Iraqi Journal of Information and Communications Technology(**IJICT**)
Vol. 6, Issue 2, August 2023
www.ijict.edu.iq
ISSN:2222-758X
e-ISSN: 2789-7362

TRANSMISSION OF PHYSICAL LAYER NETWORK CODING BASED ON MASSIVE MIMO OVER MILLIMETER WAVE CHANNEL

Alza A. Mahmood [1], **Abdulkareem A. Kadhim** [2], **Hamed S. Al-raweshidy** [3]
[1] University of Technology, Computer Engineering Department, Baghdad, Iraq.
[2] College of Information Engineering, Al-Nahrain University, Baghdad, Iraq.
[3] College of Engineering, Design and Physical Sciences, Brunel University, London, United Kingdom.
Alza.A.Mahmood@uotechnology.edu.iq [1], ak_kadhim@nahrainuniv.edu.iq [2],
hamed.al-raweshidy@brunel.ac.uk [3]
Corresponding Author: Hamed S. Al-raweshidy
Received: 03/08/2022; Revised: 04/11/2022; Accepted: 20/11/2022
DOI:**10.31987/ijict.6.2.220**

Abstract- **Massive Multiple Input Multiple Output system and physical layer network coding (PNC) are two important technologies that are considered in new generation networks. In this paper, we investigate the effect of increasing the number of antenna elements at user nodes and relay nodes in the presence of PNC. Two-way wireless relay transmission is considered in conjunction with a massive number of antennas at the relay node, assuming a millimeter wave (mmWave) band channel environment. End-to-end transmission is considered using the 3-D QUAsi Deterministic RadIo channel GenerAtor (QuaDRiGa) channel model. The performance measures used are the bit error rate (BER) and throughput. The main paper findings indicate that the non-PNC system has the same BER performance as the PNC system over the mmWave channel model while its throughput has improved by about 100%. The BER performance is improved only when the number of relay node antennas is much higher than that of the user node. Combining mMIMO with PNC gives better throughput without affecting the BER at high SNR. This is achieved with a reasonable number of antennas at the user nodes.**

keywords: **Massive MIMO, Physical Layer Network Coding, Millimeter Wave; QuaDRiGa Channel Model, Throughput.**

I. INTRODUCTION

Device-to-device (D2D) communications have been realized as an effective means to improve network capacity, reduce transmission latency, and extend cellular coverage in new networks. It allows two devices in close proximity to send and receive data directly. With the ever-growing service demands for extended coverage, however, the traditional single-hop D2D communications paradigm is no longer able to deal with such demands. The allowable communication range between two devices in such a paradigm is quite limited. As a result, relay-based D2D communications mechanisms, also known as multi-hop D2D communications mechanisms, are essential for meeting the aforementioned service needs, expanding network coverage, and further improving system performance [1]. So, relaying will play an important role in fulfilling the goals of new generation networks, especially in mmWave transmission, where signals are easily blocked by obstacles [2]. As an extension of conventional Multi-Input Multi-Output (MIMO), massive MIMO (mMIMO) exploits a large array of antennas in the range of 100's and even 1000's. The massive array of antennas provides higher channel capacity and throughput gains [3]. Implementing mMIMO also benefits from spatial diversity by improving link reliability. Additionally, by focusing energy solely on targeted terminals, mMIMO can reduce interference and expand coverage with the help of

ISSN:2222-758X
e-ISSN: 2789-7362

beamforming. Due to these advantages, mMIMO is currently a significant physical layer technology for the next generation of networks [4]. Further, different detection and equalization algorithms can be used in mMIMO systems to detect the transmitted signals [5]. Another significant technique that can be used besides mMIMO at the physical layer is Physical Network Coding (PNC), which applies network coding techniques at the physical layer rather than the network layer. PNC generates an outgoing bit stream as a function of incoming bit streams from many users at intermediate nodes, allowing all users to simultaneously receive and decode the sent data, which improves network utilization [6]. PNC needs only two time slots, while the uncoded (non-network coding) system needs four time slots. As a result, PNC adoption can be expected to increase network throughput [7,8]. Furthermore, there is a requirement for PNC to function correctly. To make sure that the carrier wave and the code are synchronized, the synchronization clock must be closely adhered to [9]. Furthermore, many researchers have investigated channel coding with the PNC system [10]-[12].

Most of the previous work focused on conventional MIMO. For example, in [13], researchers used 2x2 MIMO with network coding (MIMO-NC), which increased throughput over the original MIMO system by about 33% at the expense of a slight loss in error at high SNR range. To enhance the MIMO-based orthogonal frequency division multiplexing systemâs performance, it is integrated with PNC, as in [14]. In [15], the proposed system achieved an increase in the transmission rate when multiple antennas were used at the source nodes. In [16], the concept of successive interference cancelation is concatenated with PNC, where the new strategy of multi-way relaying is used with MIMO systems. The multi-user MIMO (MU-MIMO) scheme for several precoding schemes with network coding in downlink transmission (DL) has been exploited in [17], where MU-MIMO outperformed the system of network coding. A full-duplex scheme combined with a massive array for reception at the relay node is presented in [18], which reduced the interference as the number of antennas at the relay node increased. In [19], an energy-efficient spatial modulation (SM) with PNC scheme was proposed, outperforming the conventional PNC scheme. In [20], a design of a two-way relay MIMO-PNC system using the space-time block code is considered. The work showed an improvement in system performance with relatively low complexity at all nodes. In new generation networks, physical layer network coding is used to reduce the backhaul load, as in [21], using a two-stage search algorithm that also reduces the computational complexity in the uplink transmission (UL) of MIMO networks. MU-mMIMO with a PNC scheme in the uplink transmission has been presented in [3], where the BER performance of mMIMO joined with PNC performed better than mMIMO without PNC. The non-orthogonal multiple access (NOMA) uplink-based MIMO system with PNC was proposed to improve the spectral efficiency and reduce the delay to fulfill the requirements of future IoT applications [22]. To the best of our knowledge, no research has been presented on the use of joint PNC and mMIMO over the mmWave channel. Previous research also concentrated on the 6 GHz frequency band. This paper assesses the integration of the three technologies- relaying, PNC, and massive MIMO- in a two-way relay channel (TWRC) over mmWave bands in an indoor environment. The organization of the paper is as follows: Section II introduces the system model, while the signal transmission model is presented in Section III. The findings and their analysis are presented in Section IV. Section V primarily covers the conclusions.

II. SYSTEM PARAMETERS AND CHANNEL MODEL

A TWRC scenario is considered, consisting of two source nodes (S_1 and S_2) exchanging information through the relay node (R). The relay node has an enormous number of antennas. Two source (user) nodes are equipped with N_u antennas, while the relay node is equipped with N_r antennas. The indoor environment is considered with a 30 GHz carrier frequency and a transmission bit rate of 100 Mbps for each source node. The signal modulation considered is QPSK. The model of the mmWave channel used here is based on the QuaDRiGa model [23]. QuaDRiGa is a three-dimensional stochastic channel model based on geometry. Fig. 1 shows a simplified geometric structure of this model, where θ and φ represent the departure and arrival angels in the zenith and azimuth directions, respectively, and m represents the paths. The main QuaDRiGa features are as follows: it supports large arrays, indoor and outdoor usage, consideration of spherical waves, dual-mobility (the transmitter or receiver can be mobile), 3D (elevation), mmWave band coverage, spatial consistency, and high mobility [23]. The source node antenna height in the model is assumed to be 1.5 m, and that of the relay node is 3 m. The number of clusters (multipath components) is 19, and the number of rays per cluster is 20 [23].

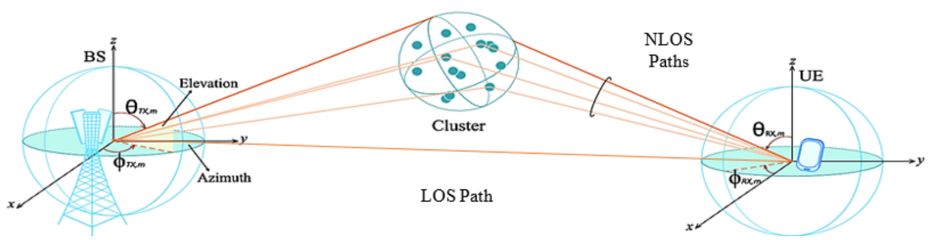

Figure 1: Geometric modeling used in QuaDRiGa channel model [23].

III. SIGNAL TRANSMISSION MODEL

Without network coding, four time slots are needed to exchange two symbols, one in each direction. As shown in Fig. 2, this non-network-coded scheme is known as the Uncoded System (US). In time slot #1, S1 transmits a symbol x_{s1} to R node, while in time slot #2, the relay node forwards x_{s1} to S2. The notation applied in this paper is as follows: Uppercase letters represent vectors and matrices, and lowercase letters denote the symbols. The $\oplus$ operator represents an XOR operation. In time slot #3, S2 transmits the symbol x_{s2} to the relay node, and in time slot #4, the relay node forwards x_{s2} to S1. All nodes are half-duplex, i.e., a node cannot transmit and receive simultaneously. Utilizing PNC reduces the time slots to only two. It permits S1 and S2 to transmit together and achieves the network coding operation provided by nature in the superimposed electromagnetic waves (EM).

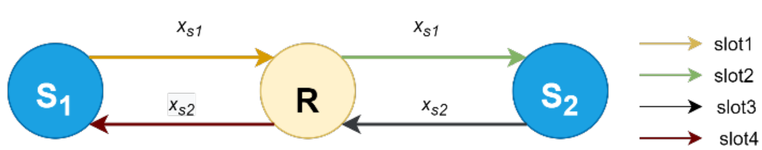

Figure 2: Two-way relay channel model for non-network-coded scheme

ISSN:2222-758X
e-ISSN: 2789-7362

By doing so, PNC can improve the throughput performance as shown in Fig.3. In the first time slot, S1 and S2 transmit x_{s1} and x_{s2} simultaneously to R node. Based on the superimposed EM waves that carries x_{s1} and x_{s2}, the relay node deduces $x_R = x_{s1} \oplus x_{s2}$. Then, in the second time slot, the relay node broadcasts x_R to both S1 and S2 nodes. There is no direct link between S1 and S2. Fig. 4 shows the whole schematic diagram of the mMIMO with PNC scheme.

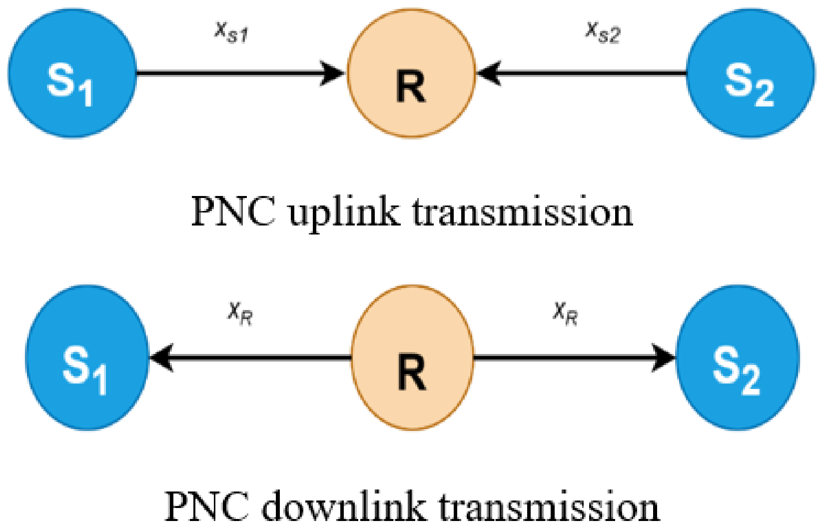

Figure 3: Two-way relay model with PNC

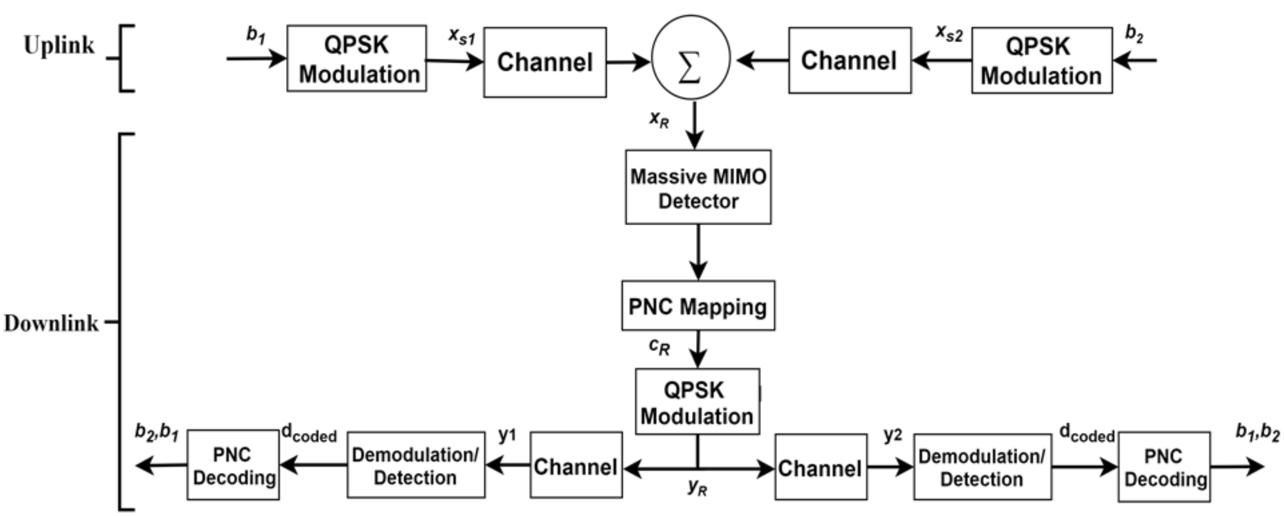

Figure 4: Block diagram PNC based TWRC system using mMIMO

The PNC transmission consists of two phases: uplink and downlink phases. In the first phase, both source nodes send

www.ijict.edu.iq
ISSN:2222-758X
e-ISSN: 2789-7362

their information to the R node at the same time. For the node S_i, the transmitted signal is given by:

$$\mathbf{X}_{si} = \begin{bmatrix} x_1 & x_2 & \dots & x_{N_u} \end{bmatrix}^T \tag{1}$$

where i is the number of the source node. The coefficients of the channel can be represented by the following matrix:

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \dots & h_{1,N_u} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r,1} & h_{N_r,2} & \dots & h_{N_r,N_u} \end{bmatrix} \tag{2}$$

where h_{N_r,N_u} is the coefficient of the channel from the N_u^{th} transmitting antenna to the N_r^{th} receiving antenna. It is assumed here that correct symbol synchronization at the R node is always achieved. The received signal at the R node $X_R \in \mathbb{C}^{N_r \times 1}$ can be expressed as:

$$X_R = H_1 X_{s1} + H_2 X_{s2} + W_r \tag{3}$$

where H_1 and $H_2 \in \mathbb{C}^{N_u \times N_r}$ represent the channel matrices from S_1 and S_2, respectively, to the R node in the uplink transmission, and W_r is an $N_r \times 1$ Additive White Gaussian Noise (AWGN) vector. It is supposed that the R node is aware of the Channel Status Information (CSI). In fact, the CSI is typically estimated using the channel estimation technique. The PNC mapping is illustrated in Table I, where b_{si} is the binary data bit of the source node S_i that is modulated to the x_{si} symbol. The QPSK is considered here as two BPSK streams. The first stream is modulated by the in-phase carrier, while the other is modulated by the quadrature carrier. Table I represents the mapping and coding of the in-phase (real part) stream. A similar processing of the quadrature (imaginary part) stream also followed Table I. The distorted and noisy signal x_R was delivered to the relay node, where it was de-mapped and detected using the Minimum Mean Square Error (MMSE) method [24]. The MMSE detection is obtained by minimizing the mean square error in estimating the channel matrix H. Equivalently, estimating G, the pseudo-inverse of H, which is given by:

$$[G = \arg\min \mathbb{E}\left[||X_{si} - H^H X_R||^2\right]] \tag{4}$$

where $\mathbb{E}$ represents the expectation operator, and the conjugate transpose of H matrix stated as H^H. It can be shown that the MMSE detection takes the effect of noise into account, so that Eq.(4) can be written as:

$$G = \left((H^H H + \frac{N_u}{\text{SNR}} I_{N_u} \right)^{-1} H^H \tag{5}$$

where I_{N_u} is the identity matrix of size N_u. The output of MMSE detector represents the estimated vector $\hat{X}_R$ which can be written as:

$$(\hat{X}_R = G X_R) \tag{6}$$

ISSN:2222-758X
www.ijict.edu.iq
e-ISSN: 2789-7362

TABLE I
PNC Mapping for QPSK Modulation

b_{s1}	b_{s2}	x_{s1}	x_{s2}	$\hat{x}_R$	PNC Mapping (c_R)
1	1	1	1	2	0
0	1	-1	1	0	1
1	0	1	-1	0	1
0	0	-1	-1	-2	0

Following the MMSE detection, the relay node performs PNC mapping according to Table I. The value of $\hat{x}_R$ (the detected value of $xs1 + x_{s2}$) is estimated after the threshold test. Two thresholds were used, Th_1 and Th_2, as given by Eq. (7) and (8), respectively [7].

$$Th_1 = -1 - \frac{N_0}{4} \ln \left(1 + \sqrt{1 - e^{-\frac{8}{N_0}}} \right) \tag{7}$$

$$Th_2 = 1 + \frac{N_0}{4} \ln \left(1 + \sqrt{1 - e^{-\frac{8}{N_0}}} \right) \tag{8}$$

where $N_0/2$ is the power spectral density of the additive white Gaussian noise. The PNC mapping uses $\hat{x}_R$ to find the decoded bit c_R, which may take either a binary "0" or a binary "1" as given in Table I. The relay node then performs QPSK modulation using c_R and transmits its output Y_R to S1 and S2 nodes. Nodes S1 and S2 receive signals that are provided by the following equations, respectively:

$$Y_1 = H_1 \cdot Y_R + W_1 \tag{9}$$

$$Y_2 = H_2 Y_R + W_2 \tag{10}$$

where $H_i \in \mathbb{C}^{N_u \times N_u}$ represents the channel matrix for the DL of node S_i, and W_1 and W_2 are AWGN vectors $\in \mathbb{C}^{N_u \times 1}$ at S_1 and S_2 node inputs, respectively. The two source nodes, S_1 and S_2, use N_u antennas for both sending and receiving. While the R node exploits N_u antennas for transmission and N_r antennas for reception to realize $N_r \gg N_u$. After the demodulation and detection of Y_1 and Y_2, we obtain d_{coded} where S_1 and S_2 nodes employ their own bits to obtain the message bits of the other source node from the PNC coded bits d_{coded}. At S_1, one may get the message bits of S_2 ($\hat{b}_2$) by calculating the XOR-ed operation among d_{coded} and b_1, as given by (11).

$$\hat{b}_2 = d\text{coded} \oplus b_1 \tag{11}$$

likewise, at node S2, the message bits of the S1 ($\hat{b}_1$) can be derived by replacing $\hat{b}_1$ by $\hat{b}_2$ and b_2 by b_1 in (11).

ISSN:2222-758X
e-ISSN: 2789-7362

IV. IV. SIMULATION TESTS AND RESULTS

The full transmission cycle, including user transmission (UL) to the R node and R node retransmission to both source nodes (DL), was covered by the simulated testing. The simulation of the system is done in Matlab R2019a, version 9.6. Table I shows that the system either retransmits the individual signals (uncoded system) or combines the two signals in PNC form. The test results represent measures of both the BER and the throughput against the SNR. The average energy per data bit (Eb) is used to define the SNR, which is expressed as Eb/N_0 in dB per user. After at least 10^6 data bits have been transmitted, the BER is evaluated. The throughput is defined as the ratio of the number of successively received bits to the overall number of transmissions in the system multiplied by the nominal bit rate. The experiments take into account various numbers of antennas at both the user and relay nodes.To depict massive MIMO, two examples for the number of antenna elements at the R node (Nr) are considered: 128 and 256. There are 8, 16, 32, and 64 antennas (Nu) utilized for each case of the used Nr. The BER performance is shown in Figs. 5 and 6 for the PNC and uncoded systems, with the number of antennas at the relay (Nr) node being 128 and 256, respectively.Two values representing Nr and Nu for each system are used as the legend's labels for the BER and throughput performance graphs (uncoded or PNC-coded). For example, the curve labeled "PNC 128x8" represents the PNC coded system with Nr=128 and Nu =8.Figs. 5 and 6 show that the BER of PNC systems is close to the BER of the corresponding uncoded systems having the same number of antennas at user nodes (Nu). When Nu = 8, the best BER performance is obtained in both figures. A considerable reduction in performance is observed as Nu increases toward its maximum number tested here for both uncoded and PNC-coded systems.

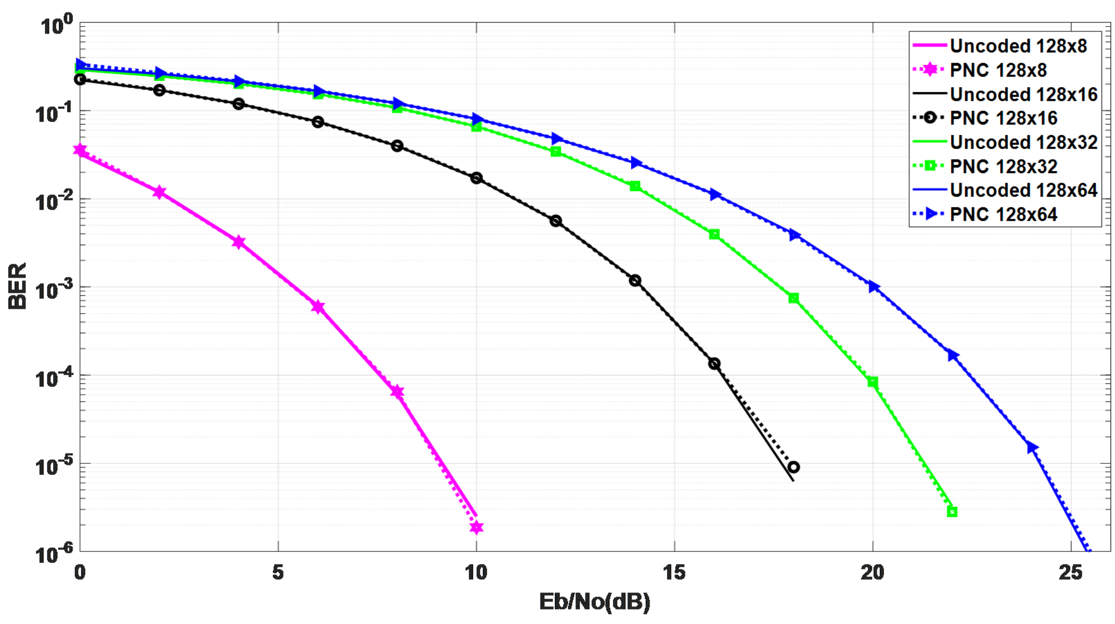

Figure 5: BER performance of uncoded and PNC coded systems with 128 antennas at the relay node.

ISSN:2222-758X
e-ISSN: 2789-7362

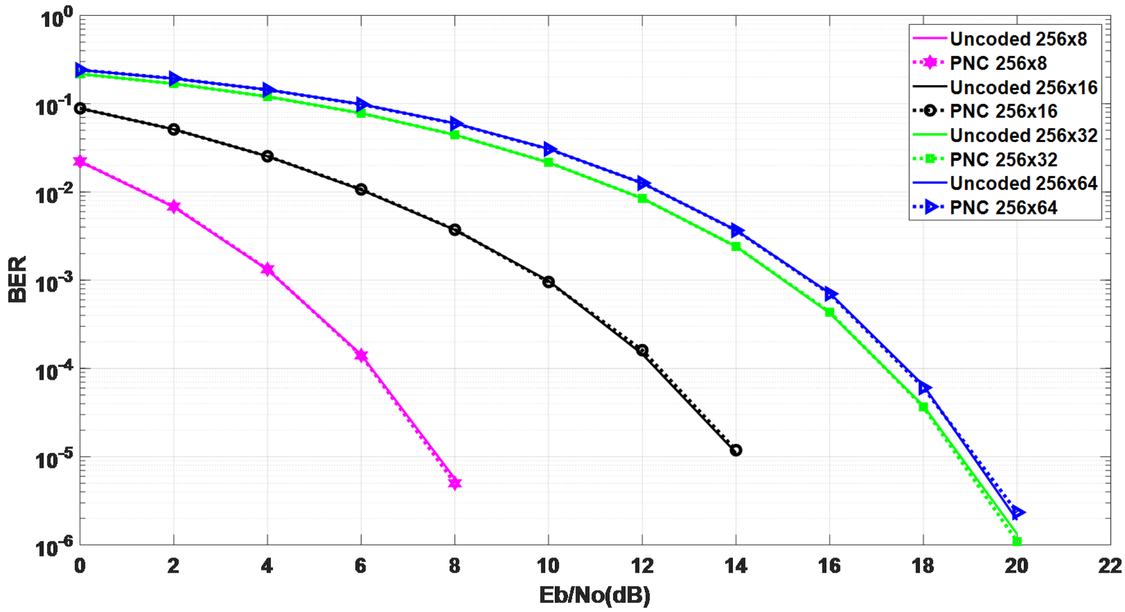

Figure 6: BER performance of uncoded and PNC coded systems with 256 antennas at the relay node.

Figs. 7 and 8 show the throughput performances of uncoded and PNC coded systems, with clear improvements in the throughput of PNC systems over the corresponding uncoded systems having the same numbers of antennas Nr and Nu. Two time slots are used in transmission with PNC, compared to four time slots in the case of an uncoded system. Both Figs. 7 and 8 show that better throughput performance is achieved when using a larger number of antennas Nr whether the system is PNC-coded or not. Further, as the number of user antennas Nu increases, the throughput performance decreases for both the uncoded and PNC-coded systems. The PNC-coded systems achieve up to 100% better throughput when compared to the corresponding uncoded systems having the same number of antennas at high SNRs. The best BER performance is achieved when we have a small number of antennas at the user node (i.e., $N_u = 8$) for both uncoded and PNC-coded systems using $N_r = 128$ and 256, as shown in Figures 5 and 6, respectively. On the other hand, the best throughput performance is obtained by using a PNC-coded system when using a large number of user antennas ($N_u = 8$ combined with $N_r = 128$ and 256, as shown in Figures 7 and 8, respectively). Further, for a fixed number of user antennas N_u, better BER performance is obtained when a large number of relay node antennas N_r is used, as shown in Figures 5 and 6 for the cases of $N_r = 128$ and 256, respectively.

ISSN:2222-758X
e-ISSN: 2789-7362

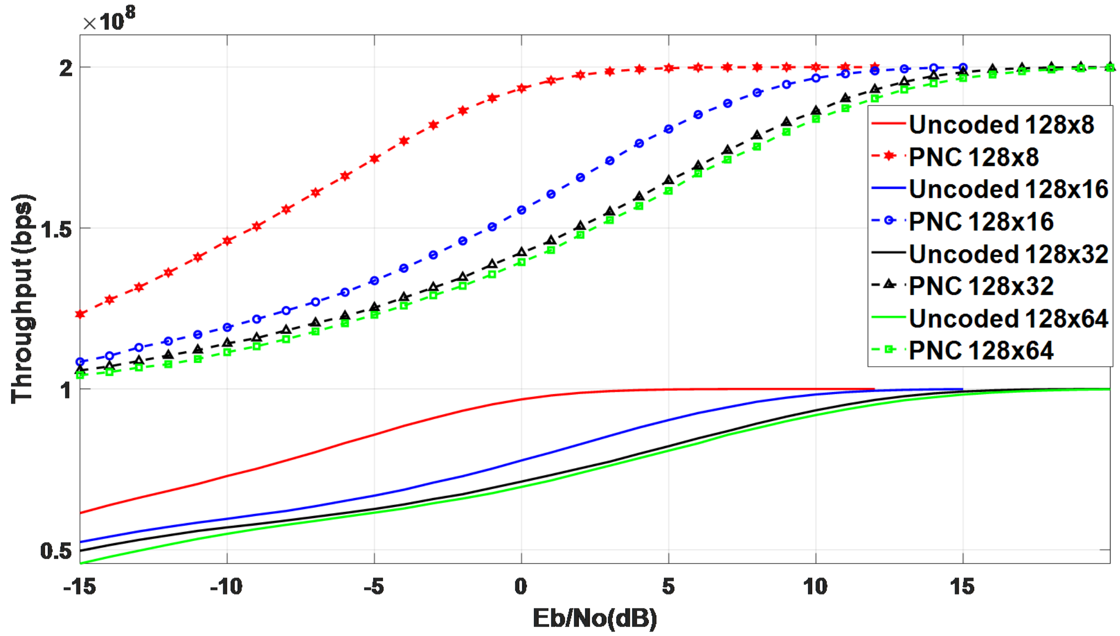

Figure 7: Throughput performance of uncoded and PNC coded systems with 128 antennas at the relay node.

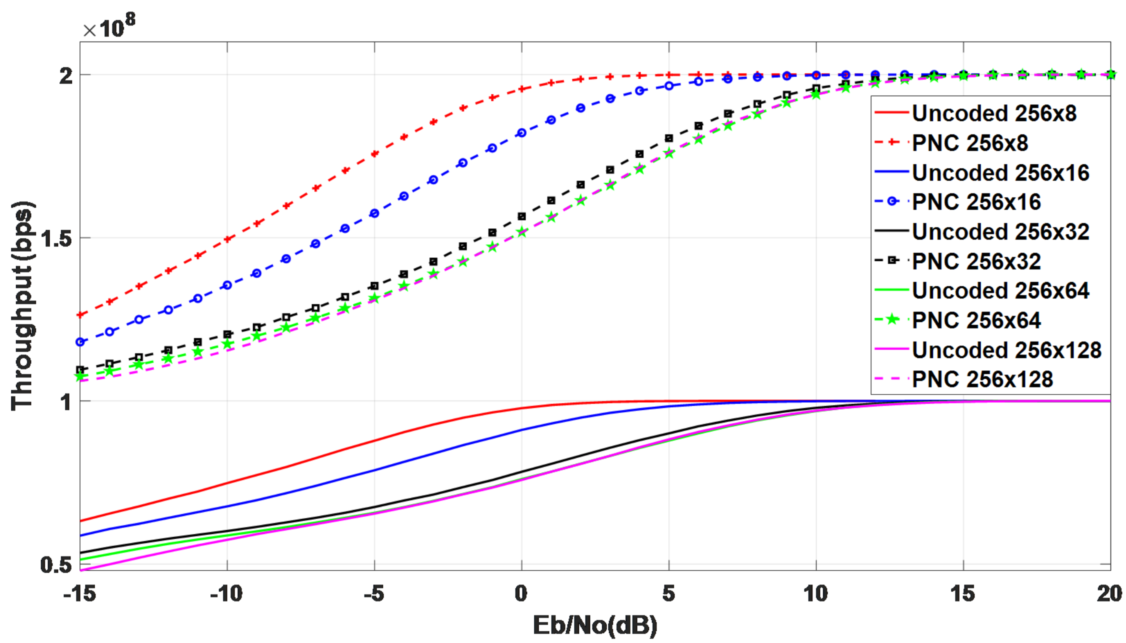

Figure 8: Throughput performance of uncoded and PNC coded systems with 256 antennas at the relay node.

Finally, according to the results, the best arrangement is obtained when considering PNC with a large number of N_r

ISSN:2222-758X
e-ISSN: 2789-7362

and a small number of N_u (i.e., massive MIMO case).

V. CONCLUSIONS

This paper presents an investigation into combining two technologies, PNC and mMIMO, for new generation networks. BER and throughput performances of the system are measured when data is transmitted over a model of mmWave channel using a two-way relay node scenario where the relay node is equipped with mMIMO. The simulation tests showed that the BER performances of both uncoded and PNC-coded systems are almost the same, while the throughput performance of PNC is improved. The PNC system's throughput can be increased by up to 100%. The BER performance is improved only when the number of relay node antennas is much higher than that of the user node. Massive MIMO combined with PNC appears to improve throughput without sacrificing BER performance at high SNR. The improvement achieved is related to the number of antenna elements in the relay and user nodes (N_r and N_u). The bigger the number of N_r compared to N_u, the better the performance. In other words, when the value of $\frac{N_r}{N_u}$ increased, the performance improved.

Funding

None

ACKNOLEDGEMENT

The author would like to thank the reviewers for their valuable contribution in the publication of this paper.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

REFERENCES

[1] J. Huang, H. Gharavi, H. Yan, C-C. Xing, "Network Coding in Relay-Based Device-to-Device Communications", *IEEE Network*, vol. 31, no. 4, pp. 102-107, 2017, DOI: 10.1109/mnet.2017.1700063.

[2] M. R. Akdeniz, Y. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter wave channel modeling and cellular capacity evaluation", *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, 2014, DOI: 10.1109/JSAC.2014.2328154.

[3] B. Okyere, L. Musavian, and R. Mumtaz, "Multi-user massive MIMO and physical layer network coding", in *Proc. IEEE Globecom Workshop*, Waikoloa, USA, 2019, DOI: 10.1109/GCWkshps45667.2019.9024478.

[4] A. Ghosh, "5G New Radio (NR): Physical Layer Overview and Performance", *IEEE Communication Theory Workshop*, May 2018, Nokia Bell Labs.

[5] A. Mahmood and A. Kadhim, "Performance Analysis of Massive MIMO Uplink Detection over Millimeter Wave Band Channel Model", *16th Middle Eastern Simulation Modelling Conference*, Amman, Dec. 2020.

[6] J. Huang, H. Gharavi, H. Yan, and C. Xing, "Network Coding in Relay-Based Device-to-Device Communications", *IEEE Network*, vol. 31, no. 4, 2017, DOI: 10.1109/MNET.2017.1700063.

[7] A. Kadhim, T.A. Sarab, and H. Al-Rewasdy, "Improving Throughput Using Simple Network Coding", *DESE2011 Conference*, Dubai, UAE, Dec. 2011, DOI: 10.1109/DeSE.2011.51.

[8] S. Abdulkhudhur, and A. Kadhim, "Performance of Network Coding Schemes for 5G System", *Iraqi Journal of Information and Communications Technology (IJICT)*, vol. 4, no. 2, pp. 1-8, 2021, DOI: 10.31987/ijict.4.2.147.

[9] S. Zhang, S. C. Liew, and P. P. Lam, "Physical layer network coding", in *Proc. 12th Ann. Int. Conf. on Mobile Com. and Net, MOBICOM*, LA, USA, Sept. 2006, DOI: 10.1145/1161089.1161129.

[10] Y. Zhao, M. Johnston, C. Tsimenidis, and L. Chen, "Link-by-link coded physical layer network coding on impulsive noise channels", *2015 Sensor Signal Processing for Defence (SSPD)*, Edinburgh, pp. 1-5, 2015, DOI: 10.1109/SSPD.2015.7288508.

[11] H. Wang, and Q. Chen, "LDPC based network coded cooperation design for multi-way relay networks", *IEEE Access*, vol. 7, pp. 62300â62311, 2019, DOI: 10.1109/ACCESS.2019.2915293.

[12] Z. Xie, P. Chen, Z. Mei, S. Long, K. Cai, and Y. Fang, "Polar-coded physical layer network coding over two-way relay channels," *IEEE Commun. Lett.*, vol. 23, no. 8, pp. 1301-1305, Aug. 2019, DOI: 10.1109/LCOMM.2019.2922633.

www.ijict.edu.iq
ISSN:2222-758X
e-ISSN: 2789-7362

[13] A. Kadhim and A. Alubaidy, “Throughput improvement for wireless networks using MIMO network coding”, *2012 First National Conference for Engineering Sciences (FNCES 2012)*, Baghdad, Iraq, 2012, DOI: 10.1109/NCES.2012.6740485.
[14] M. Wu, D. Wubben, and A. Dekorsy, “Physical-Layer Network Coding in Coded OFDM Systems with Multiple-Antenna Relay”, In: *2013 IEEE 77th Vehicular Technology Conference (VTC Spring)*, Dresden, Germany, 2013.
[15] H. Vu, V.B Pham, and X.N Tran, “Physical Network Coding for Bidirectional Relay MIMO-SDM System”, *2013 International Conference on Advanced Technologies for Communications (ATC 2013)*, Ho Chi Minh City, Vietnam, pp. 141-147, 2013, DOI: 10.1109/ATC.2013.6698094.
[16] F.S Bras, F.E Ferreira, F.A Monteiro, and A.Rodrigues, "Interference Suppression with Physical-Layer Network Coding and MIMO for Multi-Way Channels", *2014 IEEE Workshop on Signal Processing Systems (SiPS)*, Belfast, UK, 2014, DOI: 10.1109/SiPS.2014.6986065.
[17] K.Ratajczak, K.Bakowski and K.Wesolowski,"Two-way relaying for 5G systems: Comparison of network coding and MIMO techniques", *2014 IEEE Wireless Communications and Networking Conference (WCNC)*, Istanbul,Turkey pp 376-381 , April , 2014 , DOI:10.1109/WCNC.2014 .6952037
[18] J.S Lemos , F.A Monteiro , "Full-Duplex Massive MIMO with Physical Layer Network Coding for the Two-Way Relay Channel", *2016 IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM)*, Rio de Janeiro , Brazil , July , pp 1-5 , 2016 , DOI:10 .1109/SAM .2016 .7569755
[19] B.C Jung ,J.S Yoo , W.Lee,"A Practical Physical-Layer Network Coding with Spatial Modulation in Two-Way Relay Networks",*The Computer Journal*, Vol61 ,Issue2 ,pp264 -272 , February , 2018 , DOI:10 .1093/comjnl/bxx065
[20] D.Vu,V Pham,X Tran,C Ta,"Design of Two Way Relay Network Using Space-Time Block Coded Network Coding and Linear Detection",*IEEE Vehicular Technology Conference (VTC) -Spring*,Seoul,Korea ,May ,pp1-6 , May , 2014 , DOI:10 .1109/VTCSpring .7023160
[21] T.Peng,Y.Wang,A.G Burr,M.S Bahaei,"Physical Layer Network Coding in Network MIMO: A New Design
[22] S. Yilmaz, B. Ozbek, M. Ilguy, B. Okyere L. Musavian, J. Gonzalez, “User Selection for NOMA based MIMO with Physical Layer Network Coding in Internet of Things Applications”, *IEEE Internet of Things Journal*, vol. 9, no. 16, 2022, DOI: 10.1109/jiot.2021.3079157.
[23] S. Jaeckel, L. Raschkowski, K. Borner, L. Thiele, F. Burkhardt, and E. Eberlein, "QuaDRiGa-Quasi Deterministic Radio Channel Generator, User Manual and Documentation", Fraunhofer Heinrich Hertz Institute, Tech. Rep. v2.2.0, June 2019.
[24] A. Mahmoud, J. Markku, and Sh. Shahriar, “Massive MIMO Detection Techniques: A Survey”, *IEEE Communications Surveys & Tutorials*, vol. 21, no. 4, pp. 3109â3132, 2019, DOI: 10.1109/COMST.2019.2935810.

