Performance of MIMO and Relay Communication System using TGn and HH Channel

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Abstract. The research on relay communication systems and MIMO has been done by researchers. Both systems have advantages in improving the system performance and capacity. While the OFDM transmission technique has the advantage to avoid ISI from receiving signals. Systems are simulated to obtain BER as a system performance parameter and determine the increase in BER due to the use of a relay and 2 antennas in communication systems. Systems are compared between relay system with the non-relay system, where both systems are simulated too for using 2 antennas and 1 antenna. Messages are sent using the OFDM technique over TGn and the HH channel. Systems with 2 antennas use the Alamouti scheme. Received messages are combined using MRC, and the original messages are detected using an ML detector at the receiver. The increase in BER obtained between relay systems compared to non-relays is 1.69 and 2.02 times when using 1 and 2 antennas on Eb/No = 9 dB. Increased BER also occurs between 2 antenna systems compared to system 1 antenna, which is 79.71 times in non-relay systems and 94.93 times in relay system on Eb/No = 9 dB. From these results, it can be seen that there is an increase in BER in the use of a relay and 2 antennas in the system. The BER system that occurs, both using the TGn channel and the HH channel, shows relatively the same results.

1. Introduction

The research on increasing digital communication system performance has been done a lot by a researcher. Performance parameter that often examined is Bit Error Rate (BER). Two common ways to increase this BER are by using a multi-antenna on the transmitter or receiver side, also known as the (multiple input multiple output) MIMO systems, and use additional stations between the transmitter and receiver that function as relay stations. This relay will receive a signal from the transmitter and will send this receiving signal to the receiver [1][2][3][4][5].

MIMO is one of the features in the IEEE 802.11n standard. Another feature of the IEEE 802.11n standard is the use of orthogonal frequency-division multiplexing (OFDM) technology that has the ability to eliminate ISI using a cyclic prefix (CP). Multiplexing techniques in IEEE 802.11n standards that use MIMO features such as spatial-division multiplexing (SDM), space-time block coding (STBC) and transmitter beamforming [6].
One of the researchers who proposed a scheme of communication systems using multi-antennas was Alamouti. Alamouti proposed a simple diversity transmission technique that could improve signal quality at the receiver by applying 2 transmitter antennas. The system applied is a system with 2 transmitting antennas and 1 receiving antenna, otherwise known as the multiple-input single-output (MISO) system, and a system with 2 transmitting antennas and 2 receiving antennas (MIMO). The diversity of orders obtained is the same as the application of maximal ratio combining (MRRC) with 2 receiving antennas. This system can improve system performance [1].

Communication systems that use relay stations as nodes that help in forwarding information from the source to the destination are called cooperative communication systems. Relays used in this type of communication system can be classified into two modes, namely amplify and forward (AF), and decode and forward (DF) [2][3][7][8]. The AF system only forwards signals received by the relay to the destination without having to demodulate or decode the relay. The DF system demodulates or decodes the receiving signal on the relay, and modulates or encodes the relay before sending the signal back to the destination [5][7]. The application of this cooperative system can reduce the effect of fading so that it can improve capacity and system performance [2][3][4][5].

Research on radio transmission was also carried out by Handayani and Hendrantoro, and Medbo, et al. The research conducted is the measurement of radio characteristics in the indoor environment. Handayani and Hendrantoro implemented a multi-relay system with relay AF mode with 2.5 GHz channel frequency and 25 ns delay spread. Measurements made by Medbo, et al. performed 5 GHz channel frequencies, and delay spreads 50 ns, 100 ns, 140 ns, 150 ns, and 250 ns. The measurement specifications carried out by Medbo, et al. use the IEEE 802.11n specification. The measurement results of these researchers are PDP. The measurement results obtained by Handayani and Hendrantoro became a channel model called the Handayani-Hendrantoro (HH) channel model, and channel systems that use the 802.11n standard are called TGn channel model [9] [10][11].

In this paper, we will discuss the effect of using 2 antennas and a single relay on BER in communication systems, and determine how much reinforcement BER occurs. Systems are simulated using TGn and HH channels. The transmission technique uses the Alamouti scheme for 2 antenna systems, and the OFDM technique, with additive white Gaussian noise (AWGN).

2. Method

2.1. System Model

Figure 2.1 is a communication system using a relay station between the transmitter and receiver. The source node (S) sends information to the Destination node (D) and a Relay node (R) in the 1st time slot. R sends information to D in the 2nd time slot. R in decode and forward (DF) mode. This means the signal received by R will be decoded before it is encoded again to be sent to D [7][12].

![Figure 2.1 Relay Communication System](image)

Based on Figure 2.1, the system is simulated in two schemes, they are:
1) The System consisting of S and D only, but without the S-R and R-D links.
2) The System consisting of S, R, and D, consists of S-D, S-R, and R-D links. Each system is tested in two conditions. First, the system is equipped with one antenna on each node, and second, the system will be equipped with two antennas at each node.

S sends messages \( (x_s) \) with power \( P_s \) and \( E[|x_s(n)|^2] = 1 \) for all \( n \), and R sends messages \( (x_r) \) with power \( P_r \) and \( E[|x_r(n)|^2] = 1 \) for all \( n \) [7][12]. So, received signal equations in R and D, as shown in Equations (2.1-2.3).

\[
y_r^{(1)}[n] = \sqrt{P_r} h_{r,s} x_s[n] + w_r^{(1)}[n] \quad (2.1)
\]

\[
y_d^{(1)}[n] = \sqrt{P_r} h_{d,s} x_s[n] + w_d^{(1)}[n] \quad (2.2)
\]

\[
y_d^{(2)}[n] = \sqrt{P_r} h_{d,r} x_r[n] + w_d^{(2)}[n] \quad (2.3)
\]

where \( n = 0, 1, \ldots, N - 1 \); \( y_r \) and \( y_d \) is the signal received by R and D with superscript is time slot; \( h_{r,s} \), \( h_{d,s} \), and \( h_{d,r} \) is channel coefficient, S-R, S-D, and R-D are independent of each other; and \( w_r[n] \sim CN(0, \sigma_r^2) \) dan \( w_d[n] \sim CN(0, \sigma_d^2) \) is AWGN in R and D [7][12].

2.2. MRC

On D side, two or more signals are combined using maximal ratio combining (MRC). Received signal equation as shown in Equation (2.4).

\[
z[n] = \sum_{k=1}^{M} \alpha_k y_d^{(k)}[n], \quad k = 1, 2, \ldots, M \quad (2.4)
\]

where \( k \) is a time slot, \( M \) is the number of signals received by D, \( \alpha \) is weighting factor \( \left( h_k^* / \sigma_k^2 \right) \), \( y_d^{(k)} \) is received signals in \( k \) time slot, \( h_k^* \) is conjugate channel coefficient of S-D or R-D link in \( k \) time slot, and \( \sigma_k^2 \) is noise variant in \( k \) time slot[7].

2.3. Alamouti System Model

Figure 2.2 is the MIMO diversity transmission system with \( N_t \) transmitter antenna and \( N_r \) receiver antenna [7][13].

![Figure 2.2 MIMO Channel Model N_t x N_r antennas][7]

Messages transmission for \( N_t = N_r = 2 \) uses the Alamouti scheme. Messages sent as shown in Table 2.1[1][14][15].

| Time Slot | 1st Antenna | 2nd Antenna |
|-----------|-------------|-------------|
| First (t) | \( x_1 \)    | \( x_2 \)    |
| Second (t+T) | \( -x_2' \) | \( x_1' \) |
The channel impulse response is expressed as $h_{Nr, Nt}$. Channel assumptions are independent complex Gaussian random process with zero mean and variant units $\sigma^2$, with $\sum_{j=1}^{N_c} E[|h_{Nr, Nt}[n]|^2] \leq 1$. The transmission power of each antenna is assumed to be the same, and equal to $P/N_t$.[3][7][15].

Received signal equations as shown in Equations (2.5-2.8).

$$y_{1}^{(1)} = \sqrt{\frac{P}{2}} (h_{1,1}x_1 + h_{1,2}x_2) + w_1^{(1)}$$ (2.5)

$$y_{1}^{(2)} = \sqrt{\frac{P}{2}} (h_{1,2}^* x_2 + h_{1,1}^* x_1) + w_1^{(2)}$$ (2.6)

$$y_{2}^{(1)} = \sqrt{\frac{P}{2}} (h_{2,1,1} + h_{2,2} x_2) + w_2^{(1)}$$ (2.7)

$$y_{2}^{(2)} = \sqrt{\frac{P}{2}} (h_{2,2}^* x_2 + h_{2,1}^* x_1) + w_2^{(2)}$$ (2.8)

where $y_1$ and $y_2$ are receiving antenna 1 and 2, and superscript (1) and (2) are time slot t and t + T; $h_{1,1}$, $h_{1,2}$, $h_{2,1}$, and $h_{2,2}$ are channel coefficient $S_1$-D$_1$, S$_2$-D$_1$, S$_1$-D$_2$, and S$_2$-D$_2$; and $w$ is Gaussian random noise complex $w^{(n)}[n] \sim CN(0, \sigma^2_w)$.

Decoding message in D as shown in the Equations (2.9 and 2.10).

$$\hat{x}_1 = h_{1,1}^* y_1^{(1)} + h_{1,2}^* y_1^{(2)*} + h_{2,1}^* y_2^{(1)} + h_{2,2}^* y_2^{(2)*}$$ (2.9)

$$\hat{x}_2 = h_{1,2}^* y_1^{(1)} - h_{1,1}^* y_1^{(2)*} + h_{2,2}^* y_2^{(1)} - h_{2,1}^* y_2^{(2)*}$$ (2.10)

The maximum likelihood (ML) detector makes a decision by taking the shortest Euclidian distance. The x variable is selected using Equations (2.11-2.12) [1].

$$d^2(\hat{x}_1, x_i) \leq d^2(\hat{x}_i, x_k) \quad \forall i \neq k$$ (2.11)

$$d^2(\hat{x}_2, x_i) \leq d^2(\hat{x}_1, x_k) \quad \forall i \neq k.$$ (2.12)

2.4. OFDM System
Messages are sent using OFDM multiplexing technique. Figure 2.3 is an OFDM transmission system using 1 antenna. The system uses pilot and null on each OFDM symbol, and a cyclic prefix (CP) to eliminate inter-symbol interference (ISI) [16].

![OFDM Transmission System](image-url)

Figure 2.3 OFDM Transmission System uses 1 antenna [7] [16]
Systems use the QPSK gray code modulation. The number of QPSK symbol subcarrier data (Nsd) is 52, mapped into 64 subcarriers, by adding several pilots (8 symbols) and several null (4 symbols). The number of CP used is 16 subcarriers [6] [14][15].

2.5. TGn and HH Channel Model
Systems were tested using two-channel models. The first channel model is using TGn channel. TGn channel model is an IEEE 802.11n standard channel model for wireless local area network (WLAN). This channel model uses the MIMO-OFDM feature. Bandwidth provided is 20 MHz and 40 MHz at the frequency of 2.4 GHz and 5 GHz [17].

WLAN channel model developed by Medbo and friends consists of the A-E model, which is proposed for several different environments. For model B, environmental conditions are the office and open space environment, NLOS, and delay spreads rms 100 ns [11].

The second channel model is using the HH channel. HH channel is an indoor double-directional NLOS channel model proposed by P. Handayani and G. Hendrantoro for multi-terminal communication. A multi-terminal system can be in the form of several terminals which act as amplify and forward (AF) relays, with S, R, and D having a non-fixed number of antennas. The antenna used is a 3D synthetic array antenna in a frequency of 2.5 GHz [9].

Power delay profile (PDP) model of both channels above as shown in Table 2.2.

| Tap | Delay (ns) | Average Relative Power of TGn Channel (dB) | Average Relative Power of HH Channel(dB) |
|-----|------------|------------------------------------------|----------------------------------------|
| 1   | 0          | 0                                        | 0                                      |
| 2   | 30         | -1.3                                     | -5.6308                                |
| 3   | 60         | -2.6                                     | -7.6537                                |
| 4   | 90         | -3.9                                     | -16.3775                               |

2.6. Result Parameter
The simulation result parameter is BER. BER is obtained by comparing the sequence of bits received with the sequence of bits sent. BER is calculated for each different Eb/No. The results obtained are the BER waterfall curve used to determine how much BER reinforcement occurs due to the use of MIMO and relay in systems using the TGn and HH channels.

3. Result and Discussion
Simulation results of a system as shown in Figure 4.1. Based on this figure, the performance of BER increases when a system uses a relay, and add the number of antenna. BER continues to increase until Eb/No reaches 14 dB. But this 14 dB is not a maximum limit. In Figure 4.1, maximum BER is limited to $10^{-5}$, so that the BER above this number cannot be seen.

Given Eb/No = 9 dB, BER that occurs in non-relay and relay systems 1 antenna are $2.89 \times 10^{-2}$, and $1.7 \times 10^{-2}$ respectively. In sequence, BER that occurs in non-relay and relay systems 2 antennas are $3.62 \times 10^{-4}$ and $1.78 \times 10^{-4}$. BER amplifying of relay compared to non-relay systems 1 antenna, and the same comparing systems but with 2 antennas are 1.69 and 2.02 times respectively.

Based on the number of antennas used in the system, it can be seen also the increase in BER between system 2 antennas compared system 1 antenna. Given Eb/No = 9 dB, BER amplifying of non-relay and relay the system are 79.71 and 94.93 times respectively.

BER amplifying that occurs as a result of using a relay and increasing the number of antennas is caused by the use of MRC on the receiver. This performance improvement applies to both channel model testing conditions, namely TGn and HH channel models.
The simulation results in Figure 4.1 can be plotted again as in Figure 4.2, to compare results based on the use of the channel model. Based on this figure, it can be seen that the BER performance shows a relatively similar value between the system with the TGn channel model and the system with the HH channel. This condition occurs for all systems.

4. Conclusion
Based on the discussion above, it can be concluded that:

1) BER amplifying occurs when the system uses a relay than no relay. BER increases 1.69 times when using 1 antenna, and 2.02 times when using 2 antennas on Eb/No = 9 dB.

2) BER amplifying occurs when a system using 2 antennas than 1 antenna. BER increased 79.71 times on non-relay systems, and 94.93 on relay systems.

3) BER systems that use the HH channel model compared to systems using the TGn channel model are relatively the same.
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