Relay Selection in Cooperative Wireless System

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Summary
The interest in cooperative relaying has boosted after the advent of simultaneous wireless information and power transmission (SWIPT) concept. Energy harvesting is seen as a promising candidate to solve the charging issue of small sensor networks that are not feasible to change periodically. We have considered two types of hardware for energy harvesting from radio frequency in this research; time switching (TS) architecture and power splitting (PS) architecture. In our research, a cooperative relaying system of single intermediate node is assumed. The relay node is following amplify and forward protocol. Only destination node is harvesting energy and have focused on two issues for both TS and PS architectures (resulting four problem in total); one is to optimize the data rate while ensuring the power-harvesting rate achieved at destination higher than given threshold and other is optimizing power-harvesting rate at destination while ensuring the data rate is higher than given threshold. We have plotted the performance of all four problems for different scenarios.

Key words:
Relay system, cooperative relaying, energy harvesting, simultaneous wireless information and power transfer, power-harvesting rate

1. Introduction

An increasing interest in cooperative relaying was observed in recent past, this increase in interest was because of its ability to fully utilize the spatial diversity and enhance the performance of system as compared to conventional systems. A node can communicate with nearby nodes to achieve cooperation thus creating a network that requires less transmission power and have larger coverage range [1]. This interest in cooperative relaying has boosted after the advent of simultaneous wireless information and power transmission (SWIPT) concept. Energy harvesting is seen as a promising candidate to solve the charging issue of small sensor networks that are not feasible to change periodically [2].

In wireless communication system, the signal is broadcasted in the medium for the transmission of data from the sending user device to receiving user device. The neighboring devices can also receive these signals. This phenomenon can be used for the long transmissions. In cooperative wireless communication systems the neighboring user device which is called relay nodes/devices, are can receive and forward the data to the end user device [3] [4] [5]. The relay nodes can be used to increase the performance of the communication systems. In a system, wireless devices may have a limited energy sources. In such scenarios, the cooperative relaying systems can also be used to transfer energy from the source node having a sufficient amount of energy to the destination requiring energy in form of radio-frequency (RF) signals [6] [7] [8]. The additive white Gaussian noise (AWGN) is one of the reasons for the performance degradation of communication systems. Cooperative relaying communication systems are no exception. The aim of this research work is to analyze energy-harvesting rate and data rate in cooperative relaying communication systems.

In [9], Liu et al. and in [10], Krikidis et al. have discussed the SWIPT enabled system with co-operative relaying but they have considered energy harvesting at relay node. In [11], Gautam et al. have discussed the co-operative relaying with SWIPT enabled network but they have considered only two noises (i.e. one noise at relay and other at destination).Different from the above, we are considering individual noise and Nakagami distribution for individual channel path. We have considered path-loss effect, as it can be shown in Fig. 1. For simulation, authors in above mentioned reference papers have neglected the circuit noise whereas we have considered the circuit noise as well. In our system, all parameters of relays are independent and non-identical to make our results more close to practical results.

In this paper, we are investigating the problem of selection of relay in wireless cooperative relaying network where destination node is enabled for SWIPT. The problem of selection of optimal relay is divided in two parts; optimizing data rate for a given power-harvesting rate and optimizing power-harvesting rate for a given data rate. Furthermore, this optimization is performed for both TS and PS architectures. In this work, a single relaying node system is considered for the analysis. Each of the channels in the system is considered to be Nakagami distributed. The generalized nature of the Nakagami distribution makes it suitable for the research purpose. It also includes many important fading distributions as its special cases [12]. This paper is continuation of our previous work [13], in which we have just analyzed the system and in that work, we had not considered the path-loss in the system. The rest of paper is organized as follows. The system model is

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presented in Section 2. Section 2 also formulates the data rate and energy-harvesting rate. In section 3 optimization of data rate for given power-harvesting rate is discussed. In section 4 optimization of power-harvesting rate for given data rate is discussed. Section 5 gives numerical results and discussion on the numerical results. Finally, Section 6 concludes this research work.

2. System Model and Formulation

In this paper, we have considered a SWIPT system with cooperative relaying, which consists of a single source, a single destination and rn number of relays. There are two paths for source to communicate with the destination, one is direct link i.e. direct communication of source with destination and second is indirect link i.e. communication of source with destination through relay as shown in Fig. 1. The end receiver is assumed to be SWIPT enabled i.e. destination can decode information and power- harvesting simultaneously with respect to time switching (TS) architecture or power splitting (PS) architecture as depicted in Fig. 2 and 3 respectively.

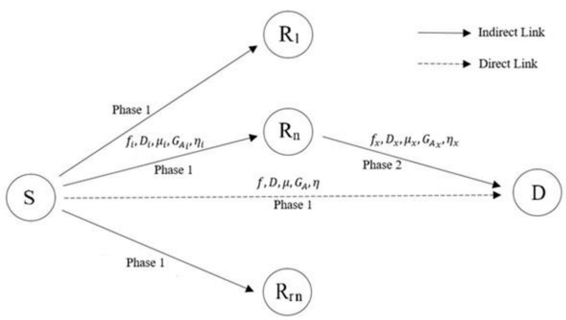

Fig. 1 System Model

2.1 System modeling for 1st Phase

Nakagami distribution has two parameters, namely shape parameter λ_m which is used for controlling severity of fading and λ_Ω (average power) this is used for the average power. Mathematical formula for Nakagami probability density function (PDF) is [14],

$$f(x;\lambda_m,\lambda_\Omega)=\frac{2\lambda_m^{\lambda_m}}{\Gamma(\lambda_m)\lambda_\Omega^{\lambda_m}}x^{2\lambda_m-1}\exp(-\frac{\lambda_m}{\lambda_\Omega}x^2) \quad (1)$$

$$\therefore x>0, \lambda_m>\frac{1}{2}, \lambda_\Omega>0$$

A symbol s $(s\in C)$ is broadcast by source in 1st phase, that is received at destination and relays. For simplicity we assume that $\mathrm{E}\{|s|^2\}=1$. The signal received at receiver r_D through direct link can be described as,

$$r_D=\sqrt{P_t D^{-\mu}}s\,f+\eta \quad (2)$$

where P_t is the power transmitted by the source, D is distance between source and destination, μ is path-loss factor of channel, f is channel path gain and η is Additive White Gaussian Noise (AWGN), which is an independent and identically distributed (i.i.d) complex Gaussian random variable with zero mean and variance σ_η^2. Whereas, the signal received by relay can be presented as,

$$r_r=\sqrt{P_t D_i^{-\mu}}s\,f_i+\eta_i \quad (3)$$

where D_i is distance between source and relay, μ_i is path-loss factor, f_i is channel path gain and η_i is AWGN, which is i.i.d same as η, have zero mean and variance of $\sigma_{\eta_i}^2$.

There can be any of the following two architectures at the destination for SWIPT. TS architecture or PS architecture. In TS architecture, we are assuming a time splitting ratio α, where $0\le\alpha\le1$. In this architecture, at first α duration of time period signal is used for energy harvesting whereas the remaining (1 - α)th duration of time period the signal is used for information transfer, as shown in Fig. 2.

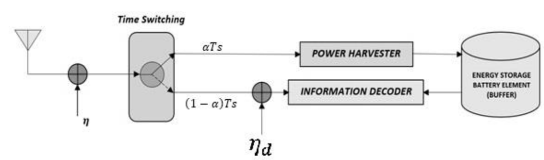

Fig. 2 TS architecture of receiver [11]

We are assuming a power splitting ratio β, where $0\le\beta\le1$, PS architecture destination. For PS architecture a fraction of signal defined by β, is used for energy harvesting, whereas remaining fraction of signal i.e. (1 – β) is used for information transfer, as shown in Fig. 3.

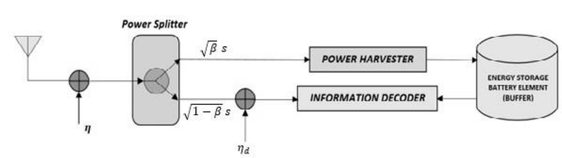

Fig. 3 PS architecture of receiver [11]

The signal to noise ratio (SNR) estimated at the receiver of direct-link for the TS and PS architectures, can be presented as,

$$\gamma_{D\_TS} = \frac{P_t D^{-\mu} |f|^2}{\sigma_\eta^{\ 2} + \sigma_{\eta_d}^{\ 2}} \tag{4}$$

$$\gamma_{D\_PS} = \frac{(1-\beta) P_t D^{-\mu} |f|^2}{(1-\beta)\sigma_\eta^{\ 2} + \sigma_{\eta_d}^{\ 2}} \tag{5}$$

where $\eta_d \in C\left(0, \sigma_{\eta_d}^{\ 2}\right)$ is the noise of circuit as shown in Fig. 2 and 3 respectively. The power harvested at the receiver of the direct link communication, can be written as,

$$P_{D\_TS} = \xi\alpha\left(P_t D^{-\mu} |f|^2 + \sigma_\eta^{\ 2}\right) \tag{6}$$

$$P_{D\_PS} = \xi\beta\left(P_t D^{-\mu} |f|^2 + \sigma_\eta^{\ 2}\right) \tag{7}$$

where ξ is efficiency of energy harvesting circuit [15], which is assumed to be known. We are assuming a normalized time with the objective of using power and energy reciprocally for the sake of simplicity.

2.2 System Model for 2nd Phase

For the 2nd phase of the system, relay amplify the received signal by a complex coefficient and re-transmit the signal. The signal received at destination through relay, can be described as,

$$r_{rD} = \psi\sqrt{P_t D_x^{-\mu_x}}\ f_x r_r + \eta_x \tag{8}$$

where, D_x is distance between relay and destination, μ_x is path-loss factor of the channel, f_x is the channel path gain and η_x is AWGN of the channel, which is i.i.d and have zero mean and variance of $\sigma_{\eta_x}^{\ 2}$. An upper bound for the power available at relay is defined for the feasibility of system,

$$0 < |\psi|^2 \le \tilde{P}_R \tag{9}$$

where $\tilde{P}_R = \frac{P_{\max} - P_t}{P_t D_i^{-\mu_i} |f_i|^2 + \sigma_{\eta_i}^{\ 2}}$ is the value of maximum power can be present at relay and overall power of this relay system is limited by P_{max}, such that $P_{\max} > \max\left(P_t, \tilde{P}_R\right)$. The SNR estimated at the destination for the indirect-link i.e. through relay, by considering the TS and PS architectures can be presented as,

$$\gamma_{rD\_TS} = \frac{|\psi|^2 D_x^{-\mu x} |f_x|^2 D_i^{-\mu i} |f_i|^2 P_t}{|\psi|^2 D_x^{-\mu x} |f_x|^2 \sigma_{\eta_i}^2 + \sigma_{\eta_x}^2 + \sigma_{\eta_d}^2} \tag{10}$$

$$\gamma_{rD\_PS} = \frac{(1-\beta)|\psi|^2 D_x^{-\mu x} |f_x|^2 D_i^{-\mu i} |f_i|^2 P_t}{(1-\beta)\left(|\psi|^2 D_x^{-\mu x} |f_x|^2 \sigma_{\eta_i}^2 + \sigma_{\eta_x}^2\right) + \sigma_{\eta_d}^2} \tag{11}$$

The energy harvested at the destination for indirect link i.e. through relay by considering the TS and PS architectures, can be presented as,

$$P_{rD\_TS} = \xi\alpha\left(|\psi|^2 D_x^{-\mu x} |f_x|^2 \left(P_t D_i^{-\mu i} |f_i|^2 + \sigma_{\eta_i}^2\right) + \sigma_{\eta_x}^2\right) \tag{12}$$

$$P_{rD\_PS} = \xi\beta\left(|\psi|^2 D_x^{-\mu x} |f_x|^2 \left(P_t D_i^{-\mu i} |f_i|^2 + \sigma_{\eta_i}^2\right) + \sigma_{\eta_x}^2\right) \tag{13}$$

2.3 Overall Data Rate and Energy Harvesting Rate

At the destination maximal ratio combining (MRC) technique is used to combine signal received via direct channel and the signal received via relay [16]. The SNR at the output of the combiner for TS and PS architectures, can be presented as [11],

$$\gamma_{TS} = \gamma_{D\_TS} + \gamma_{rD\_TS} \tag{14}$$

$$\gamma_{PS} = \gamma_{D\_PS} + \gamma_{rD\_PS} \tag{15}$$

The overall data rate for TS and PS architecture, can be written as [11],

$$R = \begin{cases} R_{TS} = \frac{1}{2}(1-\alpha)\log_2\left(1+\gamma_{TS}\right) \\ R_{PS} = \frac{1}{2}\log_2\left(1+\gamma_{PS}\right) \end{cases} \tag{16}$$

where the factor 1/2 is for the two time slot which is required for the relaying. The power-harvesting rate for TS and PS architecture, can be written as [11],

$$P = \begin{cases} P_{TS} = P_{D\_TS} + P_{rD\_TS} \\ P_{PS} = P_{D\_PS} + P_{rD\_PS} \end{cases} \tag{17}$$

3. Optimizing Data Rate for Given Power-Harvesting Rate

3.1 Time Switching Architecture

In this case we are considering to optimize the effective data source-destination rate in TS architecture, while given that the destination should be able to harvest power higher then given threshold. We are considering a cooperative relaying system as shown in Fig. 1. The mathematical representation of this optimization problem is,

$$\begin{aligned} (O1): \quad & \max_{n \in C, \alpha, \psi_n} \quad R \\ \text{subjected to}: \quad & P_{rate} \le P \\ & 0 < |\psi_n|^2 \le P_R \\ & 0 \le \alpha \le 1 \end{aligned} \tag{18}$$

Where, n is the relay index, C is the set of indices of relay having value as $C = 1, 2, 3, \cdots, rn$. P_{rate} is the threshold of power-harvesting rate, P_R is the upper bound of relay power $P_R \le \tilde{P}_R$ and α is time switching ratio. The problem defined above have a difficult solution because it contains non-linear mixed-integer optimization for TS architecture. For the simplicity, we are breaking this problem in two parts, one is to optimize the parameter of individual relay in such a way that it guarantees the power harvesting at destination to be higher than given threshold and optimized data rate source-destination should be achieved, second is to select the relay with the highest data rate.

3.1.1 Optimization of TS Ratio and Relay Amplification parameters

In this part, we want to optimize α and relay amplification parameters for individual relay and the mathematical representation of this optimization problem is as follows,

$$\begin{aligned} (O2): \quad & \max_{\alpha,\ \psi_n} \quad R \\ \text{subjected to}: \quad & P_{rate} \le P \\ & 0 < |\psi_n|^2 \le P_R \\ & 0 \le \alpha \le 1 \end{aligned} \tag{19}$$

Finding the optimized solution for the stated problem involves the calculation of both parameters i.e. α and ψ_n. This problem can be solved by using Langrange dual method. By considering a domain Γ that has sets of $\alpha,\ (\psi_n)^2$, $n = 1, 2, 3, \cdots, r\ n$, that satisfies (19). The Langrangian equation for solution of problem stated in ($O2$) is given as

$$\begin{aligned} \mathcal{L}(\alpha, \psi_n; L) = R + L_1(P - P_{rate}) + \\ L_2(P_R - |\psi_n|^2) + L_3(1 - \alpha) \end{aligned} \tag{20}$$

where $L = (L_1; L_2; L_3) \ge 0$ as these are the vectors of variable associated with power harvesting, α and relay amplification parameter. The Langrange function for ($O2$) can be given as:

$$\mathcal{L}_D(L) = \max_{\{\alpha, \psi_n\}\ \epsilon\ \Gamma} \mathcal{L}(\alpha, \psi_n; L) \tag{21}$$

As described in [17], that $\mathcal{L}_D(L)$ will be a convex function, so we can apply the gradient and sub-gradient method [18] that promises for the convergence. The found solution for maximization of Langragian in (20) is given as

$$|\psi|^2 = P_R \tag{22}$$

$$\alpha = \frac{P_{rate}\left(\zeta^{-1}\right)}{\begin{array}{c} P_t D^{-\mu} G_A |f|^2 + P_R D_x^{-\mu_x} G_{A_x} |f_x|^2 \\ \left(P_t D_i^{-\mu_i} G_{A_i} |f_i|^2 + \sigma_{\eta_i}^2\right) + \sigma_{\eta_x}^2 + \sigma_\eta^2 \end{array}} \tag{23}$$

3.1.2 Selection of Best Relay

As earlier, we divide the optimization problem stated in ($O1$) in two parts. First, optimizing parameters and second selection of optimized best relay of available relay. As in previous section, we have optimized the parameters for all relays and making that we can select our best relay based on that can provide the highest data rate. The index of relay selected can be defined as $i^* = \arg\max_{i \in (1,2,3,\cdots,rn)} R_i^*$, here R_i^* is the data rate achieved in *i-th* relay.

3.2 Power Splitting Architecture

In this case, we are considering optimizing the effective data rate in PS architecture, while given that the destination should be able to harvest power higher then given threshold. We are considering a cooperative relaying system depicted in Fig.1. The mathematical representation of this optimization problem is as follows,

$$\begin{aligned} (O3): \quad & \max_{n \in C, \beta, \psi_n} \quad R \\ \text{subjected to}: \quad & P_{rate} \le P \\ & 0 < |\psi_n|^2 \le P_R \\ & 0 \le \beta \le 1 \end{aligned} \tag{24}$$

where, n is the relay index, C is the set of indices of relay having value as $C = 1, 2, 3, \cdots, rn$. P_{rate} is the threshold of power-harvesting rate, P_R is the upper bound of relay power $P_R \le \tilde{P}_R$ and β is power splitting ratio. The problem defined above contains non-linear mixed-integer for optimization for the PS architecture. Therefore, is difficult to solve. For simplicity, we are dividing the problem in two parts. First is to optimize the parameter of individual relay in such a way that it guarantees the power harvesting at destination to be higher than given threshold and optimized data rate should be achieved, second is to select the relay with the highest data rate.

3.2.1 Optimization of PS Ratio and Relay Amplification parameters

In this part, we want to optimize β and relay amplification parameters for individual relay. The mathematical representation of the optimization problem is,

$$
\begin{aligned}
(O4):\quad & \max_{\beta,\ \psi_n} \quad R \\
\textit{subjected to}: \quad & P_{rate} \le P \\
& 0 < |\psi_n|^2 \le P_R \\
& 0 \le \beta \le 1
\end{aligned}
\qquad (25)
$$

Finding the optimized solution for the stated problem involves the calculation of both parameters, i.e. β and ψ_n. This problem can be solved by using Langrange dual method. By considering a domain Γ that has sets of $\beta, (\psi_n)^2$, $n = 1,2,3,\cdots,r\ n$, that satisfy (25). For the Langrangian equation for solution of problem stated in ($O4$) can be represented as,

$$
\begin{aligned}
\mathcal{L}(\beta, \psi_n; K) = R + K_1(P - P_{rate}) + \\
K_2(P_R - |\psi_n|^2) + K_3(1 - \beta)
\end{aligned}
\qquad (26)
$$

where $K = (K_1; K_2; K_3) \ge 0$ as these are the vectors of variable associated with power harvesting, β and relay amplification parameter. The Langrange function for ($O4$) can be given as,

$$
\mathcal{L}_D(K) = \max_{\{\beta, \psi_n\}\ \epsilon\ \Gamma} \mathcal{L}(\beta, \psi_n; K) \qquad (27)
$$

$\mathcal{L}_D(K)$ is a convex function [17], so we can apply the gradient and sub-gradient method as in [18] that promises for the convergence. The found solution for maximization of Langragian in (26) can be given as,

$$
|\psi|^2 = P_R \qquad (28)
$$

$$
\beta = \frac{P_{rate}\left(\zeta^{-1}\right)}{\dfrac{P_t D^{-\mu} G_A |f|^2 + P_R D_x^{-\mu_x} G_{A_x} |f_x|^2}{\left(P_t D_i^{-\mu_i} G_{A_i} |f_i|^2 + \sigma_{\eta_i}^2\right) + \sigma_{\eta_x}^2 + \sigma_\eta^2}} \qquad (29)
$$

3.2.2 Selection of Best Relay

As earlier we divide the optimization problem stated in ($O3$) in two parts. First, optimizing parameters and second, selecting the optimized best relay of existing relays. As in previous section, we have optimized the parameters for all relays and making that we can select our best relay based on that can provide the highest data rate. The index of best-chosen relay can be defined as $i^* = \arg\max_{i\in(1,2,3,\cdots,rn)} R_i^*$, here R_i^* is the data rate achieved in *i-th* relay.

4. Optimizing Power-Harvesting Rate for Given Data Rate

4.1 Time Switching Architecture

In this section, we are considering optimizing the overall power-harvesting rate at destination for TS architecture, while given that the destination should be able to achieve data rate higher then given threshold. We are considering a cooperative relaying system depicted in Fig. 1. This optimization problem can be presented as,

$$
\begin{aligned}
(O5):\quad & \max_{n\in C,\alpha,\psi_n} \quad P \\
\textit{subjected to}: \quad & D_{rate} \le R \\
& 0 < |\psi_n|^2 \le P_R \\
& 0 \le \alpha \le 1
\end{aligned}
\qquad (30)
$$

where, n is the relay index, C is the set of indices of relay having value as $C = 1,2,3,\cdots,rn$, D_{rate} is the threshold of data rate, P_R is the upper bound of relay power $P_R \le \tilde{P}_R$ and α is time switching ratio. The problem defined above is a complex to solve because it contains non-linear mixed-integer optimization for TS architecture. For simplifying, we are dividing this problem in two parts, one is optimizing the parameter of individual relay in such a way that it guarantees the power harvesting at destination to be higher than given threshold and optimized data rate should be achieved, second is to select the relay with the highest data rate.

4.1.1 Optimization of TS Ratio and Relay Amplification parameters

In this part, we want to optimize α and relay amplification parameters for individual relays. Mathematically, this optimization problem can be presented as,

$$(O6): \quad \max_{\alpha,\ \psi_n} \quad P$$
$$\text{subjected to}: \quad D_{rate} \le R$$
$$0 < |\psi_n|^2 \le P_R \tag{31}$$
$$0 \le \alpha \le 1$$

Finding the optimized solution for the stated problem involves the calculation of both parameters (i.e. $\alpha,\ \psi_n$). This problem can be solved by using Langrange dual method. By considering a domain Γ that has sets of $\alpha, (\psi_n)^2$, $n = 1,2,3,\cdots,r\ n$, that satisfy (31). The Langrangian equation for solution of problem stated in ($O6$) can be presented as,

$$\mathcal{L}(\alpha, \psi_n; H) = P + H_1(R - D_{rate}) + H_2(P_R - |\psi_n|^2) + H_3(1-\alpha) \tag{32}$$

where $H = (H_1; H_2; H_3) \ge 0$ as these are the vectors of variable associated with power harvesting. The α and relay amplification parameter and the Langrange function for ($O6$) can be given as,

$$\mathcal{L}_D(H) = \max_{\{\alpha, \psi_n\} \in \Gamma} \mathcal{L}(\alpha, \psi_n; H) \tag{33}$$

As described in [17], that $\mathcal{L}_D(H)$ is a convex function, so we apply the gradient and sub-gradient method [18] that promises for the convergence. The found solution for maximization of Langragian in (32) can be given as,

$$|\psi|^2 = P_R \tag{34}$$

$$\alpha = 1 - \frac{2D_{rate}}{\log_2(1+\gamma_{TS})} \tag{35}$$

4.1.2 Selection of Best Relay

As earlier we divided the optimization problem stated in ($O5$) in two parts. First optimizing parameters and second selection of optimized best relay of available relay. As in previous section, we have optimized the parameters for all relays and making that we can select our best relay based on that can provide the highest power-harvesting rate. The index of best-chosen relay can be defined, $i^* = \arg\max_{i\in(1,2,3,\cdots,rn)} P_i^*$, here P_i^* is the power-harvesting rate achieved in *i-th* relay.

4.2 Power Splitting Architecture

In this case, we are considering optimizing the overall power-harvesting rate at destination in PS architecture, while given that the destination should be able to achieve data rate higher then given threshold. We are considering a cooperative relaying system as shown in Fig. 1. This optimization problem can mathematically be presented as,

$$(O7): \quad \max_{n\in C,\beta,\psi_n} \quad P$$
$$\text{subjected to}: \quad D_{rate} \le R$$
$$0 < |\psi_n|^2 \le P_R \tag{36}$$
$$0 \le \beta \le 1$$

Where, n is the relay index, C is the set of indices of relay having value as $C = 1,2,3,\cdots,rn$, D_{rate} is the threshold of data rate, P_R is the upper bound of relay power $P_R \le \tilde{P}_R$ and β is power-harvesting ratio. The problem defined above is not easy to solve because it contains non-linear mixed-integer optimization for PS architecture. For simplifying, we are dividing this problem in two parts, first is optimizing the parameter of individual relay in such a way that it guarantees the power harvesting at destination to be higher than given threshold and optimized data rate should be achieved, second is to select the relay with the highest data rate.

4.2.1 Optimization of PS Ratio and Relay Amplification parameters

In this part, we want to optimize β and relay amplification parameters for individual relays and this optimization problem can be represented mathematically as,

$$(O8): \quad \max_{\beta,\ \psi_n} \quad P$$
$$\text{subjected to}: \quad D_{rate} \le R$$
$$0 < |\psi_n|^2 \le P_R \tag{37}$$
$$0 \le \beta \le 1$$

Finding the optimized solution for the stated problem involves the calculation of both parameters, i.e. β and ψ_n. This problem can be solved by using Langrange dual method. By considering a domain Γ that has sets of $\beta, (\psi_n)^2$, $n = 1,2,3,\cdots,r\ n$, that satisfy (37). For the Langrangian equation for solution of problem stated in ($O8$) can be represented as

$$\mathcal{L}(\beta, \psi_n; G) = P + G_1(R - D_{rate}) + G_2(P_R - |\psi_n|^2) + G_3(1-\beta) \tag{38}$$

where $G = (G_1; G_2; G_3) \ge 0$ as these are the vectors of variable associated with power harvesting, β and relay amplification parameter. The Langrange function for ($O8$) can be given as,

$$\mathcal{L}_D(G) = \max_{\{\alpha, \psi_n\} \epsilon \Gamma} \mathcal{L}(\beta, \psi_n; G) \tag{39}$$

As described in [17], that $\mathcal{L}_D(G)$ is a convex function, so we apply the gradient and sub-gradient method [18] that promises for the convergence. The found solution for maximization of Langragian in (39) can be given as

$$|\psi|^2 = P_R \tag{40}$$

$$\beta = 1 - \frac{-B + \sqrt{B^2 + 4AC}}{2A} \tag{41}$$

In (41),

$$\begin{aligned} A = {} & P_t D^{-\mu} G_A |f|^2 \left(|\psi|^2 D^{-\mu_x} G_{A_x} |f_x|^2 \sigma_{\eta_i}^2 + \sigma_\eta^2 \right) \\ & + |\psi|^2 D^{-\mu_x} G_{A_x} |f_x|^2 P_t \sigma_{\eta_x}^2 \\ & - \left(2^{2D_{rate}} - 1 \right) \left(|\psi|^2 D^{-\mu_x} G_{A_x} |f_x|^2 \sigma_{\eta_i}^2 \sigma_{\eta_x}^2 + \sigma_\eta^4 \right) \end{aligned} \tag{42}$$

$$\begin{aligned} B = {} & P_t D^{-\mu} G_A |f|^2 \sigma_{\eta_d}^2 + |\psi|^2 D_x^{-\mu_x} G_{A_x} |f_x|^2 P_t \sigma_{\eta_d}^2 \\ & D_i^{-\mu_i} G_{A_i} |f_i|^2 - \left(2^{2D_{rate}} - 1 \right) \Big[\sigma_\eta^2 \sigma_d^2 + \Big(|\psi|^2 D_x^{-\mu_x} \\ & G_{A_x} |f_x|^2 \sigma_{\eta_i}^2 + \sigma_{\eta_x}^2 \Big) \sigma_d^2 \Big] \end{aligned} \tag{43}$$

$$C = -\left(2^{2D_{rate}} - 1 \right) \sigma_d^4 \tag{44}$$

4.2.2 Selection of Best Relay

As earlier we divide the optimization problem stated in ($O7$) in two parts. First optimizing parameters and second selection of optimized best relay of available relay. As in previous section, we have optimized the parameters for all relays and making that we can select our best relay based on that can provide the highest power-harvesting rate. The index of selected relay can be expressed as $i^* = \arg\max_{i \in (1,2,3,\cdots,rn)} P_i^*$ here P_i^* is the power-harvesting rate achieved in *i-th* relay.

5. Simulation Results

All the simulations are implemented for 10,000 instances of time. Each instance can represent 1 second. Five available relays are considered. The number of instances and number of relays can be easily increased or decreased. We have designed algorithm in such a way that all relays in our system are independent and non-identical, all parameters of relays are completely independent from the values of other relays. Whereas assigning the values of distance to the relay, it has focused that the values of distances of relay from source and destination should provide a valid geometry, so the system can be more flexible and can be more close to practical conditions. For the simulation value of λ_Ω parameter is kept 1, mean values of noises η, η_i, η_x and η_d are considered 0 and combined transmit and receive antenna gain G_A is considered to be 1. By considering the maximum power of system to be twice of the source transmit power, hence P_{max} is considered as twice of power transmit by source P_t and this results in the power available at relay to be equal to P_t. In Fig. 4 effects of change of D, D_i and D_x (distances of channel paths) for optimization of data rate in TS architecture is analyzed. There are two conditions plotted in the graph. The value of these conditions are; in ***case 1:*** distance between source and destination D is kept 8m, the distances between source and relay D_i are kept [4.2, 5.5, 5.2, 5.1, 3.9] m respectively and the distances between relay and destination Dx, are kept [4.9, 5.5, 6, 6.3, 5] m respectively. In ***case 2:*** the value of D is kept 10 m, the values of D_i are kept [5.2, 7.2, 7.3, 6.8, 5] m respectively and the values of Dx are kept [6.1, 7.9, 8.4, 6.9, 6.1] m respectively. Whereas, the value of P_t is considered to be 10dB. The value of fading shape parameter for the direct link $\lambda_m = 4$. The values of fading shape parameter of channel from source to relay λ_{mi} are assumed to be [5, 6.5, 5.5, 3.5, 6] respectively. The values of fading severity parameter of relay to destination channel λ_{mx} are considered to be [7.5, 6, 5.5, 3.5, 6.5] respectively. The value of power conversion efficiency ζ is considered 0.8. The values of variance σ_η^2 of direct link noise η is considered −12dB. The values of variance $\sigma_{\eta i}^2$ of noise in channel source to relay η_i are chosen to be [−10, −11.2, −10.5, −11, −10.8] dB respectively. The values of variance $\sigma_{\eta x}^2$ of noise in channel from relay to destination η_x are chosen to be [−9, −9.2, −10.5, −10.2, −9.5] dB respectively. The values of variance $\sigma_{\eta d}^2$ of η_d for is set to be −13dB respectively. The values of path-loss factors μ, μ_i and μ_x are fixed at 2.5, 2.2 and 2.1 respectively. The value of P_{rate} is kept 0.2 watt. It is clear from the graph that lesser the distance between nodes higher the data rate can be achieved. Although it can be noted that system have behaved best for case 1, i.e. less distance. Yet there are very few instances when even case 1 system has performance remained lower than case 2 this effect is observed because of instantaneous value of fading.

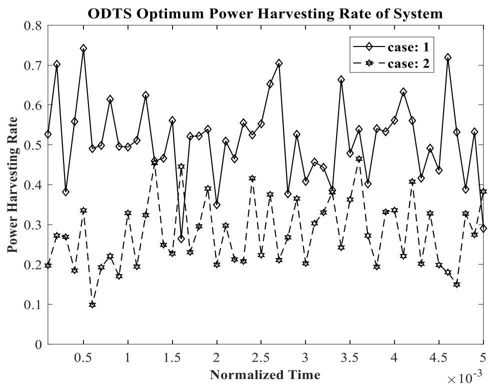

Fig. 4 ODTS optimum data rate of system with changing distances of nodes (50 instances)

In Fig. 5 effects of change in path-loss factor μ, μ_i and μ_x for optimization of data in PS architecture is analyzed. There are two conditions plotted in the graph. Value of these conditions are; in ***case* 1**: the values of path-loss factor μ, μ_i and μ_x are assumed to be 2, 2.2 and 2.1 respectively. In ***case* 2**: the values of path-loss factor μ, μ_i and μ_x are set to be 2.5, 2.6 and 2:55 respectively. Whereas the value of P_t, λ_m, λ_{mi}, λ_{mx}, ζ, σ_η^2, $\sigma_{\eta i}^2$, $\sigma_{\eta x}^2$, $\sigma_{\eta d}^2$, D, D_i, D_x, and P_{rate} are assumed to be 10dB, 4.5, [6.5, 3.5, 4.5, 6, 5], [6, 5.5, 6.5, 7.5, 7], 0.8, −12dB, [−11.5, −9.5, −10, −9.5, −11] dB, [−10.5, −9.5, −11, −9.5, −11]dB, −12.5dB, 10m, [5, 5.2, 5.8, 6.5, 6] m, [5.3, 6, 6.7, 6.3, 5.8] m and 0.2 watt, respectively. From the Fig. 5 it is observed that path-loss factor has high effect on the performance of system, when a smaller increase in the value of path-loss factor can decrease the performance of system with large ratio.

In Fig. 6 effects of changing in variance of system noises (σ_η^2 , $\sigma_{\eta i}^2$, $\sigma_{\eta x}^2$ and $\sigma_{\eta d}^2$) for optimization of power-harvesting rate in TS architecture is analyzed. There are two conditions plotted in the graph. The value of these conditions are as follows. In ***case 1:*** the values of σ_η^2, $\sigma_{\eta i}^2$, $\sigma_{\eta x}^2$ and $\sigma_{\eta d}^2$ are considered to be −12dB, [−10.9, −9.1, −10.3, −9.2, −11.3dB], [−12.1, −10.5, −9.2, −8.6, −10.2dB], and −14dB respectively. In ***case* 2:** the values σ_η^2, $\sigma_{\eta i}^2$, $\sigma_{\eta x}^2$ and $\sigma_{\eta d}^2$ are considered −8dB, [−7, −6, −6.5, −5.5, −8]dB, [−6.5, −6, −5.5, −5, −7]dB and −8dB respectively. Whereas the values of P_t, λ_m, λ_{mi}, λ_{mx}, ζ, μ, μ_i, μ_x, D, D_i, D_x and D_{rate} are considered to be 10dB, 5, [5, 7, 6.5, 6, 5.5], [6.5, 6, 5, 5.5, 7], 0.8, 2.5, 2.2, 2.1, 10m, [5.8, 5.2, 6.5, 6, 5] m, [6, 5.3, 6.7, 6.3, 5.8] m and 0.2 bits/sec/Hz, respectively. Greater value of noise in system less efficient of the system would be and our system is not an exception. In our system higher, the value of noise in our system lower the performance of system get. Best performance is noticed when system have smaller noise i.e. case 1 and as noise is increased performance of system is decreased. It can also be seen that in case 02, at some instances the system is achieving 0 power-harvesting rate. This is because at these instances signal received is unable to achieve required data rate and as our algorithm of optimizing power-harvesting rate for given data rate prioritize the achieving data rate and all the signal is used for data rate and no portion of signal was used for power harvesting. Hence resulting in zero power-harvesting rate. Moreover, in our system higher the value of noise in the system lower the performance of system gets. As noise increase in signal, data rate would decrease to achieve required data rate, therefore signal will be used for data rate for higher ratio of time resulting in less ratio of time left for power harvesting. Which results in less power harvested with increase in noise.

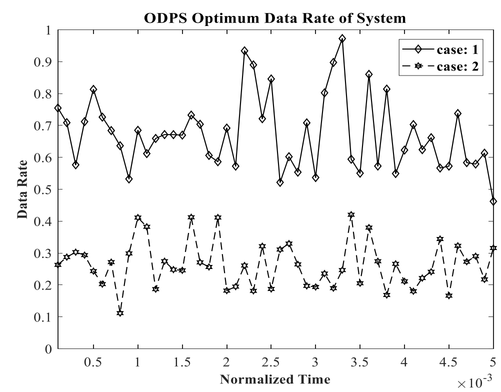

Fig. 5 ODPS optimum data rate of system with changing path-loss factor of system (50 instances)

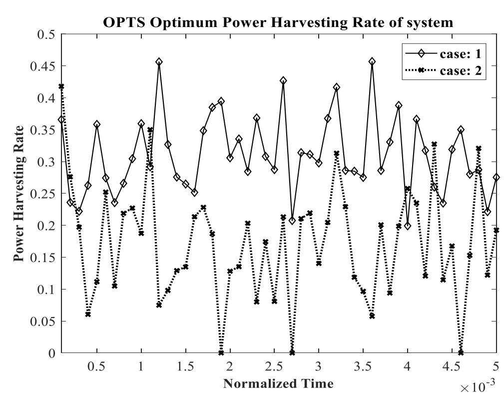

Fig. 6 OPTS optimum power-harvesting rate of system with changing noises of systems (50 instances)

In Fig. 7 effects of change of D, D_i and D_x for optimization of power-harvesting rate in TS architecture is analyzed. There are two conditions plotted in the graph. Value of these conditions are as follows. ***Case 1:*** The values of D,

D_i and D_x, are set to be 8m, [5, 4.2, 5.2, 5.4, 4.3] m and [5, 5.5, 5.8, 6, 5.1] m, respectively. In ***case 2:*** The values of D, D_i and D_x, are kept 12m, [8.5, 8.2, 8, 9.4, 8.5] m and [11.1, 9.8, 10.3, 9.3, 9] m respectively. Whereas the value of P_t, λ_m, λ_{mi}, λ_{mx}, ζ, σ_{η}^2, $\sigma_{\eta i}^2$, $\sigma_{\eta x}^2$, $\sigma_{\eta d}^2$,, μ, μ_i, μ_x and D_{rate} are assumed to be 10dB, 3.5, [5.5, 6, 4.5, 5, 6.5], [7.8, 5.5, 6, 6.3, 6.5], 0.8, −12dB, [−10, −11.2, −10.5, −11, −10.8] dB [−9, −9.2, −10.5, −10.2, −9.5] dB, −13dB, 2.5, 2.2, 2.1 and 0.2 bits/sec/Hz. It is clear from the graph that lesser the distance between nodes higher the power-harvesting rate can be achieved.

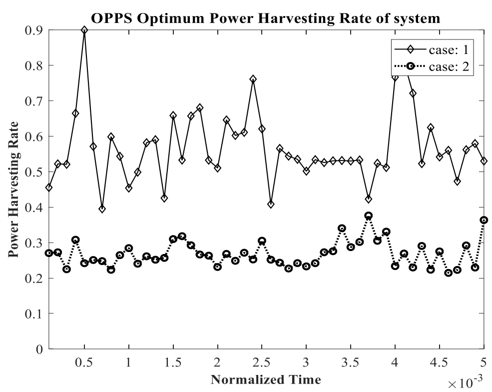

Fig. 7 OPPS optimum power-harvesting rate of system with changing distances of nodes (50 instances)

6. Conclusion

We have investigated the SWIPT based relaying network with one intermediate relay node. The destination was enabled for power harvesting and relays followed amplify-and-forward protocol, as for this protocol relay does not need to have information about coding algorithm of system. Relay node can independently receive signal amplify it and re-transmit the signal for destination. We have considered two architectures for relaying, namely time switching (TS) and power splitting (PS) architectures. In this paper, our focus was to select the optimal relay. For selection of relay we investigated the two problems; optimizing data rate for given power-harvesting rate and optimizing power-harvesting rate for given data rate. We have studied both problems for TS and PS architectures individually and equation for the optimum conditions were presented. For simulation, we have considered the five relays in system and found that the change in distance and path-loss factor counted for higher change in performance of system. Whereas system noises also affected the performance of system but their effect were comparatively smaller as compared to effect of changes in distance and path-loss factors. As our system can have any number of relays and system is flexible to switch the connected relay for better performance and due to switching to relays a better performance is observed.

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