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Enhancement of a SWIPT Based Amplify and Forward Cooperative Relaying Protocol for Wireless Communication System

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Abstract: *Communication through unbounded environment known as Wireless Communication (WC) undergoing rapid expansion driven by the escalating demand for its services. However, WC system is subjected to severe multipath propagation due to obstruction in the medium of transmission thereby resulting in signal fading that degrades system performance. SWIPT based Amplify and Forward (AF) relaying protocol previously used in addressing signal fading is characterized with poor performance due to noise amplification. Hence, this paper, enhanced a SWIPT based AF relaying technique for WC system using angular beamforming at the source and spectral subtraction at the relay node. The transmitting signal at the source was beamformed using angular beamforming technique at varying angles of* 30^0 *and* 60^0*. The received signal was made to pass through Power Splitter (PS) energy harvester where the signal power P was splited into two fractions,* δP *and* $(1-\delta)P$*. The first fraction that is* δP*, was used for energy harvesting by making it to pass through energy harvester device to scavenge energy and store in the power storage. The remaining fraction that is,* $(1-\delta)P$*, was made to pass through spectral subtraction and amplify using relay gain before forwarded to the destination during second hop transmission. The enhanced technique's performance was assessed using BER and TP, comparing it to the existing SWIPT-based AF relaying technique. The enhanced SWIPT based AF gave better performance with reduce BER and improve TP which justify the reduction of amplify noise in the propose technique. The proposed technique can be integrated into wireless communication systems to improve their overall performance.*

Keywords: *Amplify and Forward (AF), Angular Beamforming, Power Splitter Energy Harvesting, Spectral Subtraction and SWIPT*

1. INTRODUCTION

Wireless communication is a rapidly evolving field that impacts our lives significantly. Signals in wireless systems travel through the air as electromagnetic waves. However, these waves don't follow a direct path, but instead are influenced by factors like reflection, diffraction, refraction, and scattering. This leads to multiple signal paths, causing fluctuations in the received signal strength – a phenomenon known as multipath fading. These fluctuations can weaken the signal below the receiver's sensitivity, resulting in poor reception and degraded system performance [1, 2, 3, 4, 5]. To overcome this, techniques like Cooperative Diversity (CD) are employed. In CD, multiple nodes (relays) assist in signal transmission between the source and destination. This enhances system reliability and efficiency by strategically placing relay nodes along the communication path. Two primary relaying mechanisms within cooperative networks are AF and DF. [6, 7, 8, 9, 10, 11].

AF is the most widely used CD technique in wireless communication due to its simplicity and lower hardware requirements. However, in DF, if the signal from the source to the relay is severely distorted by fading, the relay may not decode it correctly, leading to signal loss at the destination. While simpler, AF generally performs worse than DF. This is because AF amplifies both the signal and the accompanying noise before forwarding it, degrading the signal quality at the destination [12, 13, 14, 15, 16]. Additionally, the power consumption of AF is directly related to the relay's gain. Higher gains, while potentially improving performance, also increase power consumption. Therefore, in order to improve energy efficiency of AF relaying protocol, Simultaneous Wireless Information and Power Transfer (SWIPT) in which Radio Frequency (RF) signals concurrently carry energy and information is incorporated with AF technique. In SWIPT based AF technique, the energy contained in the RF signal is harvested and converted to electrical energy to recharge a battery for powering relay node. Power Splitting (PS) and Time Switching are the most commonly used energy harvesting technique due to their reduced hardware complexity [11, 17, 18, 19]. In this paper, PS is adopted due to its ability to harvest information and energy simultaneously. RF energy harvesting has been a major technique in combating the problem of energy constraint in cooperative communication network due to the fact that it avoids frequent battery replacement.

However, SWIPT based AF relaying protocol is characterized with pure performance due to noise amplification at the relay node [20, 21, 22]. Therefore, this paper proposed an enhanced SWIPT based AF relaying network using angular beamforming at the source.
Spectral subtraction that suppressed the noise power is adopted at the relay node to reduce the noise amplification that degrade the system performance.

Several studies have explored the use of SWIPT with AF relaying to mitigate multipath fading in wireless communication systems. In [5], Performance Analysis of AF Cooperative Relaying Networks with SWIPT technique is carried out to address the challenges of power constraint in AF cooperative network. The study found that communication systems using SWIPT only exhibit improved outage probability when the relay node is relatively close to the source node. This suggests that for the system to outperform traditional cooperative communication, the relay node must harvest sufficient energy for effective signal transmission. However, the performance of SWIPT-based systems can be inconsistent, making them less reliable. Also, an outage analysis for two-way spectrum sharing communication systems that utilize cooperative relaying (Amplify and Forward/Decode and Forward) with Simultaneous Wireless Information and Power Transfer (SWIPT) is proposed in [23] for energy efficiency improvement of cooperative communication scheme. The results of the paper revealed that the technique outperforms the existing protocol without SWIPT scheme with energy efficiency percentage increase of 209% and 49% for DF and AF relaying techniques, respectively. Furthermore, in [24], SWIPT with AF cooperative networks was proposed to address the issue of limited power at relay nodes. The study demonstrated that this energy-harvesting AF technique surpasses traditional approaches in terms of outage probability and data throughput. However, the inherent noise amplification in AF can still limit performance. To overcome this limitation, this paper proposes an enhanced SWIPT-based AF cooperative relaying technique to further improve the system's performance. The following outlines the significant contributions of this paper:

(i) establishing a new SWIPT based AF cooperative relay technique with reduced noise amplification due to spectral subtraction used at the relay node.
(ii) derive mathematical expressions of BER and Throughput (TP) for the enhanced technique over log-normal fading channel.

The remainder of this paper is organized as follows: Section 2 provides a comprehensive description of the research methodology. Section 3 presents simulation results, comparing the proposed technique with existing approaches. Finally, Section 4 concludes the paper.

2. PROPOSED SWIPT BASED AF COOPERATIVE RELAYING NETWORK

In this paper, the transmitting signal is beamformed at the source using angular beamforming technique at vary angles of 30^0 and 60^0. Single relay system is used to receive the transmitted signal at the relay node and the signal received is made to pass through Power Splitter (PS) energy harvester where the signal power P is split into two fractions, δP and $(1-\delta)P$. The first fraction that is δP, is used for energy harvesting, while the remaining fraction that is, $(1-\delta)P$, was used for information decoding as depicted in Figure. 1. Therefore, the signal power used for energy harvesting is obtained as

$$\rho_{EH} = \frac{(q_r H q_t \delta P \emptyset)^2}{\sigma_n^2} \tag{1}$$

where: δP is the received signal for energy harvesting, q_r is the received beamforming vector, q_t is the transmitting beamforming vector H is the gain of channel, $\emptyset$ is the beamforming angle and σ_n^2 is the noise present

while, the signal power used for information decoding is obtained as

$$\rho_{ID} = \frac{(q_r H q_t \emptyset (1-\delta)P)^2}{\sigma_n^2} \tag{2}$$

where: $(1-\delta)P$ is the received signal for information decoding
The strength of the signal received at the relay node as depicted in Equation (2) is made to pass through spectral subtraction to remove the noise that might present. Therefore, the desired signal at the relay node $x_R(t)$ is obtained as

$$x_R(t) = \rho_{ID}(t) - n_R(t) \tag{3}$$

where: $n_R(t)$ is the noise power at the relay node
In [25], noise power is given as

$$\sigma_n^2(t) = KTB \tag{4}$$

where: K is Boltzman constant, B is the bandwidth, T is the temperature
Therefore, by substituting Equations (2) and (4) into (3), the signal at the relay nodes is obtained as

$$x_R(t) = \frac{(q_r H q_t \emptyset (1-\delta)P)^2}{\sigma_n^2} - KTB \tag{5}$$

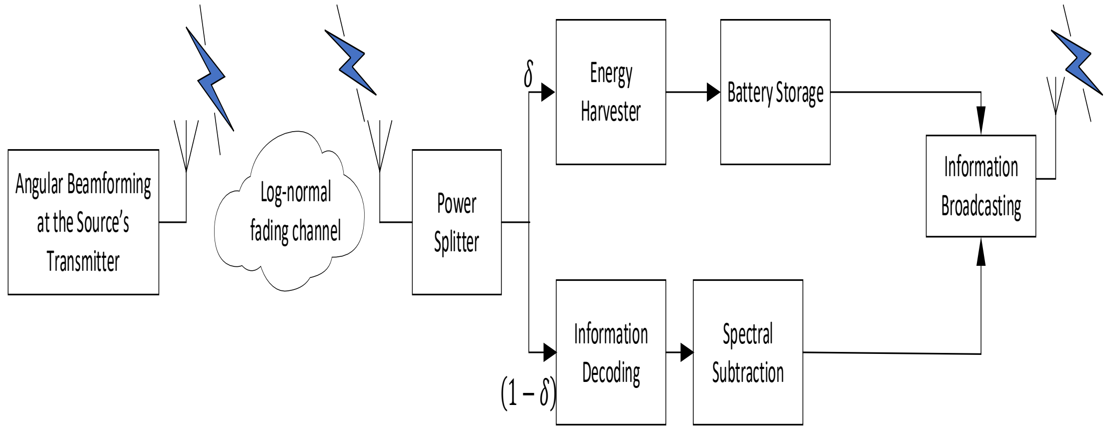

Figure. 1: The enhanced SWIPT based AF cooperative relaying scheme

The resultant signal which is expected to be a clean signal is amplified by multiplying with relay gain given. In this paper, the amplify signal is the product of relay gain and the signal output of spectral subtraction. Therefore, by using Equations (5), the amplified signal $\gamma_a(t)$ for the enhanced technique is obtained as

$$\gamma_a(t) = \left(\left(\frac{(q_r H q_t \emptyset (1-\delta)P)^2}{\sigma_n^2}\right) - KTB\right) \times \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}} \tag{6}$$

The resultant signal in Equation (6) is radiated to destination as transmission of second hub. The received signals at the destination are combined using Maximal Ratio Combiner. Using Equation (6), the SNR of output signal is obtained as

$$SNR_{DMRC} = \frac{\left(\sum_{i=1}^{L}\left(\left(\frac{(q_r H(i) q_t \emptyset (1-\delta)P)^2}{\sigma_n^2}\right) - KTB\right) \times \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w} \tag{7}$$

The PDF of the received signal "$P_r(r)$"over log-normal fading channel for the proposed technique is obtained

$$P_r(r) = \frac{10/ln10}{\sigma(SNR_{DMRC})(2\pi)^{\frac{1}{2}}} exp\left(-\frac{(ln(SNR_{DMRC})-\mu)^2}{2\sigma^2}\right) \tag{8}$$

$$P_r(r) = \frac{4.343}{\sigma(SNR_{DMRC})(2\pi)^{\frac{1}{2}}} exp\left(-\frac{(ln(SNR_{DMRC})-\mu)^2}{2\sigma^2}\right) \tag{9}$$

$$P_r(r) = 4.343\left(\left(\sigma(SNR_{DMRC})(2\pi)^{\frac{1}{2}}\right)^{-1}\right) exp\left(-\frac{(ln(SNR_{DMRC})-\mu)^2}{2\sigma^2}\right) \tag{10}$$

where: σ and μ are the standard deviation and mean, respectively

2.1 Throughput for the Proposed Technique

The proposed enhanced technique is evaluated using TP and BER. In this paper, TP is the rate at which messages are delivered successfully over log-normal fading channel. The expression of throughput 'TP' for the proposed technique is obtained as shown in Equation (11)

$$TP = B \times log_2(1 + SNR_{DMRC})(1 - OP) \tag{11}$$

where: B is the bandwidth, SNR is the signal-noise-ratio of the signal received at the destination, OP is the outage probability. But, the expression of SNR for the enhanced technique is given in Equation (7), therefore, using Equations (7) and (11), the expression for throughput for the proposed technique is obtained as

$$TP = Blog_2\left(1 + \frac{\left(\sum_{i=1}^{L}\left(\left(\frac{(q_r H q_t \emptyset (1-\delta)P)^2}{\sigma_n^2}\right) - KTB\right) \times \left(\frac{P_r}{P_r h_{sr}^2 + N_r}\right)^{\frac{1}{2}}\right)^2}{\sum_{i=1}^{L} a_i^2 w}\right)(1 - OP) \tag{12}$$

Equation (12) is the throughput for the enhanced technique and outage probability is obtained by comparing the SNR of the received signal with the set threshold. If the SNR of the received signal fall below the set threshold, there is signal outage at the destination, otherwise there is no outage at the destination.

2.2 Bit Error Rate for the Proposed Technique

Using the PDF of the received signal for the proposed technique given in Equation (10), the Bit Error Rate ($P_b(E)$) for the proposed technique is obtained as given in Equation (13)

$$P_b(E) = \int_o^{\infty} P_b\left({}^{E}/_{\gamma}\right) \times 4.343\left(\left(\sigma(\gamma_{DMRC})(2\pi)^{\frac{1}{2}}\right)^{-1}\right) exp\left(-\frac{(ln(\gamma_{DMRC})-\mu)^2}{2\sigma^2}\right) d\gamma \quad (13)$$

However, according to [2], error probability conditional $P_b\left({}^{E}/_{\gamma}\right)$ is obtain as

$$P_b\left({}^{E}/_{\gamma}\right) = 0.5\exp(0.5\gamma) \quad (14)$$

Therefore, by using Equations (14) and (13) gives

$$P_b(E) = \int_o^{\infty} 0.5\exp(0.5\gamma) \times 4.343\left(\left(\sigma(\gamma_{DMRC})(2\pi)^{\frac{1}{2}}\right)^{-1}\right) exp\left(-\frac{(ln(\gamma_{DMRC})-\mu)^2}{2\sigma^2}\right) d\gamma \quad (15)$$

$$P_b(E) = 2.172\int_o^{\infty} \exp(0.5\gamma)\left(\left(\sigma(\gamma_{DMRC})(2\pi)^{\frac{1}{2}}\right)^{-1}\right) exp\left(-\frac{(ln(\gamma_{DMRC})-\mu)^2}{2\sigma^2}\right) d\gamma \quad (16)$$

$$P_b(E) = 2.172\int_o^{\infty} \exp(0.5\gamma)\left(\left(\sigma(\gamma_{DMRC})(2\pi)^{\frac{1}{2}}\right)^{-1}\right)\left(\frac{(ln(\gamma_{DMRC})-\mu)^2}{2\sigma^2}\right) d\gamma \quad (17)$$

2. SIMULATION RESULTS AND DISCUSSION

This paper utilizes MATLAB R2021a for simulations. Data is generated using the built-in random integer generator within MATLAB. Figure 2 illustrates the flowchart for the enhanced technique, while Table 1 summarizes the simulation parameters. One of the key performance metrics employed in this paper is BER, used to assess the performance of the proposed SWIPT-based AF cooperative relaying system operating over log-normal fading channels. The values of BER at varying propagation paths with different angle of beamforming were obtained and compared with [5]. In this paper, conventional SWIPT based AF technique represent the work in [5]. Fig. 3 presents the BER against SNR for enhanced and conventional SWIPT based AF technique at L = 2 and beamforming angle of 30^0 over log-normal fading channel. At SNR 6 dB, BER values of 1.08×10^{-9} and 2.71×10^{-6} were obtained for the enhanced and conventional SWIPT based AF technique, respectively. While the corresponding BER values obtained at SNR of 10 dB were 4.39×10^{-14} and 1.11×10^{-9}. The BER values obtained for the enhanced SWIPT based AF technique using beamforming angle of 60^0 were 2.15×10^{-9} and 8.77×10^{-14} at SNR of 6 dB and 10 dB, respectively. The results obtained revealed that the enhanced SWIPT based AF technique gave better performance at the two beamforming angles considered with low BER than the conventional SWIPT based AF technique. This is due to spectral subtraction used in the enhanced technique that reduced the amplified noise that occurs during signal amplification. Also, the enhanced technique gave better performance at beamforming angle of 30^0 with lower BER than beamforming angle of 60^0 and this is due to lower angle of broadcasting when using 30^0 making the signal to be more focus in a certain direction thereby forming a focused beam of electromagnetic energy that enhances signal strength.

The BER values obtained at L = 4 using 30^0 and 60^0 beamforming angle for the enhanced and conventional SWIPT based AF technique over log-normal fading channel is presented in Figure 4. The BER values obtained at SNR of 6 dB with 30^0 beamforming angle were 1.62×10^{-9} and 9.05×10^{-7} for the enhanced and conventional SWIPT based AF technique, respectively, while the corresponding BER values obtained at SNR of 10 dB were 6.58×10^{-14} and 3.68×10^{-10}. The BER values obtained for the enhanced SWIPT based AF technique at SNR of 4 dB were 1.18×10^{-8} and 2.36×10^{-8} using beamforming angles of 30^0 and 60^0, respectively. The results obtained revealed that for the two techniques, BER values reduces as the number of paths increases. This is due to reduction in error rate as the signal strength increases. The results obtained also revealed that, the enhanced technique as the best performance compare with the conventional technique at all the SNR considered and this is due to spectral subtraction used at the relay node that suppressed the noise before signal amplification. However, the performance of the enhanced technique increases as the value of SNR increases and this is due to reduction in erroneous bit as the strength of the signal increases. The effect of angle of beamforming on the performance of the enhanced technique is depicted in Figure 5. The results obtained revealed that, the enhanced technique gave better performance with lower BER values at beamforming angle of 30^0 when compare with beamforming angle of 60^0 and this is due to lower angle of broadcasting that makes the signal to be more focus in a certain direction thereby forming a focused beam of electromagnetic energy that enhances signal strength and reduces erroneous bit at the receiving end. The results obtained also revealed that, for the two beamforming angles considered, it was observed that as the number of paths increased, the BER values decreased. This improvement can be attributed to the enhancement in signal strength resulting from a higher number of propagation paths. However, in all the considered scenarios, the enhanced SWIPT-based AF technique consistently exhibited superior performance with lower BER values when compared to the conventional SWIPT-based AF technique and this is due to spectral subtraction and angular beamforming technique used in the enhanced technique that reduces the amplified noise and increase the signal strength, respectively.

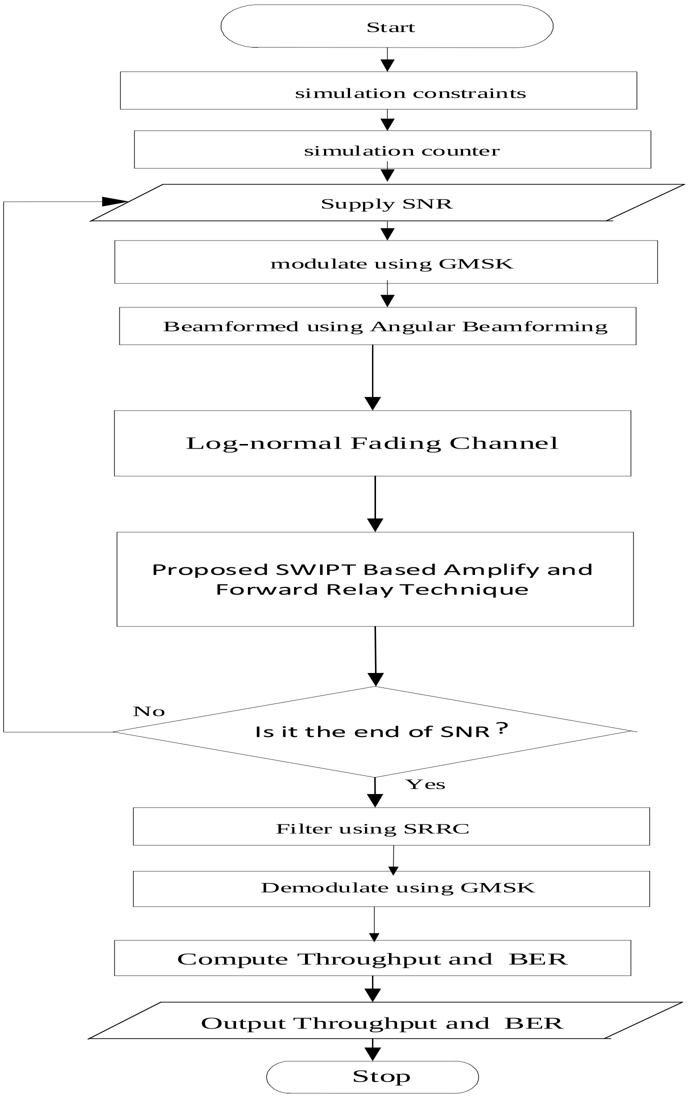

Figure 2: Flowchart of the Simulation Process.

Table 1: System simulation parameters for the proposed technique

Parameter	Specifications
Modulation schemes	GMSK
Channel	Log-normal channel
Carrier Frequency	2300MHz
Noise	AWGN
Filter	SRRC
Signal Bandwidth	2 MHz
SNR	0,2,4.........,10
Number of data length	10,000
Bit rate	2 Mbps
Threshold SNR	2dB

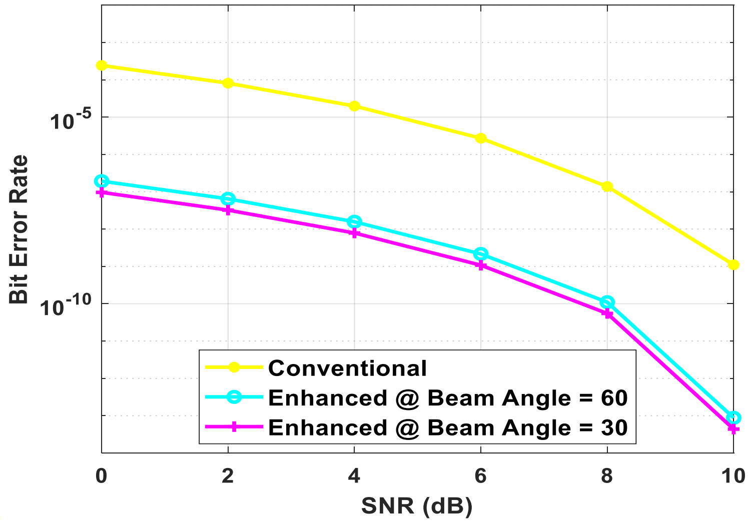

Figure 3: BER versus SNR for the conventional and enhanced and SWIPT based AF technique at L = 2 with different beamforming angle

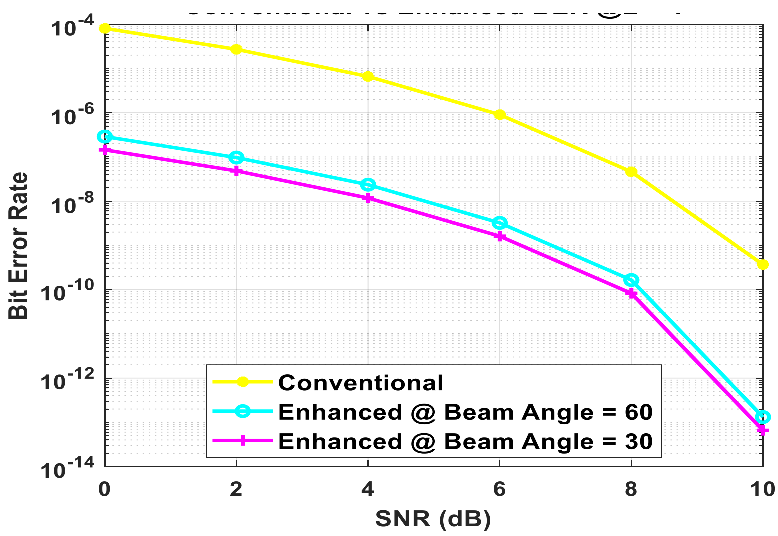

Figure 4: BER versus SNR for the conventional and enhanced SWIPT based AF technique at L = 3 with different beamforming angle

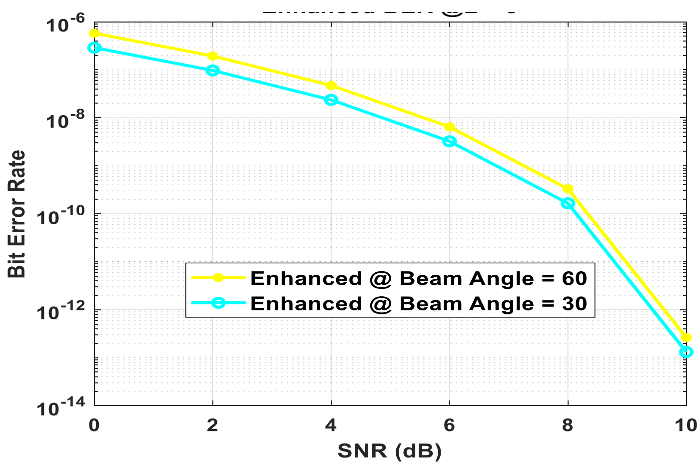

Figure 5: BER versus SNR for the enhanced SWIPT based AF technique at L = 3 with different beamforming angles

Throughput (TP) was another performance metric evaluated for the enhanced and conventional SWIPT-based AF techniques. TP values were calculated under various conditions, including different propagation paths, Signal-to-Noise Ratios (SNR), and beamforming angles. Figure 6 illustrates the TP versus SNR performance for both techniques at L=2, using beamforming angles of [specific angles] over a log-normal fading channel. At an SNR of 6 dB, the enhanced technique achieved a TP of 4.6472 bit/sec, while the conventional technique reached 1.7471 bit/sec. Similarly, at 10 dB SNR, the enhanced technique's TP was 5.0248 bit/sec, compared to 2.0890 bit/sec for the conventional technique. When using beamforming angles of 30^0, the enhanced technique yielded TP of 2.3236 and 2.5124 bit/sec at 6 dB and 10 dB SNR, respectively. The enhanced technique consistently outperformed the conventional one in terms of TP. This improvement can be attributed to the combination of spectral subtraction and angular beamforming, which effectively reduces noise amplification and increases signal strength. Both techniques exhibited higher TP values with an increasing number of propagation paths, as shown in Figure 7. This is because more paths lead to stronger signals. Additionally, for both techniques, TP increased as the beamforming angle decreased. A narrower beam focuses the electromagnetic energy, resulting in a stronger signal. The enhanced SWIPT-based AF technique demonstrated superior performance in terms of TP, due to its innovative approach of combining spectral subtraction and angular beamforming.

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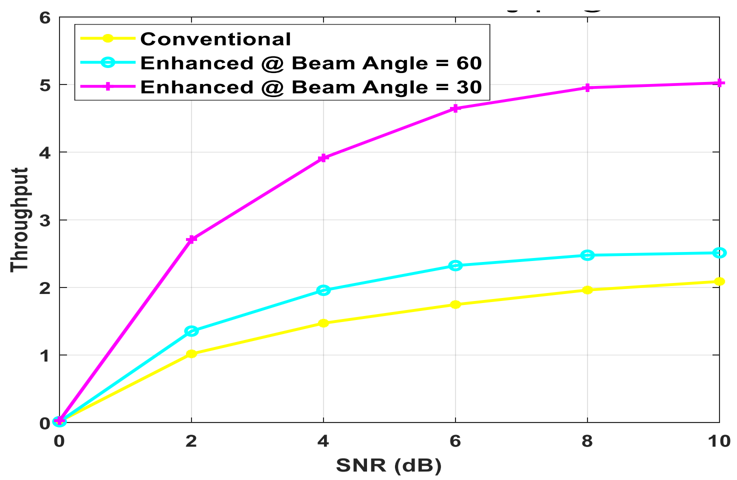

Figure 6: TP versus SNR for the enhanced and conventional SWIPT based AF technique at L = 2 with different beamforming angle

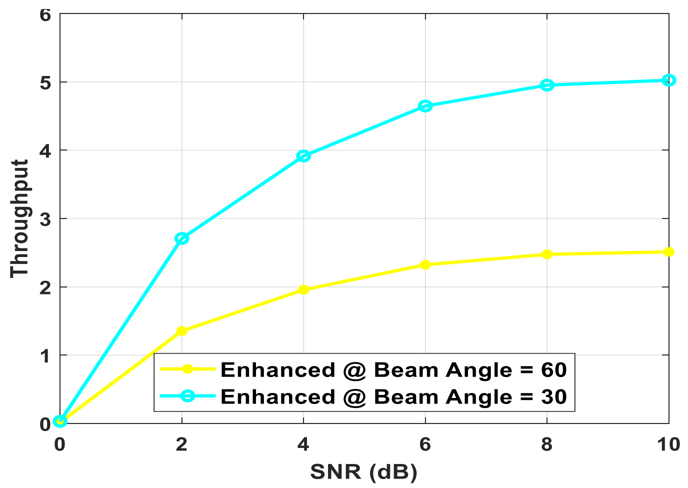

Figure 7: TP versus SNR for the enhanced SWIPT based AF technique at L = 2 using different beamforming angles

3. CONCLUSION

This paper proposes an enhanced SWIPT technique for AF cooperative relaying over log-normal fading channels. The source node employs angular beamforming to direct the transmitted signal, improving signal strength and focusing the energy. Also, at the relay node, before amplification, spectral subtraction is applied to the received signal, reducing noise and improving signal quality. The source transmits a beamformed signal over the log-normal fading channel and the signal are received at the relay node. The received signal is split into two parts: One part is used to harvest energy for the relay using a power-splitting (PS) technique and other part is used for information decoding. The information-bearing signal undergoes spectral subtraction and amplification before being forwarded to the destination. The destination receives multiple copies of the signal from different paths (L = 2, 4) and combines them using Maximum Ratio Combining (MRC). Bit Error Rate (BER) and Throughput (TP) are used to evaluate system performance. Log-normal fading channels are modeled for both source-to-relay and relay-to-destination links. Additive White Gaussian Noise (AWGN) is considered. Simulations are conducted at varying Signal-to-Noise Ratios (SNRs) and with different numbers of propagation paths (L). The enhanced technique consistently outperforms conventional SWIPT-based AF technique due to spectral subtraction and angular beamforming. BER decreases and TP increases with increasing SNR and the number of propagation paths (L). The beamforming angle of 30° results in lower BER and higher TP compared to other angles due to more focused energy transmission. In essence, this paper demonstrates the effectiveness of incorporating angular beamforming and spectral subtraction into SWIPT-based AF relaying systems for improved performance in log-normal fading environments.

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