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Network Coding Schemes and Cooperative Communication Systems Amplify and Forward in Outdoor Environments

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ABSTRACT

Fading is a phenomenon of decreasing signal strength during transmission, caused by changes in environmental conditions or physical obstacles in the propagation path. Fading can cause interference in signal reception, such as distortion or loss of information, especially in Non-Line of Sight (NLoS) paths, where signals must pass through many paths or obstacles such as buildings, trees, or other objects. To eliminate fading interference, a cooperative communication system is created to reduce the effects of fading in wireless networks. The cooperative communication system works by utilizing other nodes in sending signals to the destination. The relay protocol used in this study is amplify and forward, where the signal to be sent will be amplified and forwarded to the destination by the relay node. A network coding scheme is added to the cooperative communication system to improve network performance. This scheme encodes each piece of information with the XOR technique. The parameters used in measuring the network coding scheme in the cooperative communication system are BER and throughput. Viewed from the BER value, the conventional cooperative communication system has better performance compared to the cooperative communication system with network coding. Cooperative communication system scheme without NC BER value is 0 when the transmit power value is -19 dBm or Gain 32. While for the cooperative communication system scheme with network coding BER value is 0 when transmit power of -9.25 dBm. Throughput system with network coding has increased by 17% compared to the conventional system.

Keywords: network coding system communication cooperative; BER; throughput;

1. INTRODUCTION

Over the past two decades, wireless communication has advanced significantly. Each new generation of wireless devices has introduced notable improvements in reliability, data speeds, device size, battery efficiency, and network connectivity. Despite these advancements, wireless communication performance is still hindered by issues like fading. Cooperative communication systems aim to mitigate the effects of fading on wireless channels, thus improving overall system performance. This system represents a novel approach in LTE (fourth generation) networks and is anticipated to play a significant role in the advancement of 5G technology

Network coding provides solutions to challenges such as download speeds, storage, messaging, content distribution, and packet loss, ultimately boosting network performance. One approach within network coding is Physical Network Coding (PNC), which combines symbol and phase levels assuming synchronized signal arrival and disregarding noise. This research about cooperative communication systems based on amplify-and-forward relay will be integrated with network coding (PNC) and implemented on the SDR to compare the performance of systems with and without network coding.

2. LITERATURE REVIEW

The advancement of wireless communication continues to progress, driven by technology that is now considered to be nearing perfection. In the future, wireless technology will change various strategies, where central infrastructure will no longer be the main component in telecommunication systems. LOS (Line of Sight) refers to a condition where signal propagation from the transmitter to the receiver occurs without obstacles. In contrast, NLOS (Non-Line of Sight) occurs when there are physical obstructions, such as walls or buildings, that block the signal from the transmitter to the receiver, resulting in a decrease in signal quality and data speed. NLOS conditions often trigger fading. Fading is a phenomenon where signal strength diminishes during transmission, caused by changes in environmental

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conditions or physical barriers in the propagation path. Fading can cause disruptions in signal reception, such as distortion or loss of information, especially in NLOS paths, where the signal must pass through multiple paths or obstacles like buildings, trees, or other objects.

The main concept of a cooperative communication system is to improve the reliability of signal transmission by utilizing multihop paths or other nodes in delivering messages. The method is by using spatial diversity techniques, namely using multiple antennas on one device (MIMO). This diversity can reduce the fading effect that reduces signal quality caused by NLOS conditions. A cooperative communication system is a technique in wireless communication where several devices or nodes in a network work together to improve the reliability, efficiency, and range of data transmission. In this system, devices that are not directly involved in communication between the source (S) and destination (D) function as relay (R) nodes to help send messages. By using this relay (R) node, the receiver can receive signals from several different paths using the AF and DF protocol, which can then be combined at the destination (D) node to improve the quality and reliability of transmission.

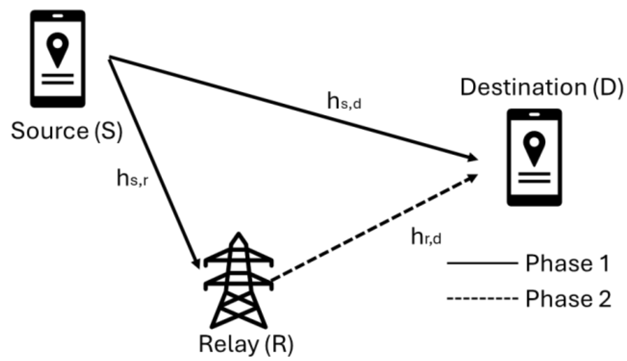

Fig. 1 system model of Coomunication cooperative

The source node and relay transmit information to the destination simultaneously. The signals received over the SD and SR links are represented by equation 1, where n denotes the channel noise:

$$Y_{s,r} = noise_{s,r} + \sqrt{p}\, h_{s,r} X$$
$$Y_{s,d} = noise_{s,d} + \sqrt{p}\, h_{s,d} X \quad (1)$$

The signal received at the relay node from the source node will be amplified or coded and then sent to the destination node with the following equation 2:

$$Y_{r,d} = h_{r,d} q(Y_{s,r}) + noise_{r,d} \quad (2)$$

Amplify-and-Forward (AF) is a relaying scheme in cooperative communication systems. In this scheme, a relay receives a signal transmitted by a source, amplifies it, and then forwards it to the receiver without further decoding or signal processing. The amplify and forward scheme can be seen in Figure 2. Cooperative communication system with Amplify-and-Forward (AF) is one of the techniques in cooperative communication networks where the signal received by the relay is amplified and then forwarded to the receiver. The relay then amplifies this signal by a gain factor G so that the signal forwarded to the receiver is:

$$Xr = G.Y_{s,r} \quad (3)$$

Signal from Relay to Receiver is:

$$Y_{r,d} = h_{r,d}\, G.Y_{s,r} + noise_{r,d} \quad (4)$$

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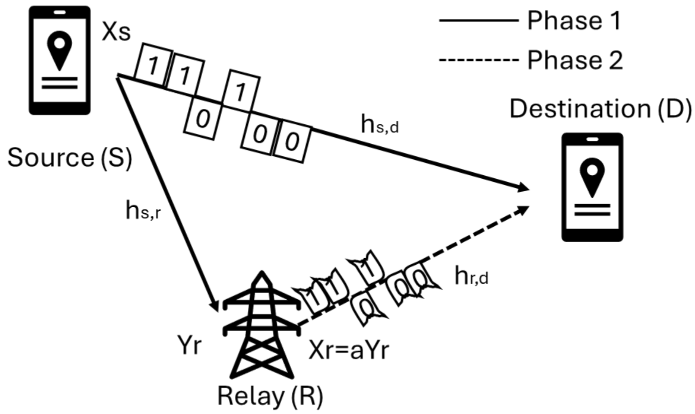

Fig. 2 Amplify-and-Forward scenario

Maximum Ratio Combining (MRC) is a signal combining technique used in cooperative communication systems to maximize the signal-to-noise ratio (SNR) at the receiver end. In the context of Amplify-and-Forward (AF), MRC is used to combine the signal received from the source directly with the signal forwarded through the relay. The purpose of MRC is to improve the reliability and quality of the received signal by taking into account the signal strengths of the various transmission paths. Suppose the receiver receives signals from N independent paths (e.g., the direct path from the source and the relay path), then the combined signal:

$$Z_{MRC}[n] = \sum_{i=1}^{k} \alpha_k y_k[n] \quad (5)$$

$$\alpha_k = |h_k| e^{-j\phi_k} / \sigma_k^2$$

In QPSK (Quadrature Phase Shift Keying) modulation, each symbol represents two bits of information. QPSK encodes digital data into a carrier signal by changing (modulating) the phase of the carrier wave. In QPSK, there are four possible phases used, such as 0, π / 2, π, and 3π / 2. To connect the bit with phase change is called with bit phase mapping. The bit 00 is represented by 0 phase, bit 01 is represented by 90 phase, bit 10 is represented by 180 phase, and bit 11 is represented by 270 phase. Figure 3 show QPSK modulation.

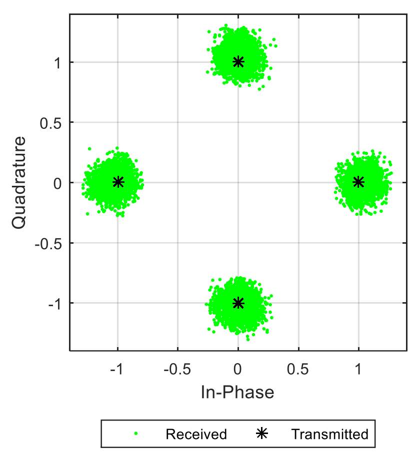

Fig. 3 QPSK modulation

A network coding scheme is added to the cooperative communication system to improve network performance. This scheme encodes each piece of information with the XOR technique. Source 1 and source 2 send information

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simultaneously to each Destination node. The information data of each Source Node is received at the Relay Node then encoded using the XOR technique and broadcast to each Destination Node. At Node Destination 1 and Node Destination 2, the data received from the Relay Node will be XOR again with the information at its Source, so that the desired information is obtained. Figure 4 show explanation of how information is conveyed in network coding:

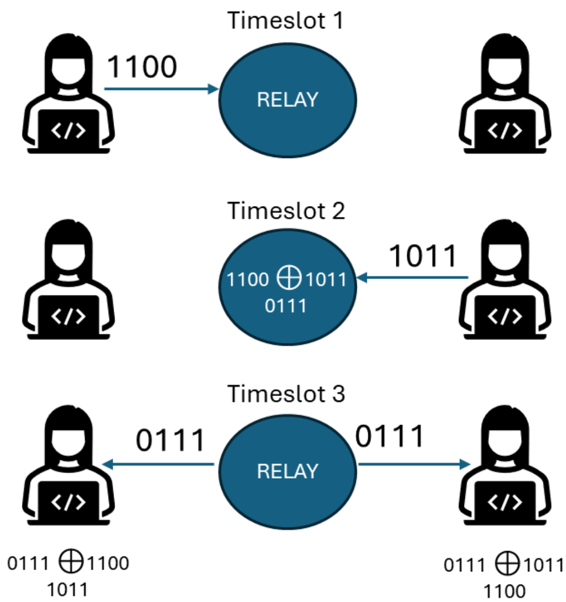

Fig. 4 Network coding Scheme

Information data from node A and node B are received at relay with the same phase and amplitude. In PNC mapping, EM waves are added with noise for output packets forwarded by the relay. The main key in PNC is how the relay forms $S_R = S_1 \oplus S_2$ from electromagnetic waves. This process is called "PNC mapping". In general, PNC mapping is the process of mapping the received EM waves plus noise into several packets to be forwarded by the relay. All PNC mappings share the keys needed by node 1 and node 2 to produce information from other nodes based on the packets generated by the relay and the node's own information. All nodes use QPSK modulation to transmit signals, the symbol level and carrier phase are considered synchronous. For the time being, noise is ignored. In one part of the symbol period, nodes A and nodes B will be modulate the symbol with RF at frequency ω, so node I is written to send a signal $Re[(a_1 + jb_1)e^{j\omega t}$. The combination of bandpass signals received by the R relay during one period is:

$$\begin{aligned} y_R(t) &= S_1(\mathrm{t}) + S_2(\mathrm{t}) \\ &= [a_1 \cos(\omega \mathrm{t}) - b_1 \sin(\omega \mathrm{t})] + [a_2 \cos(\omega \mathrm{t}) - b_2 \sin(\omega \mathrm{t})] \end{aligned} \quad (6)$$

Software Defined Radio (SDR) is an approach to radio systems where functions that are usually implemented in hardware are moved to software. This allows for greater flexibility in signal processing and modification of the radio system. Software Defined Radio (SDR) works by using software to perform functions that are usually implemented in hardware, such as modulation, demodulation, and signal processing. Software used that can be programmed such as FPGA (Field-Programmable Gate Array) or DSP (Digital Signal Processor). SDR is used to process RF signals. In traditional communication systems, an antenna captures RF signals, and then special hardware (such as analog circuits) processes them. In SDR, the antenna still captures RF signals, but most of the processing of these RF signals is done by software.

3. METHOD

The design flow of a cooperative communication system with a network coding scheme can be seen in Figure 5.

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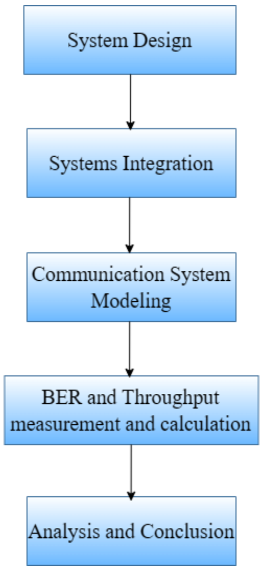

Fig. 5 Flow System Design

The system design outlined in this research involves running simulations in MATLAB. Initially, user 1 and user 2 transmit their information to the relay node as well as to other user nodes, with the signals being mixed with noise (channels). Before transmission, the information is encoded and modulated using QPSK modulation. At the relay node, the information symbols from user 1 and user 2 are then processed through network coding, where the symbols from both users are combined using the network coding principle. This is followed by the application of the amplify and forward protocol, after which the combined information is decoded and modulated with QPSK again. The relay then broadcasts this information to both user 1 and user 2 (the destination nodes). The broadcasted information also includes additional noise. At the destination nodes, the network coding process involves subtracting the information received from the relay from the information received at the destination. This subtraction results in new information, and the MRC process is applied so that user 1 receives information from user 2, and vice versa. Figure 6 illustrates the design flow of a cooperative communication system employing network coding.

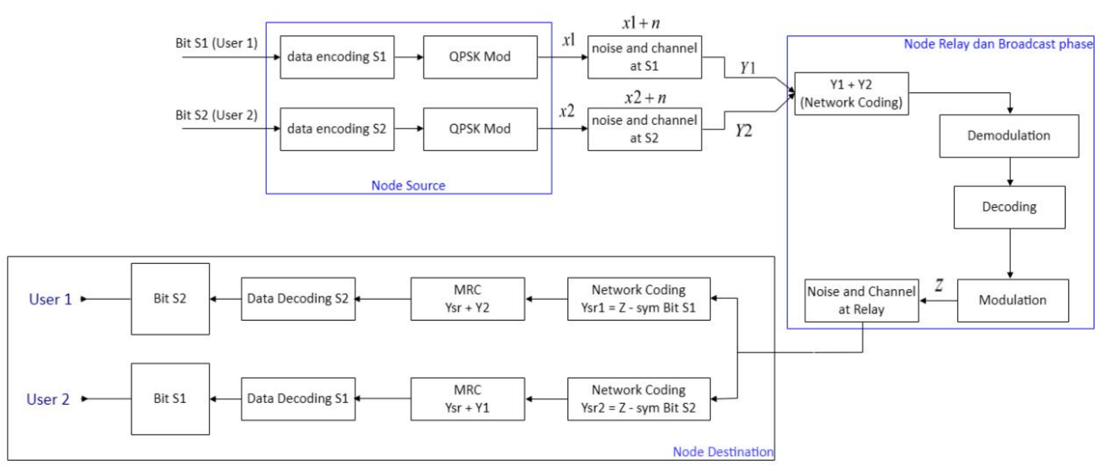

Fig. 6 System Design Before Implementation

In this study, during simulation using MATLAB, the channel used is Additive White Gaussian Noise (AWGN). The parameters used to measure the performance of this system are BER and Throughput. The AWGN channel is used

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in conventional cooperative communication systems and cooperative communication systems with network coding. The simulation results of the cooperative communication system with and without network coding can be seen in Figure 7.

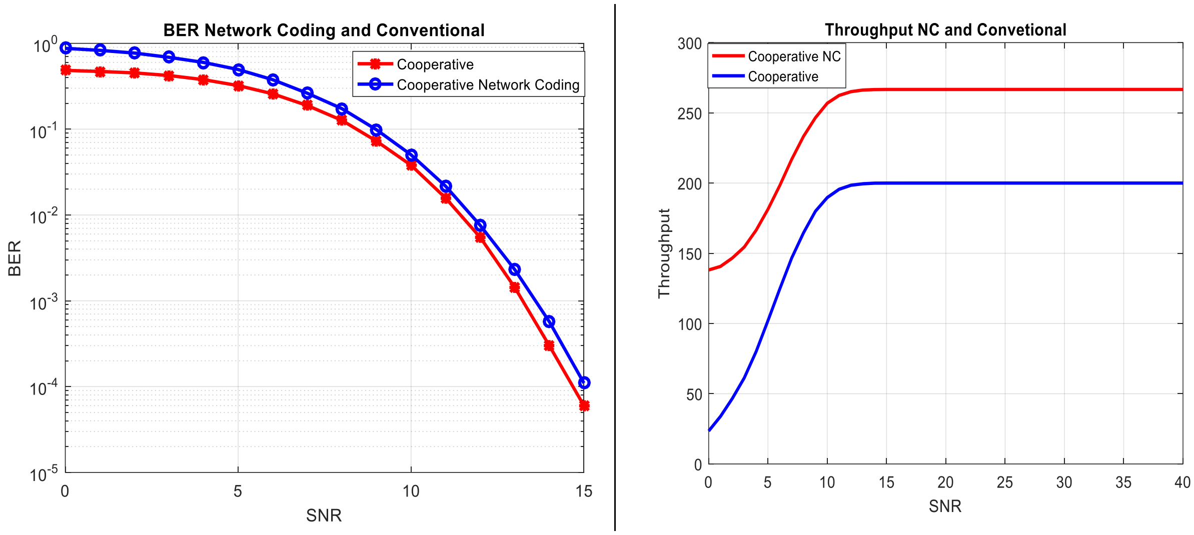

Fig. 7 BER and Throughput System Coventional and Network Coding

The system simulation results in Figure 7 show that the conventional cooperative communication system is better than the network coding scheme in the cooperative communication system. From the throughput parameter, the network coding scheme has increased by 30% from the conventional cooperative system.

After the system design and simulation in Matlab, the cooperative communication system with network coding is implemented in the SDR module. The SDR module used here is the Wireless Open-Access Research Platform (WARP). Each node programmed through MATLAB is connected to the computer via an ethernet switch. By using this system, nodes can be programmed to send data and receive data through MATLAB. The following is a picture of how the system is implemented in the SDR module.

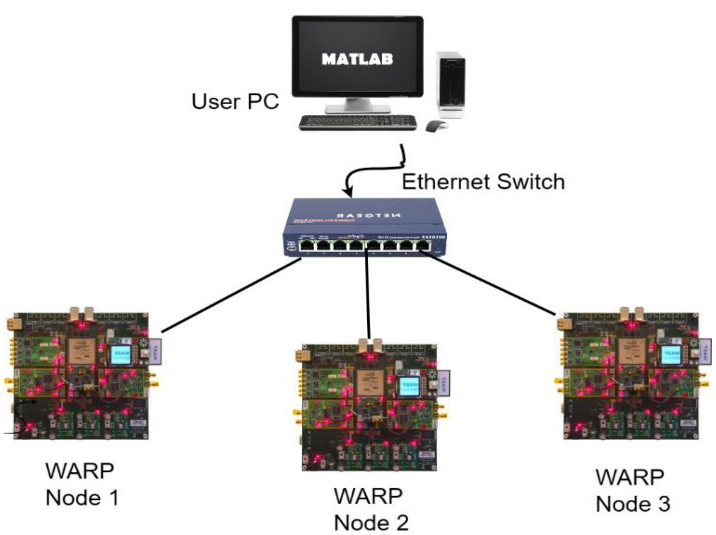

Fig. 8 System Model

The measurement process in this outdoor environment is carried out with 2 conditions, namely LOS (Line of Sight) conditions and NLOS (Non-Line of Sight) conditions (figure 9). Measurements are carried out by changing the

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distance function, both LOS and NLOS conditions are carried out by changing the distance between the source node and the destination node, at a distance of 4m, 6m, 8m, 12m, 18m and 24m and 30m to obtain the Bit Error Rate (BER) value. This distance change is carried out to determine the extent to which the amplify and forward cooperative communication system with the network coding scheme works. Measurements in this outdoor environment are also carried out by changing the transmitter gain level at the same distance to obtain the BER value. The number of bits sent is 16384 bits and The parameters used in the cooperative communication system with this network coding scheme can be seen in table 1.

Table 1
Parameter system cooperative communication with network coding

Parameter	Value
Modulation	PSK, M = 4
Generate Bit	16384
Frequency Sampling	40 MHz
Symbol rate	5000000
Channel	11
Gain	15
Padding	748
Filter	SRRC
Filter order	6

In a cooperative communication system with network coding, the way signals are sent and received between devices (antennas) in the network uses the SIMO and MISO antenna configuration types. In the first timeslot, the scenario that occurs is a Single Input Multiple Output (SIMO) system, where the source simultaneously sends signals to the relay and destination. At this stage, both the relay and the destination receive signals from the source, with the relay acting as an intermediary, amplifying, and encoding with the XOR technique of bit s1 and bit s2. Furthermore, in the second timeslot, the relay takes the main role by transmitting and broadcasting the signals it receives to the destination using the Multi Input Single Output (MISO) method, where the relay functions as the only signal sender to the destination, ensuring that the signal can be received better and improving the overall transmission quality in an environment that may experience fading or interference. The communication process in the system can be seen in Figure 9.

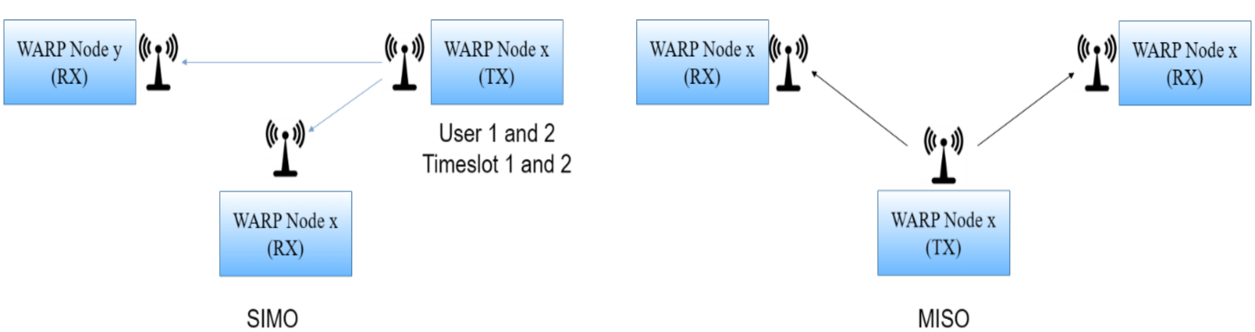

Fig 9 Diagram Block of communication system at TS 1 or 2 and 3

Network coding-based cooperative communication system is an innovative approach in wireless networks that involves cooperation between several main elements, namely source, relay, and destination, where the relay not only functions as an intermediary that retransmits signals, but also combines information received from the source with other data received through the network. In this concept, in the first stage, the source sends data simultaneously to the

* Ummul Khair

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relay and destination, where the relay receives and stores the data. Furthermore, the relay does not simply forward data directly but recodes it (network coding) using the XOR technique and then sends it to the destination. At the destination, the signal received from the relay and source will be combined and the XOR technique will be performed again to get a signal from another source. The parameters measured in this system are BER and Throughput using the equation 7.

$$BER = \frac{Bit\ Received}{Bit\ Send}$$
$$Throughput\ (bps) = \frac{number\ of\ bits\ received}{second} \quad (7)$$

4. RESULT

The system simulation results in Figure 7 show that the higher the SNR, the lower the BER value. This is because with a high SNR, the received signal is stronger than the noise, so the possibility of errors in detecting the received bits is reduced. The number of bits sent is 16384 bits. The BER of the conventional cooperative communication system when the SNR value is 15 dB is 0.00006, in the cooperative communication system with network coding the BER value when the SNR is 15 dB is 0.00011. This means that in terms of BER, the conventional cooperative communication system is better than the network coding scheme in the cooperative communication system. From the throughput parameter, the network coding scheme has increased by 30% from the conventional cooperative system.

Measurements in this outdoor environment as seen in Figure 10, by changing the transmitter gain level at the same distance to obtain the BER value. The number of bits sent is 16384 bits and the gain parameters used for the measurements are in according with Table 1.

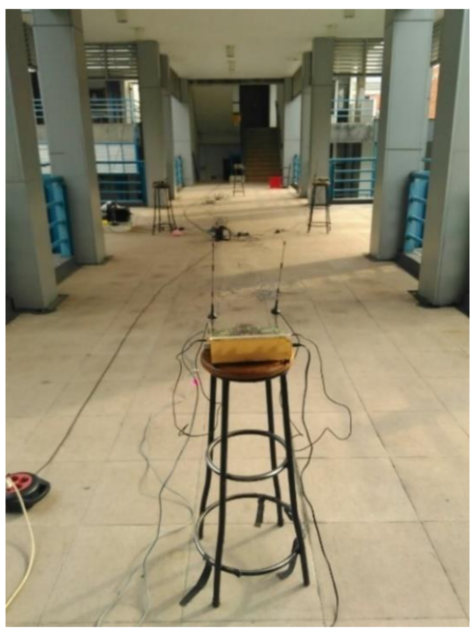

Fig. 10 Outdoor measurements

The measurements shown in figure 11 LOS conditions show that the higher the transmit power gain level, the BER value in the amplify and forward cooperative communication system with the network coding scheme will decrease. The measurements were carried out by changing the distance from 4-30 meters.

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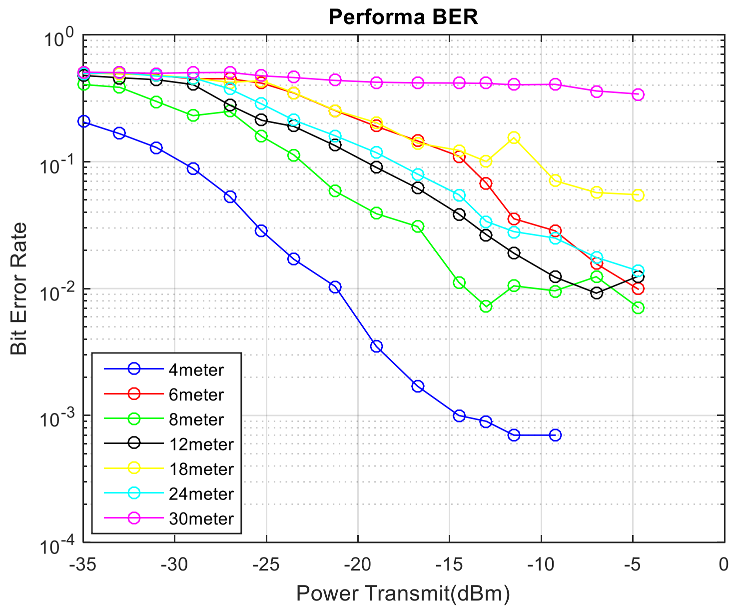

Fig. 11 BER system LOS condition

Based on table 2 and figure 12, the BER of the cooperative communication system of the LOS condition network coding scheme with different distance and transmit power variations shows a decrease along with the increase in the transmit power gain level. The LOS condition with a distance of 4 meters shows a BER of 0 when the transmit power is -7 dBm, at other distances when at the highest transmit power level of -4.7143 dBm, there are still received bit errors with a BER value of 0.3409. This is caused by the influence of LOS (Line of Sight) conditions such as minimal fading and strong source signals.

The measurements shown in figure 12 NLOS conditions show that the higher the transmit power gain level, the BER value in the amplify and forward cooperative communication system with the network coding scheme will decrease. The measurements were carried out by changing the distance from 4-30 meters.

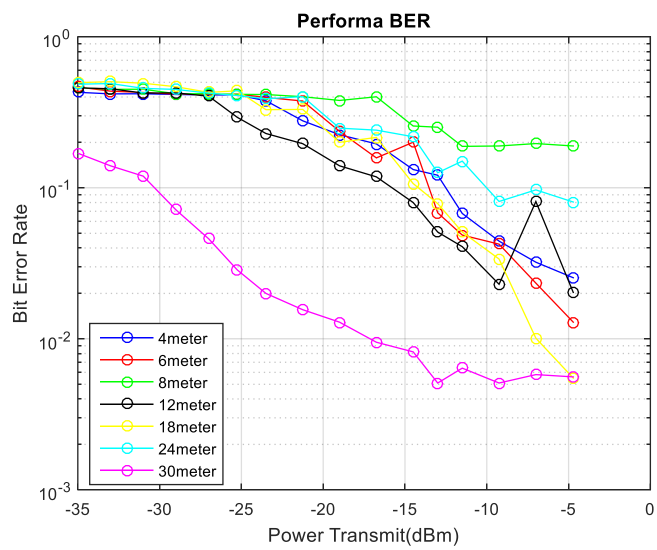

Fig. 12 BER system NLOS condition

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Based figure 13, the BER value of the NLOS condition system is measured with different distance and transmit power values. The NC cooperative communication system in NLOS condition at a distance of 30 meters has good performance compared to other distances with a BER value of 0.0056. Although at all distances with the highest Ptx level, errors still occur in the bit reception process at the receiver. This can occur due to the influence of NLOS (Line of Sight) conditions such as beneficial multipath propagation, diversity gain and the presence of relay nodes.

Comparison of cooperative communication system schemes with and without network coding is shown in Figure 13. Cooperative communication system scheme without NC BER value is 0 when the transmit power value is -19 dBm or Gain 32. While for the cooperative communication system scheme with network coding at a gain level of 52 or with a transmit power of -9.25 dBm the new BER value is 0. This means that the conventional system is better than network coding in terms of BER performance.

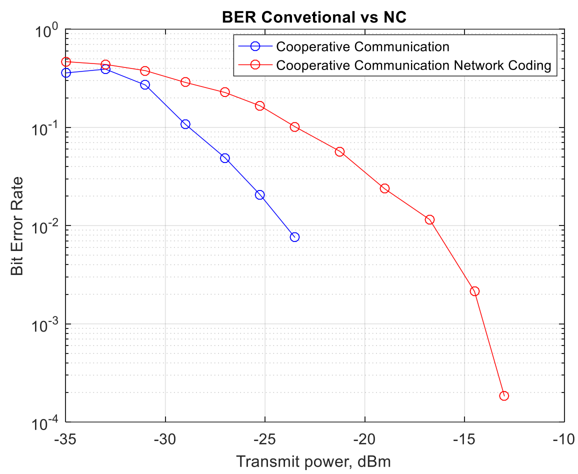
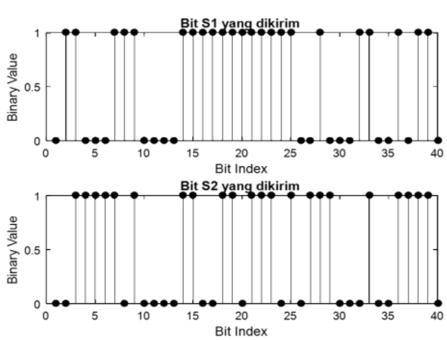
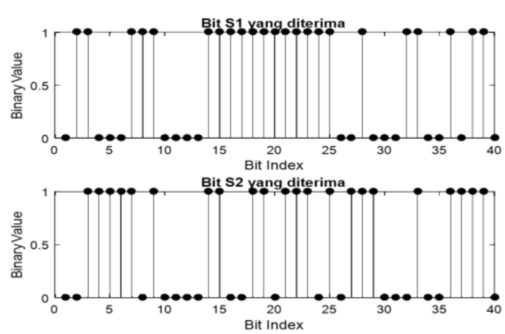


Fig. 13 BER system NLOS condition

This the Output Communication System implementation in Module SDR. Random bits generated at the source node 1 and node source 2 shown in Figure 13 a. The random bits are then sent to the relay node. At the relay node, the information received from source node 1 and source node 2 is processed in the network coding stage, where the symbols from source node 1 and source node 2 are added together, although they still contain noise (S_1n+S_2n). The result of the addition of the symbols is then converted into bit form show at figure 13 c. Information from the node relays the broadcast to the node destination 1 and 2, the node destination information from node source 1 and 2 will undergo a process of network coding again by subtracting the symbol original information to obtain information desired, then the information is in combining and revamped in the form of bits. The result of information bit receive at the node 1 and node 2 show at Figure 13 b.



(a) Random Bit Node Source 1 and 2



(b) Bit received at destination 1 and 2

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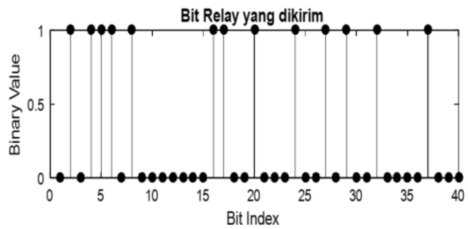

(c) Bit received at Relay node (Network Coding)

Fig 13 Bit Output Communication System implementation in Module SDR

Network coding can increase throughput in a network by reducing the number of transmissions required to send data. In a traditional network without network coding, each node simply forwards data packets individually, which can lead to inefficient use of bandwidth. However, with network coding, nodes can combine multiple packets into one, allowing data to be sent faster and more efficiently, thereby increasing throughput. The result of throughput system show at Figure 14.

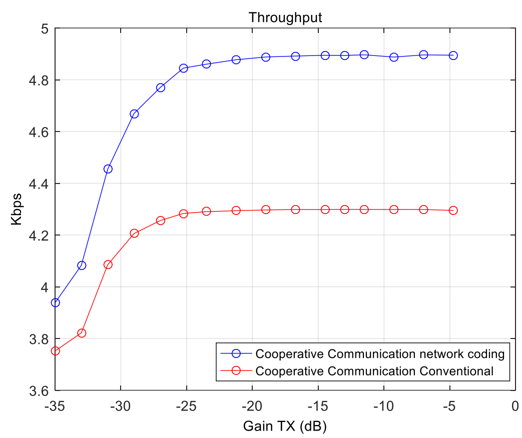

Fig.14 Throughput

Throughput results in outdoor environments by comparing the cooperative network coding communication system scheme with the conventional cooperative communication system. Based on figure 14, the throughput value of the cooperative network coding communication system has increased by $= \frac{4.9-4.19}{4.19}\ x\ 100\% \ = 17\%$ compared to the conventional method.

5. CONCLUSION

After a series of literature review, planning, implementation, measurement and analysis systems, it can be concluded:

1. The throughput of the cooperative communication system with network coding increased by 17% compared to the conventional method.
2. Viewed from the BER value, the conventional cooperative communication system has better performance compared to the cooperative communication system with network coding. Cooperative communication system scheme without NC BER value is 0 when the transmit power value is -19 dBm or Gain 32. While for the cooperative communication system scheme with network coding at a gain level of 52 or with a transmit power of -9.25 dBm the new BER value is 0
3. In NLOS condition cooperative communication network coding system at a distance of 30 meters has good performance compared to other distances with a BER value of 0.0056. Although at all distances with the highest Ptx level, errors still occur in the bit reception process at the receiver. This can occur due to the influence of NLOS (Line of Sight) conditions such as beneficial multipath propagation, diversity gain and the presence of relay nodes.

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4. In LOS condition with a distance of 4 meters shows a BER of 0 when the transmit power is -7 dBm, at other distances when at the highest transmit power level of -4.7143 dBm, there are still received bit errors with a BER value of 0.3409. This is caused by the influence of LOS (Line of Sight) conditions such as minimal fading and strong source signals.

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