C}$ be the transmit signals conveyed by the two transceiver nodes T_1 and T_2, respectively. We assume that $\mathbb{E}\{|x_1|^2\} = \mathbb{E}\{|x_2|^2\} = 1$, where $\mathbb{E}\{\cdot\}$ is the expectation operator and $|\cdot|$ denotes absolute value. The signal received by the ith relay, denoted by r_i, can be expressed as

$$r_i = \sqrt{P_1} h_i x_1 + \sqrt{P_2} g_i x_2 + \pi_i, \quad 1 \leq i \leq L, \tag{1}$$

where P_1 and P_2 are the transmit powers of T_1 and T_2 respectively, h_i denotes the channel gain from T_1 to the ith relay, g_i denotes the channel gain from T_2 to the ith relay and $\pi_i \sim \mathcal{CN}(0, \sigma_{\pi_i}^2)$ is the additive white Gaussian noise (AWGN) at the ith relay.

In the second slot, the signal received by the ith relay, r_i, is split into two parts for energy harvesting and information processing. Let $\rho \in [0,1]$ be the power splitting ratio, meaning that $\sqrt{\rho} r_i$ is used for energy harvesting and $\sqrt{(1-\rho)} r_i$ is used for information processing. The total energy harvested at the ith relay, denoted by $P_{EH}(\rho)$, can be expressed as

$$P_{EH}(\rho) = \rho\eta\mathbb{E}\{|r_i|^2\} \tag{2}$$

$$= \rho\eta[P_1|h_i|^2 + P_2|g_i|^2 + \sigma_{\pi_i}^2], \tag{3}$$

where $\eta \in [0,1]$ denotes the energy conversion efficiency. The remaining fraction of the received signal, namely, $\sqrt{1-\rho} r_i$, is retransmitted by the relay after amplifying it by a complex number. Both the transceiver nodes receive the signal transmitted by the relay node. The signal received by the transceiver T_1 can be written as

$$y_1 = \sqrt{1-\rho}[\sqrt{P_1} w_i h_i h_i x_1 + \sqrt{P_2} w_i g_i h_i x_2 + w_i h_i \pi_i] + \phi_1, \tag{4}$$

where $w_i \in \mathbb{C}$ is the amplification factor or weight coefficient of the ith relay, ϕ_1 represents the AWGN at transceiver T_1 with zero mean and variance $\sigma_{\phi_1}^2$. The signal received by the transceiver T_2 is given by

$$y_2 = \sqrt{1-\rho}[\sqrt{P_1} w_i h_i g_i x_1 + \sqrt{P_2} w_i g_i g_i x_2 + w_i g_i \pi_i] + \phi_2, \tag{5}$$

where ϕ_2 represents the AWGN at transceiver T_2 with zero mean and variance $\sigma_{\phi_2}^2$. The terms $\sqrt{P_1} w_i h_i h_i x_1$ and $\sqrt{P_2} w_i g_i g_i x_2$ in (4) and (5), respectively, represent the self-interference terms resulting from both transceivers' own transmitted signals.

The self-interference terms can be eliminated from the received signals using the knowledge of the channel state information (CSI), the amplification factor and each transceiver's transmitted signal. The SINR at transceiver T_1 after self-interference cancellation is given by

$$SINR_{i,1} = \frac{(1-\rho)P_2|w_i|^2|h_i|^2|g_i|^2}{(1-\rho)\sigma_{\pi_i}^2|w_i|^2|h_i|^2 + \sigma_{\Phi_1}^2}, \tag{6}$$

and the SINR at transceiver T_2 is given by

$$SINR_{i,2} = \frac{(1-\rho)P_1|w_i|^2|h_i|^2|g_i|^2}{(1-\rho)\sigma_{\pi_i}^2|w_i|^2|g_i|^2 + \sigma_{\Phi_2}^2}. \tag{7}$$

The transmit power of the ith relay can be expressed as

$$P_{Ri} = \mathbb{E}\{|w_i\sqrt{1-\rho} r_i|^2\} \tag{8}$$

$$= (1-\rho)[P_1|w_i|^2|h_i|^2 + P_2|w_i|^2|g_i|^2 + |w_i|^2\sigma_{\pi_i}^2], \tag{9}$$

from (9), we have

$$|w_i| = \frac{\sqrt{P_{Ri}}}{\sqrt{(1-\rho)[P_1|h_i|^2 + P_2|g_i|^2 + \sigma_{\pi_i}^2]}}. \tag{10}$$

Along the same lines, we can express the the SINR at the transceivers T_1 and T_2 in terms of P_{Ri} as follows:

$$SINR_{1,i} = \frac{P_2 P_{Ri}|h_i|^2|g_i|^2}{P_{Ri}\sigma_{\pi_i}^2|h_i|^2 + \sigma_{\Phi_1}^2(P_1|h_i|^2 + P_2|g_i|^2 + \sigma_{\pi_i}^2)}, \tag{11}$$

$$SINR_{2,i} = \frac{P_1 P_{Ri}|h_i|^2|g_i|^2}{P_{Ri}\sigma_{\pi_i}^2|g_i|^2 + \sigma_{\Phi_2}^2(P_1|h_i|^2 + P_2|g_i|^2 + \sigma_{\pi_i}^2)}. \tag{12}$$

III. OPTIMAL RELAY SELECTION AND POWER ALLOCATION

The overall problem formulation and the proposed solutions are detailed in the following. The objective of the problem is to maximize the overall rate under energy-harvesting and transmit power constraints. This objective is achieved by choosing the best relay, which operates with the energy provided by the transceivers, and by optimal resource allocation at the transceivers and the relay node. This problem can be formulated as

$$\max_{k\in\mathcal{I},(P_1,P_2,P_{R_k},\rho)\in\ \Lambda} \quad R_k, \tag{13}$$

where R_k is the achievable rate when the kth relay is operating, and $\mathcal{I}$ is the set of relay indices. The feasible set Λ is defined by the power and energy harvesting constraints. This is a joint optimization over the relay indices, the transmit powers, and the power splitting ratio. As such it is a mixed-integer program and hard to solve. However, since only one relay will be operating at any given time, this optimization can be performed in two simple steps; first over the transmit powers and the power splitting ratio and then over the relay indices, as given below:

$$\max_{k\in 1,2,\ldots,L} \quad \max_{P_1,P_2,P_{R_k},\rho\epsilon\ \Lambda} \quad R_k. \tag{14}$$

Consequently, first we intend to maximize the rate with respect to the power splitting ratio and transceiver transmit powers.

The instantaneous achievable rate of the wireless cooperative network with two-way relaying is given as

$$R_i = \frac{1}{2}\log(1 + SINR_{i,1}) + \frac{1}{2}\log(1 + SINR_{i,2}), \tag{15}$$

The factor of $\frac{1}{2}$ used in (15) results from the two time slots required to complete the information exchange between the transceivers. In order to make the mathematical analysis more viable, we follow the following high-SINR approximation of the rate:

$$R_i \approx \frac{1}{2}\log\left(\frac{P_2 P_{Ri}|h_i|^2|g_i|^2}{P_{Ri}\sigma_{\pi_i}^2|h_i|^2+\sigma_{\Phi_1}^2(P_1|h_i|^2+P_2|g_i|^2+\sigma_{\pi_i}^2)}\right) + \frac{1}{2}\log\left(\frac{P_1 P_{Ri}|h_i|^2|g_i|^2}{P_{Ri}\sigma_{\pi_i}^2|g_i|^2+\sigma_{\Phi_2}^2(P_1|h_i|^2+P_2|g_i|^2+\sigma_{\pi_i}^2)}\right) = \frac{1}{2}\log\left(\frac{P_1P_2P_{R_i}^2|h_i|^4|g_i|^4}{X_iY_i}\right), \quad (16)$$

where

$$X_i = P_{Ri}\sigma_{\pi_i}^2|h_i|^2+\sigma_{\Phi_1}^2(P_1|h_i|^2+P_2|g_i|^2+\sigma_{\pi_i}^2), \quad (17)$$

$$Y_i = P_{Ri}\sigma_{\pi_i}^2|g_i|^2+\sigma_{\Phi_2}^2(P_1|h_i|^2+P_2|g_i|^2+\sigma_{\pi_i}^2). \quad (18)$$

This high SINR approximation can significantly simplify the optimal power allocation and PS ratio computation, which can now be reformulated as

$$\begin{aligned} \max_{P_1,P_2,P_{Ri},\rho} \quad & \frac{1}{2}\log\left(\frac{P_1P_2P_{Ri}^2|h_i|^4|g_i|^4}{X_iY_i}\right) \\ \text{s.t.} \quad & P_1+P_2 \le P_T, \\ & P_{EH} \ge \theta, \\ & P_{Ri} \le \theta, \\ & 0 \le \rho \le 1, \end{aligned} \quad (19)$$

where P_T is the total transmit power of the two transceiver nodes T_1 and T_2 and θ is the minimum amount of the energy harvested at the relay. Note that θ is also the upper limit for the transmit power at the relay, meaning that the relay uses only the harvested energy to amplify and retransmit the received signal. The transmit power constraint and energy harvesting constraint acts as a safeguard such that the transmit power at the relay does not exceed the harvested power.

As the objective function of (19) is a monotonically increasing function of the transmit power of *i*th relay, P_{Ri}, it is self-evident that its optimal value is given by $P'_{Ri} = \theta$. Having realized the optimal value of P_{Ri}, we proceed to compute the optimal value of (P_1, P_2, ρ). Then, the problem in (19) can be stated as follows:

$$\begin{aligned} \max_{P_1,P_2,\rho} \quad & \frac{1}{2}\log\left(\frac{P_1P_2{P_{Ri}^*}^2|h_i|^4|g_i|^4}{X_i'Y_i'}\right) \\ \text{s.t.} \quad & P_1+P_2 \le P_T, \\ & P_{EH} \ge \theta, \\ & 0 \le \rho \le 1, \end{aligned} \quad (20)$$

where X_i' and Y_i' are obtained from X_i and Y_i, respectively, by replacing P_{Ri} with P'_{Ri} in (17) and (18). Since the logarithmic function is a monotonically increasing function, the maximization in (20) is equivalent to the minimization problem as follows:

$$\begin{aligned} \min_{P_1,P_2,\rho} \quad & \frac{X_i'Y_i'}{P_1P_2P'_{Ri}|h_i|^4|g_i|^4} \\ \text{s.t.} \quad & P_1+P_2 \le P_T, \\ & P_{EH} \ge \theta, \\ & 0 \le \rho \le 1. \end{aligned} \quad (21)$$

We describe two solutions to this problem; optimal and a low-complexity suboptimal solution. Both of the proposed solutions have closed form.

A. Optimal Scheme

We obtain optimal power allocation and power splitting ratio using the Karush-Kuhn-Tucker conditions. In order to facilitate further analysis, we rewrite (21) as follows:

$$\begin{aligned} \min_{P_1,P_2,\rho} \quad & \frac{(a_1+b_1P_1+c_1P_2)(a_2+b_2P_1+c_2P_2)}{P_1P_2} \\ \text{s.t.} \quad & P_1+P_2 \le P_T, \\ & \rho(mP_1+nP_2+q) \ge \theta, \\ & 0 \le \rho \le 1, \end{aligned} \quad (22)$$

where

$$a_1 = \frac{\sigma_{\pi_i}^2}{P_{Ri}^*|g_i|^2}\left[1+\frac{\sigma_{\Phi_1}^2}{|h_i|^2}\right], \quad a_2 = \frac{\sigma_{\pi_i}^2}{P_{Ri}^*|h_i|^2}\left[1+\frac{\sigma^2\Phi_2}{|g_i|^2}\right],$$

$$b_1 = \frac{\sigma_{\Phi_1}^2}{P_{Ri}^*|g_i|^2}, \quad b_2 = \frac{\sigma_{\Phi_2}^2}{P_{Ri}^*|g_i|^2}, \quad c_1 = \frac{\sigma_{\Phi_1}^2}{P_{Ri}^*|h_i|^2},$$

$$c_2 = \frac{\sigma_{\Phi_2}^2}{P_{Ri}^*|h_i|^2}, \quad m = \eta|h_i|^2, \quad n = \eta|g_i|^2, \text{ and } q = \eta\sigma_{\pi_i}^2.$$

Then, the Lagrangian associated with the problem in (22) is given by

$$\mathcal{L}(P_1,P_2,\rho,\mu) = f + \mu_1[\theta-\rho(mP_1+nP_2+q)] + \mu_2(P_1+P_2-P_T)+\mu_3(\rho-1)-\mu_4\rho,$$

where $f = \frac{(a_1+b_1P_1+c_1P_2)(a_2+b_2P_1+c_2P_2)}{P_1P_2}$ and $\{\mu_i\}_{i=1}^4$ are the Lagrangian multipliers. The optimal solution satisfies the following KKT conditions:

$$\begin{aligned} & \frac{\partial f}{\partial P_1} - \mu_1\rho m + \mu_2 = 0, \\ & \frac{\partial f}{\partial P_2} - \mu_1\rho n + \mu_2 = 0, \\ & \mu_1[\theta-\rho(mP_1+nP_2+q)] = 0, \\ & \mu_2(P_1+P_2-P_T) = 0, \\ & \mu_3(\rho-1) = 0, \\ & \mu_4\rho = 0, \\ & \mu_i \ge 0, \; i = 1,2,3,4, \\ & \text{and the constraints in (22).} \end{aligned}$$

By solving the set of KKT conditions given above, we obtain the optimal values of P_1, P_2, and ρ as follows:

$$P_1' = \frac{P_T\left[r_3\sqrt{1+\frac{r_1+r_2}{r_3}+\frac{r_1r_2}{r_3^2}}-(r_2+r_3)\right]}{r_1-r_2}, \quad (23)$$

$$P_2' = \frac{P_T\left[(r_1+r_3)-r_3\sqrt{1+\frac{r_1+r_2}{r_3}+\frac{r_1r_2}{r_3^2}}\right]}{r_1-r_2}, \quad (24)$$

$$\rho' = \frac{\theta}{\eta(P_1^{\backprime}|h_i^2|+P_2^{\backprime}|g_i|^2+\sigma_{\pi_i}^2)}, \quad (25)$$

where $r_1 = b_1b_2+\frac{a_1b_2}{P_T}+\frac{a_2b_1}{P_T}$, $r_2 = c_1c_2+\frac{a_1c_2}{P_T}+\frac{a_2c_1}{P_T}$, and $r_3 = \frac{a_1a_2}{P_T^2}$.

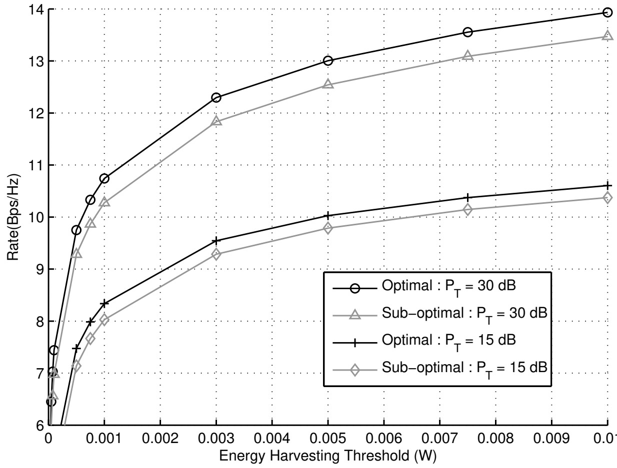

Fig. 1. Rate versus energy harvesting threshold (θ) for different values of P_T

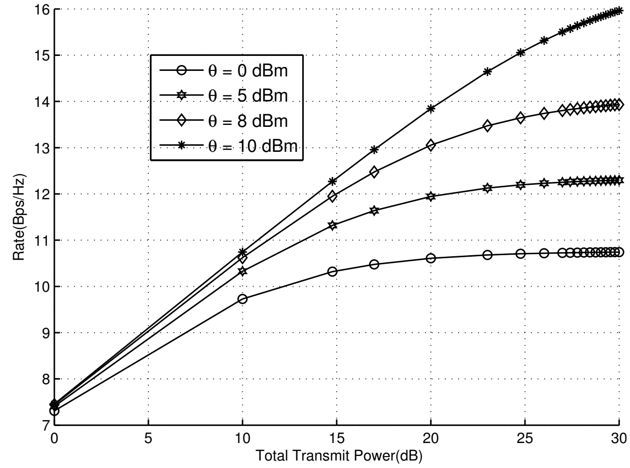

Fig. 2. Rate versus total transmit power (P_T) for different values of θ

B. Sub-optimal Scheme

In the previous section, we considered a total transceiver power constraint to obtain the optimal solution. Here, we propose a simplified sub-optimal scheme for computing power allocation and power-splitting ratio. In this sub-optimal scheme, we consider a trivial power allocation such that $P_1 = P_2 = P$ and the problem in (21) is equivalent to follows:

$$\begin{aligned} \min_{P,\rho} \quad & \left(\frac{e_1}{P} + f_1\right)\left(\frac{e_2}{P} + f_2\right) \\ \text{s.t.} \quad & P \leq P_T/2, \\ & \eta\rho(P(|h_i^2| + |g_i|^2) + \sigma_{\pi_i}^2) \geq \theta, \\ & 0 \leq \rho \leq 1, \end{aligned} \tag{26}$$

where $e_1 = P_{Ri}^* \sigma_{\pi_i}^2 |h_i|^2 + \sigma_{\pi_i}^2 \sigma_{\Phi_1}^2$, $e_2 = P_{Ri}^* \sigma_{\pi_i}^2 |g_i|^2 + \sigma_{\pi_i}^2 \sigma_{\Phi_2}^2$, $f_1 = \sigma_{\Phi_1}^2(|h_1|^2 + |g_i|^2)$, and $f_2 = \sigma_{\Phi_2}^2(|h_i|^2 + |g_i|^2)$. We can observe that the objective function in the problem given above is maximized when P takes the maximum value, i.e., $P = P_1' = P_2' = \frac{1}{2}P_T$, when $\rho' = \frac{2\theta}{\eta P_T(|h_i^2| + |g_i|^2)}$, then the minimum value of the objective function in (26) is given by $\left(\frac{2e_1}{P_T} + f_1\right)\left(\frac{2e_2}{P_T} + f_2\right)$.

C. Optimal Relay Selection

Having solved the optimal solutions for the power allocation and PS ratio, we now address the problem of selecting the relay that results in the highest achievable rate from the set of L relays. This problem can be formulated as

$$k' = \underset{k \in \mathcal{I}}{\text{argmax}}\ R_k^*, \tag{27}$$

where R_k^* is achieved when the kth relay is operating with the optimal power and PS ratio allocation described earlier. The optimal relay is selected as the one that leads to the highest R_k^*. Combining the results, we can represent the optimal solution to the problem in (13) as $(k', P_1', P_2', P_{R_{k'}}, \rho')$.

IV. Simulation Results

In this section, we illustrate the performance of the proposed joint relay selection and optimal power allocation scheme with energy harvesting through simulations. Precisely, we evaluate the performance of the optimal scheme with that of the sub-optimal scheme. We assume that all the channels undergo Rayleigh fading.

Firstly, we study the performance of the proposed schemes in terms of maximum achievable rate versus energy harvesting threshold. The corresponding results are provided for total transmit power limits of $P_T = 15$ dB and $P_T = 30$ dB. The energy harvesting threshold (θ) ranges from 1 mJ to 10 mJ. The performance results are displayed in Fig. 1. We can observe that the proposed optimal scheme outperforms the sub-optimal uniform power allocation scheme. The rates obtained in Fig. 1 are high, thus validating the high-SINR approximation used above.

Secondly, we demonstrate the performance of the proposed schemes in terms of the rate versus total transmitted power of the transceivers. The energy harvesting threshold (θ) used in this experiment are 0 dBm, 3 dBm , 8 dBm and 10 dBm. The total transmitted power P_T ranges from 0 dB to 30 dB. The performance results are displayed in Fig. 2. Here, as expected we can observe that the rates are increasing with increasing transmit power.

V. Conclusions

We considered the problem of optimal relay selection and resource allocation in a cooperative wireless network employing a two-way relay that operates using the energy harvested from the transceiver nodes. The optimal relay is selected so as to maximize the communication rate between the transceiver nodes. We proposed an optimal as well as a sub-optimal scheme for power allocation, relay selection, and PS ration computation. Analytical solutions are obtained for both the cases. It is also observed that the proposed optimal scheme performs better than the sub-optimal scheme. The performance of the proposed schemes are demonstrated via numerical simulations.

References

[1] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, “Wireless networks with rf energy harvesting: A contemporary survey,” *IEEE Communications Surveys & Tutorials*, vol. 17, no. 2, pp. 757–789.

[2] V. Raghunathan, S. Ganeriwal, and M. Srivastava, “Emerging techniques for long lived wireless sensor networks,” *IEEE Communications Magazine*, vol. 44, no. 4, pp. 108–114, 2006.

[3] K. Huang and E. Larsson, “Simultaneous information and power transfer for broadband wireless systems,” *IEEE Transactions on Signal Processing*, vol. 61, no. 23, pp. 5972–5986, 2013.

[4] P. Grover and A. Sahai, “Shannon meets tesla: Wireless information and power transfer.” in *ISIT*, 2010, pp. 2363–2367.

[5] L. R. Varshney, “Transporting information and energy simultaneously,” in *2008 IEEE International Symposium on Information Theory*. IEEE, 2008, pp. 1612–1616.

[6] X. Zhou, R. Zhang, and C. K. Ho, “Wireless information and power transfer: Architecture design and rate-energy tradeoff,” *IEEE Transactions on Communications*, vol. 61, no. 11, pp. 4754–4767, 2013.

[7] Z. Fang, X. Yuan, and X. Wang, “Distributed energy beamforming for simultaneous wireless information and power transfer in the two-way relay channel,” *IEEE Signal Processing Letters*, vol. 22, no. 6, pp. 656–660, 2015.

[8] Y. Zeng and R. Zhang, “Full-duplex wireless-powered relay with self-energy recycling,” *IEEE Wireless Communications Letters*, vol. 4, no. 2, pp. 201–204, 2015.

[9] G. Levin and S. Loyka, “Amplify-and-forward versus decode-and-forward relaying: Which is better?” in *International Zurich Seminar on Communications*, 2012, p. 123.

[10] A. A. Nasir, X. Zhou, S. Durrani, and R. A. Kennedy, “Throughput and ergodic capacity of wireless energy harvesting based df relaying network,” in *2014 IEEE International Conference on Communications (ICC)*. IEEE, 2014, pp. 4066–4071.

[11] S. T. Shah, D. Munir, M. Y. Chung, and K. W. Choi, “Information processing and wireless energy harvesting in two-way amplify-and-forward relay networks,” in *Vehicular Technology Conference (VTC Spring), 2016 IEEE 83rd*. IEEE, 2016, pp. 1–5.