Joint polar with physical layer network coding and massive multi-input multi-output: performance analysis

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ABSTRACT

Large spectral efficiency, reliability, coverage, and energy efficiency are all major requirements to meet the targets of fifth-generation (5G) and beyond communication networks. The transmitted signal is usually susceptible to errors that reduced reliability and throughput of the system. Physical layer network coding (PLNC) is a promising technology to achieve better throughput, low latency, and high transmission rate. This paper considers the combination of PLNC with polar coding using massive multi-input multi-output (MIMO) system to enhance the transmission reliability by reducing the bit error rate (BER) and improve system reliability. This arrangement is investigated in two-way wireless relay transmission over millimetre wave (mmWave) band channel model. The results of the extensive simulation tests demonstrated improvements in throughput and BER achieved using polar code with PLNC and a sufficient number of antenna elements in the mMIMO system. The BER performance of polar-coded PLNC arrangement outperformed PLNC without coding for 128 and 256 receiving antenna elements in the relay node regardless the number of antenna elements in the user equipment side. The tests showed that the combination of the polar code with PLNC and MIMO system is not encouraging at low Signal-to-noise ratio (SNR).

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1. INTRODUCTION

Polar code is a class of capacity-achieving channel coding [1]. In the past decade, both research and industry interest in polar codes has increased. Within the ongoing fifth generation (5G) standardisation process of the 3rd generation partnership project (3GPP), the polar code was used as a channel coding candidate for both uplink and downlink control information for the enhanced mobile broadband (eMBB) communication service due to its efficient encoding and decoding algorithms and high reliability [2]. Network coding is one of the techniques employed in cooperative communications to improve throughput, complexity, and security [3]-[5]. In network coding, two or more users can communicate with each other indirectly via relay nodes. The relay node receives information from different users, combined in an efficient way, and then broadcasts the combined messages to all users. Each user utilises its own information and the received combined messages to detect the information transmitted by other users. The simplest network coding architecture is the two-way relay channel (TWRC) system, in which two users communicate via a relay node. Instead of interference, the collision of the signals in the air could be viewed as network coding, which could save transmission resources and increase the throughput dramatically [6]. Physical layer network coding (PLNC) is the most suitable network coding form for wireless communications [7]. Network coding is also used with a multi-input multi-output (MIMO) system for improving the performance of wireless networks [8]. Recently, PLNC has been integrated with massive MIMO (mMIMO) to exploit a large array of antennas ranging from hundreds to thousands. This massive array of antennas provides a higher channel capacity and throughput gains [9]. The combination of millimeter wave (mmWave) with mMIMO is useful to overcome the mmWave limitations such as pathloss, directivity, and blockage [10], [11]. The combination of mMIMO and PLNC significantly increased the overall network performance. For better reliability, forward error control channel coding can be used to protect the information being transmitted. Therefore, integrating channel coding into PLNC with the mMIMO system poses an interesting prospect.

The polar code has demonstrated better performance and lower complexity than the Turbo and low-density parity check (LDPC) codes for short-length packet transmissions that meet the requirements of low-latency and reliable 5G communications [12]. Furthermore, the polar code has been integrated with the MIMO system [13] to improve the bit error rate (BER) performance of the system. Therefore, in the present work, we emphasise the integration of polar code with the mMIMO and PLNC techniques. Many researchers have studied channel coding with the PLNC system [14]-[16]. Zhang and Liew [14] the three link-by-link coded PLNC schemes are used to avoid decoding extraneous information and to make full use of the information contained in the combined signal to decode the network-coded packets. The method that uses the repeat accumulate (RA) code outperforms others in terms of the BER [14]. LDPC has also been used with PLNC to improve the performance of networks [17], [18]. A joint polar-coded PLNC system was presented with two successive cancellation list (SCL) decoding schemes [19]. The simulation results showed that the joint decoding of PLNC and SCL decoding outperformed XOR-based conventional SCL at different rates. Ferrett and Valenti [17] and Xie *et al*. [19], the performance analysis focused on the uplink transmission only. Furthermore, LDPC-PLNC was presented with a 2×2 MIMO system and non-orthogonal multiple access (NOMA) [20]. Simulation results showed that the performance of the proposed LDPC with the MIMO–NOMA system greatly outperformed conventional LDPC-coded schemes in both NOMA and MIMO–NOMA systems. This is achieved by modifying the LDPC decoding methods. Xie *et al*. [21] addressed the carrier frequency offset problem in orthogonal frequency division multiplexing (OFDM)-modulated PLNC. A joint signal detection and channel decoding scheme at the relay node in RA-coded PLNC was proposed. Channel-coded PLNC assisted wireless communication and its variants were examined [22]. Zhang and Cai [23] channel coding was integrated into heterogeneous modulation PLNC, where the sources applied different modulation schemes. The work did not clarify the required synchronization. Wang *et al*. [24], the application of PLNC to the industrial internet of things (IoT) was investigated, in which a controller and a robot exchanged messages through the relay. The authors proposed an asymmetric transmission scheme to reduce latency between the controller and the robot, but there is a great complexity of both encoding and decoding for higher order modulation than quadrature phase shift keying (QPSK). In all mentioned works, massive MIMO was not considered in addition the tests were investigated under additive white gaussian noise (AWGN) only.

The present work sheds light on the integration of three techniques: PLNC, mMIMO and polar code to achieve better performance. To the best of our knowledge, no attempt has addressed the combination of polar code with the mMIMO system and PLNC. Furthermore, transmission using these techniques over mmWave frequencies has not been studied yet. The main contributions of this work can be summarised by:

- The work provides performance measure of polar coded signal transmitted in TWRC scenario using mMIMO and PLNC over mmWave band channel model for indoor environment.
- Since PLNC is known for its advantage in improving throughput, then this work combines PLNC with polar code to enhance the performance of the network covering both BER and throughput.
- The work also provides comparison of PLNC used in mMIMO system with and without polar coding for different ranges of antenna elements at both the basestation and user equipment.

The organisation of the paper is as shown in: Section 2 presents the transmission system model. The details of signal transmission are introduced in section 3. The results and their analyses are given in section 4. Section 5 presents the concluding remarks of the work.

Notations: The notations used in this paper are as: capital letters represent matrices or vectors, while lower-case letters denote the scalor symbols. Capital letetrs are also indicate integer numbers used for the number of antenna elements used. The $\oplus$ operator represents XOR operation.

2. TRANSMISSION SYSTEM MODEL

A two-way relay channel model was considered in this work, as shown in Figure 1. The model consists of three nodes: two user equipments (UEs) represented by two sources S1 and S2 that communicate through a relay node (R) in half-duplex mode. The term "user equipment" and "source node S" are used iterchangeably in the paper. Clearly, when a particular node is considered as source node the other node will be its destination. It is assumed that the relay node is equipped with a massive number of antenna elements (M_R) and each source node has M_T antenna elements, where the ratio of M_R/M_T>>1 to realise the massive MIMO condition for the purpose of interference suppression [9]. There is no direct link between the two source nodes S1 and S2. Without network coding, four time slots are needed to exchange the two symbols generated by both source nodes, one in each direction. The use of PLNC reduces the number of time slots to just two slots, where S1 and S2 can transmit simultaneously, as shown in Figure 2.

The indoor environment is considered with a 30 GHz carrier frequency and 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 quasi deterministic radio channel generator (QuaDRiGa) model [25]. QuaDRiGa is based on 3-dimensional geometry-based stochastic channel model. Figure 3 shows a simplified schematic structure of this model, where θ and φ represent the departure and arrival angels in the zenith and azimuth directions, and m represents the paths. The main QuaDRiGa features are as follows: support of large arrays, indoor and outdoor use, consideration of spherical waves, dual-mobility (transmitter or receiver can be mobile), 3D (elevation), mmWave band coverage, spatial consistency, and high mobility [25]. The source 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 is 19, and the number of rays per cluster is 20 [25].

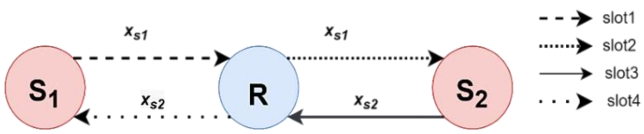

Figure 1. Two-way relay channel for the uncoded scheme

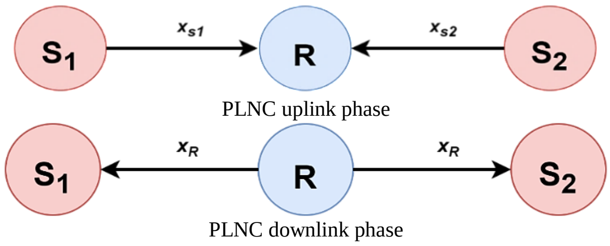

Figure 2. Two-way relay transmission with PLNC

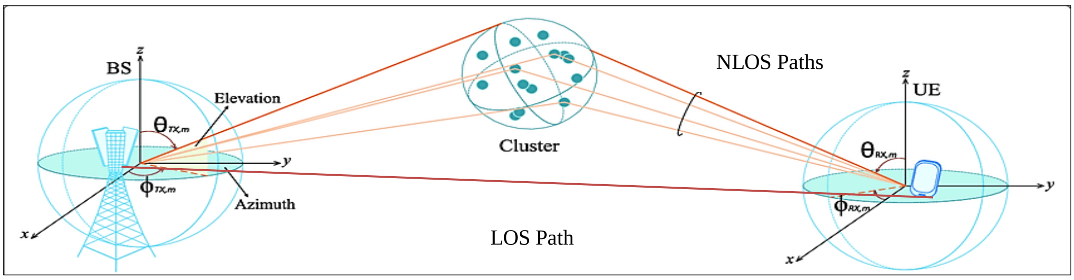

Figure 3. Geometric modelling used in the QuaDRiGa channel model [25]

3. SIGNAL TRANSMISSION

A complete transmission cycle of the system consists of user transmission (uplink) to the relay node, followed by retransmission to all nodes (downlink) by the relay node, as illustrated in Figure 4. In uplink transmission, both source nodes transmit their data to the relay node simultaneously. The data bits of the source nodes are divided into blocks $\{B_{si}\}$ of K bits, each as given (1):

$$B_{si} = [b_{si,1}\ b_{si,2} \ldots\ldots\ldots b_{si,K}] \quad (1)$$

where i represents the source node number. First, the polar codes are designed to deal with codeword length $N = 2^n$, where n is an integer. This type of polar code is represented as PC(N, K) with K data bits and a coding rate of R = K/N. Each source node in the uplink transmission stage encodes the data block B_{si} to produce polar coded codeword P_{si} using an N × N generator matrix $F^{\otimes n}$, where $F = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$ is a binary kernel and $[.]^{\otimes n}$ denotes its n-fold Kronecker power. The generator matrix accepts N encoder connected bits that are divided into K reliable channels, representing the K data bits and (N–K) frozen bits holding binary "0." The positions of the frozen bits are selected in such a way as to reduce the probability of error in decoding [2]. The polar code used in the present work is a PC (256, 128) previously considered for similar applications [26]. The QPSK signal can be considered two binary phase shift keying streams (in-phase and quadrature-phase). The QPSK modulated signal x_{si} is sent over the channel. The mMIMO channel model can be represented by matrix H, where:

$$H = \begin{bmatrix} h_{1,1} \; h_{1,2} \cdots h_{1,M_T} \\ \vdots \; \vdots \\ h_{M_R,1} \; h_{M_R,2} \cdots h_{M_R,M_T} \end{bmatrix} \quad (2)$$

where $h_{j,i}$ is the channel coefficient from the i^{th} transmitting antenna element to j^{th} receiving antenna element. The received signal $X_R \in C^{M_R \times M_T}$ at relay node can be expressed as:

$$X_R = H_{u1} X_{s1} + H_{u2} X_{s2} + W_r \quad (3)$$

where H_{u1} and $H_{u2} \in C^{M_R \times M_T}$ are the channel matrices that link nodes S_1 and S_2 to the relay node in the uplink direction, respectively. W_r is an $M_R \times M_T$ additive white gaussian noise (AWGN) matrix. The channel state information (CSI) is assumed to be known to the relay node. In practice, channel estimation is usually used to estimate CSI. The relay node receives the distorted and noisy signal X_R, which is demodulated and detected using minimum mean square error (MMSE) detection at the relay node [27].

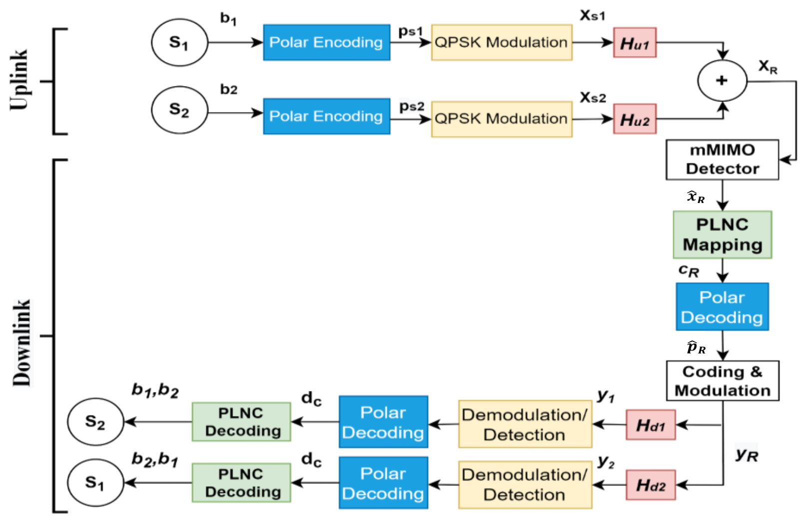

Figure 4. Block diagram of a polar-PLNC-based TWRC system using mMIMO

The estimated matrix $\hat{X}_R$ of X_R can be written as:

$$\hat{X}_R = GX_R \quad (4)$$

where G is given by [27]:

$$G = (H^H H + \frac{M_T}{SNR} I_{M_T})^{-1} H^H \quad (5)$$

and I_{M_T} is the identity matrix of size M_T, and H^H is the conjugate transpose of the channel matrix H. Link-by-link encoding is considered in transmission, where the relay node performs channel decoding first, followed by re-encoding prior to PLNC mapping. The relay node needs to first extract the XOR-ed version of $\mathrm{p_{s1}}$ and $\mathrm{p_{s2}}$ from the received signal X_R, and then transmits it in the second time slot. At the relay node and after the detection, PLNC mapping is applied to produce $\hat{c}_R$ (the decoded version of the combined signal from the two sources), followed by polar decoding to get $\hat{p}_R$. The PLNC mapping of the in-phase and quadrature streams is shown in Table 1.

Table 1. PLNC Mapping for QPSK modulation

b_{s1}	b_{s2}	x_{s1}	x_{s2}	$\hat{x}_R$	PLNC 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

Subsequently, the relay node applies polar coding, followed by QPSK modulation; it then broadcasts its output Y_R to both end nodes. The received signals at nodes S_1 and S_2 are given by (6) and (7), respectively:

$$Y_1 = H_{d1}\, Y_R + W_1 \quad (6)$$

$$Y_2 = H_{d2}\, Y_R + W_2 \quad (7)$$

where $H_{di} \in C^{M_T \times M_T}$ is the channel matrix for downlink transmission of node S_i, and W_1 and W_2 are AWGN matrices $\in C^{M_T \times M_T}$ at S_1 and S_2 node inputs, respectively. The two source nodes S_1 and S_2 use M_T antenna elements in both transmission and reception, while the relay node uses M_T elements at the transmission and M_R elements in the reception, with $M_R >> M_T$ to demonstrate mMIMO condition. After the demodulation/detection of Y_1 and Y_2, the detected signals are processed by polar decoding algorithm to obtain the decoded data d_c. The polar decoder used is the SCL with a list size of 8 [28]. Each source node uses its own data bits to obtain the data bits of the other source node from the decoded bits d_c. At S_1, one may obtain the information bits of S_2 ($\hat{b}_2$) by XOR-ed d_c with b_1, as given by (8).

$$\hat{b}_2 = d_c \oplus b_1 \quad (8)$$

Similarly, at node S_2, the information bits of the S_1 ($\hat{b}_1$) can be obtained.

4. RESULTS AND DISCUSSION

The BER performance and throughput of the transmission system are presented in this section. The system was simulated using MATLAB R2019a version 9.6. The test results are represented by the BER and system throughput against the SNR. The SNR was defined as E_b/N_0 in dB per user, where E_b is the average energy per data bit in Joules, and N_0 is the one-sided spectral density (in Watts/Hz) of AWGN. Each measured BER value was calculated after the transmission of at least 10^6 data bits. The throughput in bps was defined as the ratio of the total number of correctly received bits to the total number of actual transmitted data bits in the system multiplied by the nominal bit rate.

Extensive simulation tests were carried out for different numbers of antenna elements at both the user and relay nodes. Only two cases of the number of antenna elements at the relay node (M_R) were used (128 and 256) to represent massive MIMO arrangement. For each case, the number of considered user antenna elements (M_T) are 8, 16, 32, and 64. Figures 5 and 6 show the BER performance of the PLNC system and the polar-coded-PLNC system with M_R equals 128 and 256, respectively. The legends for the BER and throughput performance curves are labelled by two numbers representing $M_R \times M_T$ for each system (PLNC or polar-coded PLNC). For instance, the curve labelled by PLNC 128×8 represents the PLNC system with M_R =128 and M_T=8. Although adding polar coding to the system increased the complexity, it provided a noticeable coding gain. This gain was about 5 dB at a BER of 10^{-4} for both 128×8 (Figure 5) and 256×8 (Figure 6). The mentioned figures clarify that the polar-coded-PLNC system outperformed the PLNC system without polar coding for all other values of M_T.

Figures 7 and 8 show the throughput performance of the system with $M_R = 128$ and 256, respectively. It is clear that all throughput curves in these figures coincide at high SNR (> 15dB) to yield the highest throughput available, given a total bit rate of 200 Mbps. Furthermore, in the case where $M_T = 8$ (for both Figure 7 and Figure 8), the highest throughput was achieved at very low SNR (about 0 dB). The improved throughput by these two cases was due to the use of the largest ratio of M_R/M_T . Considered in the work It is worth mentioning that the improvements in throughput achieved were due to the use of PLNC. It seemed that there was no advantage in using polar coding at a relatively low SNR. There was no specific value for such a low SNR. However, it depends on the number of elements represented by the combination of M_R and M_T. For example, in Figure 7, the least SNR value required for the polar-coded PLNC system to outperform its uncoded counterpart is about 1 dB in the 128×8 case. The corresponding SNR in the 128×16 case is about 8 dB.

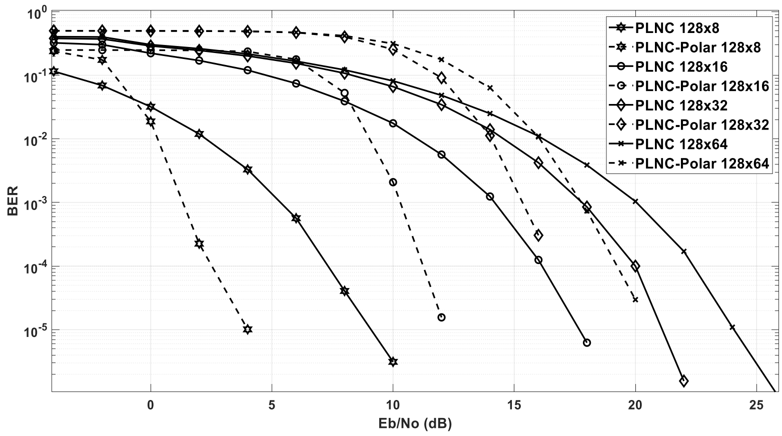

Figure 5. BER performance of different systems with $M_R = 128$

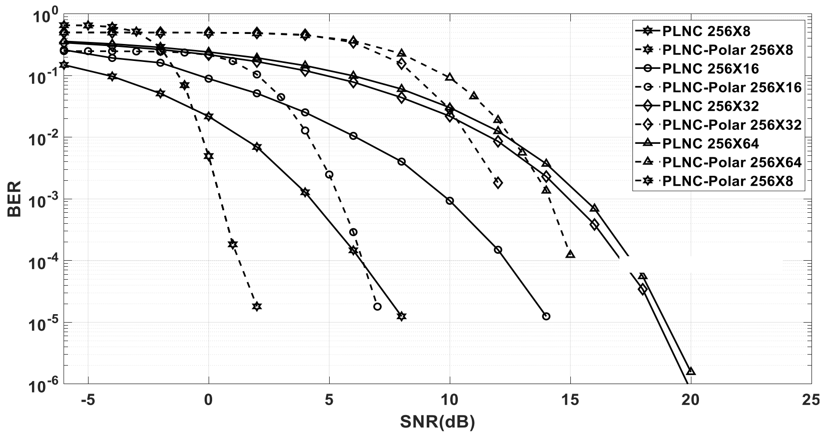

Figure 6. BER performance of different systems with $M_R = 256$

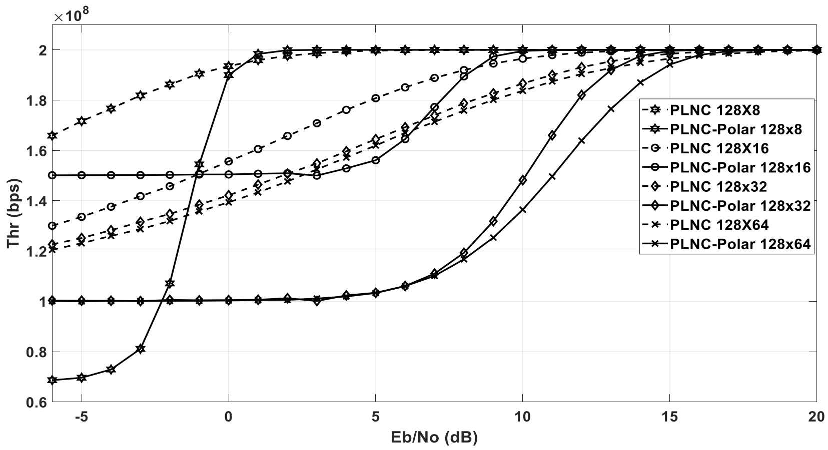

Figure 7. Throughput performance of different systems with $M_R = 128$

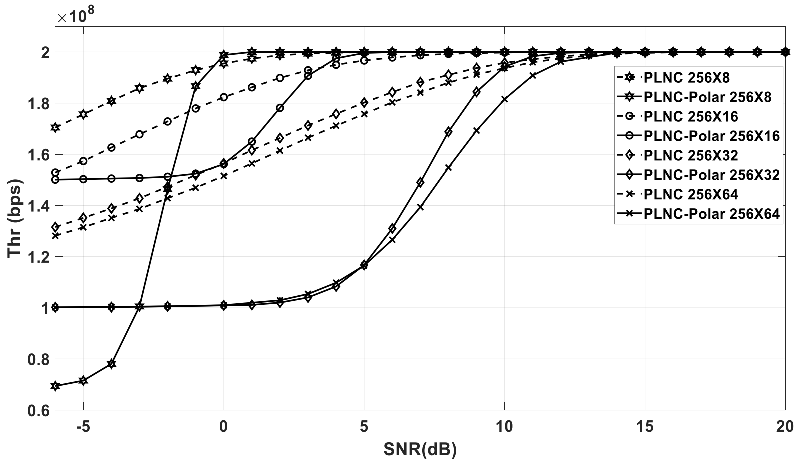

Figure 8. Throughput performance of different systems with $M_R = 256$

5. CONCLUSION

In this study, polar-coded-PLNC with a massive MIMO system was investigated in a TWRC scenario that assumed an indoor mmWave channel model. Polar coding was applied to each connected link for source or relay nodes. The performance measures considered in the simulation tests were BER and throughput. The use of polar code with massive MIMO significantly improved the BER performance compared to the system without polar coding. The tests showed that a useful gain in throughput is possible when using PLNC. Furthermore, the findings suggest that there was no advantage in using polar coding at a relatively low SNR. Such SNR depends on the number of elements M_R and M_T, where the lower the value of M_T, the higher the SNR limit to obtain better throughput. Lastly, for a large ratio of M_R/M_T, both the BER and throughput were improved, as in the case of 128 or 256 for M_R and M_T of 8, when polar code with PLNC is used.

REFERENCES

[1] E. Arikan, "Channel polarization: A method for constructing capacity achieving codes for symmetric binary-input memoryless channels," *IEEE Trans. on Inf. Theory*, vol. 55, no. 7, pp. 3051– 3073, July, 2009, doi: 10.1109/TIT.2009.2021379.

[2] V. Bioglio, C. Condo, and I. Land, "Design of polar codes in 5G new radio", *IEEE Commun. Surv. and Tutor.*, vol. 23, no. 1, pp. 29-40, Jan. 2020, doi: 10.1109/COMST.2020.2967127.

[3] R. Bassoli, H. Marques, J. Rodriguez, K. Shum, and R. Tafazolli, "Network coding theory: A survey," *IEEE Commun. Surv. and Tutor.*, vol. 15, no. 4, pp. 1950–1978, Feb. 2013, doi: 10.1109/SURV.2013.013013.00104.

[4] A. Kadhim, T. Sarab; H. Al-Raweshidy," Improving throughput using simple network coding," *2011 Developments in E-systems Engineering Conf. (DeSE)*, 2011, doi: 10.1109/DeSE.2011.51.

[5] S. Katti, S. Gollakota, and D. Katabi, "Embracing wireless interference: Analog network coding," *ACM SIGCOMM Comput. Commun. Rev.*, vol. 37, no. 4, pp. 397–408, Oct. 2007, doi: 10.1145/1282427.1282425.

[6] Z. Ma, Z. Zhang, Z. Ding, P. Fan and H. Li, "Key techniques for 5G wireless communications: network architecture, physical layer, and MAC layer perspectives," *Sci. China, Inf. Sci.*, vol. 58, pp. 1-20, Feb. 2015, doi: 10.1007/s11432-015-5293-y.

[7] S. Zhang, S. Liew, and P. Lam, "Physical layer network coding", in *Proc. 12th Annual International Conf. on Mobile Communication and Networks (MOBICOM)*, 2006, pp. 358-365, doi: 10.1145/1161089.1161129.

[8] A. Kadhim and A. Alubaidy, "Throughput improvement for wireless networks using MIMO network coding", *2012 First National Conf. for Engineering Sciences (FNCES 2012)*, 2012, pp. 1-7, doi: 10.1109/NCES.2012.6740485.

[9] R. Chataut, and R. Akl, "Massive MIMO systems for 5G and beyond networks-overview, recent trends, challenges, and future research directions", *Sensors*, vol. 20, no. 10, pp. 2753-2788, Apr. 2020, doi: 10.3390/s20102753.

[10] N. Al-Falahy, M. AlMahamdy, and A. Mahmood, "Performance analysis of millimeter wave 5G networks for outdoor environment: propagation perspectives," *Indonesian J Elec Eng & Comp Sci*, vol. 20, no. 1, pp. 214-221, Apr. 2020, doi: 10.11591/ijeecs.v20.i1.pp214-221.

[11] A. Al-Heety, M. Islam, A. Rashid, H. Ali, A. Fadil, and F. Arabian, "Performance evaluation of wireless data traffic in mm wave massive MIMO communication" *Indonesian J Elec Eng & Comp Sci*, vol. 20, no. 3, pp. 1342-1350, Jun. 2020, doi: 10.11591/ijeecs.v20.i3.pp1342-1350.

[12] X. Wu, M. Jiang, C. Zhao, L. Ma, and Y. Wei, "Low-rate PBRL-LDPC Codes for URLLC in 5G", *IEEE Wirel. Commun. Lett.* vol. 7, no. 5, pp. 800–803, 2018, doi: 10.1109/LWC.2018.2825988.

[13] A. Jalali and Z. Ding, "A joint detection and decoding receiver design for polar coded MIMO wireless transmissions," *2018 IEEE International Symposium on Information Theory (ISIT)*, 2018. doi: 10.1109/ISIT.2018.8437879.

[14] S. Zhang, and S. Liew, "Channel coding and decoding in a relay system operated with physical-layer network coding," *IEEE J. on Sel. Areas in Commun.*, vol. 27, no. 5, pp. 788–796, 2009, doi: 10.1109/JSAC.2009.090618.

[15] C. Yao, Z. Zhang, Y. Zhang, and S. Chen, "End-to-end rateless-coded physical layer network coding in two-way relay systems," *2013 IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications: Fundamentals and PHY Track*, pp.132–137, 2013, doi:10.1109/pimrc.2013.6666118.

[16] 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.
[17] T. Ferrett and M. Valenti, "Noncoherent LDPC-coded physical-layer network coding using multitone FSK," *IEEE Trans. on Commun.*, vol. 66, no. 6, pp. 2384–2395, 2018, doi: 10.1109/TCOMM.2018.2801788.
[18] H. Wang, and Q. Chen, "LDPC based network coded cooperation design for multi-way relay networks," *IEEE Access*, vol. 7, pp. 62300–62311, 2019, doi: 10.1109/ACCESS.2019.2915293.
[19] 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.
[20] N. Hlaing, A. Farzamnia, M. Mariappan, and M. Haldar, "Network coding schemes with efficient LDPC Coded MIMO–NOMA in two-way relay networks," *IET Commun.*, vol. 14, no. 14, pp. 337-348, 2019, doi: 10.1049/iet-com.2019.0503.
[21] L. Xie, I. Ho, Z. Situ, and L. Lu, "Channel-coded physical-layer network coding with OFDM modulation," *IEEE Access*, vol. 6, pp. 22267 –22280, 2018, doi: 10.1109/ACCESS.2018.2825429.
[22] P. Chen, Z. Xie, Y. Fang, Z. Chen, S. Mumtaz, and J. Rodrigues, "Physical-layer network coding: an efficient technique for wireless communications," *IEEE Network*, vol. 34, no. 2, pp. 270-276, 2020, doi: 10.1109/MNET.001.1900289.
[23] H. Zhang and L. Cai, "Design of channel coded heterogeneous modulation physical layer network coding," *IEEE Trans. on Veh. Technol.*, vol. 67, no. 3, pp. 2219-2230, 2018, doi: 10.1109/TVT.2017.2766209.
[24] Z. Wang, L. Liu, S. Zhang, P. Dong, Q. Yang, and T. Wang, "PLNC enabled IIoT: A general framework for channel-coded asymmetric physical-layer network coding," *IEEE Trans. on Wirel. Commun. (TWC)*, 2021.
[25] S. Jaeckel, L. Raschkowski, K. Borner, L. Thiele, "QuaDRiGa: A 3-D multi-cell channel model with time evolution for enabling virtual field trials", IEEE Trans. Antennas Propag., vol. 62, no. 6, pp. 3242-3256, 2014.
[26] W. Abdulwahab and A. Kadhim, "Reduced path successive cancellation list decoding for polar codes," *Int. J.of Eng. and Technol. Innovation*, vol. 11, no. 1, pp. 12-23, Jan. 2021, doi: 10.46604/ijeti.2021.6376.
[27] A. Mahmoud, J. Markku, and Sh. Shahriar," Massive MIMO detection techniques: A survey," *IEEE Commun. Surv. & Tutor.*, vol. 21, no. 4, pp. 3109–3132, 2019, doi: 10.1109/COMST.2019.2935810.
[28] W. Abdulwahab and A. Kadhim, "Adaptive reduced paths successive cancellation list decoding for polar codes," *Iraqi J. of Info. and Commun. Technol. (IJICT*), vol. 4, no. 1, 2021, doi:10.31987/ijict.4.1.136.

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