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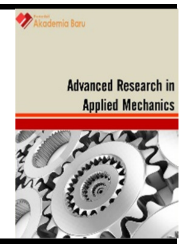

Two Way Amplify-and-Forward Relaying with RF Energy Harvesting Network Sensor for System Throughput Performance

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ABSTRACT

Wireless sensor in RF Energy Harvesting Network Sensor (RF EHNS) adopts relaying technology due to its advantages in reducing cost, extending the coverage area, and increasing the throughput. Conventional wireless relay operates in two-orthogonal channels due to half-duplex constraint. A Two-Way Relay Transmission (TWRT) is an effective technique for the system capacity improvement in RF energy harvesting compare to One-Way Relay Transmission (OWRT) since both orthogonal channels in TWRT having phase difference of 90 degree and will not interfere to each other. In addition, the antenna is assumed to receive and transmit simultaneously and efficiently uses its spectral bandwidth for its frequency channel allocation thus further enhancing the overall throughput performance of the system. Simulation results shows that TWRT in RF EHNS achieves high spectral efficiency compare to OWRT. Although wireless sensor network provides the best service for data transfer in oil and gas plant, the placement of constraint relay node must be taken into consideration to avoid shadowing effects from obstacles, path attenuation, interference, noise and half-duplex constraint. In this paper, TWRT with RF EHNS in Time Switching Relay (TSR) mechanism is being proposed while assuming the intermediate relay as a constraint relay node and uses Amplify-and Forward (AF) model to reflect the overall system performance. The objectives are to compare TWRT with OWRT in RF EHNS environment and to achieve high capacity at its destination node by placing the suitable location of the constraint relay node. A quantitative approach uses Rayleigh fading channel with a theoretical path loss exponent model. The signal model is then formulated and expressed in terms of Signal-to-Noise Ratio (SNR) expression. The result shows that the optimal value of EHNS ratio for TSR in TWRT is reduced significantly by 5% as compared to OWRT.

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1. Introduction

Wireless relaying has been recognized as the key technology to extend coverage, eliminate dead spot, increase reliability and enhance capacity and at the same time reducing the capital expenditure (CAPEX) and operational expenditure (OPEX) in wireless sensor network [1]. Relaying operation provides the means to extend the coverage of wireless sensor network to cope with diverse radio propagation conditions without a wired backhaul [2]. The Half-Duplex Constraints (HDC) is the main issue in two-way relaying since the system is unable to transmit and receive the information signal simultaneously [3], since the bandwidth allocation for the relay is not suffice for the specified time slot. The capacity relay channel over the shall be determined. The intermediate relay or sensor is used to enhance capacity in EHNS due to demand of high speed and high rate. Since the intermediate relay is assumed to be a constraint node while harvesting RF energy and information transmission at the prerequisite and given time, the placement of this relay node is critical [4]. According to Han *et al.*, [5] several factors must be considered to determine the best position of relay system to avoid the source node having interference at cell edge and shadowing effect by other object.

The relay simplifies the received signals from both source and destination nodes, amplifies and forwards back the signals to next nodes as illustrated in Figure 1. The information from the two receivers will be allocated at the relay gain [7]. The receiver stations will subtract the known data symbols transmitted by itself called the self-interference (SI) [6], hence the remaining signal data is only data symbols. The authors in [8] considered a two-way AF half-duplex relaying system where the user stations are equipped with two antennas each and the relay has only one antenna. We considered a two-way AF relaying scheme where each user station is equipped with a single antenna and the relay has multiple antennas which uses time switching relaying in energy harvesting environment. Although the AF relaying scheme is a simplest infra to deploy, it is also affected by inter-segment interference which will increase the Signal to Interference plus Noise Power ratio (SINR) [9].

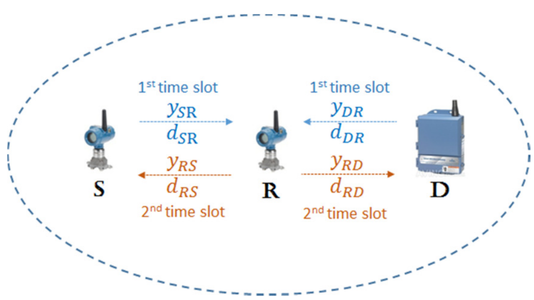

Fig. 1. Schematic Diagram for 3-Node with Two-Way Relaying

2. System Model
2.1 Received Signal Analysis

As shown in Figure 1, the energy harvesting at the relay node is a combination of multiple sources which are from source S and destination D. As of AF model from multiple sources S and D to relay R, the distance represents as d_{SR} and d_{DR}. Whereby from relay R to destination S and D, the distance represents as d_{RS} and d_{RD} and received channel represents as y_{RS} and y_{RD}

respectively. In time slot 1, a constraint node R will receive signal from both source S and destination D channels and assuming both channels are orthogonal. The channels will be amplified and forwarded to its destinations i.e. source S and destination D in time slot 2 simultaneously.

The transmission block structure in TSR scheme for energy harvesting and information processing at the relay is presented in Figure 2. In TSR scheme as depicted in [10], the TSR block time T represents the duration of time for the relay node to execute processes of either harvest energy from the received signals or transmit the information to other nodes. For the first process, the RF energy will be harvested for both the received signals S and D at time αT where α is the TSR EH ratio. If the switcher uses to process the received signals for transmission information, half of the remaining EH block time each will be used to transmit the amplified signals from S to R; D to R and from R to S; R to D i.e. $(1-\alpha)T/2$ each.

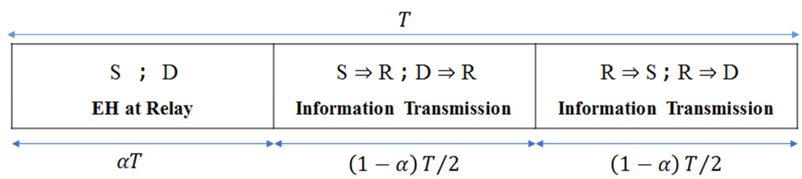

Fig. 2. Transmission Block Structure in TSR Scheme for EH and Information Transmission

In this scheme during αT, both S and D signal powers can be harvested at the constraint relay node. The energy harvesting for time switching is derived as:

$$E_h^{TS} = n\left(\frac{1}{d_{SR}^m} P_1 |h_{SR}|^2 + \frac{1}{d_{DR}^m} P_2 |h_{DR}|^2\right)\alpha T \tag{1}$$

where n is the energy conversion efficiency between 0 < n < 1, P_1 = transmitted power from source S, P_2 = transmitted power from destination D, h_{SR} = channel gain from source S to relay R, h_{DR} = channel gain from source D to relay R, d_{SR}^m = distance between source S and relay R, d_{DR}^m = distance between destination D and relay R, m = path loss exponent, α = TSR EH ratio, T = TSR EH block time.

The time slot representation based on energy harvesting E_h^{TS} can be derived in (2), (3) and (4). Time slot representation of the received signal at relay R, source S, and destination D nodes are denoted as:

Time slot no. 1, T1: S sends x_1 and D sends x_2

R receives:
$$y_R^{TS} = \frac{1}{\sqrt{d_{SR}^m}}\sqrt{P_1} h_{SR} x_1 + \frac{1}{\sqrt{d_{DR}^m}}\sqrt{P_2} h_{DR} x_2 + n_R \tag{2}$$

where y_R = the received signal at the relay, h_{SR} = channel gain from source S to relay R, h_{DR} = channel gain from source D to relay R, x_1 = information symbol from source S to relay R, x_2 = information symbol from destination D to relay R, n_R = noise at relay R.

Time slot no. 2, T2: R performs power normalization with power factor μ and sends the combination of x_1 and x_2.

$$\mu = \frac{P_R}{\sqrt{P_1 |h_{SR}|^2 + P_2 |h_{SR}|^2 \sigma^2}}$$

when $\sigma_R^2 = \sigma_D^2 = \sigma^2$

S receives: $$y_S^{TS} = \frac{1}{\sqrt{d_{RS}^m}}\sqrt{P_R}h_{RS}[\mu y_R] + n_S \tag{3}$$

D receives: $$y_D^{TS} = \frac{1}{\sqrt{d_{RD}^m}}\sqrt{P_R}h_{RD}[\mu y_R] + n_D \tag{4}$$

where y_S= the received signal at the source S, y_D= the received signal at the destination D, h_{RS} = channel gain from relay R to source S, h_{RD} = channel gain from relay R to destination D, P_R = transmitted power from relay R, n_S = noise at the relay S, n_D = noise at the destination D, μ = power normalization factor, d_{RS}^m = distance between relay R and source S, d_{RD}^m = distance between relay R and destination D.

Since S knows x_1 and D knows x_2, the self-interference can be subtracted and the equation given as per below. Also assume the channel reciprocity such that h_{SR} = h_{RS} and h_{RD} = h_{DR}.

S receives: $$y_S^{TS} = \frac{1}{\sqrt{d_{RS}^m}}\sqrt{P_R}\mu h_{RS}h_{DR}x_2 + \mu h_{RS}n_R + n_s \tag{5}$$

D receives: $$y_D^{TS} = \frac{1}{\sqrt{d_{RD}^m}}\sqrt{P_R}\mu h_{RD}h_{SR}x_1 + \mu h_{RD}n_R + n_D \tag{6}$$

The transmitted power from the relay node for $(1-\alpha)T/2$ time in relation to the harvested energy E_h^{TS} can be written as:

$$P_R = \frac{E_h^{TS}}{(1-\alpha)T/2} \tag{7}$$

Rearranging equation (5) and (6) will be:

S receives: $$y_S^{TS} = \sqrt{\frac{2\eta\left(\frac{1}{d_{SR}^m}P_1|h_{SR}|^2+\frac{1}{d_{DR}^m}P_2|h_{DR}|^2\right)\alpha}{d_{RS}^m(1-\alpha)}}\mu h_{RS}h_{DR}x_2 + \mu h_{RS}n_R + n_s \tag{8}$$

D receives: $$y_D^{TS} = \sqrt{\frac{2\eta\left(\frac{1}{d_{SR}^m}P_1|h_{SR}|^2+\frac{1}{d_{DR}^m}P_2|h_{DR}|^2\right)\alpha}{d_{RS}^m(1-\alpha)}}\mu h_{RD}h_{SR}x_1 + \mu h_{RD}n_R + n_D \tag{9}$$

2.2 Throughput Analysis

In considering (2), the SNR at the relay node, γ_R^{TS} can be derived as:

SNR at Relay $$\gamma_R^{TS} = \frac{P_1P_2|h_{SR}|^2|h_{DR}|^2}{d_{SR}^m d_{DR}^m \sigma_{n_R}^2} \tag{10}$$

where $\sigma_{n_R^{TS}} \triangleq \sigma_{n_R}^2$ is the variance of the overall AWGN at the relay node.

Using (8) and (9), the SNR at the source node, γ_S^{TS} and destination node, γ_D^{TS} can be derived as:

SNR at Destination $$\gamma_S^{TS} = \frac{2\eta\alpha\mu P_1P_2|h_{SR}|^2|h_{DR}|^2|h_{RS}|^2|h_{DR}|^2}{(1-\alpha)\mu|h_{RS}|^2 d_{SR}^m d_{DR}^m d_{RS}^m \sigma_{n_S}^2} \tag{11}$$

where $\sigma_{n_S^{TS}} \triangleq \sigma_{n_S}^2$ is the variance of the overall AWGN at the source node.

SNR at Destination $$\gamma_D^{TS} = \frac{2\eta\alpha\mu P_1 P_2 |h_{SR}|^2 |h_{DR}|^2 |h_{RD}|^2 |h_{SR}|^2}{(1-\alpha)\mu |h_{RD}|^2 d_{SR}^m d_{DR}^m d_{RD}^m \sigma_{n_D}^2} \tag{12}$$

where $\sigma_{n_D^{TS}} \triangleq \sigma_{n_D}^2$ is the variance of the overall AWGN at the destination node. The achievable throughput at relay node, τ_R^{TS} and for relay to destination link (i.e. source and destination nodes), τ_S^{TS} and τ_D^{TS} can be referred in [10]:

3. Numerical Analysis and Simulation

This section discusses numerical results and simulation analysis for TWRT and OWRT equations. Unless stated otherwise, the average SNR value is set to 20dB. The energy harvesting efficiency, η = 0.7, distance from source to relay, d_{SR} = 1, distance from relay to destination, d_{RD} = 1, transmitted power from source, P_1 = 1 watt, transmitted power from destination, P_2 = 1 watt, transmitted power from relay, P_R = 1 watt, noise power at relay, $\sigma_{n_R}^2$ = 0.1 watt, noise power at destination, $\sigma_{n_D}^2$ = 0.1 watt, pathloss exponent, m = 2.7 and the target rate, R = 1.

The system throughput versus the energy harvesting ratio with respect to the fraction of block time, α for TSR scheme is illustrated in Figure 3. The concave feature of the curves from the plots explains the signal transmission from relay to destination in the second time slot. As α increases, the system throughput increases until it reaches its optimal value, then it starts to decrease from maximum to zero. During this period, the capacity is enhanced due to the increase of energy harvesting and the system uses all the available energy to transmit information effectively to its destination. When the EH ratio reaches its optimal value, the throughput starts reducing as more EH energy is harnessed rather than the information is amplified for the information transmission at this time fraction. System throughput for TWRT is higher that OWRT since both orthogonal channels in TWRT are not interfered with each other thus will reduce the BER. The multi-antenna at relay node continuously harvests the energy and transmits and receives the information signal at specified time and thus further enhancing the overall throughput performance of the system. From the plots, the optimal value of α for the peak throughput τ in TWRT reduces significantly from 0.3 to 0.25 (by 5%) as compared to OWRT.

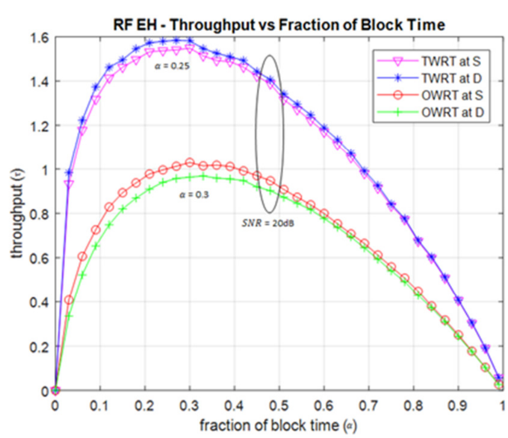

Fig. 3. Throughput vs EH Ratio at Destination Node with respect to Fraction of Block Time, $\boldsymbol{\alpha}$ for TSR Scheme, SNR=20dB

4. Conclusion

In this paper, the two-way relaying scheme in amplify-and-forward model is proposed where the energy source from user 1 and user 2 are harvested at the constraint relay node and used this harvested energy to amplify-and-forward the information signal and sent it to its destinations simultaneously. The time-switching relaying scheme is adopted in the mathematical expression to derive the instantaneous capacity in terms of SNR. TSR scheme is implemented where the receiver is switching over stipulated time in between information transmission and energy harvesting processes. The optimal value of EH ratio for TSR scheme is obtained with respect to the overall achievable throughput. It was shown in simulation that the two-way relaying scheme has significant effect on energy harvesting in terms of harvested energy loading and consumption at the constraint node. In TSR scheme, two-way relaying has substantially reduced the optimal value of EH ratio and increased the overall system throughput as compared to one-way relaying scheme.

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