Performance Evaluation of a Wireless Cooperative Network with Maximal Ratio Combining Technique

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ORIGINAL RESEARCH ARTICLE

Abstract- Research on wireless communication is on the rise due to its capability in improving communication in terms of spectrum efficiency, power and communication reliability. In wireless network, power is consumed mostly in the process of data transmission, hence, the need for cooperative relay protocol and technique to improve systems' performance through power management and quality of service (QoS). Although, there are various cooperative protocols which include: amplify-and-forward, decode-and-forward among others. However, by using these cooperative protocols, the amount of power consumed and QoS still require improvement. Thus, in this work the quest for incorporation of Maximal Ratio Combining (MRC) technique with the Decode-and-Forward (DF) relay protocol in cooperative network. The cooperative network with DF protocol considered consists of the source, destination and relay(s) nodes. The MRC was incorporated at the destination just to combine the received signals from the relay nodes. Moreover, the system's simulation was carried out by using MATLAB R2020a and evaluated using bit error rate and power consumption as the performance metrics. The obtained results showed that the QoS and power consumption of the considered cooperative network was considerably improved when MRC was employed in the network in comparison with an existing work.

Keywords- Bit Error Rate (BER), Cooperative Network, Decode-and-Forward (DF), Maximal Ratio Combining (MRC), Signal-to-Noise Ratio (SNR).

1 INTRODUCTION

Cooperative networks are gaining an increasing interest in information and communications technologies as a result of the willingness to share power and computation with neighboring nodes leading to an improvement in communication capacity and provision of a conducive environment for the growth of context-aware services (Conti et al., 2008). Cooperative communication commonly refers to a system where participants share and synchronize their resources to enhance the information transmission quality. It is a generalization of the relay communication, in which multiple sources also serve as relays for each other (Shah and Islam, 2014). Cooperative relaying is a technique in which nodes are helping each other during communication period. A relay node placed in between source and destination relays information and provides spatial diversity (Ojo *et al*., 2019; Hossain *et al*., 2019).

There are two cooperative relaying schemes, which include amplified-and-forward (AF) technique and decode-and-forward (DF) technique. In the AF technique, a relay node receives signals from a source node, amplifies the signals by a gain with noise and then forwards the amplified signals to a destination node (Yang et al., 2012; Ojo and Salleh, 2018). In the DF technique, the relay node receives signals sent by the source node, decodes and recodes the signals and then forwards the signals to the destination node (Ding et al., 2014; Kieu et al., 2016).

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Among diversity combining techniques are selection combining, equal gain combining and maximum ratio combining (MRC). Due to multipath effect in wireless communication, multiple copies of signals that are transmitted from the source can be combined at the receiver by using MRC (Mahama et al., 2017). However, power is consumed mostly in the event of information relaying.

Power control is a major issue in wireless communication networks (Alamri, 2018), since relay nodes are either energy-constrained (or have limited battery lifetime) or battery-less and so their life cycle hinges on the life cycle of the battery. Since relaying data incurs energy consumption, the energy storage of a relay node drains quicker than a non-relaying node (Hossain et al., 2019). Moreover, this can result into poor quality of service (QoS). Power control management helps to enhance the performance of the communication network or system that include energy usage, network reliability and network capacity (Sheng et. al. 2011). To enhance the QoS and network performance in terms of bit error rate (BER) and power consumption, this work proposed utilizing DF with MRC techniques in cooperative networks.

2 RELATED WORKS

There have been various existing researches on Wireless Cooperative Network most of which focus on the power consumption reduction for better QoS. The work of (Hossain *et al*., 2019) analysed that cooperative networks can be utilized for achieving overall power efficiency. This was done by evaluating the BER of the communication network at the destination. The work of (Warme, 2009) showed that relaying techniques can enhance the stability of wireless transmission and likewise reduce the error rates of the communication network. The Author investigated the communication of wireless transmission by comparing three schemes; Conventional Repetition Coding, Partial Repetition Coding and Direct Transmission. Also, Garg et al. (2013) stated that cooperative relaying provides diversity gain, reduces outage probability and improves BER performance after the authors had reviewed the cooperative communication protocol in which only the AF and DF relay protocols were focused on.

The work of Kalansuriya (2009) investigated the performance of DF cooperative relay networks with adaptive M-QAM which proved that the outage probabilities of the systems considered are lower when a system includes an under-optimized switching level, in comparison to a system with a corrected switching level. Sheng, (2012) determined the outage probability and power consumption of a cooperative communication with a DF technique. The work concluded that the transmitting power at the transmitter must be enhanced. This was achieved by Alamri (2018).

The work of Alamri (2018) considered cooperative techniques and strategies in wireless systems so as to improve the transmitting power of the investigated system model. The author compared the system model for a direct network, single relay network and multi-relay network. The BER and transmitted power for each model was observed. The results revealed that the multi-relay network reduces the power consumption considerably and yields lesser BER in comparison to the other networks. It was observed from most of the reviewed works that the issues of QoS and power consumption are still part of challenges facing cooperative communication systems. Additionally, the diversity gain that can be explored from using MRC was neglected. Therefore, this work analysed and carried out performance evaluation of a wireless cooperative network by using MRC at the destination node.

In wireless communication system, MRC is one of the methods of diversity combining in that the signals from different channels (i.e., paths) are added together. Here, the gain of each channel is made to be proportional to the root mean square of signal level and inversely proportional to the mean square noise level in that channel. Different proportionality constant is used for each channel. In addition, MRC is called ratio-squared combining and pre-detection combining. Also, it is the best combiner for independent additive white noise Gaussian noise channels. In a theoretical manner, multiple copies of the same information signal transmitted are combined at the receiver to maximize the received instantaneous SNR (Smith and Abhayapala, 2006).

3 Methodology

3.1 Cooperative System Model

The basic system model as given by Alamri, (2018) was adopted as illustrated in Figure 1. This model is very fundamental to the analysis of MRC technique based system. The system model comprises Source (S) node, Relay (R) node, and Destination (D) node. During the transmission process, S sends information to R and the R decodes the information. Later, the R re-transmits the received information to D. Additive White Gaussian Noise (AWGN) is assumed for S-R and R-D channels.

From Figure 1, x is the transmitted signal from the source, $x_{S,R}$ is the distance for the S-R link, and $x_{R,D}$ is the distance for the R-D link, while $x_{S,D}$ is the distance for the S-D link.

Mathematically, the transmitted signal received at R and D are given by equations (1) and (2), respectively,

$$x^R{}_t = \sqrt{P}\,\frac{u}{x_{S,R}}, \tag{1}$$

$$x^D{}_t = \sqrt{P}\,\frac{u}{x_{R,D}}, \tag{2}$$

Where 'P' denotes the transmitted power, which is non-negative and u denotes the scaling factor.

Furthermore, the received signal at R from S and the received signal at the D from R are given by equations (3) and (4), respectively.

$$Y_{S,R} = x^R{}_t + n_{S,R} \tag{3}$$

$$Y_{R,D} = x^D{}_t + n_{R,D} \tag{4}$$

Where $x^R{}_t$ and $x^D{}_t$ are the transmitted signal received by R and D, respectively. $Y_{S,R}$ is the received signal at R from S and $Y_{R,D}$ is the received signal at D from R. $n_{S,R}$ is the AWGN in the S-R link with a variance σ^2_R while $n_{R,D}$ is the AWGN in the R-D link with a variance σ^2_D. The AWGNs are independent complex Gaussian noises with zero mean and unit variance.

Then, the MRC technique based system is presented and analysed in the following section.

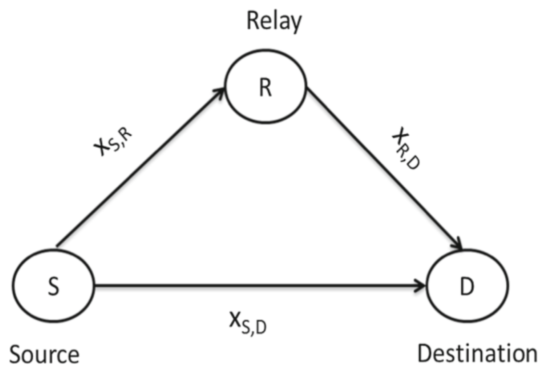

Fig. 1: Basic system model (Alamri, 2018)

3.2 Incorporation of MRC Technique

This work considered N number of relays wireless network, where transmission of information is from a source to a destination via the assistance of the relays. DF relay technique is adopted at each of the relay node. By using a simultaneous relaying, where each relay receives the transmitted signal from the source, decodes it and then re-transmits the signal to the receiver (destination) after re-encoding it again. The destination will then

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coherently combine the signals received from the source and relays as depicted in Figure 2.

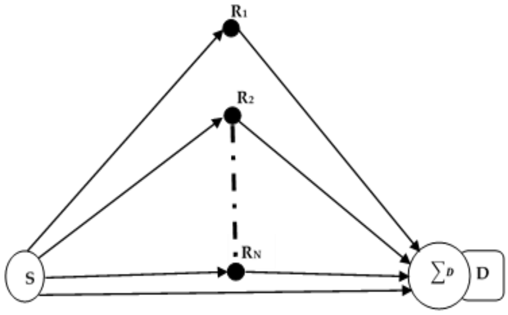

Fig. 2: Proposed system model

In the first phase, the source sends information to the destination and N relays. The received signals at the destination and the N number of relays are modelled as given in equations 5 and 6, respectively;

$$Y_{SD} = \sqrt{P_o}\, h_{SD} x + n_{SD} \quad (5)$$

$$Y_{SRi} = \sqrt{P_o}\, h_{SRi} x + n_{SRi} \quad (6)$$

for $1 \geq i \leq N$

Where P_o represents the transmitted power at the source, x represents the transmitted signal, $h_{S,D}$ and $h_{S,Ri}$ are the channel fading coefficients between the source and destination and i[th] relay, respectively. $n_{S,D}$ and $n_{S,Ri}$ are the AWGN channel noise.

In phase two, the relays decode the signals received from the source, and then send them to the destination. Finally, in the last phase, the destination coherently combines all of the received signals. This is modelled as;

$$Y_D = \sqrt{P_o}\, h_{S,D} Y_{S,D} + \sum_{i=1}^{N} \sqrt{P_i}\, h_{Ri,D} Y_{Ri,D} \quad (7)$$

3.3 Bit Error Rate (BER)

BER is the number of bit errors per unit time. It is the ratio of number of bit errors to the total number of transferred bits for a particular period of studied (Alamri, 2018). Therefore, the BER for the considered DF based system model is written as;

$$\mathrm{Pe}_{DF} = \mathrm{Pe}_1 + (1 - \mathrm{Pe}_1) \times \mathrm{Pe}_2 \quad (8)$$

Where Pe_1 is the BER for the first link of cooperation and is expressed as follows;

$$\mathrm{Pe}_1 = \frac{3}{8} Q\left(\sqrt{\frac{2\sum_i^N \gamma_{S,Ri}}{5}}\right) \quad (9)$$

Where $\gamma_{S,R}$ is the signal to noise ratio (SNR) for the S-R link and is expressed as;

$$\gamma_{S,Ri} = \frac{P}{N_0} \left| h_{S,Ri} \right|^2 \quad (10)$$

Where $h_{S,Ri}$ is the S-R_i channel fading co-efficient, N_0 is the independent random variable variance

In equation (9), Q is defined as;

$$Q_{(x)} = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{\frac{t^2}{2}}\, dt$$

Also, Pe_2 is the BER for the second link of the cooperation and is expressed as;

$$\mathrm{Pe}_2 = \frac{3}{8} Q\left(\sqrt{\frac{2(\sum_i^N \gamma_{S,Ri} + \sum_i^N \gamma_{Ri,D})}{5}}\right) \quad (11)$$

Where $\gamma_{Ri,D} = \frac{P}{N_0} \left| h_{Ri,D} \right|^2$ is the SNR of the R_i-D link.

3.4 Power Consumption of the Transmitted Signal

To investigate power relations, the SNR is defined as the ratio of total signal power at the receivers to the noise power and can be expressed as;

$$SNR = \frac{\sum signal\ power\ at\ the\ receivers}{noise\ power}$$

$$SNR = \frac{u \times \frac{1}{\beta^2} \times \sum Transmitted\ power}{noise\ power} \quad (12)$$

In this equation, β is the distance between the source and relay nodes and u is the constant factor.

3.5 Simulation Tool

For the purpose of simulation, the source signal generates binary data randomly. The AWGN was used as a channel noise in this work. Statistically, this noise is independent of the original signal. Quadrature amplitude modulation (QAM–16) was used in modulating and demodulating the signal. The DF relay protocol was utilized in this work, where the relay nodes detect, decode and re-encode the signals and then transmit the signals to the receiver. This work was implemented using MATLAB R2020a. The flow chart for executing the proposed method is shown in Figure 3 and simulation parameters are as shown in Table 1.

Table 1. Simulation Parameters

Parameters	Specification
Number of samples per symbol	1
K	Log(M)
Modulation (M)	16
Number of bits to process	50000
Modulator	QAM-16
Channel mode	AWGN
Demodulator	QAM-16
Relay protocol	DF
Number of relays (N)	4

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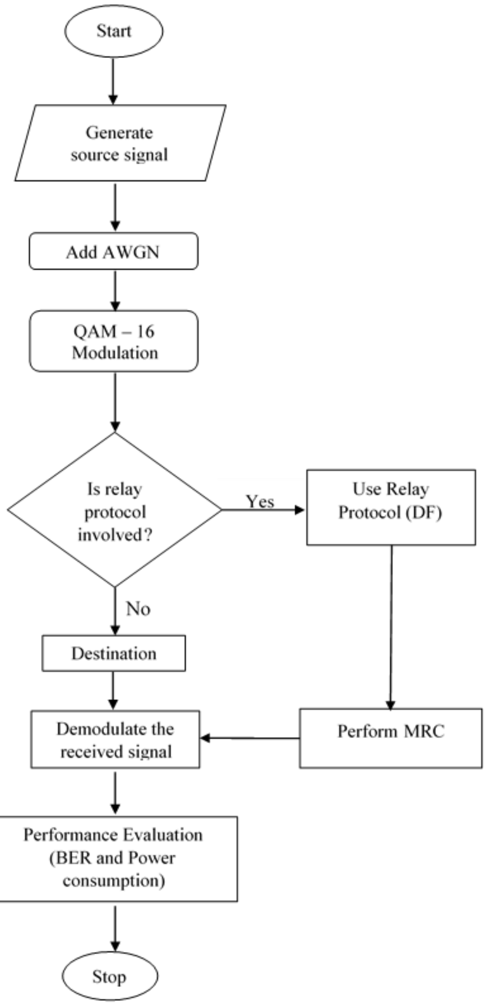

Fig. 3: Flow chart for executing the proposed method

4 Simulation Results

In this section, the results of the performance of the cooperative network with and without MRC technique are presented. Firstly, The BERs of the direct link transmission and the single relay network versus SNR (dB) are compared in Figure 4. At 3 dB, the BER of the direct link is 0.0623 and for the single relay system, it is 0.1085. Also, at 8 dB the BER is 0.0072 for the direct link and 0.0126 for the single relay system. The result revealed that the BER for the single relay is worse than the BER in the direct link as SNR (dB) increases. Thus, corresponds to the work of Alamri (2018).

Figure 5 shows the BER plot of single relay and multi-relay versus SNR (dB). It can be observed from the plot that increase in the relay node helps improving the BER of the system at 3 dB, the BER of multi relay system is 0.07574, which is lesser compare to that obtainable for the single relay network, which is 0.1085.

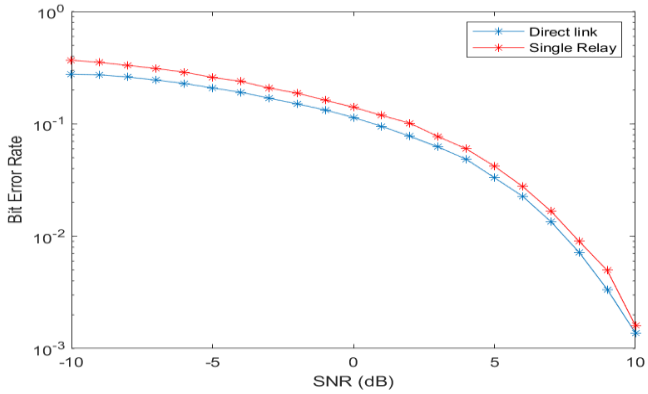

Fig. 4: BER versus SNR (dB) of direct link system and single relay system

The simulation result of multi-relay system without MRC and with MRC is depicted in Figure 6. At 3dB, the values obtained for multi-relay system without MRC is 0.07574 while that of the multi-relay system with MRC is 0.03794. Thus, implying that the presence of MRC technique in the multi-relay network significantly reduced the probability of bit error in the network. This is due to diversity advantage proffered by the MRC incorporation.

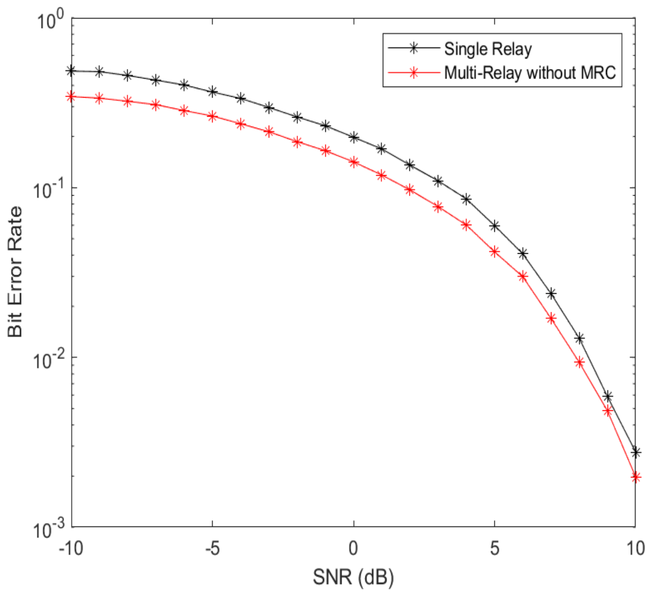

Fig. 5: BER versus SNR (dB) of single relay system and multi relay system

Figure 7 compares the BER of the single relay system, the multi relay system without MRC and with MRC. As the SNR (dB) increases, the BER reduces. Moreover, it can be seen from the results plotted that multi-relay system with the incorporation of MRC gives the best performance. Thereby, showing that incorporation of MRC technique in the considered cooperative network improves the system QoS.

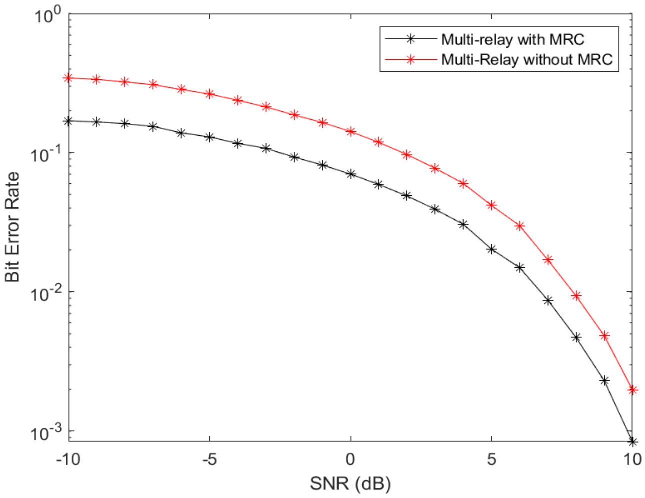

Fig. 6: BER versus SNR (dB) of multi relay system without and with MRC

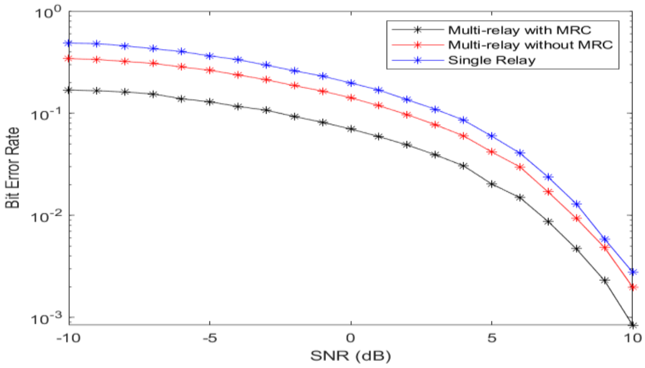

Fig. 7: BER versus SNR (dB) of the single relay system, multi-relay system and the multi relay system with MRC.

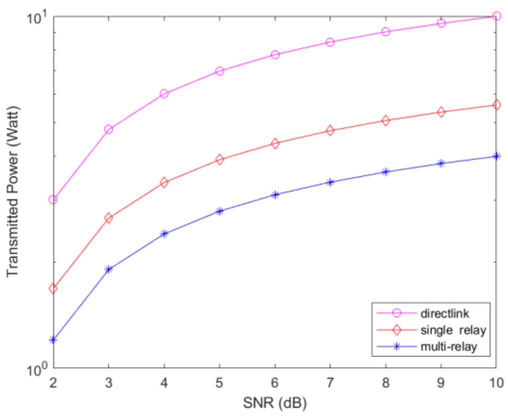

Fig. 8: Transmitted power versus SNR (dB) of the direct link system, single relay system and the multi relay system.

To show the power consumption evaluation in the direct link, single relay network and multi relay network, Figure 8 is presented. The results show that as SNR (dB) increases, the power consumed by each of the scenario increases. At SNR of 6 dB, the transmitted power for the direct link system is 7.782 Watts, 4.558 Watts for single relay system and 3.113 Watts for multi-relay system. The power efficiency in the single relay network is better compared to that of the direct link while that of the multi relay network has the best performance compared to the rest, due to its inherent ability of saving power.

5 Conclusion

This work has examined the incorporation of MRC technique at the destination of a cooperative relay network that utilizes DF protocol. The performance evaluation of the considered network was carried out. The results obtained revealed that as SNR (dB) increases, the BER decreases. Also, as the SNR (dB) increases, the transmitted power increases. Furthermore, it was observed that at the inclusion of MRC for combining the multiple copies of signals from multiple relays at the destination, the BER and the power consumed were considerably reduced. Thus, enhancing the overall performance of the considered cooperative relay network.

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