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Optimized Power Allocation for Cooperative Amplify-and-Forward with Convolutional Codes

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Abstract
Future wireless communications technology should fulfill the demands of multimedia applications, interactive internet service, high data rates and power efficiency. However, wireless channel is affected by multipath fading that can degrade the system performance. To overcome the problem, cooperative communication has been introduced to be an efficient diversity technique to combat the multipath fading, to improve capacity and the system performance, and to reduce the energy comsumption by using power allocation technique in the network. This paper proposes an optimized power allocation (OPA) for cooperative amplify-and-forward (AF) protocol with convolutional codes (CC). A computer simulation model for the proposed system is developed using Matlab programming. Then, performance of the system is evaluated in terms of the system throughput, bit error rate and amplification coeficient for power allocation. Furthermore, the different rates of CC are also considered in the network. Simulation results show that multi-relay AF network can provide a higher throughput and lower bit error rate. Moreover, the performance of OPA system is better than that of non-OPA system. The using lower rate of CC in the OPA system provides coding gain for multi-relay cooperative AF network. Finally, the different amplification coeficients among relays give a significant improvement to optimize the system performance.

Keywords: *Optimized, power allocation, AF protocol, cooperative communication, convolutional codes*

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1. Introduction

Wireless communication technology has been rapidly developed over the past decade. Several factors that drived those developments are demands of wireless multimedia communication, interactive internet service, high speed data transmission and future communication system with efficient power allocation. Consequently, it is estimated in the future data traffic over the multimedia application will be significantly increased. It will be a tough challenges for multimedia application in wireless communication channel that consumed very large bandwidth [1]. Transmitted information over wireless channel will experience reflection, diffraction and scattering. In addition, wireless channel will be also affected by multipath fading which can lead to the fluctuation in amplitude, frequency and phase of original information signal and can degrade overall system performance. This problem can be overcome by increasing the transmission power and bandwidth. However, this method will require a lot of power and greater bandwidth resources. The diversity technique called Multiple-input Multiple-output (MIMO) has been introduced to deal with the problem of multipath fading in wireless communication [2, 3]. MIMO system provides diversity gain to improve the reliability of signals. MIMO system has also proved to increase channel capacity that lead to the increasing of overall throughput in wireless communication system with limited resource allocation. However, the implementation of MIMO in mobile devices, such as mobile phone, laptop, tablet, etc., still have some constraints, including the limited size of hardware, high complexity and relatively expensive cost of component. Therefore, some studies have reconsidered using the concept of cooperative communication. In this system, the source transmits information to a destination via one or multi-relay system [4–6]. The use of relay is creating virtual MIMO channel for wireless communication.

Cooperative communication system is one of the effective techniques to obtain diversity that can reduce the effect of multipath fading in a wireless communication system. The signal

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from source transmits to relay that can be in the form of fixed such as micro BTS or mobile devices to broadcast or forward the information to destination. This system has proved to be one of the powerful physical layer techniques to reduce the effect of fading and to increase the physical layer capacity in wireless relay network. There are some main transmission protocols that are widely used in cooperative communication e.g., Amplify-and-Forward (AF), Decode-and-Forward (DF) and Compress-and-Forward (CF) [5, 7, 8]. AF protocol is one of the simplest protocols in cooperative network, where the relay is only amplifying and forwarding the information to destination. However, in DF protocol, the function of relay is more complex where it has to decode information from source before it forwards those decoded information to destination. It makes AF is more realistic approach to be applied in ad-hoc wireless network. Furthermore, in cooperative network, it needs to take into account the efficient use of transmission power because most of mobile devices are limited power source. The signal power will be degraded during the process of information transmission from source due to the effect of multipath fading. Therefore, in this study, we consider the use of AF protocol because of its simple and suitable implementation for cooperative network. Thereby, we propose the new approach to optimize power allocation in AF protocol by simply using convolutional code that can be easier to be implemented together with amplification process in relay system.

Some of interesting power allocation schemes in cooperative networks have been introduced in the previous studies. The main framework for optimized power allocation scheme has been roughly discussed in [9], where optimized power allocation became the main technique to realize information transmission over relay network. Moreover, optimization issues for AF protocol over block-fading channels have been investigated in [10]. In [11], power allocation has been further studied to maximize relay fading channel capacity and to reduce the limit of ergodically channel capacity. Power allocation method using partially information feedback has also introduced in [12]. The research in [13] has studied some of the power allocation schemes for the use of relay network in multi-cell environment. Power allocation for AF cooperative network has been introduced in [15] by considering total transmit power for both source and relay nodes. Optimal combination between relay selection method and power allocation has also been studied in [15, 16]. This combination method has proved to reduce the computation time and reach solution value close to optimal power. As studied in [17], by using average gain method, it is showed that symbol error rate can be minimized for optimized power allocation.

In this paper, as previously discussed, we mainly investigate optimized power allocation in AF protocol by using one of channel coding techniques which is convolutional code. Convolutional code is one of error correction techniques that has been widely used in wireless communication system to improve bit error rate (BER). Moreover, power allocation is one of important factors in wireless transmission that was implementing to reduce the effect of fading channel and interference. Thus, an appropriate power allocation method in cooperative communication will be efficient use of power resources and increase system performance. This study will combine the technique between convolutional code with AF protocol to optimize power allocation for better power utilization and to obtain coding gain in system performance. Then, computer simulation for the proposed system is developed using Matlab programming. In the computer simulation, several parameters that have influenced in optimized power allocation are analyzed. These parameters are throughput, BER, number of relays, code rate of convolutional code and amplification coefficient of AF protocol. Generally, most of cooperative protocol strategy will be evaluated in terms of BER at specific range of SNR. The simulation results of the proposed system performance are compared to the system performance without optimized power allocation. Simulation results show that the considered parameters for power allocation are having significant influence to system performance. Moreover, the system with optimized power allocation has shown better performance compare to the system without optimized power allocation. The use of lower rate of convolutional codes can also provide coding gain to optimize the cooperative system performance.

2. System Model

AF protocol is the simplest protocol in cooperative communication system, where each relay only performs amplifying and forwarding signal to destination [14]. In AF protocol, the relay is not perfoming any coding process for the received signal from source. In this study, we are using multi-relay system with k relays. Convolutional code will be applied in source and AF protocol in relay will be functioned as power control during information transmission from source to destination through assisted one or multi-relay nodes. This system model will be a solution to increase system performance by reducing BER and amplifying attenuated power over the process of information transmission to destination.

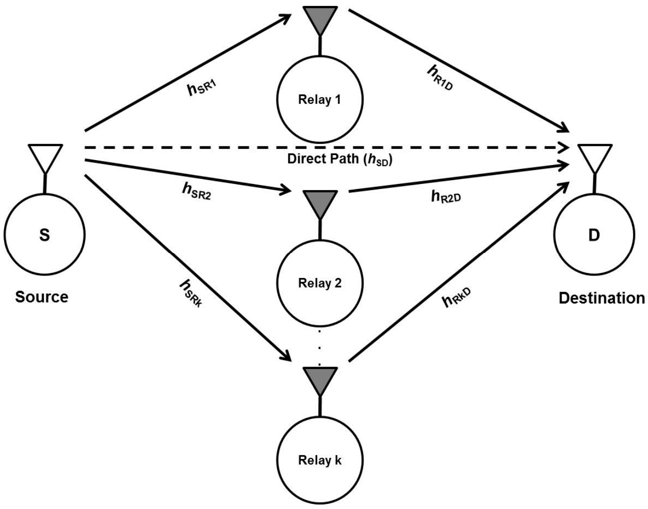

Figure 1. Cooperative multi-relay AF network model

Figure 1 shows the system model for AF protocol in half-duplex cooperative communication with multi-relay, where each node cannot simultaneously sending and receiving information at the same time. AF cooperative transmission system can be divided into 2 phases. In first phase, source (S) send information direct to destination and to k relays (S, R$_i$), where $i = 1, 2, \ldots, k$. There will be added noise for any received signal in k relays and it follows the equation as below:

$$y_{SRi} = h_{SRi}x_s + n_{Ri} \tag{1}$$

$$y_{SD} = h_{SD}x_s + n_D \tag{2}$$

where, y_{SRi} is the received information signal at relay i, h_{SRi} is coefficient of channel between source and relay i, x_s is transmitted information signal from source, n_{Ri} is noise that was generated between source and relay i, y_{SD} is received information signal at destination, h_{SD} is coefficient of channel for direct path between source and destination and n_D is noise that was generated over direct path.

In second phase, k relays (R$_i$, D) amplify the received signal and forward those amplified signal to destination (D). AF cooperative in this phase is a function as a protocol to perform amplification process for information signal which was attenuated during transmission process over source and k relays. The received signal in the destination can be expressed in equation as follow:

$$y_{RiD} = \beta_i h_{RiD}x_s + n_{RiD} \tag{3}$$

where, β_i is amplification coefficient of relay i, h_{RiD} is coefficient of channel between relay i and destination and n_{RiD} is noise that was generated between relay i and destination. Amplification coefficient in AF protocol can be calculated by using the equation as follow:

$$\beta_i = \sqrt{\frac{P_i}{(P_0|h_{SRi}|^2 + N_0)}} \tag{4}$$

where, P_i is transmitted power of relay i, P_0 is transmitted power of source and N_0 is noise variance of channel.

Channel coeficient can be modelled as independent zero mean of circularly symmetric complex Gaussian random variables with σ_{SD}^2, σ_{SRi}^2 and σ_{RiD}^2. Channel model is following Rayleigh distribution or as famously known as Rayleigh flat-fading model [14]. Furthermore, received signal for each phase can be combined by using Maximum Ratio Combiner (MRC), where output signal of MRC will follow the equation as below [14, 17]:

$$y = \alpha_{SD} y_{SD} + \sum_{i=1}^{k} \alpha_{SRi} y_{SRi} \quad (5)$$

where α_{SD} and α_{SRi} are MRC coefficient for direct path transmission and cooperative transmission and can be calculated by following the equation:

$$\alpha_{SD} = \frac{\sqrt{P_0}\, h_{SD}}{N_0} \quad (6)$$

and

$$\alpha_{SRi} = \frac{\sqrt{P_0}\, \beta_i h_{SRi} h_{RiD}}{[N_0(1+\beta_i^2 |h_{RiD}|^2)]} \quad (7)$$

3. Optimized Power Allocation and Simulation Model

3.1 Optimized Power Allocation

In this research, the optimization of the power allocation is conducted when source transmits signal to relay, where the signal power for each relay is allocated with different amount of power. On contrary, the cooperative system that does not have optimized power allocation will have the same power for each relay. At relay nodes, AF protocol will amplify the power signal and then forward to destination. The process of amplifying the signal power or optimized power allocation (OPA) strategy can be illustrated as in Figure 2. Mathematical analysis for the OPA strategy is adopted and also modified from [9-11, 14, 17].

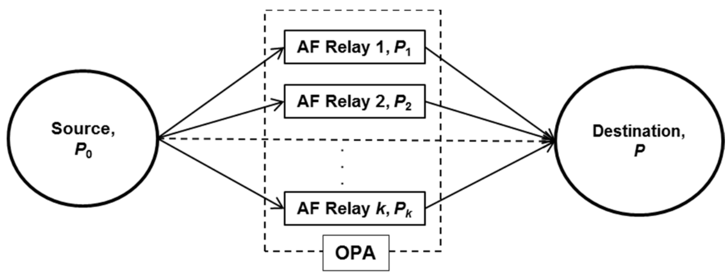

Figure 2. Optimized AF protocol strategy

In cooperative multi-relay system as highligted in Figure 2, the total transmit power (P) is the sum of transmission power source (P_0) and the power of k relays (P_i). Then the total power can be calculated by the following equation:

$$P = P_0 + \sum_{i=1}^{k} P_i \quad (8)$$

where P_0 and P_i are the transmission power of the source and the i^{th} relay, respectively.

In each section of transmission AF cooperative has each SNR value as follows:

a) SNR for the direct part can be written as follow:

$$\gamma_{SD} = \frac{|h_{SD}|^2 P_0}{N_0} \quad (9)$$

b) SNR for transmission part of the source to relay is

$$\gamma_{SRi} = \frac{|h_{SRi}|^2 P_0}{N_0} \quad (10)$$

c) SNR value when the relay transmits information to the destination is

$$\gamma_{RiD} = \frac{|h_{RiD}|^2 P_0}{N_0} \quad (11)$$

Then, the SNR value after process of MRC at the AF cooperative systems with multi-relay can be calculated by the following equation.

$$\gamma = \gamma_{SD} + \sum_{i=1}^{k} \frac{\gamma_{SRi}\gamma_{RiD}}{\gamma_{SRi}+\gamma_{RiD}} \quad (12)$$

This research uses binary phase shift keying (BPSK) modulation, so BER can be derived as follows:

$$P_e \gg \frac{3}{16}\frac{1}{\bar{\gamma}_{SD}}\prod_{i=1}^{k}\left(\frac{1}{\bar{\gamma}_{SRi}} + \frac{1}{\bar{\gamma}_{RiD}}\right) \quad (13)$$

where, $\bar{\gamma}_{SD}$, $\bar{\gamma}_{SRi}$ and $\bar{\gamma}_{RiD}$ are the average of SNR from direct transmission, transmission source to the relay and from the relay to the destination, respectively. By inserting the average value of SNR for each of the equations of (9)-(11) into the equation of (13) and then performed a mathematical manipulation, so the relationship P_0 and P_i are obtained as follows:

$$P_0 = \frac{P}{1+\sum_{i=1}^{k}\frac{\sqrt{H_{SRi}^2+8H_{SRi}H_{RiD}}-H_{SRi}}{4H_{RiD}}} \quad (14)$$

and

$$P_i = \frac{P\left(\sqrt{H_{SRi}^2+8H_{SRi}H_{RiD}}-H_{SRi}\right)}{4H_{RiD}\left(1+\sum_{i=1}^{k}\frac{\sqrt{H_{SRi}^2+8H_{SRi}H_{RiD}}-H_{SRi}}{4H_{RiD}}\right)} \quad (15)$$

where, H_{SRi} and H_{RiD} are average channel coefficient from the relay path in AF cooperative systems.

The proposed AF cooperative communication system performance in this research will be evaluated by considering the factors that have influenced in the use of network resources. The first factor is throughput, which is defined as the number of data information that can be transmitted from the source to receiver at a certain time unit. Throughput for k relays can be calculated by the following equation [18]:

$$T = \frac{N}{2}\log_2[1 + P\ln(k)] \quad (16)$$

where, *N* is paralell fading channel. The second factor is bit error rate (BER) level of the network. That is one of the bit error measurements during transmission, which is a comparison between the number of received bit errors and number of transmitted bits from the source. it also represents the quality of signal to be received by destination. In this research, BER is usually measured against the value of signal to noise ratio (SNR). For signals with BPSK modulation in Rayleigh fading channels, BER for the direct link can be calculated as follows [19]:

$$BER = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma}{1+\gamma}}\right) \quad (17)$$

where γ is signal to noise ratio. The last factor to be evaluated is the effect of amplification coeficient of the proposed system, where amplication (β) is one of the parameters for amplifying the signal on AF relay that is to be forwarded to destination. These will be an essential parameter to optimize power allocation in cooperative AF. Amplification factor can be divided into 2 categories: channel inversion [20] and constant amplification [21]. In the inversion channel, relay requires instantaneous channel estimation parameters for link from source to relay. So, relay power will be limited if the signal amplitude is low. In order to avoid signal amplitude remains high, the estimated amplitude of the signal at these links should be carried out continuously. Thus, it has a high complexity. Therefore, this paper considers the amplication factor as constant amplification.

3.2 Simulation Model

Simulation model of AF cooperative system of multi-relay (three relays in this paper) with optimized power allocation (OPA) and using convolutional codes can be seen in Figure 3. It consists of several parts, namely source, channel, relay amplification and destination. At source part, the transmitted information is in the form data that will be encoded using convolutional encoder and then modulated using BPSK modulation. Here, the use of convolutional code is to reduce the bit error rate caused by random noise, interference, and fading channels. As a result, channel error is minimized to an acceptable level, which is important to ensure reliable data transmission. In convolutional encoder, the transmitted data will be coupled with redundancy and formed to a codeword. Furthermore, the signal is transmitted to relay through a channel affected by fading and AWGN noise. The received signal in relay node will be amplified, optimized and then forwarded to destination, where each relay does not have the same power allocation. At destination, the received OPA signal will be combined by MRC and then the diversity decisions are made. The decided signal is demodulated and decoded by convolutional decoder to obtain the same data as transmitted by the source.

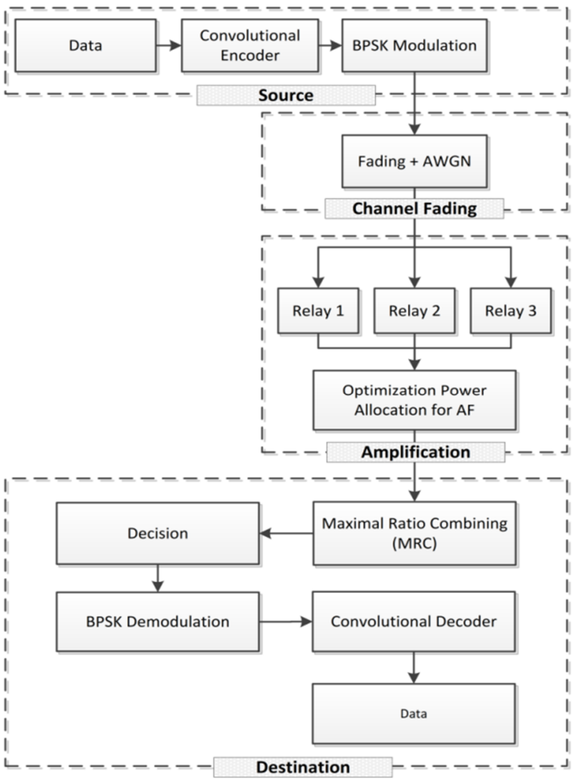

Figure 3. Computer simulation model

Based on the simulation model in Figure 3, simulation parameters, which are applied to evaluate the performance of AF cooperative system with optimized power allocation and using convolutional codes are shown in Table 1.

Table 1. Simulation Parameters

Parameter	Values
Input data	1000000 bits
Convolutional Code (CC) [22]	- (7, 5) CC for rate =1/2 - (7, 7, 5) CC for rate= 1/3
Modulation scheme	BPSK
Number of source	1
Number of relay	3
Number of destination	1
Channel	Rayleigh Fading
Noise	AWGN
SNR	0 to 30 dB
Amplification (β)	$0 \leq \beta \leq 1$
Total Power	1000 Watt
Combining technique	Maximal Ratio Combiner (MRC)

4. Results and Discussions

In this section, the performance of AF cooperative system with optimized power allocation and using convolutional codes will be evaluated by considering several parameters including throughput, BER and constant amplification coeficient at relay. These parameters are obtained from the results of computer simulation model in the proposed system. In general, the simulation results of the AF performance with OPA will be compared to the performance of non-OPA (NOPA), number of relays and the variation of the amplification coeficient among relays that are applied in the system.

First of all, Figure 4 shows the numerical results of equation (16) for throughput by optimizing the power allocation based on the number of relays and throughput for non-cooperative (direct). It is shown that throughput for AF cooperative system is much better than throughput of non-cooperative. For example, when the power is 600 W, throughput for a single relay of AF cooperative system is 3.5 bits/s, while the throughput for the non-cooperative is 2.2 bits/s. So throughput of wireless communication systems can be improved by cooperative systems. Furthermore, the number of relays will affects throughput of the system, where the throughput increases as the number of relays on the system increases. It is noticeable that when power is 600 W, throughput for 1, 2 and 3 relays used in system are 3.5 bits/s, 4.3 bits/s and 5.1 bits/s, respectively. In addition, the power used by relay also have influence to the throughput of the system. Therefore, the greater of power is used by relay, the bigger throughput is obtained in the network.

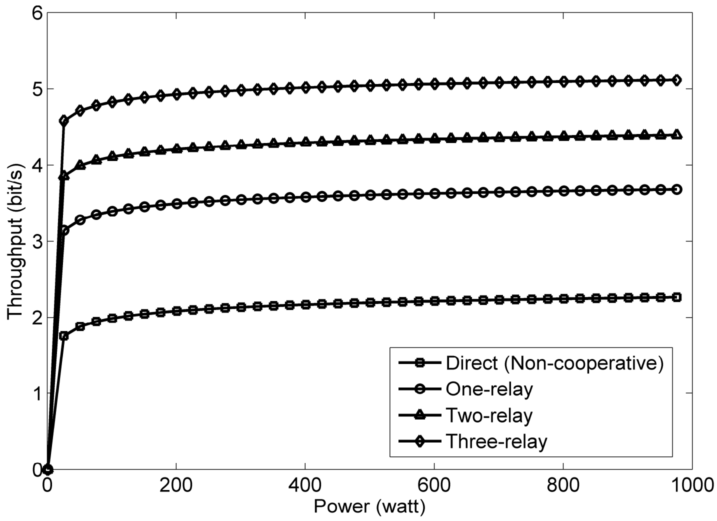

Figure 4. Throughput multi-relay AF versus power transmit

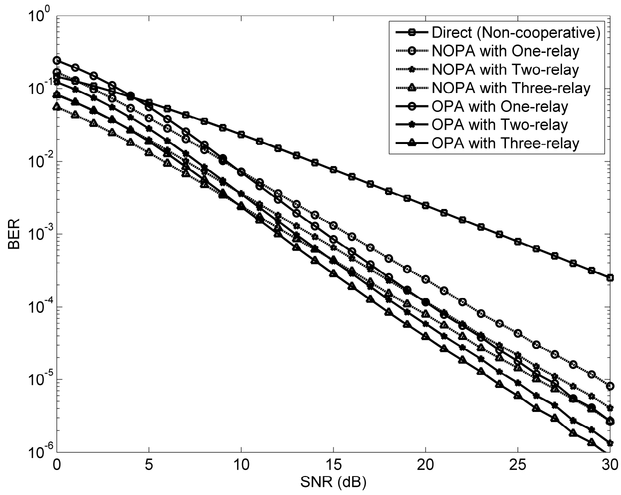

Figure 5. BER versus SNR for OPA and NOPA with convolutional code rate of 1/2

The main purpose of optimizing power allocation in the proposed AF cooperative is to minimize BER. Moreover, channel coding or error correction techniques such as convolutional codes have commonly been used and well implemented in order to minimize BER in the digital communication systems. Therefore, the combination of optimized power allocation (OPA) and convolutional codes will be a good solution for AF cooperative communication system. So, we first evaluate BER level of OPA cooperative AF using convolutional code (7, 5) for code rate of 1/2 and convolutional code (7, 7, 5) for code rate of 1/3. The simulation results of BER versus SNR for optimized power allocation of the cooperative AF with convolutional code rate of 1/2 and 1/3 are presented in Figures 5 and 6. At the OPA system, different power is allocated to each relay during transmission process, while NOPA system allocates the equal power among relays during transmission. Simulation results reveal that BER system decreases when SNR value increases. Furthermore, the BER simulation results using convolutional code rate of 1/2 is shown in Figure 5, where BER OPA system is lower than that of NOPA system. For example, when SNR value is 20 dB, so the BER for OPA is 3×10^{-5} and BER for NOPA is 7×10^{-5} by using 3 relays in the system, respectively. While BER for direct (non-cooperative) transmission is 1.5×10^{-3}. Based on the results, the BER for multi-relay of OPA system is better than that of a single-relay system and than that of multi-relay of NOPA system. As a result, performance of BER for AF cooperative systems can be enhanced by OPA and convolutional code.

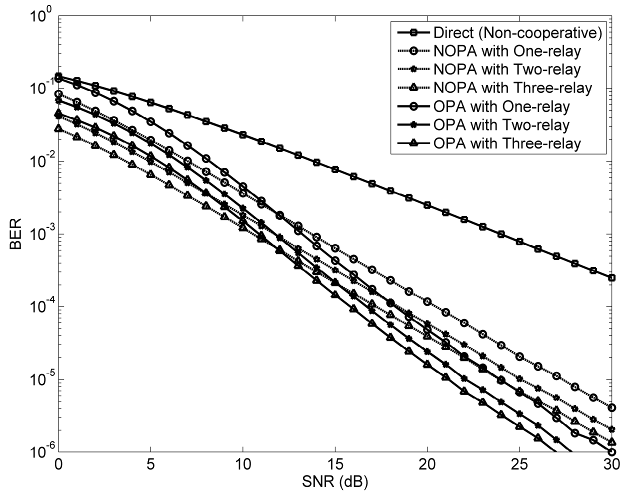

Figure 6. BER versus SNR for OPA and NOPA with convolutional code rate of 1/3

In addition, BER performance of AF cooperative with OPA and convolutional code rate of 1/3 are clearly shown in Figure 6. The simulation results also describe that BER system decreases when SNR value increases. For example, the BER for the OPA is 0.9×10^{-5} when SNR is 20 dB, and BER for NOPA is 3×10^{-5} by using 3 relays in the system, respectively. The number of relays in the system is also affect the BER performance of the system, where the BER performance decreases as the number of relays in the network increases. Moreover, the used of lower code rate will improve the use of power resource and obtain coding gain from AF cooperative relay. In order to gain BER of 10^{-6} on system with 3 relays, convolutional code rate of 1/2 requires SNR value of 29.5 dB. While the system which applies convolutional code rate of 1/3 needs SNR value of 27 dB. Thus, the system obtains coding gain of 2.5 dB using the convolutional code rate of 1/3. On the other hand, in the range of low SNR, the BER of NOPA performs better than the BER of OPA system due to the influence by typical convolutional coding performance. However, the practical communication system will employ SNR>10 dB to achieve the minimum BER. As a result, the proposed system can enhance the performance of cooperative system by minimizing BER systems.

One of other important parameters for power optimization in cooperative AF is amplification (β), which is the process of amplifying relay for the optimization of power allocation. Amplification is a basic operation on relay, where the received signal will be multiplied by constant factor of amplification and then the result of multiplying the signal is retransmitted to destination. Amplification factor is very affect on the diversity gain of cooperative OPA AF. It can be seen clearly from the simulation results in Figure 7, where each relay has different amplification coeficient. Here, it shows only the simulation results for the AF cooperative systems with OPA and convolutional code rate of 1/3, because the BER is better than that of code rate of 1/2. As depicted in Figure 7, amplification coeficient affects the BER performance of the system, where large of amplification coeficient at relay generates small BER value. Furthermore, BER acquires significant improvement to value of $\beta \leq 0.35$. While the value of $\beta \leq 0.35$, BER still gain improvement but not so significantly. For example, at SNR of 20 dB, BER for β_1 = 0.15 at relay 1, β_2 = 0.35 at relay 2 and β_3 = 0.5 at relay 3 are 7×10^{-5}, 2.5×10^{-5} and 1.7×10^{-5}, respectively.

Finally, as clearly shown in Figure 8, BER for multi-relay system is evaluated. To reduce the complexity of simulation, it is assumed that the value of total amplification $\beta_1 + \beta_2 + \beta_3 = 1$ and $\beta_1 = \beta_2$. The simulation results shows the BER performance obtained by varying the value of β_3 from 0.1, 0.3, 0,5 and 0.9, respectively. The BER performance have gained significantly when β_3= 0.3. It is noticeable to say that the optimal power allocation is quite well obtained when three-relay system allocates to each value of β_1 = 0.25, β_2 = 0.25 and β_3 = 0.5, respectively.

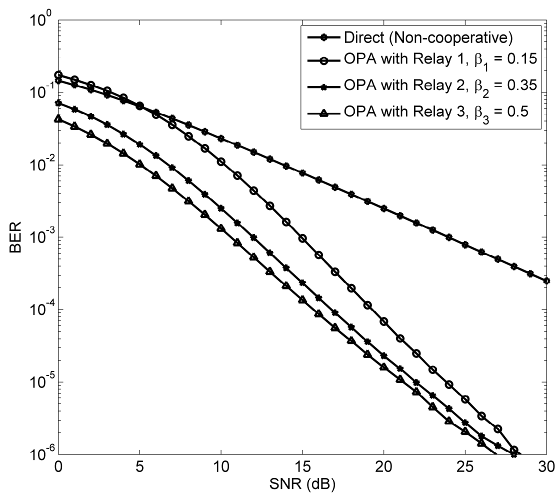

Figure 7. BER versus SNR for different amplification with convolutional code rate of 1/3

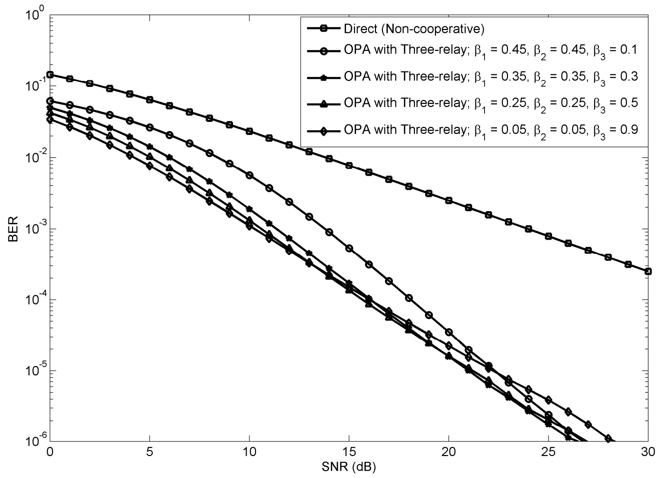

Figure 8. BER versus SNR for varying amplification with convolutional code rate of 1/3

5. Conclusion

This paper has been investigated an optimized power allocation for cooperative amplify-and-forward (AF) protocol with convolutional codes. In the proposed cooperative system, we have considered a multi-relay network with three-relay and convolutional code with rates of 1/2 and 1/3. A computer simulation model has been developed to evaluate the performance of the proposed system. Several performance parameters have been demonstrated to optimize the power allocation among cooperating relays. Simulation results have shown that throughput and BER performance are improved as the number of relays in the network increases. BER performance with optimized power allocation outperforms the system without optimized the power among relays. Furthermore, the use of lower rate of convolutional codes could provide coding gain to optimized the performance of the proposed cooperative system. Several scenarios for power allocation in terms of the amplification coeficient of relays have been simulated which give influence into the system performance. Based on the simulation result, the distribution of the power allocation among relays based on amplification coeficient is very important to optimize the performance of cooperative AF system.

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