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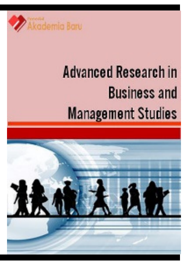

RF energy harvesting with multiple sources and co-channel interference assisted

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ABSTRACT

Wireless Energy Harvesting (EH) from the ambient Radio Frequency (RF) has emerged a solution in recent technology which can prolong the consumption of conventional battery in any constraint nodes. In this paper, a 3-node decode-and-forward (DF) model is proposed where the relay node is subject to an energy constraint. Multiple sources and co-channel interference (CCI) are added in the system model known as Multiple-Source and Single-Relay (MSSR). A mathematical model is derived in Time Switching Relaying (TSR) scheme to obtain an average system throughput at a destination. Several numerical simulations with respect to the average throughput and system parameters were performed and compared with both ideal receiver and Single-Source and Single-Relay (SSSR) schemes. By applying multiple sources and CCI as an energy enhancement at the constraint node, the optimal value of EH ratio for TSR can be reduced significantly by 10% as compared to the ideal receiver and SSSR.

1. Introduction

Energy harvesting also known as energy scavenging is a process to harness an ambient RF energy to provide electrical power for wireless sensor devices [1]. The wireless sensor operates in Industrial, Scientific and Medical (ISM) radio band that operates between 2.400-2.480 GHz. It uses several techniques to coexist with other wireless applications in the same spectrum bands [2]. One of the techniques is the channel hopping to ensure that the interference on one or several channels will not occur, thus improving the signal-to-noise ratio (SNR). This criterion seems vital to convey and adapt MSSR in RF wireless multi-hop networks environment to scavenge multiple sources including CCI. The performance analysis, such as relay operation policy, relay selection and power allocation are discussed in [3]. RF wireless networks can transport information as well as power signal from source to its destination [4, 5]. As in [6]-[8], the proposed two (2) schemes in DF model with relaying scheme,

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namely TSR and Power Splitting Relaying (PSR) have been introduced for Simultaneous Wireless Information and Power Transfer (SWIPT).

In the conventional relaying concept, CCI within the same bandwidth as transmitted signal will deteriorate the overall system performance and should be eliminated by several methods [9] and [10]. In this work, CCI signal is treated as a new source of EH rather than a waste energy. Particularly, in [11] and [12], the authors propose a system model in DF network using time switching scheme where the constraint relay node harvests energy from both source and interference signals, and uses to decode the source signal and forwards it to the destination. The results in [11] conclude that as SIR increases with a fixed SNR, the optimal value of EH ratio increases. This is because when the received average SNR is constant, the increase power in CCI signal can degrade the system performance, but reduces the optimal value of EH ratio effectively. The results in [12] are obvious as compared to the previous works without CCI assistance [6]-[8] where the overall throughput is enhanced with better outage performance. The drawback of the previous works [6]-[8] is that the numerical equation does not consider multi-source as the primary signals in contrast to the work which considers multi-interference from other networks. This motivates the work to implement a multi-source as primary signals and CCI as secondary signals as part of harvested power at the relay node. The objectives of the paper are to develop relaying protocol of TSR in numerical form by applying multi-source with interference signals assisted and to validate the proposed technique in relation to overall system throughput against the EH ratio.

2. System Model

2.1 S ⇒ R Energy Harvesting and Information Transmission with Multiple Sources

In this model, the energy constraint at relay node harvests energy from both source and interference signals, and uses the harvested energy to decode the source signal and forward it to the destination. As depicted in Figure 1, T is the total block time in TSR scheme in which the information signal is transmitted from the source node to the destination node. The $\alpha \in (0,1)$ denotes the fraction of block time in which the relay harvests energy from the source and interferer signals, while the remaining block time represents as $(1-\alpha)T$ is used for the information transmission. In this manner, half of the $(1-\alpha)T$ which is $(1-\alpha)T/2$ is used for the source to relay information transmission, and the remaining half is used for the relay to destination information transmission. It is assumed that the relay would consume all the harvested energy prior to forwarding the source signal to its destination. The fraction of time α controls the achievable throughput at the destination node. The only difference in this MSSR as compared to a single source is the available energy harvesting sources which are the sum of source and interferers. The details presentation of the received signal and its achievable rate at the relay node and destination node is analysed in below section [13].

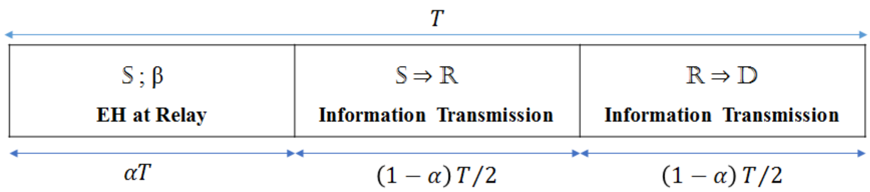

Fig. 1. Transmission Block Structure in TSR Scheme for EH and Information Transmission with Co-Channel Interference

The received signal, i at the relay node, $y_R(k)$ can be derived as:

$$y_R(k) = \sum_{i=1}^{M} \frac{1}{\sqrt{d_i^m}} \sqrt{P_i} h_i s_i(k) + \sum_{j=1}^{N} \frac{1}{\sqrt{d_j^m}} \sqrt{P_j} \beta_j s_j(k) + n_{a,R}(k) + n_{c,R}(k) \quad (1)$$

where k = 1, 2, …,integer denotes symbol index, d_i = distance from source i to relay, d_j = distance from interferer j to relay, h_i = channel gain from source i to relay, P_i = transmitted power from source i, β_j = channel gain from interferer j to relay, P_j = transmitted power from interferer j, m = path loss exponent, M = the no. of sources, N = the no. of interferers, $s_i(k)$ = k_{th} normalized information symbol from the source i, i.e. E $\{|s_i(k)|^2\}$ = 1, $s_j(k)$ = k_{th} normalized information symbol from the interferer j, i.e. E $\{|s_j(k)|^2\}$ = 1, $n_{a,R}(k)$ = baseband addictive white Gaussian noise (AWGN), $n_{c,R}(k)$ = AWGN due to RF band to baseband signal conversion.
The energy harvesting during αT time can be written as:

$$E_h^{TS} = \eta \left(\sum_{i=1}^{M} \frac{1}{d_i^m} P_i |h_i|^2 + \sum_{j=1}^{N} \frac{1}{d_j^m} P_j |\beta_j|^2 \right) \alpha T \quad (2)$$

where η = energy conversion efficiency is 0 < η < 1 which depends on energy harvesting efficiency and the rectification process.

2.2 R ⇒ D Information Transmission

The decoded source signal at the relay node is forwarded to the destination node with power P_R^{TS} as described in earlier section. The power use for the information transmission is the available harvested energy power during energy harvesting period. The received signal at the destination node, $y_D^{TS^{MSSR}}(k)$ is given as:

$$y_D^{TS^{MSSR}}(k) = \frac{1}{\sqrt{d_{RD}^m}} \sqrt{P_R^{TS}} g . \bar{s}(k) + n_{a,D}(k) + n_{c,D}(k) \quad (3)$$

where d_{RD}= distance from relay to destination, g = channel gain from relay to destination, P_R= transmitted power from relay, $\bar{s}(k)$ = decoded version of the signal $s(k)$, $n_{a,D}(k)$ = baseband addictive white Gaussian noise (AWGN), $n_{c,D}(k)$ = AWGN due to RF band to baseband signal conversion.

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:

$$P_R^{TS} = \frac{E_h^{TS}}{(1-\alpha)T/2} \quad (4)$$

Substitutes (2) into (4) and into (3) will yield the received signal at the destination node:

$$y_D^{TS^{MSSR}}(k) = \sqrt{\frac{2\eta\alpha\left(\sum_{i=1}^{M} \frac{1}{d_i^m} P_i |h_i|^2 + \sum_{j=1}^{N} \frac{1}{d_j^m} P_j |\beta_j|^2\right)}{d_{RD}^m (1-\alpha)}}\, g\bar{s}(k) + n_D(k) \quad (5)$$

2.3 Throughput Analysis

In considering equation (1), the SNR/SIR at the relay node, $\gamma_R^{TS^{MSSR}}$ can be derived as:

$$\gamma_R^{TS^{MSSR}} = \sum_{i=1}^{M}\sum_{j=1}^{N}\frac{P_i|h_j|^2 d_j^m}{P_j|\beta_j|^2 d_i^m+\sigma_{n_R^{TS}}^2} \quad (6)$$

where $\sigma_{n_R^{TS}}^2 \triangleq \sigma_{n_{a,R}}^2 + \sigma_{n_{c,R}}^2$ is the variance of the overall AWGN at the relay node.

Using (5), the SNR/SIR at the destination node, $\gamma_D^{TS^{MSSR}}$ can be derived as:

$$\gamma_D^{TS^{MSSR}} = \sum_{i=1}^{M}\sum_{j=1}^{N}\frac{2\eta\alpha\left(P_iP_j|h_i|^2|\beta_j|^2\right)|g|^2}{d_i^m d_j^m d_{RD}^m \sigma_{n_D}^2(1-\alpha)} \quad (7)$$

where $\sigma_{n_D}^2 \triangleq \sigma_{n_{a,D}}^2 + \sigma_{n_{c,D}}^2$ is the variance of the overall AWGN at the destination node.

For the achievable throughput of the ergodic capacity for source to relay link, C_R^{TS} and for relay to destination link, C_D^{TS} is evaluated and determined using the received SNR/SIR for both link respectively. Thus, the ergodic capacity of source to relay link can be written as:

$$C_R^{TS} = E_{h,\beta}\left\{log_2\left(1+\gamma_R^{TS^{MSSR}}\right)\right\} \quad (8)$$

whereas, the ergodic capacity of relay to destination link is given by:

$$C_D^{TS} = E_{h,\beta,g}\left\{log_2\left(1+\gamma_D^{TS^{MSSR}}\right)\right\} \quad (9)$$

3. Numerical Analysis

This section discusses numerical results and simulation analysis for MSSR. All related parameters and values are selected based on MSSR equations. Unless stated otherwise, the number of source M is set to 2, while the number of interferer, N is set to 2. Integers i and j are referring to M and N accordingly. The average SNR and SIR values are set to 20dB respectively. The energy harvesting efficiency, η = 0.7, distance from sources i to relay, d_i = 1, distance from interferers j to relay, d_j = 1, distance from relay to destination, d_{RD} = 1, transmitted power from sources, P_i = 1 watt, transmitted power from interferers, P_j = 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 2. In this case, the SSSR model is matching perfectly with ideal receiver [8]. 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 decoded for the information transmission at this time fraction. From the plot, the optimal value of α for the peak throughput in MSSR is at 0.2 as compared to 0.3 in ideal receiver, which reduces significantly the value of EH ratio by 10%. The impact of multiple sources including CCI is demonstrated in Figure 3. From the TSR scheme, when both SNR and SIR increase, the system throughput with respect to the EH ratio is decreased. It means when the received average power for

SNR and CCI power for SIR are increased, the overall system performance in terms of throughput is significantly deteriorated, but effectively reduces the optimal value of α for the peak throughput in MSSR.

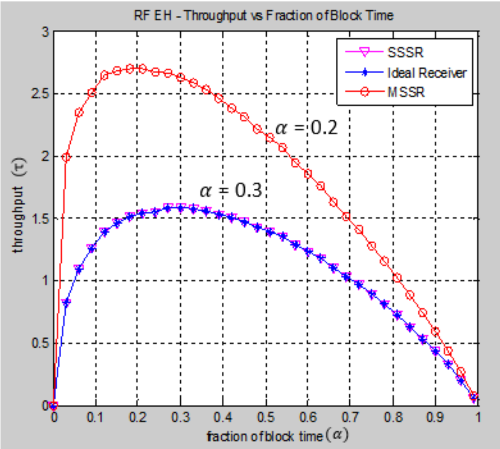

Fig. 2. Throughput vs EH Ratio at Destination Node with respect to Fraction of Block Time, α for TSR Scheme

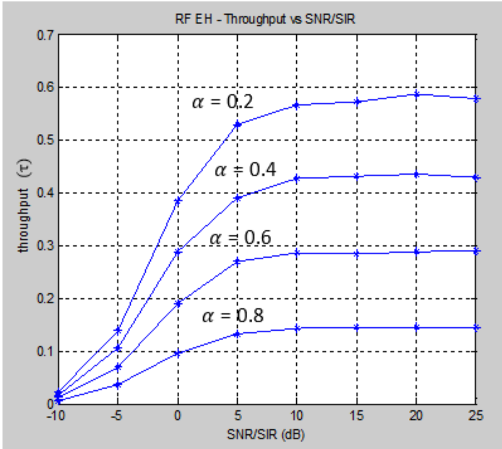

Fig. 3. Throughput vs Average SNR/SIR with respect to EH Ratio at Destination Node for TSR Scheme

4. Conclusion

In this paper, the MSSR scheme in decode-and-forward model with multiple sources including CCI signal is proposed where the multiple sources and CCI are harvested at the constraint relay node and used this harvested energy to decode-and-forward the information signal from source to destination. The optimal value of EH ratio for TSR scheme is obtained with respect to the overall achievable throughput. It was shown in simulation that multiple sources have substantially reduced the optimal value of EH ratio and increased the overall system throughput as compared to SSSR and ideal receiver.

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