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Performance of OFDM Communication System with Network Coding using Wireless Open-Access Research Platform

***Abstract**. Network coding in communication systems is increasingly popular and growing because of its ability to reduce delay and increase throughput. At the same time, OFDM (Orthogonal Frequency Division Multiplexing) modulation technique is also increasingly popular and growing with the advantages of efficient use of bandwidth spectrum and resistance to ISI (Inter Symbol Interference). The merger of the second technology is expected to combine the advantages of the second system. This article describes the implementation of an OFDM communication system with a network coding scheme using the Wireless Open-Access Research Platform. For its performance, an OFDM communication system with direct and multihop schemes has also been built. Furthermore, the parameters analysed are the bit error rate, the time of one transmission cycle and the trial of sending the image. Then these parameters are analysed and compared their performance. The results of the test show that conventional multihop and network coding schemes improve the average BER performance of the direct scheme by 10 dB at a value of 10^{-3}. from the time of one transmission cycle an average of 27%, the increase in throughput is 28% faster and the PSNR improvement in image transmission is sent an average of 11 dB*

Streszczenie.** Kodowanie sieciowe w systemach komunikacyjnych jest coraz bardziej popularne i rośnie ze względu na jego zdolność do zmniejszania opóźnień i zwiększania przepustowości. Jednocześnie technika modulacji OFDM (Orthogonal Frequency Division Multiplexing) jest również coraz bardziej popularna i zyskuje coraz większą popularność dzięki zaletom efektywnego wykorzystania widma pasma i odporności na zakłócenia ISI (Inter Symbol Interference). Oczekuje się, że połączenie drugiej technologii połączy zalety drugiego systemu. W artykule opisano implementację systemu komunikacyjnego OFDM ze schematem kodowania sieciowego z wykorzystaniem platformy badawczej Wireless Open-Access Research Platform. Do jego wykonania zbudowano również system komunikacji OFDM ze schematami direct i multihop. Ponadto analizowanymi parametrami są bitowa stopa błędów, czas jednego cyklu transmisji oraz próba wysłania obrazu. Następnie te parametry są analizowane i porównywane ich działanie. Wyniki testu pokazują, że konwencjonalne schematy kodowania wieloprzeskokowego i sieciowego poprawiają średnią wydajność BER schematu bezpośredniego o 10 dB przy wartości 10-3. od czasu jednego cyklu transmisji średnio o 27%, wzrost przepustowości jest o 28% szybszy a poprawa PSNR w transmisji obrazu przesyłana jest średnio o 11 dB* (Wydajność systemu komunikacji OFDM z kodowaniem sieciowym z wykorzystaniem bezprzewodowej platformy badawczej Open-Access***)

Keywords: network coding, OFDM, multihop, direct
Słowa kluczowe: kodowanie w sieci, OFDM, wydajność sieci

Introduction

In existing research, orthogonal frequency division multiplexing (OFDM) has attracted attention as a transmission technique in modern wireless networks that can carry relatively large data. There are many advantages of OFDM, such as effective use of a large frequency band, and resistance to frequency selective fading [1]. Therefore OFDM has a role in the development of broadband wireless communication systems such as Wi-Fi, WiMax, and long term evolution (LTE) [2].

In a multihop relay network communication system, if there are 2 communication source points (nodes S_1 and S_2) and there is 1 node as an intermediary (node R). if the transmission technology uses the principle of time division duplexing (TDD), then to be able to exchange information on multihop communication requires at least 4 timeslots. Among them: Timeslot 1, S_1 sends to R. Timeslot 2, R forwards S_1 information by broadcasting so that S_2 receives S_1 information. Timeslot 3, S_2 sends to R. Timeslot 4, R forwards S_2 information by broadcasting so that S_1 receives S_2 information. A total of 4 timeslots are required for the two to communicate. By using network coding, it takes only 3 timeslots [3]. So with network coding is expected to increase throughput.

Network coding performs XOR operations, sending data simply by doing XOR between node 1 and node 2 (coding), then XOR again to decode the data. So that later with network coding can increase throughput and reduce delay.

Basic Teory

A. Orthogonal Frequency Division Multiplexing

Orthogonal frequency division multiplexing or hereinafter referred to as OFDM is a form of multi-carrier modulation (MCM) which can be achieved by dividing a single transmission channel into several subchannels or carriers that are perpendicular to each other (orthogonal) to optimize data transmission efficiency. The carrier signal from OFDM is the sum of the number of orthogonal subcarriers[11], with the baseband data on each subcarrier being modulated with the desired modulation technique. The use of mutually orthogonal frequencies in the OFDM system allows contact between frequencies without causing interference with one another. In a mathematical approach [4], the orthogonality of the OFDM system can be explained as follows, for example the function $X_m(t)$ is the m-subcarrier and $X_n(t)$ is the nth subcarrier. These two subcarriers are said to be orthogonal to each other at the interval a<t<b if they satisfy the following conditions:

$$\int_a^b X_m(t) * X_n(t)dt = 0 \quad (1)$$

The main method of the OFDM system is where the modulation scheme is with a low symbol ratio so that it only gets a little from the influence of intersymbol interference from multipath fading[12]. Therefore, it is possible to transmit a number of low-rate streams in parallel instead of a single or serial high-rate stream. Since the symbol duration is longer when compared to high-rate streams, it is possible to insert guard intervals between OFDM symbols, thereby eliminating intersymbol interference.

B. Network Coding

The concept of Network Coding was first introduced in 2000 by Ahlswede, Cai, Li, and Yeong. The performance of network coding compared to non-network coding is better and more efficient because the data sent is combined with coding from several sources with one delivery [5]. Network coding can increase throughput, robustness, complexity, and security. There are 3 concepts of network coding, namely the traditional scheme without network coded (TS), the straightforward network coding (SNC) scheme and the physical layer network coding (PNC) scheme [6].

Scheme In the traditional scheme without network coding, using 4 timeslots using 2 packets. In timeslot 1, node 1 sends packet S_1 to relay R. In timeslot 2, Relay R sends back S_1 to node 2. In timeslot 3, node 2 sends packet S_2 to relay R and In timeslot 4, relay R sends back information S_2 to relay R. node 1. The illustration can be seen in Figure 1 [6].

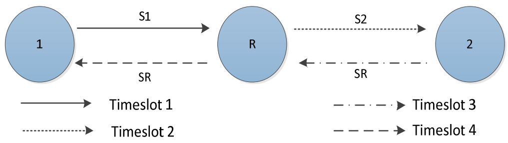


Fig. 1.Traditional without Network Coding

In network coding, using timeslot 3 so that it can have the ability to increase throughput by 33%. Figure 2 illustrates the illustration of SNC using 3 timeslots for the process of sending information data. In timeslot 1, node 1 sends S_1 to the relay. Then in timeslot 2, node 2 sends information S_2 to the relay. After receiving information from S_1 and S_2, the relay then helps mapping the network coding $S_R = f(S_1,S_2)$ While in S_1, S_2 consists of modulation symbols and $f(S_1,S_2)$ is XOR, as follows:

(2) $$S_R = S_1 \oplus S_2$$

In 3rd timeslot, relay R broadcasts S_R to node 1 and node 2. When node 1 receives information from S_R, S_2 extracts information from S_R using information from S_1. So it can be written as follows:

(3) $$S_1 \oplus S_2 = S_1 \oplus (S_1 \oplus S_2) = S_2$$

Likewise at node 2, extract the information S_1 from $S_2 \oplus S_R$. The network coding process is carried out by the relay after passing through the decoding process of node 1 and 2 packets in different timeslots [6].

C. Wireless Open-Acces Research Platform

WARP is a programmable wireless platform that can prototype wireless networks from basic to complex. WARP combines high-performance programmable hardware with an open-source repository of reference designs and source materials [7].

The WARP project was started in 2006 by Prof. Ashu Sabharwal at Rice University, USA [7]. Previously, this project was funded by the National Science Foundation with direct assistance from Xilinx [7].

The WARP project has grown into an independent, open source venture with users around the world. In using WARP in research, there are several methods for programming the device. This platform consists of hardware and FPGA implementation which is the key to communication between blocks. WARP's hardware consists of FPGA-based processing boards that incorporate wideband radio and I/O interfaces. The architecture of WARP is shown in Figure 3 which consists of 4 main components.

Design and Implementation

The things built include the SISO OFDM communication system design a direct OFDM communication system between sending and receiving nodes without relays, conventional multihop OFDM communication systems a two-way communication system with 4 time slots for sending/receiving between source 1 and source 2 by passing the relay and the last is OFDM communication with network coding a two-way communication system with 3 time slots for sending/receiving between sources 1 and 2 passing through a relay with a network coding system [8][9].

In carrying out the implementation design, several stages need to be carried out. The first step is system design, simulation in Matlab. Simulations in Matlab are applied in noiseless conditions with the aim of ensuring the system runs correctly. Indications of the truth is not to pay attention to the condition of the information sent and received is the same as a whole. Then simulated using AWGN noise additive. At this stage, we want to show an initial picture of the BER response to AWGN additional noise to be compared with the implementation results. The third step is implementing the system on WARP, then the BER value will be obtained for performance analysis. The system design flow is shown in Figure 4.

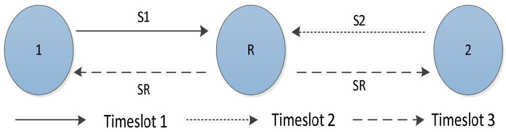


Fig. 2. Network Coding Scheme

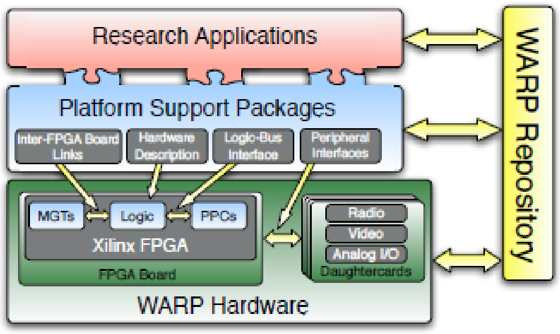


Fig. 3. Components of Platform Design[7]

Table 1. OFDM system Design Parameters

Parameters		Value
FFT Value		64
CP Value		16
Number of Subcarriers	*Payload*	48
	Pilot	4
	Null	12
	total	64
interpolarization		2 times
Mapping Baseband		QPSK

A. OFDM sender system design

The OFDM sender consists of several parts, including information generator, QPSK mapping, serial to parallel, pilot insertion, IFFT, parallel to serial, adding preamble and CP then Interpolarization. Technical parameters as shown in Table 1.

B. Direct OFDM communication system design

In the direct OFDM communication system design, two WARP devices are used, as shown in Fig 5. Each node functions as a sender and a receiver.

In Figure 6 shows the stages of the sending and receiving process, in the first timeslot S_1 sends to node S_2 then finally in the second timeslot node 2 sends information to node S_1.

C. Conventional multihop OFDM communication system design

The conventional multihop system uses a scheme as shown in Figures 6 and 7. This scheme uses three WARP devices, two of which are used as send/receiver nodes and one node is used as a relay node. This step of the scheme to perform one sending and receiving cycle requires four timeslots as shown in Figure 8.

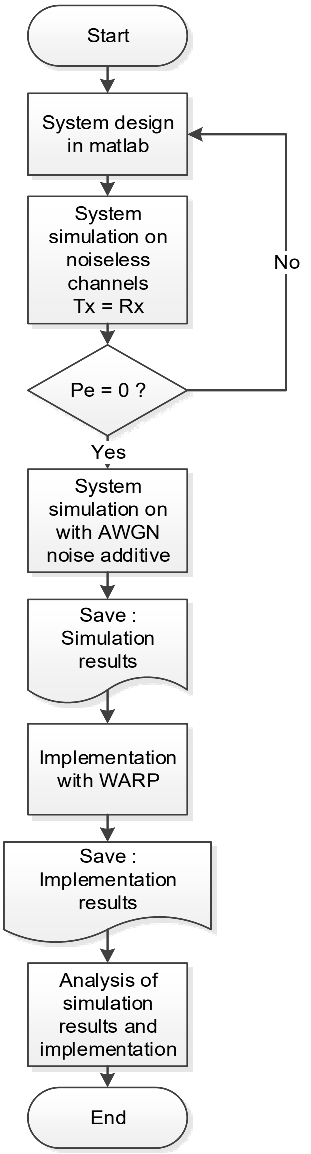


Fig. 4. System design flow

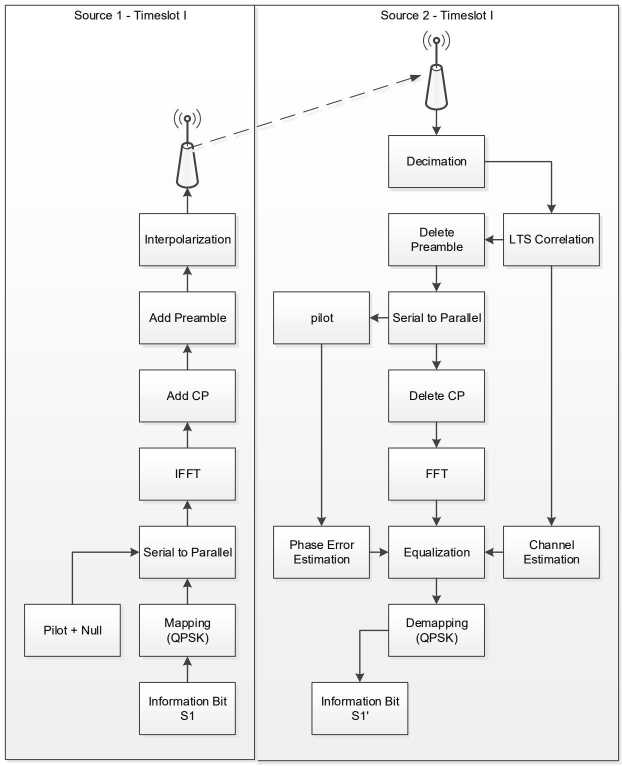


Fig. 5. Direct OFDM communication scheme

In the first timeslot node S_1 sends data to node relay, node S_1 is configured as sender and node relay as receiver. Furthermore, in the second timeslot, the relay node forwards the received data from S_1 to the S_2 node, in other words, the relay node is configured as the sender and the S_2 node as the receiver. Then in the third timeslot, node S_2 is configured as sender and node relay as receiver, node S_2 sends data to node relay. Then in the last timeslot node relay forwards data to node 2, node relay sends data to node S_1, node relay is configured as the sender and node S_1 as the receiver.

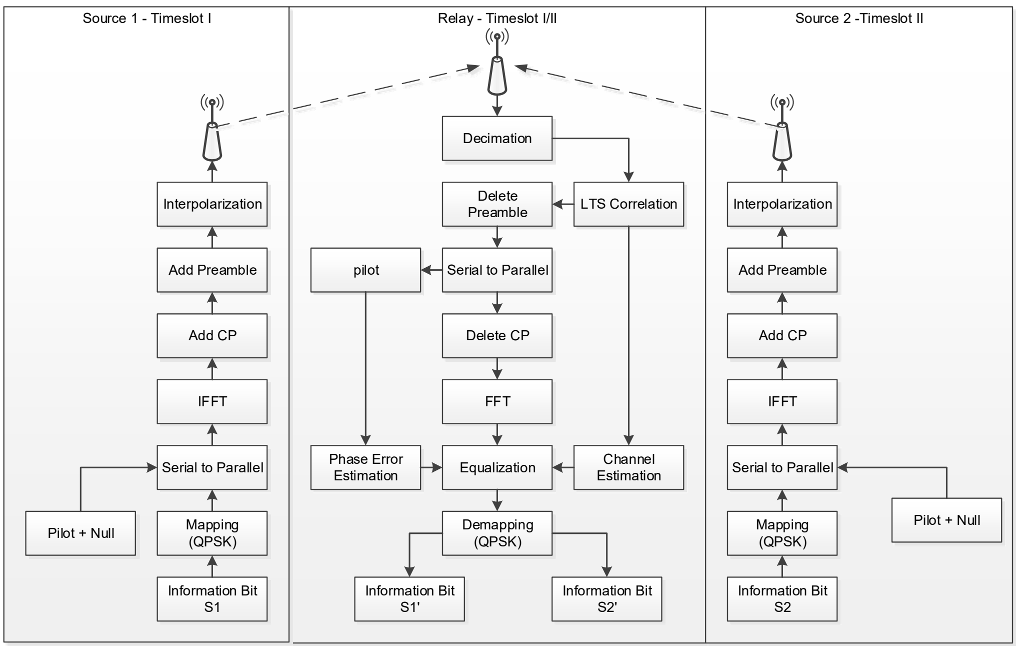


Fig. 6. The process of sending and receiving multihop schemes in timeslots 1 and 2

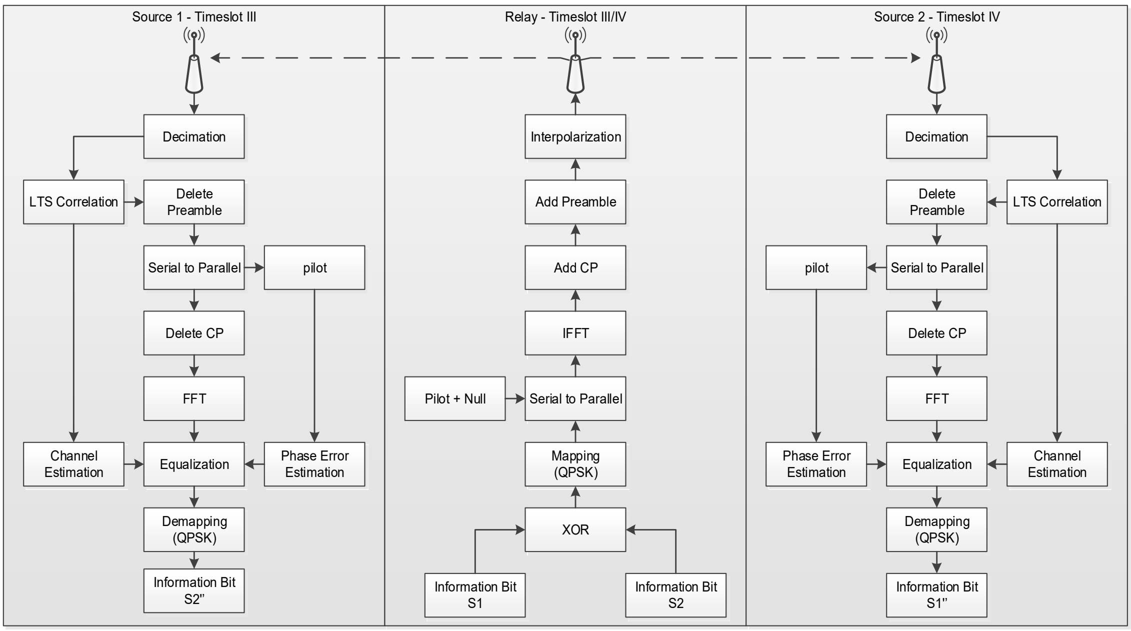


Fig. 7. The process of sending and receiving multihop schemes in timeslots 1 and 2

In the first timeslot node S_1 sends data to node relay, node S_1 is configured as sender and node relay as receiver. Furthermore, in the second timeslot, the relay node forwards the received data from S_1 to the S_2 node, in other words, the relay node is configured as the sender and the S_2 node as the receiver. Then in the third timeslot, node S_2 is configured as sender and node relay as receiver, node S_2 sends data to node relay. Then in the last timeslot node relay forwards data to node 2, node relay sends data to node S_1, node relay is configured as the sender and node S_1 as the receiver.

D. OFDM communication system design with network coding

The conventional multihop system uses a four timeslots scheme, whereas with a network coding scheme, the system only uses three timeslots to perform one cycle of the sending and receiving process. This scheme uses three WARP devices, two of which are used as sending/receiving nodes and one node is used as a relay node. The stages of this scheme to perform a cycle of sending and receiving are shown in Figures 9 and 10.

In Figure 11 it can be explained that the first timeslot of node S_1 sends data to the relay node, node S_1 is configured as the sender and the relay node is the receiver. Next, in the second timeslot, node S_2 is configured as the sender and node relay as the receiver, node S_2 sends data to node relay. the configuration difference between the conventional multihop scheme and the network coding scheme is that in the third timeslot, the relay node performs an additional function in the third timeslot, which is to combine the two information received from S_1 and S_2, the intended combination is in the form of an XOR of bits. information received from both sources. In this last timeslot, after node relay performs the network coding function, node relay forwards data to node 2 and node 3, node relay is configured as the sender while node S_1 and node S_2 are the recipient. At the receiver, the data that has been obtained is then XORed again with the data sent by each node, so that the data sent from each sender can be translated.

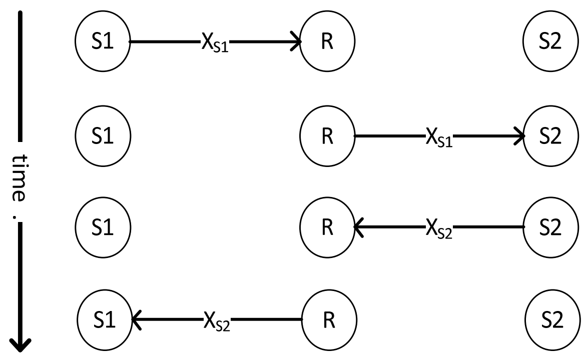


Fig. 8 Overview of conventional multihop OFDM communication stages

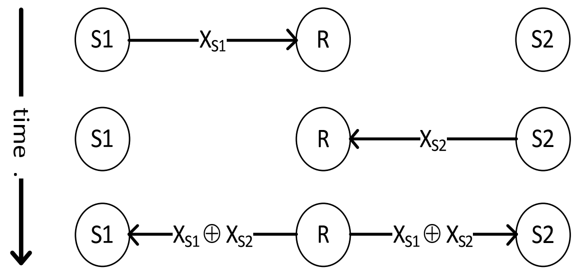


Fig. 9 Overview of OFDM network coding communication stages

Results and Analysis

A. BER Measurement

Figure 12 shows three graphs of the BER function of the transmit power. Data obtained from the results of measurements in the room with LOS conditions with a distance between S1 and S2 as far as 4 meters. It can be seen that the performance of the multihop and network coding scheme is better than the direct scheme. To achieve a BER value of 10^{-2} in the direct scheme, a transmit power of ± -11dBm is required, while each in the network coding and multihop schemes only requires a transmit power of ± -20 dBm. So that the use of network coding and multihop schemes has a relative gain of ± -9dB of the power required by the direct scheme to get a BER value of 10^{-2}.

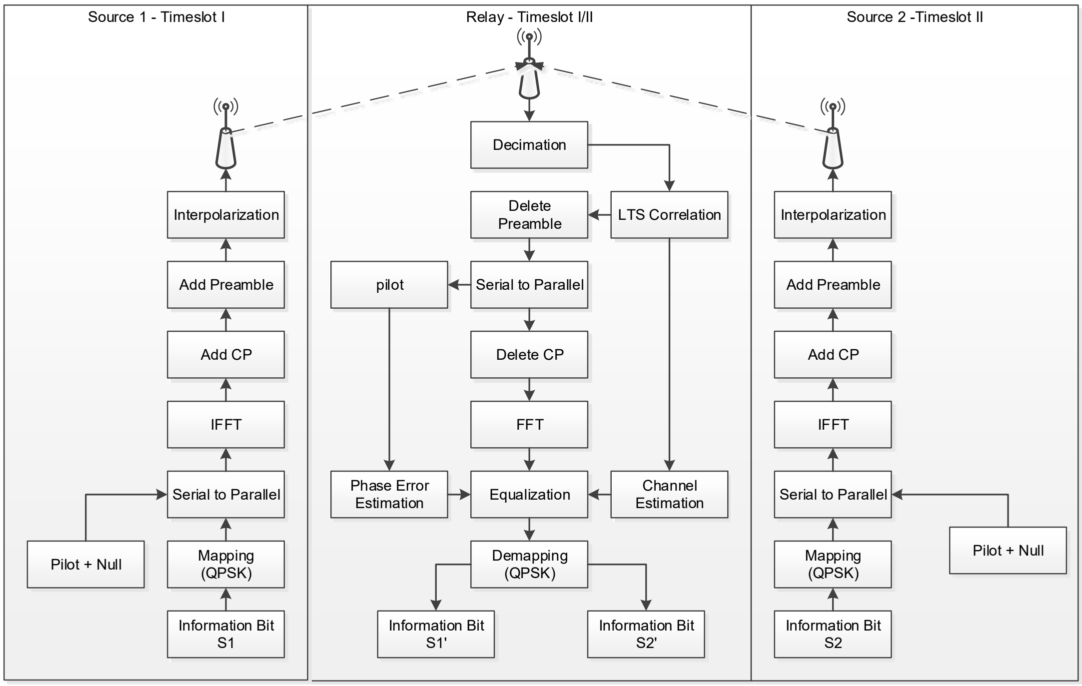


Fig. 10 The process of sending and receiving network coding schemes in timeslots I and II

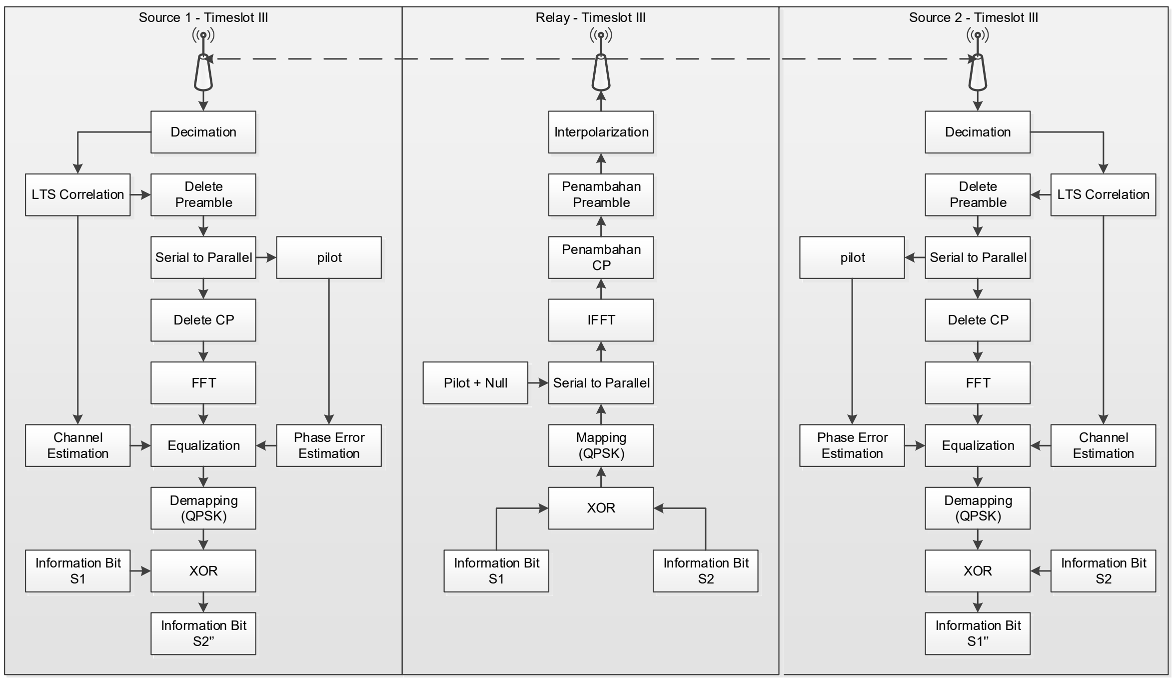


Fig. 11 The process of sending and receiving network coding schemes in timeslots III and IV

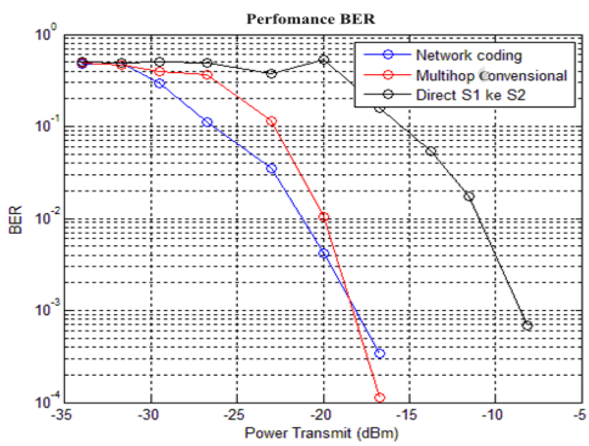


Fig. 12 BER performance under LOS conditions

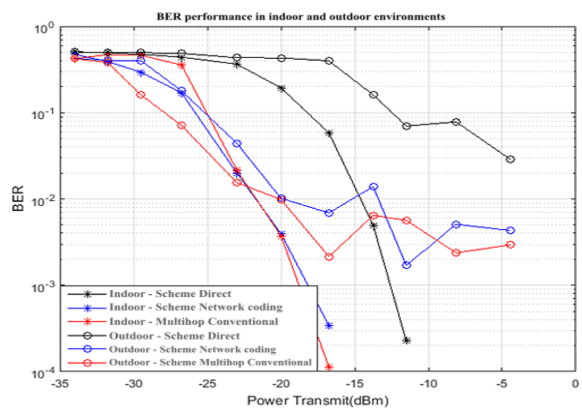


Fig. 13 BER performance in indoor and outdoor environments

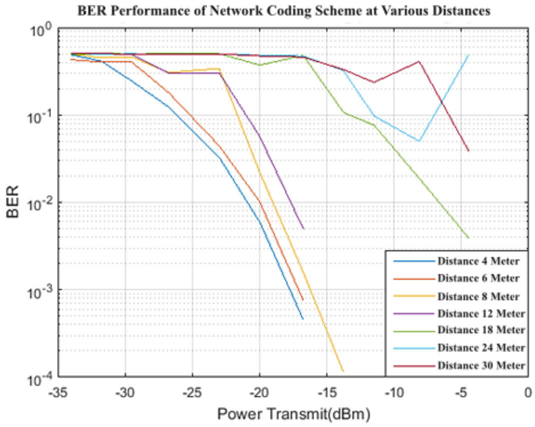


Fig. 14 Results from measurements at various distances

B. BER measurement in outdoor and indoor environments

Figure 12 shows the measurement results in an indoor environment showing better measurement results. When the transmit power is -20dBm, the network coding scheme in the indoor environment has a BER value of ± $3x10^{-3}$ while outdoor has a value of $\pm 10^{-2}$. The multihop scheme shows the same results when observed at a transmit power of -20dBm, in the indoor environment it has a BER value of ± $3x10^{-3}$ while outdoor has a value of $\pm 10^{-2}$. And lastly, the direct scheme in the indoor environment has a BER value of ± $1x10^{-1}$. Meanwhile, outdoor has a value of $\pm 3x10^{-1}$. The three schemes show that the measurement results in indoor conditions are better. Some of the factors that can affect it include, in measuring the outdoor environment, indirect power has a not too big effect, but there is a lot of interference from Wifi transmitting devices whose working frequency is the same as the system being built.

C. Measurement of network coding scheme BER at various distances

Furthermore, the measurement is carried out with different distance scenarios, so that later it is expected to know the optimum distance of the system. Measurements were made at a distance of 4 meters, 6 meters, 8 meters, 12 meters, 18 meters, 24 meters and 30 meters. The results of the measurements are shown in the following figure 14.

The Figure 14 shows that to get a BER performance of 10^{-3} at a transmit power below -15 dBm, the distance that can be achieved is when the distance is below 12 meters. At a distance of 18, 24 and 30 meters the measured BER value is still greater than 10^{-1}.

D. Results and Analysis of Communication Time Measurement

The BER measurement was carried out by testing the direct, multihop and network coding schemes, it was found that the BER performance of the multihop and network coding schemes was better than the direct scheme, so to show which performance was better than the multihop or network coding scheme, a measurement of the transmission time of each was carried out. scheme. Measurement of communication time is carried out on each multihop communication scheme and network coding. The time measured is the time during one cycle of sending and receiving information from S1 and S2. Furthermore, the results are shown in the Figure 15 below.

Seen in Figure 15 are two graphs of the measurement results of the transmission time from several times of transmission with different transmit power. The transmission time of the network coding (blue graph) is noticeably faster than the transmission time of the multihop scheme (red graph). Each is worth an average of 1.3 seconds and 1.8 seconds. This means that the network coding scheme is 0.5 seconds faster or 27% of the multihop scheme.

This increase is because the multihop scheme requires 4 timeslots to transmit and receive, while the network coding requires only 3 timeslots to transmit and receive.

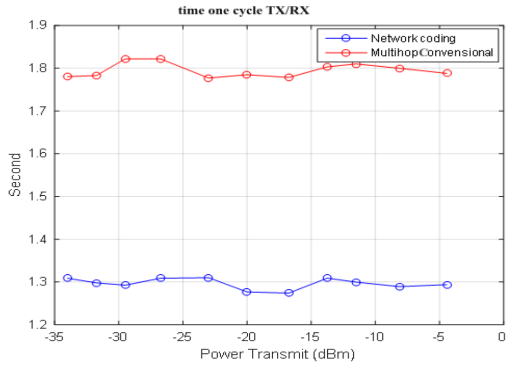


Fig. 15 One time transmission in LOS conditions indoors with a distance of 4 meters

E. Results and Analysis of Throughput Measurement

Figure 16 shows that the throughput is relatively stable at the power at the transmitter is more than -20 dBm. And it can be seen that the maximum throughput value is different between network coding and multihop schemes. The networkcoding scheme produces a maximum throughput of 3.5 Kbps and a multihop scheme of 2.5Kbps. The networkcoding scheme is able to provide improvisation for throughput greater than ± 28% of the maximum throughput of the multihop scheme.

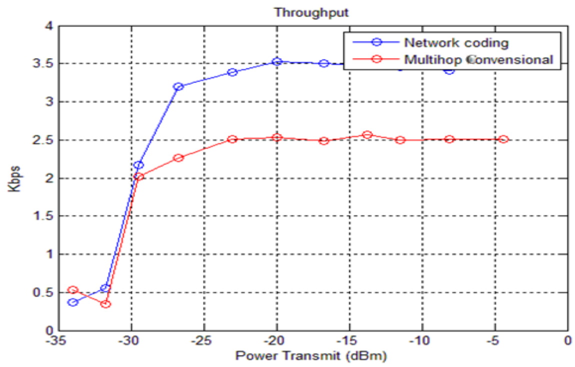


Fig. 16 Throughput of network coding and multihop schemes

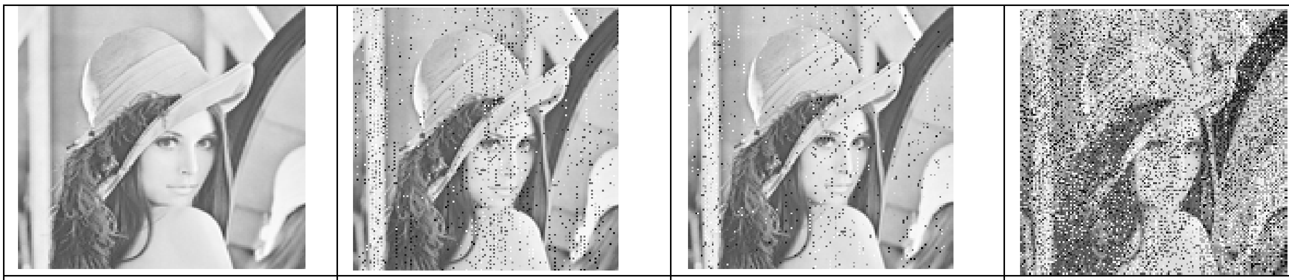
F. Image Sample Delivery Results

Figure 17 show the results of sending images from each scheme. From the results of the images received using the three schemes, then the MSE and PSNR of the images are calculated.

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \quad (4)$$

$$PSNR = 10log_{10}\frac{MAX^2}{MSE} \quad (5)$$

The network coding and multihop schemes provide improvements to the direct delivery scheme, which is ±7dB. Some things that are suspected of being the factor that causes this to happen are interference, when outdoors there are many frequencies that interfere with the system, because WARP uses a working frequency on the 2.4 GHz band and Wifi in the ITS Electrical Building area also uses the same frequency.



(a) Original Image	MSE = 627.71 PSNR = 20.19 (b) Image of network coding	MSE = 326.26 PSNR = 23.03 (c) Multihop Image	**MSE = 3239.30** **PSNR = 13.06** **(d) Direct image**

Fig. 17 The result of sending pictures outdoors with LOS conditions

Conclusion

Based on planning, implementing and measurement result of the system, it can be concluded:

Network coding works by utilizing the savings in the use of communication timeslots, where the conventional multihop scheme uses 4 timeslots while the network coding scheme uses 3 timeslots. In the network coding scheme, the relay sends data in the form of XOR results from the two sources information in the third timeslot, then the data receiver is re-XORed with the results sent by the relay and data sent by each node to the relay node to get the information sent by the node other.

The process of merging information using the XOR mechanism in the OFDM communication system is carried out on the demodulation bits on the relay node, then at the receiver to get the information sent is also carried out using the XOR mechanism which is carried out on the demodulated bits at the receiver.

The performance of the network coding system on the OFDM communication system in this study is as follows:

a. The use of the network coding scheme can improve the BER performance of the direct scheme, as evidenced by the measurements taken, it is shown that to get a BER value of 10^{-2} in the direct scheme, a transmit power of ± -11dBm is required, while the network coding scheme only requires a transmit power of ± - 20 dBm, but in the network coding scheme it is necessary to add a resource in the form of a relay node.

b. The transmission time of the network coding scheme is faster than the transmission time of the multihop schemes. They are worth an average of 1.3 seconds and 1.8 seconds, respectively. This means that the network coding scheme is 0.5 seconds faster or 27% of the multihop scheme

c. The application of network coding schemes in OFDM communication systems can increase throughput because transmission with network coding is done faster than using conventional multihop schemes, precisely the network coding scheme in this study has a transmission time performance of ± 28% faster than traditional multihop schemes.

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REFERENCES

[1] S. Weinstein and P. Ebert, “Data Transmission by Frequency-Division Multiplexing Using the Discrete Fourier Transform,” IEEE Trans. Commun. Technol., vol. 19, no. 5, pp. 628–634, Oct. 1971.

[2] X. Wang, Y. Xu, and Z. Feng, “Physical-layer network coding in OFDM system: Analysis and performance,” in 2012 7th International ICST Conference on Communications and Networking in China (CHINACOM), 2012, pp. 139–143.

[3] H. TRACEY and L. DESMOND S., NETWORK CODING : An Introduction. The Edinburgh Building, Cambridge

[4] Y. S. Cho, Jaekwon Kim, Won Young Yang, and Chung-Gu Kang, MIMO-OFDM Wireless Communications with MATLAB. Singapore: John Wiley & Sons (Asia) Pte Ltd, 2010.

[5] C. Fragouli, Soljanin, and Emina, “Network Coding Fundamentals, Foundation and Trends R in Networking,” 2007.

[6] C. L. Soung and Shengli Zhang, “Physical Layer Network Coding: Tutorial, Survey And Beyond,” 2013.

[7] “WARP Project.” [Online]. Available: http://warpproject.org/trac. [Accessed: 15-Dec-2015].

[8] Hasan, IMPLEMENTASI DAN EVALUASI KINERJA ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) MENGGUNAKAN WARP. Jurusan Teknik Elektro ITS, 2015.

[9] Endroyono, Suwadi, Achmad Ansori, Ummul Khair, “Implementation of wireless communication system using network coding on WARP”, Journal of Theoretical and Applied Information Technology, Vol.95, No.8, April, 2017, pp. 1745-1753.

[10] Suwadi, Endroyono, Titiek Suryani, Ummul Khair, “Performance of cooperative communication system with network coding using software defined radio”, Journal of Theoretical and Applied Information Technology, Vol.96, No. 1, January 2018, pp. 1–9.

[11] R. C. Cortez, G. P. Arada, R. C. Gustilo and E. R. Magsino, "Performance Improvement of the DWT-OFDM System Using Convolutional Coding," 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), 2021, pp. 1-4, doi: 10.1109/HNICEM54116.2021.9732041.

[12] G. P. Kumar, M. Dileep, B. V. V. Satyanarayana and S. P. Manikanta, "Modified Channel Estimation Techniques for DCT based OFDM Systems," 2022 International Conference on Computer Communication and Informatics (ICCCI), 2022, pp. 1-6, doi: 10.1109/ICCCI54379.2022.9740842.