Wireless Energy Harvesting with Amplify-and-Forward Relaying and Link Adaptation under Imperfect Feedback Channel

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***Abstract*—Energy harvesting is an alternative approach to extend the lifetime of wireless communications and decrease energy consumption, which results in fewer carbon emissions from wireless networks. In this study, adaptive modulation with EH relay is proposed. A power splitting mechanism for EH relay is used. The relay harvests energy from the source and forwards the information to the destination. A genetic algorithm (GA) is applied for the optimisation of the power splitting ratio at the relays. Two scenarios are considered namely, perfect and imperfect feedback channels. Results show that the spectral efficiency (SE) degradation, which is due to an imperfect feedback channel, was approximately 14% for conventional relays. The use of energy harvesting results in a degradation in the performance of SE of approximately 19% in case of a perfect feedback channel. Finally, an increase in the number of energy harvesting relays enhances the SE by 22%.**

***Index Terms*—Adaptive Modulation; Energy Harvesting Relaying; Green Communications; Outage Probability; Spectral Efficiency.**

I. INTRODUCTION

Cooperative relaying is one of the recent developments that contribute toward energy-efficient transmission techniques by mitigating fading [1]. This technique includes two main relaying schemes: Amplify-and-Forward (AF) and Decode-and-Forward (DF). The considered two schemes send the signals with the use of orthogonal channels to prevent the occurrence of interference between the sources and relay links [2]. However, using relaying leads to many challenges in wireless networks.

One of these challenges is throughput loss because of extra relaying resources, which can be reduced to 50% for a single relay compared with a direct link. Therefore, various efforts have been conducted in recent years to enhance the performance and to solve the throughput loss problem. Adaptive modulation is utilised in wireless systems by choosing the appropriate modulation type and constellation size, depending on the resultant SNR on the receiver side. This method depends on transforming the SNR gain into throughput [3]. Adaptive modulation and cooperative relaying are used to meet the requirements for the potential Fifth Generation (5G) networks. Another challenge in cooperative relaying is the limited battery life in the relays, which, in turn, causes a limited network lifetime. Traditional energy harvesting sources, such as the wind, solar, and thermal, are not always available because of their nature and seasonality, which decreases the reliability of the wireless network [4]. Furthermore, in specific applications, some of these sources are impossible to recharge. Recently, the use of radio-frequency (RF) signals for the Simultaneous Wireless Information and Power Transfer (SWIPT) has become a valuable source of energy harvesting because of being able to carry energy and information simultaneously [5].

Energy harvesting has emerged as a potential power source to increase the lifetime of a future wireless network. EH brings more improvement in energy efficiency (EE) than conventional cooperative relaying, which decreases energy consumption and operational cost [6]. EH using RF is considered as a green communication technique because traditional energy harvesting requires a certain amount of fuels to generate electric power, which results in CO2 emissions [7].

The work introduced in [8] proposed the best cooperative mechanism (BCM) algorithm to be used for spectrum sharing and EH within 5G networks. EH, and data transfer is performed in the designed time slot. In BCM algorithm, secondary users (SUs) perform the EH from primary users (PUs) and surrounding signals. With BCM, the optimal duration is allowed for transferring the data at each time slot. An optimisation problem has been formulated to maximise the SUs, and PUs throughput considering the constraints on EH save ratio and data rate.

In [8], two EH ratios were used, which is the first ratio, ρ_1, related to SU ratio from ambient RF signals and the second ratio, ρ_2 related to SU ratio from PU RF signals. Both ratios represent the optimisation problem to maximise throughput for both PUs and SUs. The authors in [8] focused on the throughput with timeslot transmission, which needs more detailed channel information especially by increasing the number of SUs and PUs. In this work, only ρ_2 is considered as an optimisation problem to achieve the best throughput value in EH relaying, to reduce the overall system complexity which reflects an increasing number of SUs and PUs. Also, adaptive modulation is used in this work, to minimise the throughput loss of using cooperative relaying, which can reach 50% loss due to extra relaying resources. Finally, this study considered the practical case in wireless networks, by evaluating the effect of the imperfect feedback channel.

In this study, energy harvesting communication using RF is used with the AF scheme and adaptive transmission. Two main scenarios are considered: a perfect feedback channel and an imperfect feedback channel condition. The contributions of this study can be summarised as follows:

i. A novel energy harvesting (EH) relay with link adaptation under an imperfect feedback channel scenario is proposed by maximising the throughput to meet the main requirements in green wireless communication systems. In [9], a single EH relay was used to compute the SE with link adaptation. This work is an extension to the multi-EH relay using the all-relays-participate (ARP) scheme.
ii. The effect of the imperfect feedback channel on the decision of the transmitter to choose the best modulation scheme is derived.
iii. Outage probability is derived for EH relay and compared with the conventional cooperative relay. EH relay can be more valuable over small areas. Consequently, the proposed system is considered in which the source, relay and destination are located in a small territory. In this case, outage probability will be beneficial due to the restrictions decreed on the relays by the energy constraints.

The remainder of the paper is organised as follows. Section II discusses recent developments and a critical review of the previous studies. Section III describes the proposed system with adaptive modulation in EH relaying. Section IV describes the channel model with noisy feedback channel. In Section V, performance analysis for energy harvesting relaying is presented. In Section VI, the SE for adaptive modulation with cooperative EH relaying for different feedback errors is illustrated. Moreover, the impact of the EH relays on the outage probability is also described. Conclusions are presented in Section VII.

II. RELATED WORKS

The authors in [10] considered a cooperative network with EH nodes that act as relays with the AF protocol in cases where they have an adequate amount of energy for transmission. They presented the notion of energy unconstrained and energy constrained relays. The symbol error rate (SER) was then characterised analytically for the cooperative system. The authors also performed an asymptotic analysis under the condition of multiple relays or SNR. The energy usage was quantified at the target relay node.

Furthermore, they also quantified the relaying capability based on the energy harvesting process for that relay in addition to the amount of transmitted power. Their results illustrated the differences between a cooperative system that uses EH relays and conventional cooperative systems. Utilizing EH nodes as relays are considered a promising alternative solution. The energy is harvested via these nodes from the surrounding environment to perform their communication tasks [11, 12].

In [13], the authors investigated the best transmission protocols for hop communication systems using both a non-EH relay and an EH source. In [14], the authors analysed the outage behaviour from cooperative transmission using EH relay nodes.

In [15], the authors proposed an analytical model to study the energy efficiency of cellular networks using EH relay nodes based on the derivation of the coverage probability expressions and mean achievable rates for various links. Results revealed that the use of such nodes outperformed non-EH relayed transmission in enhancing the energy efficiency. In [16], the use of the RF energy was proposed as an efficient EH technique by exploiting the ambient RF signals, such as those from cellular communications and TV broadcast, which are broadly available in urban regions.

The ambient RF radiation was captured using the receiver antennas of wireless devices and then transformed into a voltage using suitable circuits [17, 18]. Several investigations concerning the real-time wireless information, information-carrying signals, and power transfer were conducted, which assumed that the receiver could decode information and harvest energy from such signals [19, 20]. Two processes were found to be difficult to be performed together. Researchers in [9, 21-23] proposed two models to perform such processes separately, namely, the Time-Switching (TS) and Power-Splitting (PS) models. In the TS model, the receiver switches between the two processes over time. By contrast, in the PS model, a part of the received power is deployed for energy harvesting, whereas the remaining part is deployed for decoding the information.

In cooperative networks, both the capacity and coverage can be improved using relays between the source and destination. However, relays have restricted battery life, in which the use of a wired charging method becomes a critical problem. Thus, several researchers [22, 24-25] have proposed that the wireless EH at relays is necessary to enhance the lifetime of relaying systems. The authors in [26] examined a directional water-filling technique that provides a brief interpretation of the necessary optimality conditions to achieve the optimal throughput for a wireless channel, considering an energy harvesting transmitter. Non-causally known channel fading and harvested energy were assumed during their evaluation.

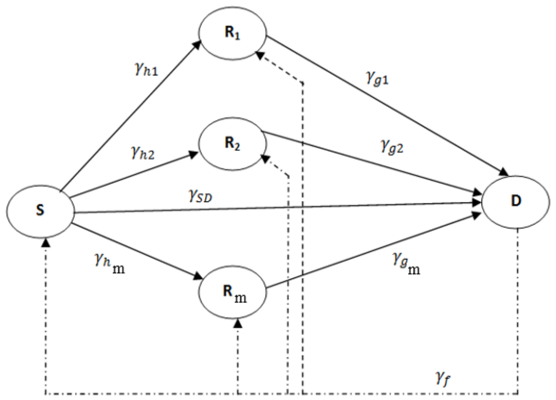
III. SYSTEM MODEL

In this paper, the transmitter, destination, and relays are assumed to be a single antenna. Figure 1-a represents the system model for link adaptation with cooperative relaying, where the source, *S*, transmits data to the destination, *D*, and Relays, R_i , $i \in \{1,2,\ldots m\}$. In the first time slot, the source transmits the data with energy, E_s, to the relays. The same data received to the destination via the direct path between the source and destination. In the second time slot, the i^{th} relay amplifies and forwards the data to the destination. Orthogonal transmission is assumed for both time slots, as shown in Figure 1-b. The channel coefficients between *S* and R_i is h_i, and between R_i and *D* is g_i. The SNR of the direct path between *S* and *D* is related to γ_{SD}. In an energy harvesting system, each relay assumed a harvest portion of the received signal by power splitting.

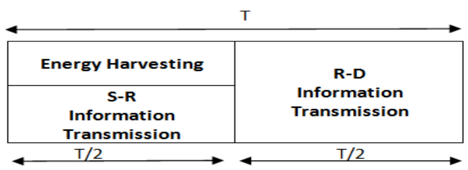
A portion of the received signal to each relay is divided for information decoding by a value of α_i; thus, the rest of the signal will be represented by $1-\alpha_i$, as shown in Figure 1-c. For adaptive modulation systems, a noisy feedback SNR γ_f is expected to be the source of feedback errors, which will be explained in detail in Section IV.

Adaptive transmission is considered to enhance the spectral efficiency in cooperative relaying, where the transmitter decides the best modulation scheme depending on the feedback channel from the receiver. Based on this reason, a feedback channel is considered.

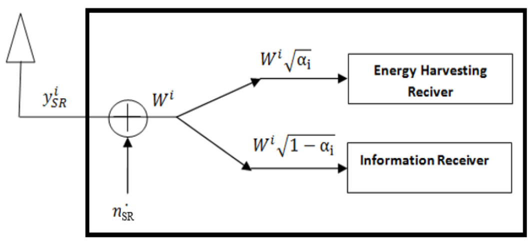
On the other hand, the optimised power splitting factor is considered as an essential parameter to decide the percentage of the required energy to the relay operation and the remaining energy to the information decoding in EH relaying. Based on this reason, GA optimisation is used.



(a)



(b)



(c)

Figure 1: (a) System Model (b) Time frame structure for power splitting (c) Block Diagram for power splitting at the relay

Without EH, the combined signals at the destination for *m*-relays can be computed using all relay participate (ARP), where total SNR can be shown as [27, 28]:

$$\gamma_{tot} = \gamma_{SD} + \sum_{i=1}^{m} \frac{\gamma_{hi}\gamma_{gi}}{\gamma_{hi}+\gamma_{gi}+1} \tag{1}$$

where $\gamma_{hi} = |h_i|^2 E_s/N_o$ is the instantaneous SNR between S and R_i , $\gamma_{gi} = |g_i|^2 E_s/N_o$ is the instantaneous SNR between R_i and D. The SNR between a direct path between S and D is considered as γ_{SD} with channel coefficients h_{sd}. All nodes are assumed with a single antenna and all nodes operate in a half-duplex mode. All links are assumed to undergo Rayleigh fading channel.

In this paper, QPSK, 16-QAM, and 64-QAM are used for link adaptation. Target bit error rate, *BERT* of 10^{-5} is assumed to be suitable for the higher modulation mode and Quality of Service (QoS) for future wireless services. SNR values can be divided into *N+1* regions, where *N* is a number of thresholds of SNR values. The instantaneous BER of M-QAM and regions of SNR in link adaptation system can be calculated using [29]:

$$\mathrm{BER}_{\mathrm{M-QAM}} \approx 0.2\mathrm{e}^{\left(\frac{-1.5\gamma}{\mathrm{M}-1}\right)} \tag{2}$$

$$\gamma_1 = [erfc^{-1}(2BERT)]^2 \tag{3}$$

where $erfc^{-1}(.)$ represents the inverse complementary error function. The thresholds can be found by inverting (2) to be as:

$$\gamma_n = \frac{2}{3}k_0(2^n - 1) \quad ,n = 2,4,6 \tag{4}$$

$$\gamma_{N+1} = \infty \tag{5}$$

where;

$$k_0 = -ln\,(5\,BERT) \tag{6}$$

where $BERT$ is the target bit error rate.

In the case of AF, assuming P_s as the transmit power, the received signal at each relay is $P_s h_i$ while, $P_s h_i(1-\alpha_i)$ is the transmitted signal from the relay. The total rate can be written as [27].

$$R = \frac{1}{2}log_2\left(1 + \sum_{i\in m} \frac{\zeta P_s h_i \alpha_i P_s h_i (1-\alpha_i) g_i}{1 + P_s h_i \alpha_i + \zeta P_s h_i (1-\alpha_i) g_i}\right) \tag{7}$$

where ζ is the energy conversion efficiency. The main optimization goal in the above equation is to maximize rate. As shown from equation (7), the optimization of the problem is described as a non-convex problem, where the maximization will be on α_i.

$$Max\left\{\frac{\zeta {P_s}^2 {h_i}^2 \alpha_i (1-\alpha_i) g_i}{1 + P_s h_i \alpha_i + \zeta P_s h_i (1-\alpha_i) g_i}\right\} \tag{8}$$

GA begins with a randomised population through a generation that is considered as a set of chromosomes. Every chromosome contains a fitness, in which an evaluation is conducted based on the objective function. As stated by the survivor selection approach, chromosomes with high fitness ability will have high chances of surviving for the evolution, while those with limited fitness has great possibilities of being discarded. Optimal power splitting ratio for *m*-relays create a chromosome for EH cooperative relaying, where the objective function in (8) is used to compute the chromosome's fitness.

GA is considered a global optimisation method [30], which defined as an initial population of many optimisation problems to reach the best solution. In this work, continuous GA optimisation technique is used to solve (8), which is considered as a non-convex problem, since GA can optimise concave or non-convex functions and provides suitable results compared to other complex methods. The main parameters of GA are shown in Table 1.

Table 1
Parameters of GA Algorithm for the Optimisation of Equation (8)

Population size	Maximal generation times	Cross-over fraction	Mutation rate
50	200	0.8	0.01

IV. CHANNEL MODEL

For Rayleigh fading channel, the moment generating function (MGF) of the direct path can be computed as:

$$M_{\gamma_{SD}}(s) = \int_0^\infty \frac{1}{\bar{\gamma}_{SD}} \exp\left(\frac{-\gamma}{\bar{\gamma}_{SD}}\right) \exp(-s)\, d\gamma \tag{9}$$

$$M_{\gamma_{SD}}(s) = (1+\bar{\gamma}_{SD}s)^{-1} \tag{10}$$

Without EH relaying, received SNR is independent and identical distribution (i.i.d.) for each path, then we can write that MGF of γ_tot as:

$$M_{\gamma_{tot}}(s) = M_{\gamma_{SD}}(s) \prod_{i=1}^{m} M_{\gamma_i}(s) \tag{11}$$

To find M_(γ_i) (s), the cumulative distribution function (CDF) of γ_i should be computed as:

$$P_{\gamma_i}(\gamma) = 1 - Prob(\gamma_{hi} > \gamma) Prob(\gamma_{gi} > \gamma) \tag{12}$$

where,

$$Prob(\gamma_{hi} > \gamma) = \int_\gamma^\infty \frac{1}{\bar{\gamma}_{hi}} \exp\left(\frac{-\gamma}{\bar{\gamma}_{hi}}\right) d\gamma = \exp\left(\frac{-\gamma}{\bar{\gamma}_{hi}}\right) \tag{13}$$

Assume $\bar{\gamma}_{hi} = \bar{\gamma}_{gi} = \bar{\gamma}$,

$$P_{\gamma_i}(\gamma) = 1 - \exp(\frac{-2\gamma}{\bar{\gamma}}) \tag{14}$$

The probability density function (PDF) of γ_i can be computed as:

$$p_{\gamma_i}(\gamma) = \frac{2}{\bar{\gamma}} \exp(\frac{-2\gamma}{\bar{\gamma}}) \tag{15}$$

and MGF of γ_i can be computed as:

$$M_{\gamma_i}(s) = (1+0.5\bar{\gamma}s)^{-1} \tag{16}$$

The combined MGF can be computed as:

$$M_{\gamma_{tot}}(s) = (1+\bar{\gamma}_{SD}s)^{-1}(1 + 0.5\bar{\gamma}s)^{-m} \tag{17}$$

In the case of cooperative energy harvesting, the received signal at the relay i, can be written as:

$$y_{SR}^i = \sqrt{P_s} h_i s + n_{SR} \tag{18}$$

where $n_{SR} \sim CN(0, \sigma_{SR}^2)$ is AWGN with noise varience σ_{SR}^2. In this paper, a dynamic power splitting ratio is used, so each relay harvest a different portion of the received signal. While, some of the previous literature assumed the same power splitting ratio, which was called static power splitting [31]. Assuming PS scheme, $\sqrt{\alpha_i} y_{SR}^i$ is used for energy harvesting to relay *i*, where the remaining $\sqrt{1-\alpha_i} y_{SR}^i$ is used for information detection for relay *i*. The harvested energy at relay *i*, at time $\frac{T}{2}$, where *T* is the block time can be presented as follows:

$$E^i = \zeta \alpha_i P_s |h_i|^2 . \left(T/_2\right) \tag{19}$$

After power splitting, at the input of the energy harvester and after power splitting, the received signal can be written as:

$$R^i = \sqrt{1-\alpha_i}\left(\sqrt{P_s} h_i s + n_{SR}\right) + \dot{n_{SR}} \tag{20}$$

where $\dot{n_{SR}} \sim \mathrm{CN}(0, \dot{\sigma}_{SR}^2)$ is AWGN from the information receiver. In the second time slot, the transmitted power of the relay *i* is given by:

$$P_R^i = \frac{E^i}{T/2} = \zeta \alpha_i P_s |h_i|^2 \tag{21}$$

The relay amplifies the signal and forwards it to the destination. Thus, the transmitted signal at the relay can be written as:

$$W^i = \sqrt{P_s P_R^i (1-\alpha_i)} G h_i s + \sqrt{P_R^i} G n_W \tag{22}$$

where, $n_W = \sqrt{(1-\alpha_i)} n_{SR} + \dot{n_{SR}}$, *G* is the gain of relay *i*, we assume fixed gain to all relays, *G*, which is given as:

$$G = \frac{1}{\sqrt{(1-\alpha_i) P_s {h_i}^2 + \sigma_W^2}} \tag{23}$$

The received signal at the destination

$$y_{RD}^i = g_i W^i + n_{RD} \tag{24}$$

After substituting Equation (22) and Equation (23) into Equation (24), the combined SNR can be written as:

$$\gamma_{tot} = \frac{\zeta\alpha(1-\alpha)\bar{\gamma}}{\zeta\alpha + \zeta\alpha(1-\alpha) + (1-\alpha)} \tag{25}$$

Assuming that $\dot{\sigma}_{SR}^2 = \sigma_{SR}^2$, $\sigma_{RD}^2 = \sigma_{SD}^2$, $\mathbb{E}\{|h_i|^2\} = \mathbb{E}\{|g_i|^2\} = 1$. In the case of cooperative energy harvesting, Equation (11) can be rewritten as:

$$M_{\gamma_{tot}}(s) = (1+\bar{\gamma}_{SD}s)^{-1} \prod_{i=1}^{m} (1+C_i s)^{-1} \tag{26}$$

where C_i is the SNR at relay *i*. After using a partial fraction, the total MGF can be written as;

$$M_{\gamma_{tot}}(s) = R_{SD}(1+\bar{\gamma}_{SD}s)^{-1} + \sum_{i=1}^{m} R_i(1+C_i s)^{-1} \quad (27)$$

where;

$$R_{SD} = \prod_{i=1}^{m}\left(1-\frac{C_i}{\bar{\gamma}_{SD}}\right)^{-1} \quad (28)$$

$$R_i = (1-\frac{\bar{\gamma}_{SD}}{C_i})^{-1}\prod_{w=1,w\neq i}^{m}\left(1-\frac{C_w}{C_i}\right)^{-1} \quad (29)$$

After taking the inverse Laplace transform, the total PDF can be written as:

$$p_{\gamma_{tot}}(\gamma) = \frac{R_{SD}}{\bar{\gamma}_{SD}}exp\left(\frac{-\gamma}{\bar{\gamma}_{SD}}\right) + \sum_{i=1}^{m}\frac{R_i}{C_i}exp\left(\frac{-\gamma}{C_i}\right) \quad (30)$$

For adaptive modulation systems, a noisy feedback channel is supposed to be the source of feedback errors or interference. It is assumed that the optimal CSI is achieved at the network destination node. In practice, due to feedback errors, instead of using the probability of constellation i, the probability of constellation j is used. The resultant transition probability can be presented in a matrix denoted by $Q = [q\_(i,j)]$, where $q\_(i,j)$ represents the transition probability of the constellation size. In practice, the $q\_(i,j)$ is a function of both the feedback channel quality and the utilised signalling model over the defined feedback channel. By receiving the j^{th} symbol at the transmitter, the j^{th} modulation size is selected for the transmission. Therefore, one symbol is required for the feedback that considerably decreases the channel overhead. The j^{th} constellation size is assumed to be the wedge-shaped region modelled as:

$$a = min\{|i-j|, N+1-|i-j|\} \quad (31)$$

$$\theta_1 = \frac{(2a-1)\pi}{N+1},\ \theta_2 = \frac{(2a+1)\pi}{N+1} \quad (32)$$

After that, $q_{i,j}$ can be achieved by averaging the instantaneous transition probability over that channel.

$$q_{i,j} = \int_0^{\infty}\varphi(\gamma_f;\theta_1,\theta_2)p_\gamma(\gamma)d\gamma \quad (33)$$

where $p_\gamma(\gamma)$ stands for the PDF of the received instantaneous SNR of the channel. γ_f represents the instantaneous received SNR for the feedback channel. $\varphi(\gamma_f;\theta_1,\theta_2)$ is the instantaneous transition probability [32].

V. Performance Analysis

A. Spectral Efficiency

The following expression can be used to compute the spectral efficiency for a point-to-point adaptive modulation system, denoted by η without any feedback error:

The factor 1/2 related to the fact that transmission process of cooperative diversity occurred in two time slots.

$$\eta = \frac{1}{2}\sum_{n=1}^{N} log_2{}^{M_n} F_n \quad (34)$$

where F_n represents the probability of selecting the n^{th} modulation model for the transmission. This probability can be computed by the difference between the next modulation index and the current modulation index as follows:

$$F_n = P_\gamma(\gamma_{n+1}) - P_\gamma(\gamma_n) \quad (35)$$

where γ_n is the threshold of SNR and $P_\gamma(.)$ is the CDF of received SNR. In the presence of feedback errors, the spectral efficiency can be expressed as follows:

$$\eta_{tot} = \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} log_2^{(M_j)} q_{i,j}\, F_j \quad (36)$$

B. Outage Probability

During the adaptive modulation, there are no performed transmissions below specific threshold SNR. Practically, when a fast process in digital mobile radio systems is superimposed on a slow one, the description of the link quality then depends on outage probability. It is a rational measure of performance, where it is associated with the channel slow variations [33]. It can be presented as the instantaneous probability that exceeds a predefined threshold or the probability that an output SNR value is below the cut-off SNR, γ_TH. The following expression represents the outage probability for a specific BERT.

$$P_{out} = \int_0^{\gamma_{TH}} p_\gamma(\gamma)d\gamma \quad (37)$$

The next problem is to find the best γ_{TH} value, using the following formula:

$$\int_{\gamma_{TH}}^{\infty}\left(\frac{1}{\gamma_{TH}}-\frac{1}{\gamma}\right)p_\gamma(\gamma)d\gamma = 1 \quad (38)$$

Equation (38) can be rewritten as:

$$\frac{1}{\gamma_{TH}}\int_{\gamma_{TH}}^{\infty} p_\gamma(\gamma)d\gamma - \int_{\gamma_{TH}}^{\infty}\frac{1}{\gamma}p_\gamma(\gamma)d\gamma = 1 \quad (39)$$

By using GA as an optimisation technique, the above equation can be minimised to:

$$Min\left\{\frac{1}{\gamma_{TH}}\int_{\gamma_{TH}}^{\infty} p_\gamma(\gamma)d\gamma - \int_{\gamma_{TH}}^{\infty}\frac{1}{\gamma}p_\gamma(\gamma)d\gamma - 1\right\} \quad (40)$$

The output of GA will be an optimised value of γ_TH. The main parameters of GA are shown in Table 2.

Table 2
Parameters of GA Algorithm for the Optimisation of Equation (40)

Population size	Maximal generation times	Cross-over fraction	Mutation rate
50	100	0.8	0.01

VI. SIMULATION AND NUMERICAL RESULTS

In this section, two scenarios are presented. The first scenario is perfect feedback channel and the second scenario is noisy feedback channel. The number of thresholds of SNR values N=3, target bit error rate BERT = 〖10〗^(-5), and the number of relays m = 2, 5.

Figure 2 shows the SE for conventional and EH relays under a perfect feedback channel for m = 2. Cooperative EH relay causes a degradation in the SE compared with the conventional cooperative relay. For example, at 20 dB SNR, the SE for the conventional relay for the perfect feedback channel is 2.1 bits/sec/Hz and that for the EH relay is approximately 1.7 bits/sec/Hz. Therefore, a 0.4 bits/sec/Hz loss is observed in the EH relay in comparison with the conventional cooperative relay, which translated to a 19% loss in SE.

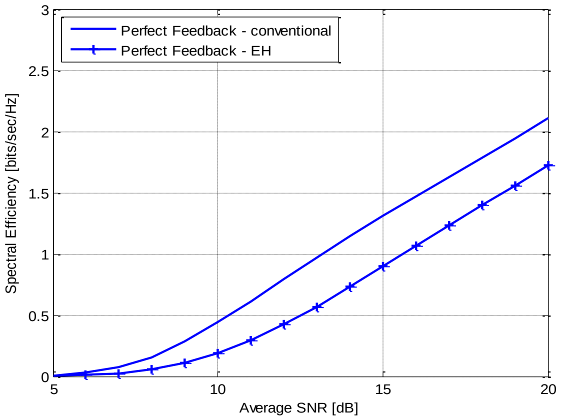


Figure 2: Spectral Efficiency of conventional and EH relaying under perfect feedback channel, m = 2

Figure 3 shows the SE of the imperfect feedback with feedback SNRs of 0 dB and −10 dB to represent the noisy feedback channel. The noisy feedback affects the performance of SE. At 20 dB SNR, the SE for the perfect feedback for the conventional and EH relays are 2.1 and 1.7, respectively. However, in case of an imperfect feedback channel, the SE for the conventional and EH relays are 1.8 and 1.4 for a 0 dB feedback channel and 1.6 and 1.3 for a −10 dB feedback channel, respectively. The percentage of the loss in SE is explained as follows. In a conventional relay at 20 dB SNR, the results of the SE decrease from 2.1 bits/sec/Hz at the perfect feedback to 1.8 (at 0 dB) and 1.6 bits/sec/Hz (at −10 dB) at the SNR feedback. This finding shows the loss in SE of approximately 14% in the 0 dB feedback channel and 24% in the −10 dB feedback channel.

Figs. 4 and 5 represent the SE for the perfect and imperfect feedback for m = 5. From these figures, the performance of the SE enhances with the increase in the number of relays. For example, for m = 2, the SE with perfect feedback of the conventional and EH relays are 2.1 and 1.7, respectively. Meanwhile, for m = 5, the SE with perfect feedback of the conventional and EH relays are 2.6 and 2.2, respectively, which translate to a 20% and 22% improvement in the SE, respectively. Furthermore, a 0.4 bits/sec/Hz loss is observed in the EH relay compared with the conventional cooperative relay, which translates to a 15% loss in the SE in the case of m = 5.

As shown in the previous figures, the EH relay incurred a loss in comparison with the conventional relay due to the decoding of information from the harvested energy. Previous works in this field have focused on the degradation of the SE due to the EH. For example, in [34], simultaneous wireless information and power transfer (SWIPT) was proposed for orthogonal frequency-division multiplexing (OFDM) of a decode-and-forward (DF) relay. The results show that the degradation of SE reached approximately 40%.

Figure 6 represents the effect of the power-splitting ratio on the SE. From the figure, the noisy feedback channel decreases the SE compared with the perfect feedback channel. This result applies to different cases of SNR feedback. The maximum SE is 1.78 bits/sec/Hz for the perfect feedback channel, which is approximately 1.55 and 1.37 for 0 dB and −10 dB, respectively. When α is too small, only a limited amount of energy is harvested, which can directly affect the performance of the SE. By contrast, when α is extremely large, the energy harvested at the relay exceeds the required level, which decreases the SE level. As shown in Figure 6, the maximum SE occurs at approximately 0.5 power splitting ratio, which implies that the relay is positioned between the transmitter and receiver. Thus, the optimisation that involves the selection of the optimum value of α is important in the EH system.

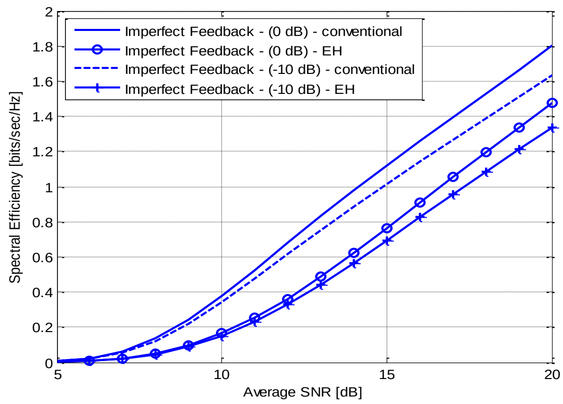


Figure 3: Spectral Efficiency of conventional and EH relaying under imperfect feedback channel, m = 2

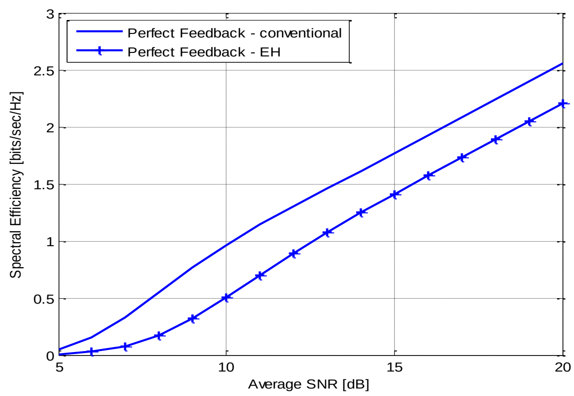


Figure 4: Spectral Efficiency of conventional and EH relaying under perfect feedback channel, m = 5

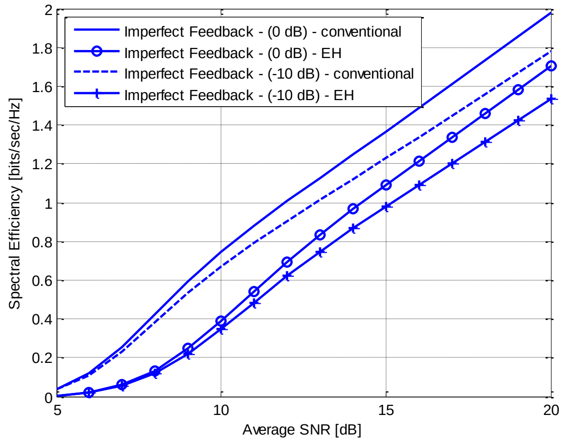


Figure 5: Spectral Efficiency of conventional and EH relaying under imperfect feedback channel, m = 5

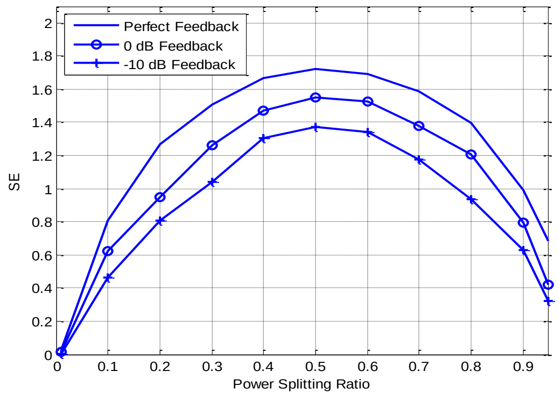


Figure 6: SE for Single Relay at 20 dB Average SNR for Different Values of Power Splitting Ratio

Figure 7 shows the outage probability between the conventional cooperative relay system and cooperative EH relay. The main parameters are γ ̅=10 with an output of γ_(TH)= 0.53.

A degradation in the outage probability performance is observed when EH is used. Achieving Pout = 〖10〗^(-5) requires a conventional outage probability of approximately 14 dB SNR.

A portion of the power that should be received at the destination is consumed at the relays for EH. Therefore, approximately 18 dB SNR is required because achieving a certain value of outage probability in the EH relay requires a higher power level than the conventional cooperative relay.

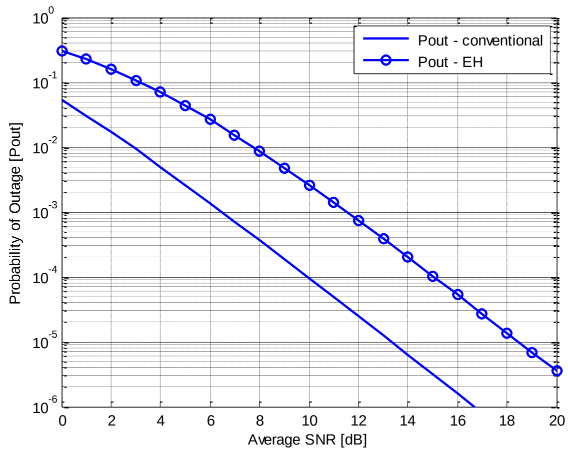


Figure 7: Outage Probability with and without EH, m = 2

VII. CONCLUSION

In this study, an AF-EH relay with an adaptive transmission was introduced, where a PS relay was adopted. The imperfect feedback channel affects the decision of the transmitter in selecting the best modulation scheme. This condition results in an instantaneous transition probability over that channel, which reflects on the performance of the SE. Meanwhile, as opposed to the conventional relay that works without recharging, the EH provides a source of power in relaying networks, which can be considered as a green wireless communication technique. A degradation in the SE due to the imperfect feedback channel is observed. Using the EH degrades the performance of the SE of the perfect feedback channel to 19% and 15% for m = 2 and m = 5, respectively.

Meanwhile, the increase in the number of relays enhanced the SE of the perfect and imperfect feedback channels. Furthermore, a closed-form expression of the outage probability of an EH relay was shown. The effect of the EH on the outage probability, which causes a shift in the performance of approximately 4 dB SNR, was also shown.

The significant finding from this paper indicates the potential of WEH technique that can be applied in the spectral efficiency of wireless cooperative relaying systems, which expected to solve the problem of the conventional battery operated relay in future 5G wireless networks, such as machine type communications (MTC) and device-to-device (D2D) communication. Wireless energy harvesting relaying can be employed in a scenario where the MTC requests for D2D relays to forward the data to the MTC devices due to limited energy.

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