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User selection protocol in DF cooperative networks with hybrid TSR-PSR protocol based full-duplex energy harvesting over rayleigh fading channel: system performance analysis

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ABSTRACT

Cooperative communication has been recently proposed in wireless communication systems for exploring the inherent spatial diversity in relay channels. In this work, we investigate the system performance of the energy harvesting full-duplex (FD) decode-and-forward (DF) hybrid time switching-power splitting relaying TSR-PSR (TPSR) protocol relaying network. In the selection scheme, the best user selection protocol is proposed and investigated. Mainly we derive the closed-form expression for the outage probability, system throughput and the symbol error rate (SER) of the system. Numerical results are also presented by the Monte Carlo simulation to validate the theoretical analysis in connection with the all possible parameters in the comparison between TSPR, TSR and PSR cases. The research results show that TPSR case is better than the others in term of outage probability and SER.

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1. INTRODUCTION

In recent years, the wireless transmission has experienced rapid development. Relaying has been proved to be an efficient way to extend the coverage area of wireless networks and increase transmission reliability without additional transmit power at the transmitters. However, the forwarding operations at the relay still require extra energy. For relay nodes powered by power limited batteries instead of the regular power grid, such as mobile devices, such extra energy consumption may cause serious concerns. Recently, harvesting energy from ambient radio-frequency (RF) energy was proposed, and it has been well studied. The idea that receiving information and harvesting energy simultaneously is not only appealing but also worth further investigating. The recent works suggested that data transmitting and battery charging could be fulfilled at the same time, and therefore, the combining of energy harvesting module and relay could be an available solution of extra energy consumption problem at the relay [1-6].

Recently, deploying energy harvesting (EH) relays that utilize the energy collected from the source signal for data transfer has received considerable attention. With EH capabilities, relays can be installed conveniently without wiring cost and the need for battery replacement. Besides, substantial transmission power can be saved because the inter-node distance is shortened using multihop transmissions. However, information relaying consumes additional resources (i.e., time and bandwidth) compared to the direct transmission and hence some early work has been conducted focusing on assessing the feasibility of EH relays. The gain offered by the EH relay based on time switching relaying (TSR) is analyzed theoretically in [7] for both decode-and-forward (DF) and amplify-and-forward (AF) relaying approaches with a significant gain. The EH relay based on DF is also considered in [8], where the relay determines whether to perform EH or information relaying before the source transmission according to a greedy policy. On the other hand, an analytical framework is proposed in [9] to evaluate the performance of the EH relay based on AF for both TSR and power splitting relaying (PSR)under the effect of the critical system parameters such as noise variances, source to relay distance, transmission rate, and energy conversion efficiency. Moreover, relay selection (RS) is a practical approach to balance the tradeoff between reliability improvement and spectral efficiency loss due to information repetition [10]. In [11], two RS schemes aiming to attain the optimal tradeoff between energy transfer and outage probability/ergodic capacity for DF relays are studied.

In this work, we propose and investigate the system performance of the energy harvesting full-duplex (FD) decode-and-forward (DF) hybrid TSR-PSR protocol relaying network. For details on this analysis, the energy, and information are transferred from the source to the relay nodes, and all channels are considered as the Rayleigh fading channels. The main contributions of the paper are summarized as follows:

1. The system model of the energy harvesting full-duplex (FD) decode-and-forward (DF) hybrid TSR-PSR protocol relaying network over the Rayleigh fading channels and the comparison between hybrid TSR-PSR (TPSR), TSR and PSR cases are proposed and investigated.
2. The closed-form expressions of the outage probability and the system throughput are derived. Moreover, the best user selection protocol is proposed and investigated.
3. The symbol Error Ratio (SER) analysis of the proposed model system is presented and demonstrated.
4. The influence of the main parameters on the system performance is demonstrated entirely by the Monte Carlo simulation.

The structure of this paper is proposed as follows. Sections II presents the system model of the relaying network. Sections III derives the system performance of the model system. Section IV provides the numerical results and some discussions. Finally, Section V concludes the paper.

2. SYSTEM MODEL

In this paper, the system model is the energy harvesting full-duplex (FD) decode-and-forward (DF) hybrid TSR-PSR protocol relaying network as shown in Figure 1. In this model, the information is transferred from the source (S) to the multi-destination (D_i), through energy constrained intermediate relay (R). The energy harvesting and information processing of the system model with hybrid TSR-PSR protocol are proposed in Figure 2. In this scheme, T is the block time in which the source fully transmits the information data to the multi-destination. In the first interval time (αT), the relay harvests energy from the source signal, where α is the time switching factor α ∈ (0, 1). In the remaining interval time (1-α)T, the relay node harvests ρP_s energy from the source and use $(1-\rho)P_s$ energy to transfer information to the multi-destination nodes, which ρ is the power splitting factor ρ ∈ (0, 1). All the fading channels from S to R and R to D are proposed as the Rayleigh fading channels. More details of the analytical mathematical model of the outage probability and throughput of the system model is presented and analyzed in the following sections [12-16]. If α = 0, this scheme becomes PSP. If ρ = 0 then it becomes the TSP protocol.

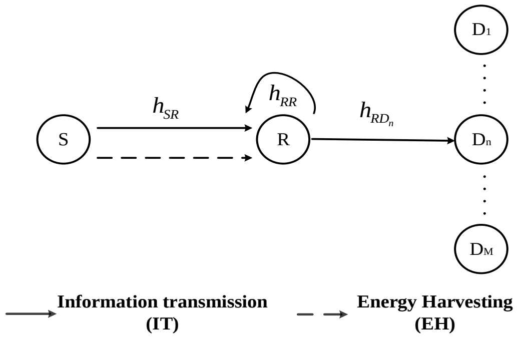

Figure 1. System model

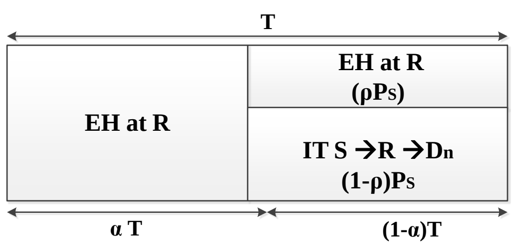

Figure 2. The power splitting protocol

3. THE SYSTEM PERFORMANCE

In this section, we analyzed and demonstrated the system performance analysis of the model system [12-14].

3.1. Energy harvesting phase

In the first interval, the average transmitted power at the relay can be calculated as:

$$P_{r1} = \frac{E_1}{(1-\alpha)T} = \frac{\eta\alpha T P_s |h_{SR}|^2}{(1-\alpha)T} = \frac{\eta\alpha}{1-\alpha} P_s |h_{SR}|^2 \tag{1}$$

where $0 < \eta \le 1$ is energy conversion efficiency, $0 \le \alpha < 1$ is time switching factor, P_s is the transmitted power at source, h_{SR} is the source to relay channel gain, respectively.

In the second interval, once again average transmitted power at the relay can be given as:

$$P_{r2} = \frac{E_2}{(1-\alpha)T} = \frac{\eta\rho(1-\alpha)T P_s |h_{SR}|^2}{(1-\alpha)T} = \eta\rho P_s |h_{SR}|^2 \tag{2}$$

where $0 \le \rho < 1$ is the power splitting factor.

Finally, the amount of average transmitted power at the relay can be obtained as:

$$P_r = P_{r1} + P_{r2} = \kappa P_s |h_{SR}|^2 \tag{3}$$

where we denote $\kappa = \eta\rho + \frac{\eta\alpha}{1-\alpha}$.

3.2. Transmission phase

The received signal at the relay can be expressed as:

$$y_r = \sqrt{1-\rho} h_{SR} x_s + h_{RR} x_r + n_r \tag{4}$$

where we denote $\mathrm{E}\left\{|x_s|^2\right\} = P_s$, $\mathrm{E}\left\{|x_r|^2\right\} = P_r$, $\mathrm{E}\{\bullet\}$ is expectation operator, h_{RR} is loopback interference channel, and n_r is the additive white Gaussian noise (AWGN) with variance N_0.

The received signal at the n^{rd} destination can be formulated as:

$$y_{d_n} = h_{RD_n} x_r + n_{d_n} \tag{5}$$

where h_{RDn} is the relay to the n^{rd} destination channel gain, n_{dn} is the additive white Gaussian noise (AWGN) with variance N_0, and $n \in (1, 2, ..., M)$.

In this model, we consider decode and forward protocol (DF). From (4), the signal to noise ratio (SNR) at the relay can be calculated as

$$\gamma_1 = \frac{(1-\rho)|h_{SR}|^2 P_s}{|h_{RR}|^2 P_r + N_0} \tag{6}$$

Substituting (3) into (4) and using the fact that $N_0 << P_s$, we have

$$\gamma_1 = \frac{(1-\rho)|h_{SR}|^2 P_s}{\kappa P_s |h_{SR}|^2 |h_{RR}|^2 + N_0} \approx \frac{(1-\rho)}{\kappa |h_{RR}|^2} \tag{7}$$

From (5) and substituting (3), the SNR at the destination can be calculated as;

$$\gamma_2 = \frac{P_r \left|h_{RD_n}\right|^2}{N_0} = \frac{\kappa P_s \left|h_{SR}\right|^2 \left|h_{RD_n}\right|^2}{N_0} \tag{8}$$

Finally, the end to end SNR of the proposed system can be obtain as:

$$\gamma_{e2e} = \min\left(\gamma_1, \gamma_2\right) \tag{9}$$

In this analysis, please note that all of the channel belong to Rayleigh fading channels.

Remark 1: **The best user selection protocol.**

From (9), we propose the optimal user selection protocol in which the best selection user is selected as follows:

$$\omega_2 = \max_{n=1,2,\ldots,M} (\left|h_{RD_n}\right|^2) \tag{10}$$

In [17], the Cumulative Distribution Function (CDF) of ω_2 can be given by the following

$$F_{\omega_2}(y) = \sum_{p=0}^{M} (-1)^p C_M^p \times e^{-py/\lambda_2} \tag{11}$$

where λ_2 is the mean of RV ω_2, and $C_M^p = \dfrac{M!}{p!(M-p)!}$.

Then, the corresponding Probability Density Function (PDF) can be obtained by the following

$$f_{\omega_2}(y) = \frac{1}{\lambda_2} \sum_{p=0}^{M-1} \left(-1\right)^p C_{M-1}^p M \times e^{-(p+1)y/\lambda_2} \tag{12}$$

Remark 2: **Outage probability (OP).**

From (9), the OP of DF system can be expressed as:

$$\begin{aligned} OP &= \Pr\left(\gamma_{e2e} < \gamma_{th}\right) = \Pr\left[\min\left(\gamma_1, \gamma_2\right) < \gamma_{th}\right] \\ &= \Pr\left[\min\left(\frac{(1-\rho)}{\kappa\left|h_{RR}\right|^2}, \frac{\kappa P_s \left|h_{SR}\right|^2 \max\limits_{1\le n\le M}\left|h_{RD_n}\right|^2}{N_0}\right) < \gamma_{th}\right] \\ &= \Pr\left[\min\left(\frac{(1-\rho)}{\kappa\omega}, \kappa\gamma_0\omega_1\omega_2\right) < \gamma_{th}\right] \end{aligned} \tag{13}$$

where we denote $\omega = \left|h_{RR}\right|^2, \omega_1 = \left|h_{SR}\right|^2, \omega_2 = \max\limits_{1\le n\le M}\left|h_{RD_n}\right|^2, \gamma_0 = \dfrac{P_s}{N_0}, \gamma_{th} = 2^{2R} - 1$, and R is the source rate.

From (13), the OP can be rewritten as the following

$$OP = 1 - \Pr\left[\frac{(1-\rho)}{\kappa\omega} \ge \gamma_{th}\right] \Pr\left(\kappa\gamma_0\omega_1\omega_2 \ge \gamma_{th}\right) \tag{14}$$

In (14), we denote

$$I_1 = \Pr\left[\frac{(1-\rho)}{\kappa\omega} \ge \gamma_{th}\right] = \Pr\left[\omega \le \frac{(1-\rho)}{\kappa\gamma_{th}}\right] = 1 - e^{-\frac{(1-\rho)}{\kappa\gamma_{th}\lambda}} \tag{15}$$

where λ is the mean of RV ω. And

$$I_2 = \Pr\left(\kappa\gamma_0\omega_1\omega_2 \ge \gamma_{th}\right) = 1 - \Pr\left(\omega_1 < \frac{\gamma_{th}}{\kappa\gamma_0\omega_2}\right) = 1 - \int_0^\infty F_{\omega_1}\left(\frac{\gamma_{th}}{\kappa\gamma_0\omega_2} \mid \omega_2\right) f_{\omega_2}(\omega_2)d\omega_2 \quad (16)$$

Substituting (12) into (16), we have

$$\begin{aligned} I_2 &= \frac{1}{\lambda_2}\int_0^\infty \sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M \times e^{-(p+1)\omega_2/\lambda_2} \times e^{-\frac{\gamma_{th}}{\kappa\gamma_0\omega_2\lambda_1}} d\omega_2 \\ &= \sum_{p=0}^{M-1}\frac{(-1)^p C_{M-1}^p M}{\lambda_2}\int_0^\infty e^{-\frac{\gamma_{th}}{\kappa\gamma_0\omega_2\lambda_1}} \times e^{-(p+1)\omega_2/\lambda_2} d\omega_2 \end{aligned} \quad (17)$$

where λ_1 is the mean of RV ω_1.

Applying table of integral eq (3.324,1) in [18], the (17) can be reformulated as

$$I_2 = 2\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M \sqrt{\frac{\gamma_{th}}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}} \times K_1\left(2\sqrt{\frac{\gamma_{th}(p+1)}{\kappa\gamma_0\lambda_1\lambda_2}}\right) \quad (18)$$

where $K_v(\bullet)$ is the modified Bessel function of the second kind and v[th] order.

Substituting (16), (18) into (14), OP can be calculated as

$$\begin{aligned} OP &= 1 - \left(1 - e^{-\frac{(1-\rho)}{\kappa\gamma_{th}\lambda}}\right)\left\{2\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M \sqrt{\frac{\gamma_{th}}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}} \times K_1\left(2\sqrt{\frac{\gamma_{th}(p+1)}{\kappa\gamma_0\lambda_1\lambda_2}}\right)\right\} \\ &= 1 - 2\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M \sqrt{\frac{\gamma_{th}}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}} \times K_1\left(2\sqrt{\frac{\gamma_{th}(p+1)}{\kappa\gamma_0\lambda_1\lambda_2}}\right) \\ &+ 2\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M \times e^{-\frac{(1-\rho)}{\kappa\gamma_{th}\lambda}} \times \sqrt{\frac{\gamma_{th}}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}} \times K_1\left(2\sqrt{\frac{\gamma_{th}(p+1)}{\kappa\gamma_0\lambda_1\lambda_2}}\right) \end{aligned} \quad (19)$$

Remark 3: **Throughput.**

$$\tau = (1-OP)\frac{R(1-\alpha)T}{T} = (1-OP)R(1-\alpha) \quad (20)$$

Remark 4: **The symbol Error Ratio (SER) analysis**

In this section, we obtain new expressions for the symbol Error Ratio (SER) at the destination. We first consider the outage probability, which was obtained in [19,21]. Thus, we have

$$SER = \mathrm{E}\left[\phi Q(\sqrt{2\theta\gamma_{e2e}}\right] \quad (21)$$

$Q(t) = \frac{1}{\sqrt{2\pi}}\int_t^\infty e^{-x^2/2}dx$ is the Gaussian Q-function, ω and θ are constants which is specific for modulation type. $(\phi,\theta) = (1,1)$ for BPSK and $(\phi,\theta) = (1,2)$ for QPSK. As a result, before obtaining the SER performance, the distribution function of γ_{e2e} is expected. Then, we begin rewriting the SER expression given in (21) directly in terms of outage probability at the source by using integration, as follows

$$SER = \frac{\phi\sqrt{\theta}}{2\sqrt{\pi}}\int_0^\infty \frac{e^{-\theta x}}{\sqrt{x}} F_{\gamma_{e2e}}(x)dx \quad (22)$$

Substituting (19) into (22) and replace $\gamma_{th} = x$, we have:

$$SER = \frac{\phi\sqrt{\theta}}{2\sqrt{\pi}}\int_0^\infty \frac{e^{-\theta x}}{\sqrt{x}}\left\{\begin{array}{l} 1-2\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M\sqrt{\frac{x}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}}\times K_1\left(2\sqrt{\frac{x(p+1)}{\kappa\gamma_0\lambda_1\lambda_2}}\right) \\ +2\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M\times e^{-\frac{(1-\rho)}{\kappa x\lambda}}\times\sqrt{\frac{x}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}}\times K_1\left(2\sqrt{\frac{x(p+1)}{\kappa\gamma_0\lambda_1\lambda_2}}\right)\end{array}\right\}dx$$

$$= \frac{\phi\sqrt{\theta}}{2\sqrt{\pi}}\int_0^\infty \frac{e^{-\theta x}}{\sqrt{x}}dx - \frac{\phi\sqrt{\theta}}{\sqrt{\pi}}\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M\sqrt{\frac{1}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}}\int_0^\infty e^{-\theta x}\times K_1\left(2\sqrt{\frac{(p+1)x}{\kappa\gamma_0\lambda_1\lambda_2}}\right)dx \quad (23)$$

$$+\frac{\phi\sqrt{\theta}}{\sqrt{\pi}}\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M\sqrt{\frac{1}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}}\int_0^\infty e^{-\theta x}e^{-\frac{(1-\rho)}{\kappa x\lambda}}\times K_1\left(2\sqrt{\frac{(p+1)x}{\kappa\gamma_0\lambda_1\lambda_2}}\right)dx$$

Here we denote that

$$J_1 = \frac{\phi\sqrt{\theta}}{2\sqrt{\pi}}\int_0^\infty \frac{e^{-\theta x}}{\sqrt{x}}dx \quad (24)$$

Applying table of integral eq(3.361,2) in [18]

We have $J_1 = \frac{\phi}{2}$ and we denote J_2 as following

$$J_2 = \frac{\phi\sqrt{\theta}}{\sqrt{\pi}}\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M\sqrt{\frac{1}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}}\int_0^\infty e^{-\theta x}\times K_1\left(2\sqrt{\frac{(p+1)x}{\kappa\gamma_0\lambda_1\lambda_2}}\right)dx \quad (25)$$

Applying table of integral eq(6.614,5) in [18], we have

$$J_2 = \frac{\phi}{4\theta}\sum_{p=0}^{M-1}(-1)^p C_M^p \frac{M}{\kappa\gamma_0\lambda_1\lambda_2}\times e^{-\frac{p+1}{2\kappa\gamma_0\lambda_1\lambda_2\theta}}\left[K_1\left(\frac{p+1}{2\kappa\gamma_0\lambda_1\lambda_2\theta}\right)-K_0\left(\frac{p+1}{2\kappa\gamma_0\lambda_1\lambda_2\theta}\right)\right] \quad (26)$$

$$J_3 = \frac{\phi\sqrt{\theta}}{\sqrt{\pi}}\sum_{p=0}^{M-1}(-1)^p C_{M-1}^p M\sqrt{\frac{1}{\kappa\gamma_0\lambda_1\lambda_2(p+1)}}\int_0^\infty e^{-\theta x}e^{-\frac{(1-\rho)}{\kappa x\lambda}}\times K_1\left(2\sqrt{\frac{(p+1)x}{\kappa\gamma_0\lambda_1\lambda_2}}\right)dx \quad (27)$$

Finally, SER of the system model can be calculated as

$$SER = J_1 - J_2 + J_3 \quad (28)$$

4. NUMERICAL RESULTS AND DISCUSSION

In this section, the Monte Carlo simulation is used for validating the analytical expression in the above section. We consider a network with one source, one relay, and multi-destination, where source-relay and relay-destination distances are both normalized to unit value. Moreover, we investigate and compare TSR, PSR and TPSR cases in the connection of all possible system parameters.

The effect of η on the outage probability and system throughput of the proposed relay network system in the comparison between TSR, PSR, TPSR cases are shown in Figure 3 and 4. In these Figures, we set the main system parameters as P_s/N_0= 10 dB, R=0.5 bps, and M=2. From the results, the analytical and the simulation results match for all possible values P_s/N_0. Figure 3 shows that the outage probability has a considerable decrease while η increases from 0 to 1. On another hand, system throughput significantly increases in connection with increasing of η from 0 to 1. The research results show that the outage probability and the system throughput have the better value in the TPSR case in comparison with the others cases.

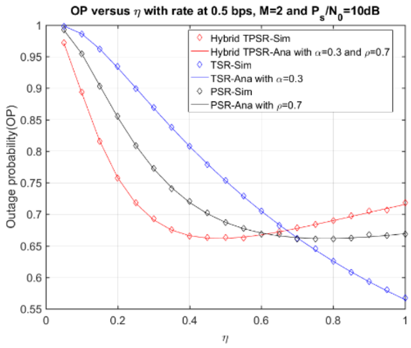

Figure 3. Outage probability versus η

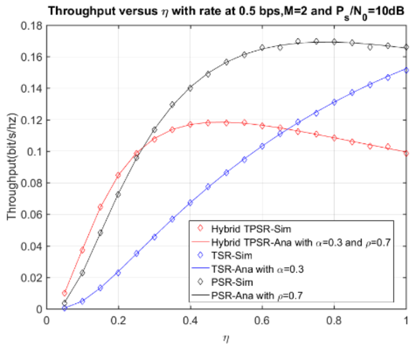

Figure 4. Throughput versus η

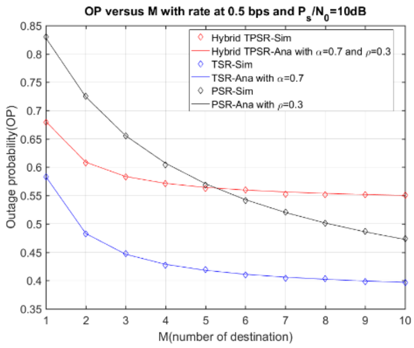

Figure 5. Outage probability versus M

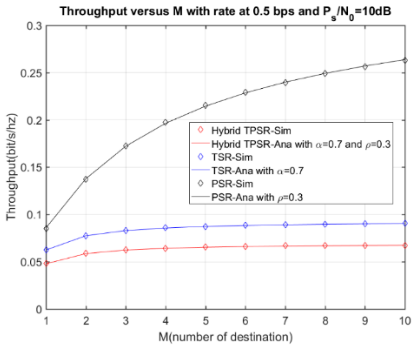

Figure 6. Throughput versus M

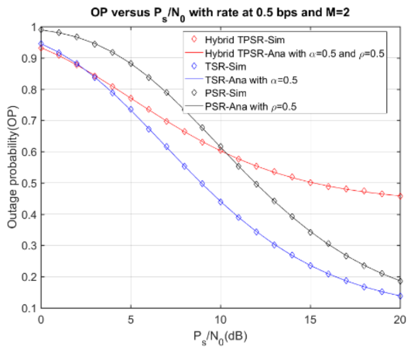

Figure 7. Outage probability versus P_s/N_0

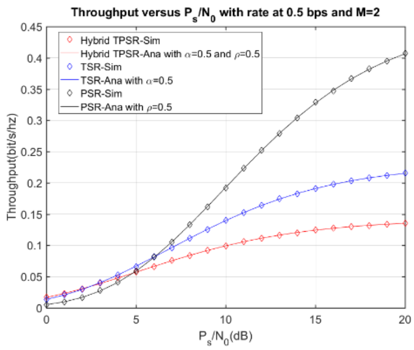

Figure 8. Throughput versus P_s/N_0

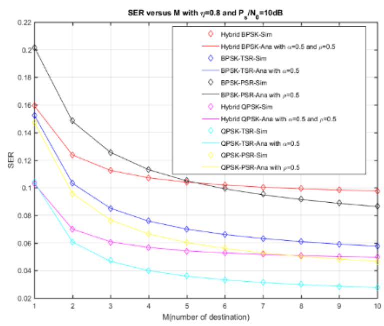

Figure 9. Comparison SER versus M

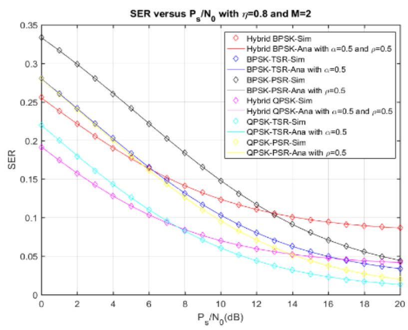

Figure 10. Comparison SER versus P_s/N_0

Finally, Figures 9 and 10 plot the effect of M and P_s/N_0 on SER in the comparison between TSR, PSR, TSPR cases with the main parameters of P_s/N_0=10, η=0.8, and M=2. The SER decreases while M and P_s/N_0 increases from 1 to 10 and 0 to 20, respectively. The results show that all simulation and analytical results are matched well with each other. Moreover, SER in case TSPR is better than the remaining cases.

Furthermore, the outage probability and system throughput of the proposed system versus M are illustrated in the Figure 5 and 6 with P_s/N_0=10 dB and R=0.5 bps. From the results, we show that the outage probability increases and the system throughput decrease remarkably with increasing M from 0 to 10. On the same way, the outage probability and the system throughput versus P_s/N_0 with R=0.5 bps and M=2 as shown in Figures. 7 and 8. All the analytical and simulation results agree well with each other.

5. CONCLUSION

In this work, we investigate the system performance of the energy harvesting full-duplex (FD) decode-and-forward (DF) hybrid TSR-PSR protocol relaying network. In the selection scheme, the best user selection protocol is proposed and investigated. Mainly we derive the closed-form expression for the outage probability, system throughput and the symbol error rate (SER) of the system. Numerical results are also presented by the Monter Carlo simulation to validate the theoretical analysis in connection with the all possible parameters in the comparison between TPSR, TSR and PSR cases. The research results show that TPSR case is better than the others in term of outage probability and SER. This paper provides the novel recommendation for the communication relaying network in the near future.

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