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Outage Probability Performance of Hybrid Time-Power Splitting Relaying Protocol with Interferers Presence

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Abstract: *Combining simultaneous wireless information and power transfer with full-duplex communication at the energy-constrained relay terminal is a practical way of improving the lifespan and data rates performance of cooperative wireless networks. However, employing the two most common radio frequency energy harvesting protocols namely: time-switching and power splitting in full duplex mode is limited in outage probability performance for 5G network and beyond. The deployment of hybrid time-power splitting relaying protocol in full-duplex mode with decodes and forward relaying is a promising solution to energy-constrained relay devices. This paper analyses the outage probability of a decode and forward, full-duplex hybrid time-power splitting relaying protocol over Rayleigh fading channel with interfering signals considered at the destination. A mathematical expression for the proposed protocol's outage probability is derived, and simulation is performed in MATLAB. The simulations explore the impact of system parameters on outage probability, demonstrating the proposed protocol's advantage over the full-duplex power splitting relaying protocol. The result obtained showed that the proposed decode and forward, full-duplex hybrid time-power splitting relaying protocol outperformed the full-duplex power splitting relaying protocol by 8.89% and 50% at signal to noise ratio of 10dB and 25dB, respectively with maximum number of interferes.*

Keywords: *Outage Probability, SWIPT, HTPSR, Full Duplex, Decode and Forward*

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1. INTRODUCTION

Recently, wireless communication research community has witnessed the improvement of relaying techniques to fulfil the ever-increasing data rate and ever-changing dynamic wireless environment due to human activities. This ever-changing activity hinders the seamless connection of energy-constrained wireless devices limiting their high data rates, increasing the data transfer delay (latency) and high energy consumption because of multipath fading. These effects become crucial in the 5G and beyond technology as mobile devices, and the Internet of Things (IoT) continue to proliferate exponentially with emerging technologies daily [1-2].

Cooperative communication is a solution to these problems most especially in infrequently serviced situations such as in areas affected by disaster, war zones etc, where limited network connectivity, is prone due to the insufficiency of standard infrastructure deployment [3]. The recharging or replenishment of these energy-constrained wireless devices becomes necessary as the lifespan of the network is jeopardized [4-5].

Cooperative communication protocol is employed to address the problem by using the broadcast nature of wireless transmission to overcome the fading problem by increasing the diversity gain [6]. The utilization of relays as an alternate channel between the transmitter and receiver, quality of service is improved with reduced energy expenditure, prolongs the life of the battery, wide coverage range and prevents interference with optimal power allocation [7-8]. The Decode and Forward (DF) protocol and Amplify and Forward (AF) protocol, are two main protocols in cooperative networks.

The DF relaying is used in digital communication applications. This occurs because the relay must successfully decode the incoming signal before retransmitting it to the destination. Though, this relaying shows superiority over AF relaying used in analogue communication applications owing to its better performance. However, additional implementation complexity is required because of sophisticated signal processing, demodulation and decoding which increases its deployment cost [9].

In recent years, Full-Duplex (FD) relaying has received research interest because of its undeniable advantages over the Half-Duplex (HD) mode by exploiting the efficient usage of the scarce frequency spectrum. This is due to its ability to allow simultaneous reception and forwarding of decoded signal at the relay node which enhances the spectral efficiency with small self-interference [10-12]. One of the most significant advantages of this capability is in its high throughput performance within the same bandwidth. In contrast, it presents problems such as additional processing power, which depletes the battery life and self-interference resulting in deterioration of the outage performance.

Apart from the self-interference at the relay, other surrounding terminal at the vicinity of the destination can also impact the outage performance of the cooperative network. While conventional cooperative relaying networks rely on the constrained-energy battery of the relay terminal resulting in shortened lifespan of the network, however, Simultaneous Wireless Information and Power Transfer (SWIPT) enabled network has been adjudged a long-lasting and eco-friendly solution which reduces the carbon footprint and improves energy efficiency of wireless devices [5], [13].

SWIPT enabled network can be categorized into three, Time Switching Relaying (TSR), Power Splitting Relaying (PSR) and Hybrid Time-Power Splitting Relaying (HTPSR) [4],[14]. While TSR alternates between energy harvesting and information decoding by dividing the available time, PSR divides the received power between energy harvesting and information decoding. Research findings [1], [14-15] have shown that the PSR protocol offers higher capacity at high Signal-to-Noise Ratios (SNRs). Conversely, the TSR protocol is more suitable for achieving a balance between capacity and hardware complexity, especially at lower SNRs or when targeting high data rates.

On the other hand, HTPSR, which combines both protocols, shows higher capacity performance in contrast to the conventional protocols [16]. In densely deployed networks, co-channel interference arising from the concurrent transmission of multiple users in the same frequency band remains an impediment to the performance of wireless networks. One of the vulnerabilities of wireless networks is interference and this degrades the network performance. This becomes a serious problem in cooperative networks most especially when interferers impact the destinations' received signal resulting in the outage performance of the network. Some of the research that falls into these scenarios are as discussed.

Rabie *et al*. [17] compared the performance of HD and FD AF and DF relaying with Energy Harvesting (EH) in Log-normal fading channels. The paper analysed the performance of two-hop relaying networks with EH over indoor channels characteristics. The system performance was evaluated using ergodic outage probability. The paper demonstrated that FD relaying systems typically perform better than HD systems, as long as the self-interference in the FD system is kept reasonably low.

Sheng *et al*. [18] examined how a hybrid protocol performs in AF EH relaying systems operating over channels with different fading characteristics. Two distinct fading channels namely Rician and Rayleigh fading channels were used at the source-relay and relay-destination, respectively. The outage probability of the lower bound and higher bound outage capacity was derived, and the system was evaluated using system network parameters. However, the protocol suffers performance limitation due to the amplification of the noise alongside the received signal at the relay terminal. In addition, the network is limited in bandwidth efficiency because of the operation of the relay in HD mode.

Tin *et al*. [11] investigated the effect of interference at the destination as it affects the performance of a DF, FD PSR network by analysing the outage probability. The paper derived closed form expression of the outage probability and showed its effect on the system performance. However, the protocol suffers from efficient and optimal allocation of power and EH factors that improves the system performance.

In the work of Chowdhury *et al*. [19], the analysis and optimization of a HD hybrid TSR-PSR protocol for relaying techniques over Weibull fading environment was performed. The work investigated a generalised Radio Frequency (RF) EH model for the hybrid protocol in HD mode through the derivation of closed form expression for outage performance analysis with a single interferer on the relay and destination sides. However, the reception and forwarding of the decoded signal was performed in different time slots and consumes more network resources making the performance of the network inefficient.

Babaei *et al*. [20] worked on the performance analysis of dual-hop AF relaying by comparing the difference between the realistic non-linear EH model and the conventional linear EH model in HD mode. The outage probability, bit error and throughput performance were analysed. The result shows that at low levels of harvested energy, both models behave similarly and provide realistic results. The work did not consider the impact of the relay operating in FD mode and the effect of interfering terminals on the performance of the network.

Vo *et al.* [21] analysed the performance optimization for hybrid TS/PS SWIPT unmanned aerial vehicle relaying in HD cooperative non-orthogonal multiple access IoT networks. The closed form expression of the outage probability of the network performance was derived. The Bat Algorithm optimization method was employed to determine the optimal working point for the network performance. The paper does not take into consideration the advantages of simultaneously receiving and forwarding the decoded signal to improve the performance of the network in terms of spectral efficiency and the effect of co-channel interference on the received signal at the destination.

It is evident that the reviewed papers have considered the outage performance analysis of the conventional TSR and PSR SWIPT enabled network in HD mode. These works suffer from spectral efficiency and optimal allocation of power and EH ratios. More so, only few works on HTPSR protocol in FD mode has received research interest. Therefore, the contributions of this paper are drawn.

- A FD HTPSR relaying using DF protocol with co-channel interference at the destination was proposed for a cooperative network.
- The outage probability closed form expression of the proposed FD HTPSR protocol was derived.
- The proposed protocol was evaluated and compared with FD PSR relaying protocol.

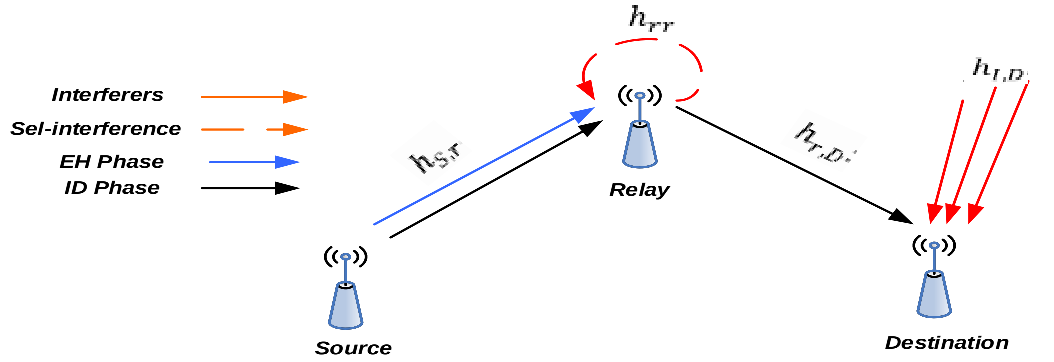
The paper organization is as follows. Section II provides the system model and wireless energy harvesting mechanism of the proposed protocol while in Section III the outage probability analysis was performed. In Section IV, the results and discussion are presented, and Section V draws the conclusion.

2. SYSTEM MODEL AND WIRELESS ENERGY HARVESTING MECHANISM OF HTPSR PROTOCOL

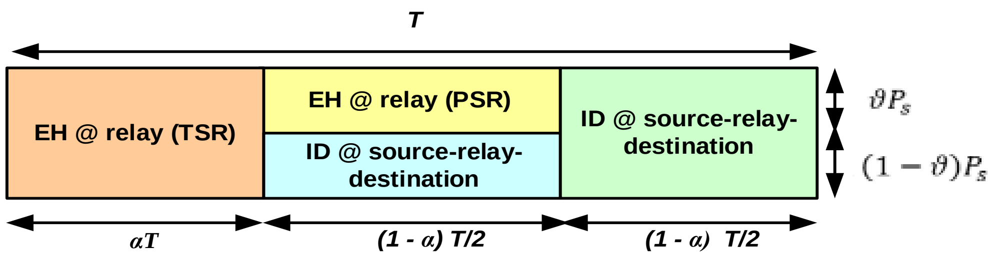
2.1 System Model

The system model and the proposed HTPSR frame are depicted in Figure 1. The system model comprises an energy unconstrained source S and destination D, with the relay been energy-constrained due to its limited battery capability. All the terminals are equipped with a single omnidirectional antenna with the relay operating in FD mode. The channel between the terminals is modelled to be identically independent distributed (iid) Rayleigh fading with severely deep fading experienced in the source-destination path. The relay terminal experiences self-interference, and the destination is being interfered by multiple surrounding terminals L in its vicinity because they share the same channel.

The frame structure of the proposed protocol with block length T is divided into three different portions. The first portion αT is used for EH using TSR while the remaining $(1-\alpha)T$ is further divided into two equal parts and the TSR factor is defined as $\alpha \in (0,1)$. The second portion is divided into two sub-portions with the first sub-portion $(1-\alpha)T/2$ further divided into ϑP_s for EH using PSR, where P_s is the transmitting power from the source and the second sub-portion $(1-\vartheta)P_s$ is used for information decoding (ID) at the relaying and onward retransmission to the destination with the PSR factor defined as $\vartheta \in (0,1)$. The last portion of the frame structure is for source-destination transmission via the energy-constrained relay terminal.



(a)



(b)

Figure 1: (a) System model (b) FD HTPSR protocol frame structure

2.2 Wireless Energy Harvesting Mechanism of HTPSR Protocol

Equations (1) and (2) are expressions of the signals received at the relay $'y_r'$ and destination $'y_D'$, respectively, given according to [11] as,

$$y_r = h_{S,r}x_S + h_{rr} + n_r \tag{1}$$

$$y_D = h_{r,D}x_r + \sum_{i=1}^{L} h_{I,D}x_I + n_D \tag{2}$$

where $h_{S,r}$ is the source-relay link channel gain, h_{rr} is the self-interference signal at the relay, $h_{r,D}$ is the relay-destination link channel gain, $h_{I,D}$ is the interferer channel gain, n_r and n_D are the noise at the relay and destination, respectively, x_S, x_r and x_I are the messages at the source, relay and interfering terminals, respectively. The total energy harvested at the relay terminal $'E_T'$ is given as [4],

$$E_T = E_{PSR} + E_{TSR} \tag{3}$$

where E_{PSR} and E_{TSR} are the energy harvested due to PSR and TSR structure. Equation (3) is further simplified as,

$$E_T = \eta P_S \left|h_{S,r}\right|^2 \alpha T + \eta \vartheta P_S \left|h_{S,r}\right|^2 \frac{(1-\alpha)T}{2} = \eta P_S \left|h_{S,r}\right|^2 T \left(\frac{1+\alpha(2-\vartheta)}{2}\right) \tag{4}$$

where $\eta \in (0,1)$ is the coefficient of energy conversion, P_S is the transmitting power at the source, α and ϑ are the TSR and PSR ratios, respectively. Consequently, the harvested energy at the relaying terminal used for transmitting decoded packet has its power written as

$$P_r = \frac{E_T}{{}^{(1-\alpha)T}/_2 + {}^{(1-\alpha)T}/_2} = P_S \left|h_{S,r}\right|^2 \beta \tag{5}$$

where $\beta = \eta \frac{1-\alpha(2-\vartheta)}{2(1-\alpha)}$.

Subsequently, the instantaneous received SNR at the relay with DF relaying according to Equation (1) is written as

$$\gamma_r = \frac{P_S |h_{S,r}|^2}{P_r |h_{r,r}|^2 + N_o} = \frac{P_S |h_{S,r}|^2}{\beta P_S |h_{S,r}|^2 |h_{r,r}|^2 + N_o} \tag{6}$$

where N_o is the noise power which is the same for all channel links. Equation (6) can further be approximated as [11]

$$\gamma_r \approx \frac{1}{\beta |h_{r,r}|^2} \approx \frac{2(1-\alpha)}{\eta(1-\alpha(2-\vartheta))|h_{r,r}|^2} \tag{7}$$

and the instantaneous received SNR at the destination is written in Equation (8) as

$$\gamma_D = \frac{P_r |h_{r,D}|^2}{\sum_{i=1}^{L} P_I [h_{I,D}]^2 + N_o} = \frac{\beta P_S |h_{S,r}|^2 |h_{r,D}|^2}{\sum_{i=1}^{L} P_I [h_{I,D}]^2 + N_o} \tag{8}$$

Equation (8) can be further simplified by dividing both the numerator and denominator by N_o is written as

$$\gamma_D = \frac{\beta \delta |h_{S,r}|^2 |h_{r,D}|^2}{1 + \sum_{i=1}^{L} \mu [h_{I,D}]^2} = \frac{\beta \delta Y}{1 + \mu Z} \tag{9}$$

where $\delta = {}^{P_S}/_{N_o}$ is the SNR of the transmitting signal measured at the destination, $\mu = {}^{P_I}/_{N_o}$ is the interferes signal at the destination, $Y = \left|h_{S,r}\right|^2 \left|h_{r,D}\right|^2$ and $Z = \sum_{i=1}^{L} \left[h_{I,D}\right]^2$.

Subsequently, the instantaneous received SNR for a DF relaying with maximal ration combiner (MRC) at the destination is written as [3-4]

$$\gamma_{DF} = \min\{\gamma_r, \gamma_D\} \tag{10}$$

3. OUTAGE PROBABILITY ANALYSIS

The outage probability of the instantaneous received SNR of the proposed HTPSR protocol can be obtained in Equation (11) according to [11] by substituting Equation (10) and is expressed as

$$P_{out} = Pr\{\gamma_{DF} < \gamma_{th}\} = Pr\{\min(\gamma_r, \gamma_D) < \gamma_{th}\} \tag{11}$$

where $\gamma_{th} = 2^{2R} - 1$ is the threshold SNR and R is the signal transmission rate. Substituting Equations (7) and (9) into (11) yields

$$P_{out} = Pr\left\{\min\left(\frac{2(1-\alpha)}{\eta(1-\alpha(2-\vartheta))|h_{r,r}|^2}, \frac{2(1-\alpha)\delta Y}{\eta(1-\alpha(2-\vartheta))(1+\mu Z)}\right) < \gamma_{th}\right\} \tag{12}$$

Equation (12) is further simplified according to [8], [11] as

$$P_{out} = 1 - Pr\left\{\frac{2(1-\alpha)}{\eta(1-\alpha(2-\vartheta))|h_{r,r}|^2} \geq \gamma_{th}\right\} Pr\left\{\frac{2(1-\alpha)\delta Y}{\eta(1-\alpha(2-\vartheta))(1+\mu Z)} \geq \gamma_{th}\right\} = 1 - P_1 P_2 \tag{13}$$

Solving the term P_1 in Equation (13) yields

$$P_1 = Pr\left\{|h_{r,r}|^2 \leq \frac{2(1-\alpha)}{\eta(1-\alpha(2-\vartheta))\gamma_{th}}\right\} = 1 - exp\left(-\frac{2\lambda_1(1-\alpha)}{\eta(1-\alpha(2-\vartheta))\gamma_{th}}\right) \tag{14}$$

where $\lambda_1 = mean\left(|h_{r,r}|^2\right)$. Similarly, P_2 is expressed as

$$P_2 = Pr\left\{\frac{2(1-\alpha)\delta Y}{\eta(1-\alpha(2-\vartheta))(1+\mu Z)} \geq \gamma_{th}\right\} = 1 - Pr\left\{Y < \frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}\right\} \tag{15}$$

$$P_2 = 1 - \int_0^\infty F_Y\left(\frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}\middle|Z = z\right) f_z(z)dz \tag{16}$$

The Cumulative Distribution Function (CDF) of Y in (16) is expressed as

$$F_Y(y) = Pr\left\{|h_{S,r}|^2 |h_{r,D}|^2 < \mathrm{y}\right\} = Pr\left\{|h_{S,r}|^2 < {}^{\mathrm{y}}\!\Big/_{|h_{r,D}|^2}\right\} \tag{17}$$

$$F_Y(y) = \int_0^\infty F_{|h_{S,r}|^2}\left(\frac{y|h_{r,D}|^2}{a} = a\right) f_{|h_{S,r}|^2}(a)da = 1 - \lambda_2 \int_0^\infty exp\left(-\frac{\lambda_2 y}{a}\right) exp(-\lambda_3 a)da \tag{18}$$

According to [22] by applying the table of integral (18) yields

$$F_Y(y) = 1 - 2\sqrt{\lambda_2\lambda_3 y}\, K_1\left(2\sqrt{\lambda_2\lambda_3 y}\right) \tag{19}$$

where $\lambda_2 = mean\left(|h_{S,r}|^2\right)$, $\lambda_3 = mean\left(|h_{r,D}|^2\right)$ and $K_1(\cdot)$ is the Bessel function of the first kind. The Probability Distribution Function (PDF) of the random variable Z in (16) is expressed using

$$f_Z(t) = \frac{(\lambda_4)^L}{(L-1)!} t^{L-1} e^{-\lambda_4 t} \tag{20}$$

where $\lambda_4 = mean\left(|h_{S,r}|^2 |h_{r,D}|^2\right)$ and t is a non-negative real number representing time.

Substituting (20) into (16) can be written as

$$P_2 = 1 - \int_0^\infty F_Y\left(\frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}\middle|Z = z\right) \frac{(\lambda_4)^L}{(L-1)!} t^{L-1} e^{-\lambda_4 t} dz \tag{21}$$

and applying (19) in (21) gives

$$P_2 = 1 - \int_0^\infty 1 - 2\sqrt{\lambda_2\lambda_3 \frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}}\, K_1\left(2\sqrt{\lambda_2\lambda_3 \frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}}\right) \frac{(\lambda_4)^L}{(L-1)!} t^{L-1} e^{-\lambda_4 t} dz \tag{22}$$

$$P_2 = 2\int_0^\infty \sqrt{\lambda_2\lambda_3 \frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}}\, K_1\left(2\sqrt{\lambda_2\lambda_3 \frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}}\right) \frac{(\lambda_4)^L}{(L-1)!} t^{L-1} e^{-\lambda_4 t} dz \tag{23}$$

Substituting Equations (14) and (23) into (13) gives the closed form expression of the proposed FD HTPSR protocol outage probability as

$$P_{out} = 1 - \left(1 - exp\left(-\frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}\right)\right) \times \left(2\int_0^{\infty} \sqrt{\lambda_2\lambda_3\frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}}\, K_1\left(2\sqrt{\lambda_2\lambda_3\frac{\eta(1-\alpha(2-\vartheta))(1+\mu Z)\gamma_{th}}{2(1-\alpha)\delta}}\right)\frac{(\lambda_4)^L}{(L-1)!}t^{L-1}e^{-\lambda_4 t}dz\right) \quad (24)$$

Finally, the closed form outage probability expression of the proposed FD HTPSR protocol is expressed in Equation (24). The algorithm for the simulation of the proposed FD HTPSR protocol outage probability is shown in Algorithm 1.

Algorithm 1: Proposed FD HTPSR protocol outage probability

1) *Begin*
2) Initialize and set values for $\alpha, \vartheta, L, \eta, P_s, T, R, \gamma_{th}, t$
3) *for* $i = 1$ *to* 10^4, *do*
4) generate $h_{S,r}, h_{r,D}, h_{r,r}$ *and* $h_{I,D}$
5) compute δ, μ, Y *and* Z
6) compute $\gamma_{S,r}$ *and* $\gamma_{r,D}$ in (7) and (9), respectively
7) compute γ_{DF} in (10)
8) *if* $\gamma_{DF} \geq \gamma_{th}$ *then*
9) compute $\lambda_1, \lambda_2, \lambda_3$ *and* λ_4
10) compute P_{out} in (24)
11) *else*
12) return to step 4
13) *end if*
14) *end for*
15) output P_{out}
16) End

4. RESULTS AND DISCUSSION

This Section presents the impact of key system parameters on outage probability performance. The simulation was conducted in the MATLAB R2023a environment using the primary system parameters used in [10] over 10^4 runs. Figure 2 shows the outage probability against SNR of the transmitting signal from the source (δ), with different number of interferes (L = 1,3,6) for a fixed signal transmission rate (R = 0.25 bps/Hz), TSR ratio ($\alpha = 0.2$), PSR ratio ($\vartheta = 0.5$), conversion coefficient ($\eta = 0.8$) and interfering signal ($\mu = 10\ dB$). The results indicate that the outage probability of the proposed FD HTPSR and FD PSR protocols decreases as δ increases over the range of 0 to 25 dB. However, an increase in the L (number of interferes) resulted in a degradation of outage probability performance for the protocols. It is seen that the outage probability of the proposed FD HTPSR protocol outperforms the FD PSR as δ increases in all values of L. With L = 1, 3 and 6, the proposed HTPSR protocol significantly outperformed the PSR protocol by 28.57%, 18.75% and 8.89%, respectively, at $10\ dB$ while the corresponding values at $20\ dB$ were 200%, 150% and 50%. This observation indicates that more interferers have a significant detrimental effect on the signal quality received at the destination.

Figure 3 demonstrates outage probability against interfering signal (μ) for different values of L. The analysis is conducted with specific parameters set at R = 0.25 bps/Hz, $\alpha = 0.2$, $\vartheta = 0.5$, $\eta = 0.8$ and $\delta = 10\ dB$. As μ increases, the outage probability generally deteriorates for all the protocols with increasing number of interferers which aligning with the observations in Figure 2. However, the outage performance of the proposed FD HTPSR showed significant performance at lower value of μ but degrades as μ increases. This indicates that at lower values of μ, the proposed FD HTPSR protocol can successfully receive transmitted signal from the source via the relay even with the presence of interferers. Conversely, as μ increases, the impact of interferers on outage probability becomes prominent, significantly affecting system performance.

Figure 4 shows outage probability against PSR ratio (ϑ) and TSR ratio (α). For fixed values of R = 0.25 bps/Hz, L= 3 and $\delta = \mu = 10\ dB$ with different values of the η set to 0.5 and 0.85. The result showed that the proposed FD HTPSR protocol obtained its optimal EH factor values at lower outage probability values compared to the FD PSR protocol with higher outage probability value. The optimal EH factor for the proposed FD HTPSR protocol can be obtained by fixing the other. For instance, at a fixed value of $\alpha = 0.2$ and $\eta = 0.85$, the optimal value of ϑ was obtained to be 0.4 with less outage probability performance compared to high outage probability obtained for $\vartheta = 0.3$ at fixed values of $\alpha = 0.2$, and $\eta = 0.5$. Similarly, at $\vartheta = 0.4$ and $\eta = 0.85$, the optimal value of α was obtained to be 0.2 which exhibits lower outage probability performance compared to the high outage probability obtained for $\vartheta = 0.3$ at fixed values of $\alpha = 0.2$ and $\eta = 0.5$. The result implies that at optimal values of α and ϑ, a lower outage probability can be obtained even in the presence of interferers as compared to FD PSR protocol which exhibits high outage probability performance at fixed value of $\eta = 0.5$ and $\eta = 0.85$.

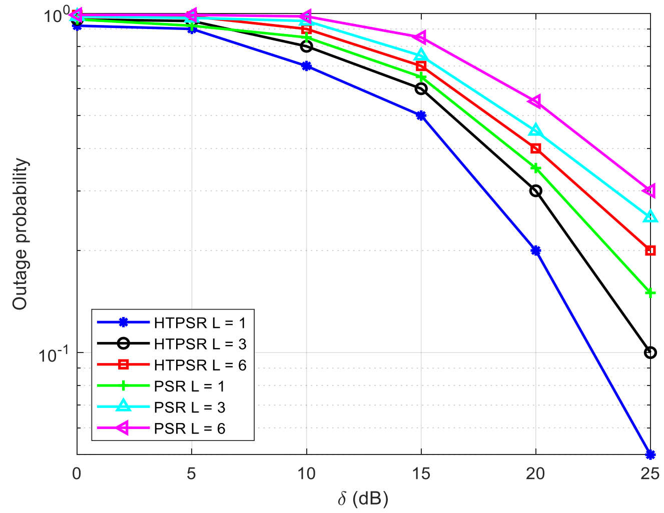


Figure 2: Outage probability against SNR of the transmitting signal (δ).

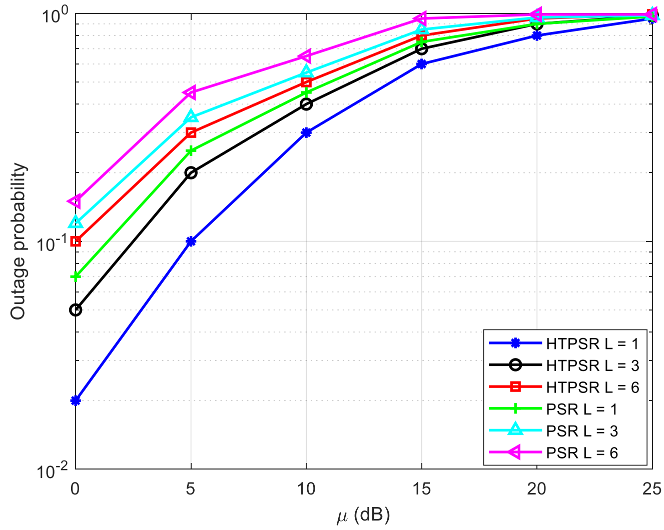


Figure 3: Outage probability against interfering signal (μ).

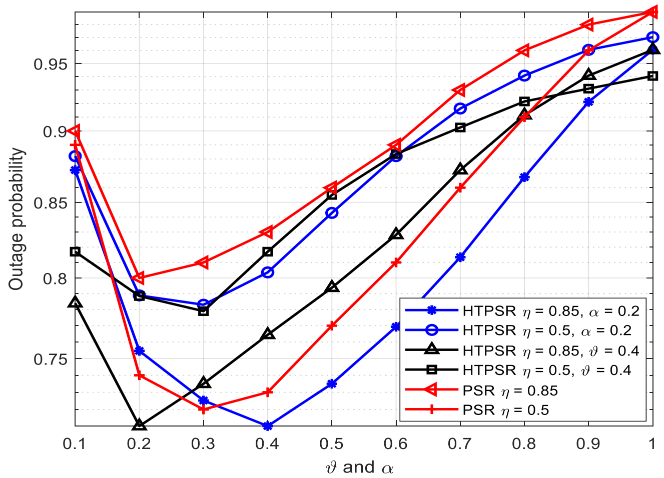


Figure 4. Outage probability against PSR ratio (ϑ) and TSR ratio (α).

Figure 5 shows outage probability against interferers (L) on the proposed FD HTPSR protocol setting the primary system parameters at R = 0.25 bps/Hz, $\alpha = 0.2$, $\vartheta = 0.4$, $\eta = 0.8$ and $\delta = 10\ dB$. The result shows that as L increases, the outage probability performance for the protocols degrades at different fixed values of μ. However, the result obtained for the proposed FD HTPSR protocol outperformed that of the FD PSR. At lower value of $\mu = 5\ dB$ and $10\ dB$ the proposed protocol revealed low outage probability compared to FD PSR at the same μ. This indicates that by increasing the transmission power with increasing number of interferes, the outage performance is adversely impacted at the destination for FD PSR as against FD HTPSR protocol.

Figure 6 presents outage probability performance against transmission rate (R) for the proposed FD HTPSR protocol by setting the primary system parameters at L = 3, $\eta = 0.8$ and $\delta = \mu = 5\ dB$. The result shows that as R increases, the outage probability performance degrades for all the protocols with the proposed FD HTPSR outperforming the FD PSR protocol. The result obtained at $\alpha = 0.2$ and $\vartheta = 0.4$ with varying value of R, shows a reduction in outage probability performance as compared to when $\alpha = 0.2$ and $\vartheta = 0.8$ for the proposed FD HTPSR. However, the proposed FD HTPSR. Protocol still shows its superiority over the FD PSR protocol which degrades significantly as more harvesting is performed at the expense of signal processing capability.

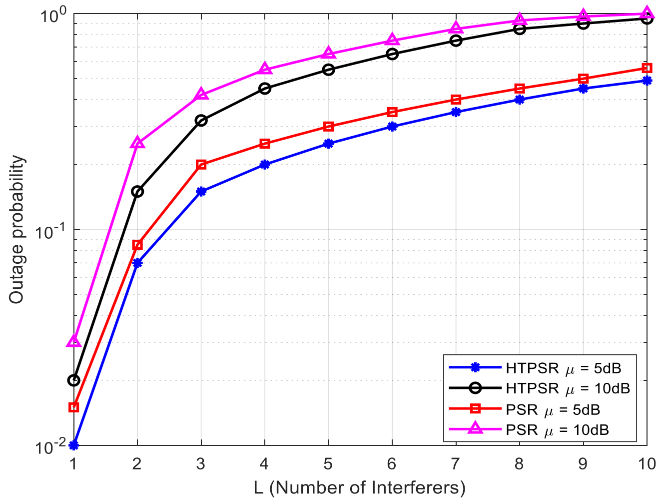


Figure 5: Outage probability against interferers (L).

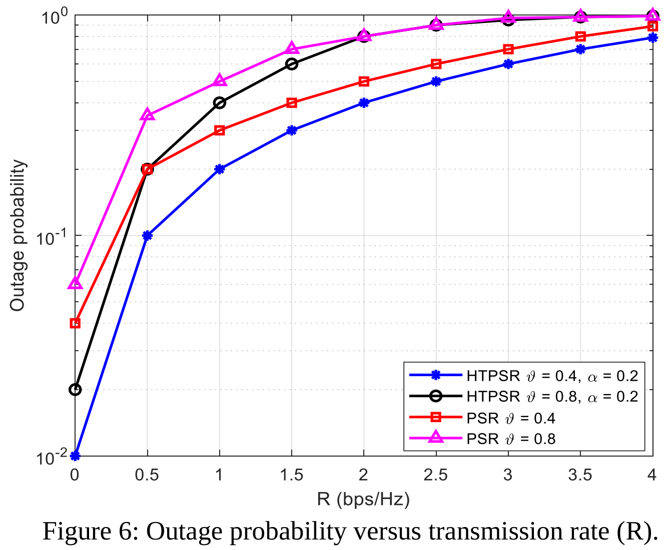


Figure 6: Outage probability versus transmission rate (R).

5. CONCLUSION

This paper focused on the performance of FD HTPSR in the presence of interference at the destination using DF relaying network. The effect of co-channel interferers on the signal quality at the destination was investigated. The outage probability closed form expression of the proposed FD HTPSR protocol was derived over Rayliegh fading channel. The proposed protocol was simulated in MATLAB software environment using the network system parameters and evaluated using outage probability performance. The results showed that outage probability performance of the proposed FD HTPSR protocol is superior to that of the FD PSR protocol in interference-prone environments under different system parameter scenarios. The proposed protocol is suitable for energy-constrained devices in emerging networks with more devices interfering the destination device. The future works can investigate the impact of applying non-linear hybrid SWIPT models with FD on the cooperative network.

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