

# BER PERFORMANCE OF JOINT POLAR CODED SIGNAL AND MIMO USING MILLIMETER WAVE

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**Abstract**– There have been active researches worldwide for evolving the next-generation networks such as 5G. The 5G network is predicted to ensure considerable mobile data traffic having large number of wireless connections. This is combined with high energy-efficiency and Quality of Service (QoS). For these reasons, 5G should be exploited the prospect of new developments, including multiple-input multiple-output (MIMO) technology and using higher frequencies such as the millimeter-wave (mmWave) frequency band. Error correction techniques are commonly utilized to reduce transmission error and enhance QoS. In the present paper, polar codes with successive cancellation list (SCL) decoding is used in conjunction with mmWave and MIMO system in order to gain the advantages of these techniques together. The mentioned combined techniques are simulated to show their performances over different wireless channel models mainly: an Additive White Gaussian Noise (AWGN) channel, flat fading channel, and mmWave indoor fading channel models. The results of the simulation tests showed that combination of polar code with MIMO system improves the Bit Error Rate (BER) performance by at least 6 dB at high SNR compared to the case where no polar code being used

**Keywords:** Data Transmission, Millimeter Wave, MIMO , Polar Coding

## I. INTRODUCTION

Millimeter wave (mmWave) and Multiple Input Multiple Output (MIMO) are considered as promising solutions to meet the huge increase in data traffic for 5G system predicted in the near future. In addition to providing larger bandwidth as compared to the 4G systems, antenna arrays can be packed into a smaller size due to the use of mmWave frequencies. Thus, the spectral efficiency can be improved considerably as large MIMO elements compensate for the high path loss experienced by high frequencies [1]. The higher spectral efficiency of MIMO is achieved when separate signal paths are provided by each pair of transmitting and receiving antennas. This increases the diversity in the wireless communication system [2,3].

As the new systems started adopting mmWave spectrum, carrier frequencies having values of 28 GHz, 38 GHz, and 73 GHz or more are apparently become available for future wireless systems [4]. General introduction to mmWave systems and its integrated antennas for 60 GHz system are already presented [5,6]. References [7,8] also presented measurements for path loss and wideband propagation for mmWave frequencies using highly directional horn antennas. Their findings are: mmWave transmission causing more signal loss with path loss proportional to the square of the frequency, while demonstrating rich multipath scattering when considering narrow angles. Theoretical studies of the spectral efficiency and outage probability analysis of mmWave transmissions are covered in references [9-11]. At higher frequencies, rain, foliage and atmospheric absorption are seriously in mmWave mobile communication, with rain and Oxygen causing attenuation around 10 to 20 dB/km. Such issues can be dealt with by considering reduced cell sizes of about 50 to 200 m, especially at 28 GHz and 38 GHz, to give an attenuation of about 1.4 dB over 200m cell [12].

The main challenge presented in 5G system, apart from the limited frequency band, is the degradation in Bit Error Rate (BER) performance. So, searching for new techniques to improve BER performance for new generation networks is desirable by using powerful error correction codes such as polar code [13]. Polar code is proposed for 60 GHz systems where promising BER performance is achieved in the presence of either linear power amplifier (PA) or nonlinear PA compared with Low-Density Parity Check (LDPC) coding scheme [13]. Detection and decoding algorithm is proposed for polar coded signal when used with massive MIMO using graphs of MIMO [14]. The proposed scheme and architecture achieved the advantages of both MIMO and polar codes.

A scheme of adaptive polar coded signal is proposed for indoor mmWave propagation which affected by the blockage with the capacity of the underlying channel is achieved [15]. The simulation results showed that the proposed adaptive transmission scheme has better error performance compared to the traditional fixed-rate transmission scheme. The authors in reference [16] studied the polar encoding process for standard 5G wireless communication systems. The study covered the polar encoding and decoding implementations which occurred to be within the feasible complexity and work within required latency in addition to its rate flexibility.

In the above mentioned references, the transmission of polar code signal using mmWave band is based on single input single output (SISO), so the present work deals with the use of MIMO technology instead of SISO. The aim here is to evaluate the performance of the transmission system when the combination of polar code signal being transmitted in mmWave band with MIMO technology to improve the BER performance of the system.

The remaining parts of the paper are organized as follows: Section-II presents the system model where polar code used is described followed by the modulation, the MIMO system, and the channel models. The results of the simulation tests and their analysis are presented in Section-III. Finally, the main concluding remarks are given in Section-V.

## II. SYSTEM MODEL

Figure 3 shows the transmission system model. The data source produces binary independent and equal probable bits. The encoder is forward error correction that add check bits to assist in correcting possible errors introduced by the channel. The modulator maps the coded bits into modulated symbols. This is followed by the MIMO encoder with its output linked to the transmission channel. Additive white Gaussian noise (AWGN) is added at the channel output. The details of the system components just mentioned are given next.

### A. Polar Coding

The forward error correction code adopted in the model is the polar code which is considered as candidate for 5G system [17]. Polar code is a list of codes that utilizing the channel polarization by using the fact that channel can be polarized into reliable and unreliable channels. This code can achieve the capacity limit for infinite block lengths. Polar code has a recursive structure with low complexity making this code desirable for hardware implementation [18]. Successive Cancellation List (SCL) decoding algorithm is usually used of polar code. SCL decoder is simple, fast, and easy to implement. SCL decoding

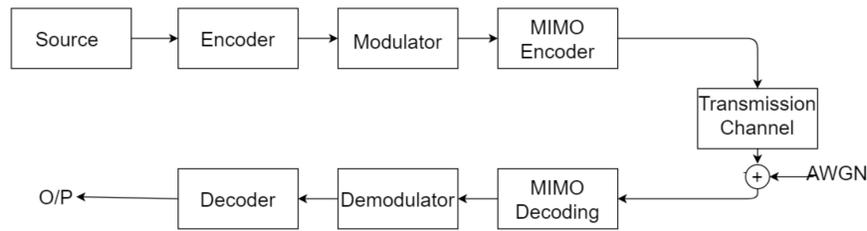


Figure 1: Model of data transmission system

is established for improving BER performance of polar codes and operated better at shorter code lengths [19]. Instead of storing the most likely paths after every decision level, in SCL decoder a list of all possible paths is considered with their calculated likelihood ratios. At the end of the decoding cycle, probabilities of all paths in the list are compared, and the most likely path is selected as the final decoded path. For polar code, with block length of  $N$  and list size of  $L$  in SCL decoder, the decoding complexity is  $O(L.N.N)$  [14]. To enhance the error correction performance, polar codes are concatenated with a high rate Cyclic Redundancy Check (CRC) code [17]. A polar code with  $(N, K)$  of  $(256,128)$  resulting in coding rate of  $\hat{\alpha}$  is used in the model with CRC as given in reference [20]. SCL decoding with list size  $L=8$  is used as polar decoder at the receiver side.

### B. The Modulator

The modulation considered in the work is Quadrature Phase Shift Keying (QPSK). The symbol rate considered here is 2.5 M Symbols/sec, thus the resultant bit rate is 5 Mbps. The baseband equivalent representation of QPSK is used in the simulation tests.

### C. The MIMO System Model

In MIMO transmission system, the signal is fed to the  $N_t$  antennas at the transmitter and received by  $N_r$  antennas at the receiver. Considering the  $N_t$ -component transmitted vector  $X$  and the  $N_r$ -component noise vector  $N$ , the received  $N_r$ -component vector  $Y$  is given by [21];

$$Y = H.X + N \quad (1)$$

$$\begin{bmatrix} y_1 \\ \vdots \\ y_{N_r} \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1,N_t} \\ \vdots & \ddots & \vdots \\ h_{N_r,1} & \cdots & h_{N_r,N_t} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_{N_t} \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_{N_r} \end{bmatrix} \quad (2)$$

Where the noise components zero mean AWGN samples with fixed variance, and  $H$  is the fading channel matrix with dimensionality of  $(N_r \times N_t)$ . Considering Alamouti Space Time Block Coded (STBC) for 2x2 MIMO, the transmitted signal is by [3,21];

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \quad (3)$$

and the channel matrix H is;

$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad (4)$$

The estimate of the transmitted symbol in the absence of noise is given by [21];

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \quad (5)$$

Where is transpose conjugate of  $H^H$ . Similarly, one may apply the above analysis to find the demodulated signals at the receiver for 4x4 MIMO or higher MIMO dimensionality. The MIMO antenna elements spacing is taken to be  $\lambda/2$  with  $\lambda$  is determined by the carrier frequency  $f_c=28$  GHz.

#### D. The MIMO System Model

Three types of wireless transmission channel models are considered in the work. These are:

1- *White Gaussian Noise Channel Model:* In AWGN channel model, complex white Gaussian noise samples (independent of each other) are added to the transmitted signal at the output of the MIMO encoder as shown below;

$$y_i = x_i + n_i \quad (6)$$

2- *Flat Fading Channel Model:* The channel is known as flat fading if the bandwidth of the transmitted signal is smaller than the coherence bandwidth of the channel. The effect of flat fading channel can be seen as a decrease in the signal-to-noise power ratio (SNR) [22]. In flat fading channel model, the received sample is given by:

$$y_i = \alpha \cdot x_i + n_i \quad (7)$$

Where  $\alpha$  is a complex quantity represents the signal path gain. This is only single path from Saleh Valenzuela (S V) model that is modeled as [23];

$$\alpha = \alpha_i \alpha_R(\theta_l) \alpha_T(\varphi_l) \quad (8)$$

where  $\alpha_l$  is the complex gain of the  $l$ th path,  $\alpha_T$  and  $\alpha_R$  are steering vectors at the receiver and transmitter, respectively.  $\theta_l$  and  $\varphi_l$  are angle of arrival and departure with,  $\theta_l \in [0, 2\pi]$  and  $\varphi_l \in [0, 2\pi]$ .

3- *Millimeter Wave Channel Model:* Due to the small wavelength of signals at mmWave frequency bands, MIMO dimensionality is used in order to get the strongest received power. There is limited spatial selectivity or scattering

characteristic in indoor scenarios with mmWave channel caused by high path loss. To represent the impulse response of a multipath channel, a tapped delay line (TDL) model is used [4, 12,24];

$$H(t, \tau) = \sum_{i=1}^{L_p} C_i(t)\delta(t - \tau_i) \quad (9)$$

where  $C_i(t)$  are channel coefficients (average path gain) which is varied with time  $t$ , and  $T_P$  is the number transmission paths. An indoor channel model is considered here with three paths. Other channel parameters used in the work are presented in Table I [21, 24].

TABLE I  
 MILLIMETER WAVE CHANNEL PARAMETERS USED IN THE MODEL

Parameter	Symbol or Abbreviation	Values
Number of Paths	$L_p$	3
Carrier Frequency	$f_c$	28 GHz
Average-Path-Gains	$C_i$	[-0.2 -18 -21] dB
Normalized Path Delay	$T_i$	[0 0.035 0.612]
Delay Spread	—	16ns
Doppler Shift	$f_d$	77.784 Hz
Channel K-Factor	—	13.3 db
QPSK Symbol Rate	$R_s$	M Symbol/sec

### III. SIMULATION TEST AND RESULTS

The model described in previous section is used to measure the BER performance of the system under different test conditions regarding the MIMO size, channel model, and the use of polar code. Fig. 2 presents BER performance for SISO, 2x2 MIMO, and 4x4 MIMO over AWGN channel. It is clear that 4x4 MIMO system provides superior BER performance as compared to others. Fig. 3 shows the results of polar code with (N,K) of (256,128) resulting in coding rate of  $(\hat{A}\alpha)$ . The list size for the SCL decoder is of 8. It is clear that the coded results with 4x4 MIMO provided better BER performance as compared to SISO and other 2x2 MIMO cases due to the additional gain provided by the 4x4 MIMO arrangement. Fig. 3 shows a performance improvement due to coding of about 6 dB in  $E_b/N_0$  for all cases as compared to uncoded counterpart at BER of  $10^{-4}$ .

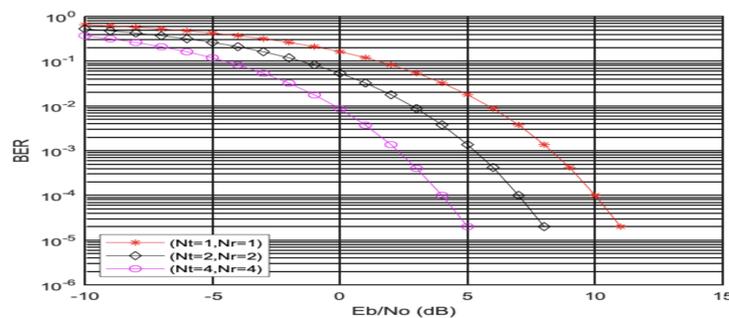


Figure 2: BER performance of uncoded QPSK over AWGN channel

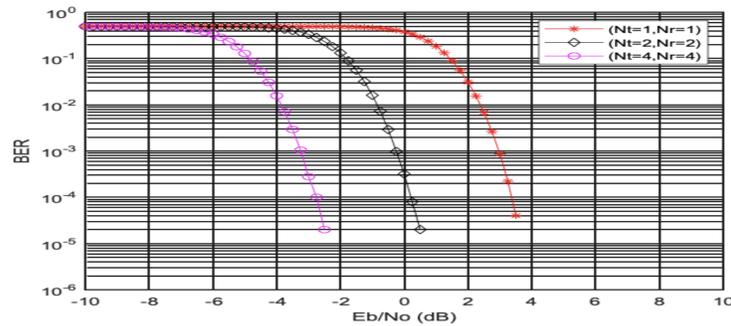


Figure 3: BER performance of polar coded QPSK over AWGN channel

Fig.4 shows BER performance of SISO and MIMO cases over flat fading channel. Fig.4 shows that with the increase in the number of antennas at the transmitting and receiving sides the performance is getting better. Again the case of 4x4 MIMO produces the best BER performance compared to other MIMO arrangement. At BER of  $10^{-4}$ , 4x4 MIMO produced 7 dB gain as compared to SISO due to the extra gain obtained by extending the MIMO diversity.

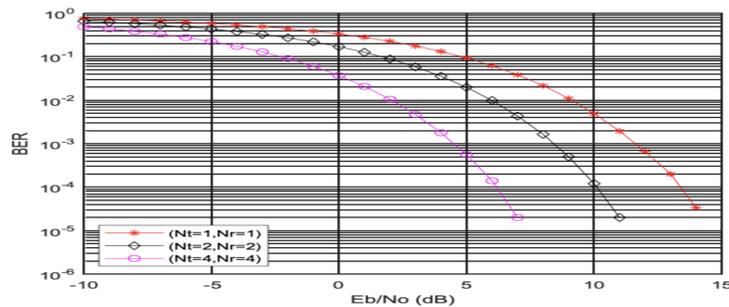


Figure 4: BER performance of uncoded QPSK over flat fading channel

Fig. 5 provides the BER performance of coded signals over flat fading channel model. Fig. 5 shows that 4x4 MIMO gives the best result with gain of about 6 dB compared to SISO at BER of. The figure also shows performance improvements due to coding of about 5.75 dB, 5.5 dB, and 5 dB in Eb/No for the cases of SISO, 2x2 MIMO, and 4x4 MIMO, respectively, compared with their corresponding uncoded performance at BER of 10<sup>-4</sup>.

Fig. 6 and 7 shows the BER performance of uncoded QPSK signal and polar coded QPSK signal, respectively, for SISO, 2x2 and 4x4 MIMO arrangements over mmWave channel model. These two figures show the role of MIMO arrangement in improving BER performance of both uncoded and coded signals. The summary of the coding gains obtained for each MIMO arrangement is shown in Table II.

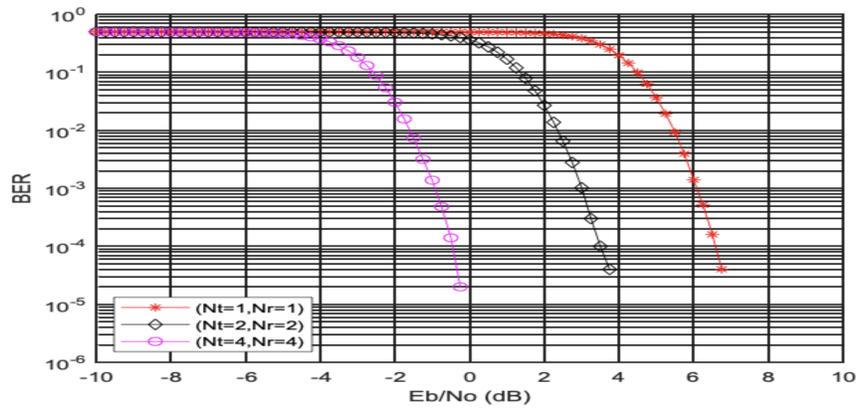


Figure 5: BER performance of polar coded QPSK over flat fading channel

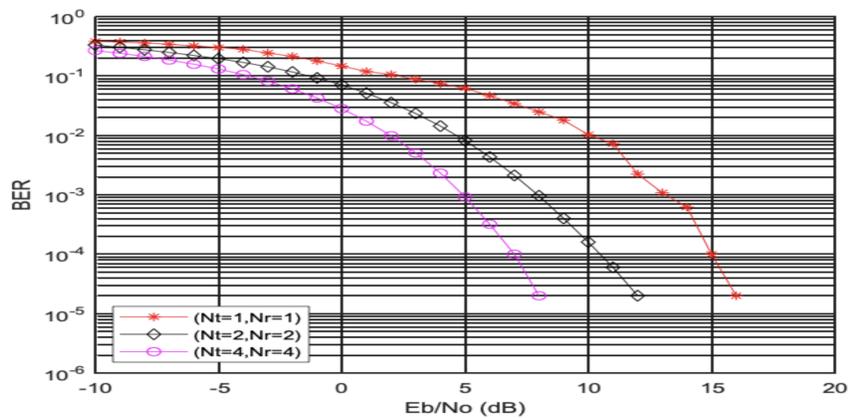


Figure 6: BER performance of uncoded QPSK over mmWave channel

Looking at the performance results obtained from Figures 2 to 7 one can summarize the results in the form of the required SNR (i.e  $E_b/N_0$ ) by each system and channel for fixed BER of  $10^{-4}$  as shown in Table II. For the uncoded case, MIMO scheme with 4x4 antennas gives 9dB gain compared with SISO while that of 2x2 MIMO gives 6dB gain over SISO. In the case of polar coded signal with MIMO results, 2x2 MIMO gives about 6dB gain compared to uncoded 2x2 MIMO. This gain in the case of 4x4 MIMO is also about 6dB, where the effect of the channel limits the gain obtained by the polar coded signal.

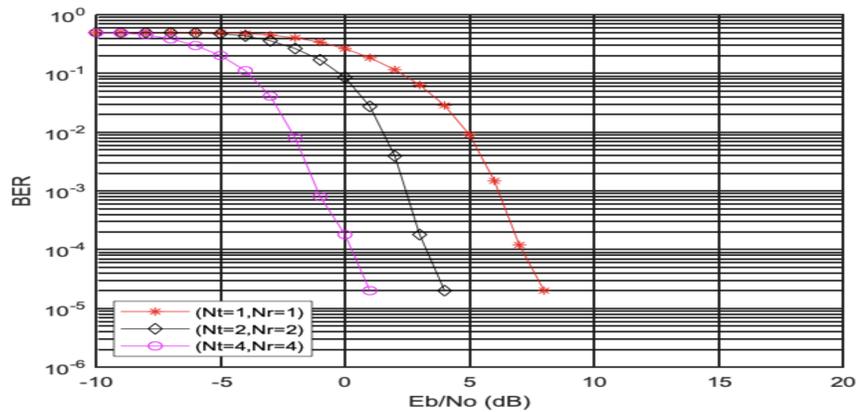


Figure 7: BER performance of polar coded QPSK over mmWave channel

TABLE II  
 REQUIRED SNR FOR DIFFERENT SYSTEMS USING MMWAVE CHANNEL MODEL AT BER OF  $10^{-4}$ .

MIMO System Arrangement	Uncode SNR (dB)	Polar Coded SNR (dB)	Coding Gain (dB)
SISO	15	7	8
2X2 MIMO	9	3	6
4X4 MIMO	6	0	6

#### IV. CONCLUSIONS

In this paper, we have introduced an arrangement of polar coded signal with MIMO system operating over a model of mmWave channel. The BER performances of different system arrangements are obtained via simulation tests. The results show that both the MIMO system and the polar code improved bit error rate performance over the channel models considered in the work. These models are AWGN, flat fading, and an indoor multipath fading mmWave channel operating at 30 GHz carrier frequency. Polar coded signal performed better over AWGN channel as compared to other two channel models. The advantages of using MIMO arrangement are enhanced by using the polar code signal. Thus, with the expected higher bandwidth provided by mmWave frequency band and hence higher bit rate, polar coded MIMO system improved the performance by at least 6 dB at BER of  $10^{-4}$  for the assumed test conditions and mmWave channel model considered in the work. Thus, it is expected to have further BER performance improvements when using higher dimensionality MIMO system.

#### REFERENCES

- [1] S. Hossain, "5G wireless communication systems", American Journal of Engineering Research (AJER), vol. 2, issue. 10, pp. 344-353, 2013.
- [2] S. Busari, K. Huq, S. Mumtaz, L. Dai and J. Rodrigues, "Millimeter Wave Massive MIMO Communication for Future Wireless Systems: A Survey", IEEE Communication Surveys and Tutorials, vol. 20, no. 2, pp. 836-869, 2018, DOI. 10.1109/COMST.2017.2787460.
- [3] P. Mishra, G. Singh, R. Vij and G. Chandil, "BER Analysis of Alamouti Space Time Block Coded 2x2 MIMO Systems using Rayleigh Dent Mobile Radio Channel", 3rd IEEE International Advance Computing Conference (IACC), Ghaziabad, India, pp. 154-158, 22-23 Feb. 2013, DOI. 10.1109/IAdCC.2013.6514212.
- [4] T. Rappaport, A. Alsanie, "Radio propagation path loss models for 5G cellular networks in the 28 GHz and 38 GHz millimeter wave bands", IEEE Communications Magazine, vol. 52, issue. 9, pp. 78-86, 2014, DOI. 10.1109/MCOM.2014.6894456.
- [5] Z. Pi, F. Khan, "An Introduction to Millimeter-Wave Mobile Broadband Systems," IEEE Commun. Mag., vol. 49, no. 6, pp. 101-107, 2011, DOI. 10.1109/MCOM.2011.5783993.

- [6] F. Khan, Z. Pi and S. Rajagopal, "Millimeter Wave Mobile Broadband with Large Scale Spatial Processing for 5G Mobile Communication", Proc. IEEE 50th Annual Allerton Conf., pp. 1517-1523, 1-5 Oct. 2012, DOI. 10.1109/Allerton.2012.6483399.
- [7] T. Rappaport, S. Sun, R. Mayzun and H. Zhao, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!", IEEE Access, vol. 1, pp. 335-349, 2013, DOI. 10.1109/ACCESS.2013.2260813.
- [8] T. Rappaport, F. Gutierrez, E. Dor and J. Murdock, "Broadband Millimeter Wave Propagation Measurements and Models Using Adaptive Beam Antennas for Outdoor Urban Cellular Communications", IEEE Trans. Antennas and Propagation, vol. 61, no. 4, pp. 1850-1859, 2013, DOI. 10.1109/TAP.2012.2235056.
- [9] S. Rangan, T. Rappaport and E. Erkip, "Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges", Proc. IEEE, vol. 102, no. 3, pp. 366-386, 2014, DOI. 10.1109/JPROC.2014.2299397.
- [10] S. Akoum, O. El Ayach and R. W. Heath, "Coverage and Capacity in mmWave Cellular Systems", Proc. IEEE Conf. 46th Asilomar Conf., Pacific Grove, CA, USA, pp. 688- 692, 2012, DOI. 10.1109/ACSSC.2012.6489099.
- [11] J. N. Murdock et al., "A 38 GHz Cellular Outage Study for an Urban Campus Environment", Proc. IEEE Wireless Commun. Net. Conf., Paris, France, pp. 3085- 3090, 2012, DOI. 10.1109/WCNC.2012.6214335.
- [12] T. Rappaport, A. Alsanie, "Radio propagation path loss models for 5G cellular networks in the 28 GHz and 38 GHz millimeter wave bands", IEEE Communications Magazine, vol. 52, issue. 9, pp. 78-86, 12 Sep. 2014, DOI. 10.1109/MCOM.2014.6894456.
- [13] Z. Wei, B. Li and C. Zhao, "On the Polar Code for the 60-GHz Millimeter Wave Systems ", EURASIP Journal on Wireless Communications and Networking, no. 31, pp. 1-11, 2015.
- [14] S. Jing, J. Yang, A. Yu, X. You and C. Zhang, "Graph Merged Detection and Decoding of Polar Coded MIMO Systems ", 9th International Conference on Wireless Communications and Signal Processing (WCSP), China, pp. 1-7, 2017, DOI. 10.1109/WCSP.2017.8171002.
- [15] K. Qin, Z. Zhang, H. Zhang and G. Chen, "Polar Coded Adaptive Data Transmission in An Indoor mmWave Scenario", International Conference on Microwave and Millimeter Wave Technology (ICMMT), Chengdu, China, 7-11 May 2018, DOI. 10.1109/ICMMT.2018.856372.
- [16] V. Bioglio, C. Condo and I. Land, "Design of Polar Codes in 5G New Radio", IEEE Communications Surveys and Tutorials, pp. 29-40, 2020. DOI. 10.1109/COMST.2020.2967127.
- [17] W. Abdulwahab, A. Kadhim, "Comparative Study of Channel Coding Schemes for 5G ", International Conference on Advanced Science and Engineering (ICOASE), Kurdistan Region, Iraq, pp. 95-102, 2018, DOI. 10.1109/ICOASE.2018.8548806.
- [18] I. Tal, A. Vardy, "List Decoding of polar Codes", IEEE Transactions on Information Theory, vol. 61, issue. 5, pp. 2213-2226, 2015, DOI. 10.1109/TIT.2015.2410251.
- [19] I. Tal, A. Vardy, "List Decoding of polar Codes", IEEE International Symposium on Information Theory, Saint Petersburg, Russia, 2011, DOI: 10.1109/ISIT.2011.6033904.
- [20] V. Bioglio, C. Condo and I. Land, "Design of Polar Codes in 5G New Radio", IEEE Communication Surveys Tutorials, pp. 29-40, 2020. DOI. 10.1109/COMST.2020.2967127.
- [21] N. Parveen, D. Venkateswarlu, "Implementation of Space-Time Block Coding (STBC) Using 2 Transmit and 2 Receive Antennas", International Journal of Emerging Technology and Advanced Engineering, vol. 2, issue. 10, 2012.
- [22] M. Simon, M. Alouin, and J. W. Sons Inc, "Digital Communication over Fading Channels", Canada, 2005.
- [23] J. Andrews, T. Bai, M. Kulkarni and A. Alkhateeb, "Modeling and Analyzing Millimeter Wave Cellular Systems", IEEE Transactions on Communications, vol. 65, no. 1, pp. 403-430, 2017, DOI. 10.1109/TCOMM.2016.2618794.
- [24] Technical Report, "5G; Study on channel model for frequencies from 0.5 to 100 GHz (3GPP TR 38.901 version 14.0.0 Release 14)", ETSI TR, pp. 138- 901, France, 2017.