National Journal of Antennas and Propagation, ISSN: 2582-2659 Vol. 6, No. 3, 2024 (pp. 118-123)
HTTP://ANTENNAJOURNAL.COM

Performance Analysis of Polar Coded Mimo Antenna System Over Rayleigh Fading Channel

Manish Nandy[1], **Ahilya Dubey**[2]
[1]*Assistant Professor, Depa rtment of CS & IT, Kalinga University, Raipur, India.*
[2]*Research Scholar, Department of CS & IT, Kalinga University, Raipur, India.*

KEYWORDS:
Polar codes,
MIMO,
STBC,
Antenna System,
Combined detection and decoding,
Quadrature Amplitude Modulation.

ARTICLE HISTORY:
Received 14.09.2024
Revised 08.10.2024
Accepted 11.11.2024

DOI:
https://doi.org/10.31838/NJAP/06.03.15

Abstract

The Multiple Input – Multiple Output (MIMO) technology employs several antennas at both the transmitter and receiver ends. These systems may attain diversity gain, mitigating fading effects, while multiplexing gain enhances the data transfer rate. Examining polar codes (PC) in fading fading channels (RFC) has significant implications for using PC in wireless communications. The combined detection and decoding (CDD) approach based on turbo codes is computationally intricate and lacks robustness. So, a Polar coded Multiple Input Multiple Output Antenna System (PC-MIMO-AS) has been suggested for operation over an RFC to enhance resilience and diminish complexity. In the course of signal evaluation and recognition, PC has been examined to improve resilience by transforming the restrictions of Galois field (GF) codes into an agile signal system. Also, PC has been included to promote spectrum efficiency and computational effectiveness for CDD in MIMO-AS. The effectiveness of the proposed PC-MIMO-AS method is evaluated under diverse simulation conditions. This study simulates MIMO-AS using four antenna configurations: (2x1), (2x2), (2x3), and (2x4), all using Alamouti's Space Time Block Codes (STBC). The antenna designs were further tested using two modulation schemes: 16-Quadrature Amplitude Modulation (16-QAM) and 64-QAM.

Author's Email id: ku.manishnandy@kalingauniversity.ac.in, dubey@kalingauniversity.ac.in

How yo cite this article: Nandy M, Dubey A. Performance Analysis of Polar Coded Mimo Antenna System Over Rayleigh Fading Channel. National Journal of Antennas and Propagation, Vol. 6, No. 3, 2024 (pp. 118-123).

Introduction and related works

PC uses the principle of distinguishing between "positive" and "negative" channels, where the former exhibits a small Bit Error Rate (BER) and the latter an elevated one by leveraging the channel's intrinsic symmetry.[1] Upon encoding, the data is sent over the reliable channels, whilst the unreliable channels are used for error correction. Consequently, we possess a coding method that is both efficient and effective, achieving performance almost equivalent to capacity even in RFC.[2,3] To construct a PC, it is essential first to ascertain the channel reliability scores associated with every bit that needs to be encoded. This verification may be conducted successfully with a specific code length and a particular signal-to-noise ratio (SNR). Nonetheless, the 5G design anticipates a diverse array of code lengths, rates, and channel circumstances, rendering it unfeasible to establish a singular reliability vector for any conceivable combination of these attributes. This is the rationale for the extensive efforts dedicated to developing PCs, which are easy to apply and need little specification difficulty while offering dependable error correction across various code and channel configurations.[14]

The performance of every mobile communication system is adversely impacted by a prevalent phenomenon known as fading.[15] The main cause of fading is its intrinsic characteristic of propagation along multiple paths. Fading is an unavoidable phenomenon; hence, this adverse perspective on fading has been rigorously contested by scholars throughout history. The predominant method to mitigate the fading effect is unequivocally a diversification strategy.[4] A diversity strategy enhances the dependability of the communication system by offering many resolvable signal routes that experience separate fading. In the last decade, a novel diversity approach called user cooperation diversity has emerged, effectively utilizing route diversity. The fundamental concept of user collaboration is that wireless nodes exchange their data and broadcast it collaboratively to a shared destination.[9] The information-theoretic research has shown that the user collaboration strategy enhances BER performance and achieves greater data speed relative to its uncooperative equivalent scheme.[19] The collaborating user is often called a gateway in an active cooperation method. The communication channel often employs either the amplify-and-transmit strategy or the decode-and-transmit method to facilitate the data transfer.[5]

A RFC is a statistical model that characterizes the fast variations in signal amplitude and phase resulting from multipath propagation in wireless communication systems.[20] This kind of fading transpires when a predominant line-of-sight connection between the transmitter and receiver is absent, resulting in the signal arriving over several dispersed pathways of differing durations and delays. The fading adheres to a Rayleigh distribution and is prevalent in urban or indoor settings. It substantially affects system performance, necessitating measures like as diversity or coding to alleviate its consequences.

Various strategies have been presented to attain system efficiency in mobile communication. A MIMO system employs numerous antennas at both the sender and receiver ends. These systems may attain diversity gain, mitigating RFC effects, while multiplexing gain enhances the data rate.[6] The MIMO system is enhanced without requiring extra bandwidth. MIMO utilizes several antennas at both the transmitter and receiver to provide independent fading routes that are spatially separated. In a deteriorating channel, the capacity of MIMO is directly correlated with the number of antennas used. The primary limitation of wireless channels is that sent information travels over several pathways. This propagation of multiple paths results in frequency-selective fading. To mitigate the impacts of RFC, MIMO is integrated with Orthogonal Frequency Division Multiplexing (OFDM). It is a multi-carrier modulation technique in wideband mobile networks.[7]

In recent years, PC has been included in the category of capacity-approaching codes. Arikan introduced the polar code in the foundational study.[1] It attains the capability of any specified binary discontinuous memoryless channel (B-DMC).[8] The fundamental principle behind the construction of a PC is the notion of network polarization. The issue of channel coding disappears immediately for two types of channels: entirely significant and entirely insignificant. The PC effectively achieves channel polarization, making it the most powerful channel code in the modern world.[13] The PC has been implemented in coded collaboration to achieve assisted diversity. The nested polar code for relay-assisted channels was first shown in,[16] where the authors demonstrated that PC continue to attain channel bandwidth even when the secondary channel significantly deteriorates relative to the primary channel. Further substantial advancements in layered polar codes in relay-assisted channels are documented in.[10] PC for relay channels affected by Gaussian noise is documented in.[11] The authors in[17] demonstrated that the extended polar code with an elevated coding rate outperforms LDPC code in reaching the Shannon capacity limit over an RFC.

Recent studies have thoroughly examined combining PC and MIMO systems in RFC situations to improve wireless communication reliability and efficiency. Arıkan's development of PC established a fundamental channel coding method that may attain Shannon's capacity. Subsequent research examined the possibilities of polar coding in MIMO systems, using spatial variety to mitigate multipath fading.

Researchers have examined the efficacy of polar-coded MIMO in RFC, concentrating on metrics such as BER, signal-to-noise ratio (SNR), and channel capacity. Using successive cancellation decoding (SCD), PC has shown improvements in BER performance and the alleviation of channel impairments.[12] Integrating MIMO technology enhances these advantages by augmenting spatial diversity and throughput. Research indicates that the efficacy of polar-coded MIMO systems is contingent upon the quantity of antennas and precise channel estimate.[18] Integrating polar codes with MIMO has shown efficacy in ensuring reliable communication in fading channels, especially in 5G and IoT applications.

PC-MIMO-AS

The amalgamation of PC with MIMO-AS provides resilient communication in RFC. This combination attains equilibrium among error correction, spectrum efficiency, and system complexity, making it appropriate for next-generation wireless networks, including 5G and beyond.

Fig. 1 depicts the framework of PC-MIMO-AS. The Polar-Coded Multiple-Input Multiple-Output Antenna System (PC-MIMO-AS) simulation model is constructed using MATLAB by coding individual blocks of the transmitter and receiver system. These blocks perform specific functions critical to the system's operation. The source generator initiates the process by producing information bits for transmission. These bits are modulated using the 16-QAM scheme, balancing spectral efficiency and noise resistance. Channel coding employs Polar Codes (PC), decoded using the Successive Cancellation Decoding

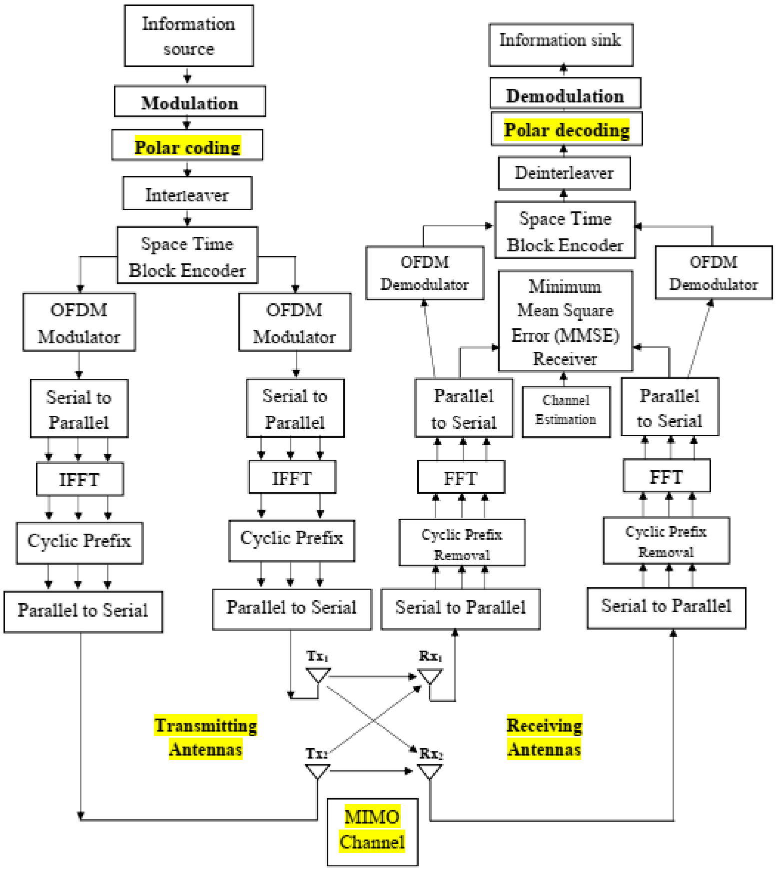

Fig. 1 Framework of PC-MIMO-AS

(SCD) algorithm, alongside Turbo Codes for error correction. To reduce burst errors, interleaving reorders the coded data before transmission.

Data conversion is managed through serial-to-parallel translation, enabling further processing. The Inverse Fast Fourier Transform (IFFT) at the transmitter converts frequency-domain data into the time domain to represent orthogonal OFDM subcarriers. A cyclic prefix is then appended to each OFDM symbol to mitigate inter-symbol and inter-carrier interference (ISI/ICI). The system employs a 2×2 Space-Time Block Coding (STBC) MIMO scheme to maximize diversity and combat fading effects. Polar Codes serve as the primary channel coding method for MIMO-OFDM systems, although alternative schemes like LDPC and Turbo Codes may also be used, enhancing system reliability and performance.

Polar Coding

A polar code is defined by the rate , where m represents the message-bit size and c denotes the codeword-bit size. The information bits are supplied so that D is a subset of . Signal polarization enables the transformation of c equivalent channel realizations into c parallel virtual bit channels, which may be either significantly noisy or completely error-resistant as c approaches infinite polarization. The essential aspect of polar code development is to choose the most reliable c data streams for data bit transmission by ranking the simulated data streams based on their efficacy. The remaining bit-channels contain fixed segments (assigned known values). The ratio of specialized simulated networks to all realistic data streams is , which asymptotically approaches the channel capacity for large c.

To facilitate downlink control, the user must measure and catalog the available Control Channel Component (CCC) quantity. This depends on the quantity of controlling units (in increments of 15 resource units), the device bandwidth, and the number of active antenna ports, which will affect the range of the modulating signal accessible. The quantity of CCC available for PDCCH is first determined by the user, who subtracts the resources allocated for physical downlink control channel (PDCCH) symbols, channel indicators, and Physical Hybrid Automatic Repeat Request (HARQ) from the total resources designated for power assignment. The first step is for the user to determine the quantity of resource units allocated for PDCCH.

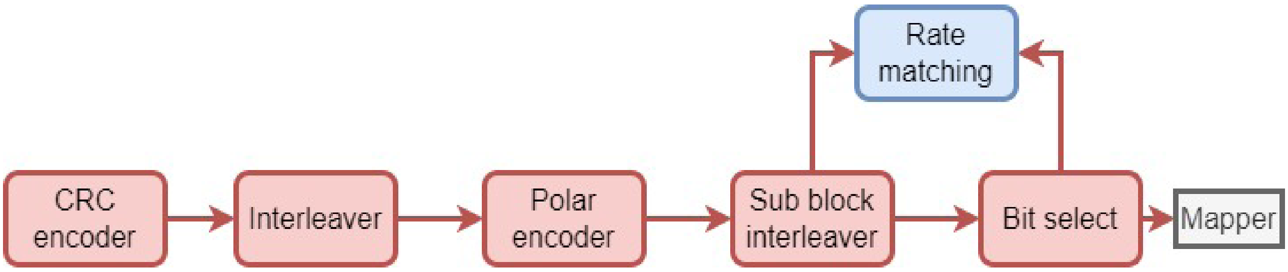

Fig. 2 5G-polar encoding process for downlink

To construct the proposed PC, the modulation signals are derived from a constellation , partitioned into real and imaginary components using the conventional 16-QAM modulation method. Specifically, inside the same constellation C, the real section , and its imaginary section constitute the coordinate. A method has been proposed to convert the linear coding constraints on Euclidean spaces from the Galois field into linear variation constraints. The fundamental approach is to relax the constraints of a linear block coding matrix to create specific linear codeword limits identified as the standard polytope. As the density of the binary parity control matrix develops exponentially relative to the number of translated linear constraints, this conversion aligns well with the less dense equality control matrices characterized by low masses in LDPC. Consequently, by integrating all elements of this original matrix to align with the polytope , where , it may be expressed in accordance with linear decoding constraints, with denoting all variables of the factor graph.

Fig. 2 illustrates the 5G encoding techniques for the downlink. A basic PC of length is constructed, in tandem with the corresponding bit channel dependability structure and frozen group, depending on the specified code rate and codeword length . The remainder bits of the N-bit s vector are fixed, and the interleaved vector c, which may additionally include parity-check bits, is sent to the information set. Upon selecting a basic PC, the vector is encoded. Following encoding, is divided into 32 blocks of uniform length by a subblock interleaver, resulting in the scrambled output , which is then fed into the circular buffer. Using puncturing, shortening, or repetition, the N-bit vector may be converted into an -bit vector . Subsequently, a channel interleaver can be used to compute the vector , which may then be modulated and sent as , following concatenation if necessary.

Results and discussion

The effectiveness of the proposed PC-MIMO-AS method is evaluated under diverse simulation conditions. This study simulates MIMO-AS using four antenna configurations: (2x1), (2x2), (2x3), and (2x4), all using Alamouti's Space Time Block Codes (STBC) in MATLAB. The antenna designs were further tested using two modulation schemes: 16-Quadrature Amplitude Modulation (16-QAM) and 64-QAM.

The fundamental system parameters are: The carrier frequency is 2.3 GHz, accompanied with a channel bandwidth of 5 MHz. The FFT size is 512. The cyclic prefix value is 1/8, while the oversampling rate is 28/25. The examined channel conditions include Rayleigh fading. The following parameters are derived: The sampling frequency (*Fs=nxBW*) is 5.6 MHz; the subcarrier spacing $\Delta f=Fs/NFFT$ is 10.94 kHz; the useful symbol time ($Tb=1/\Delta f$) is 91.4 μs; the cyclic prefix time (Tg=CPxTb) is 11.4 μs; and the OFDM symbol duration (Ts=Tb+Tg) is 102.8 μs.

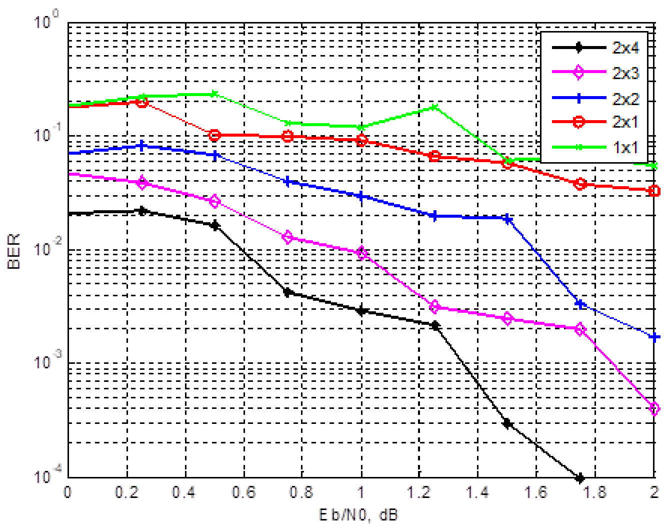

Fig. 3: BER analysis of PC-MIMO-AS in RFC

Fig. 3 shows the BER analysis of PC-MIMO-AS in RFC. The graph depicts the BER performance across several MIMO configurations (1x1, 2x1, 2x2, 2x3, and 2x4) within a specified SNR range. Higher diversity orders, such as 2x4 MIMO, clearly enhance performance with the lowest BER at a certain SNR, illustrating the advantages of spatial diversity. In contrast, systems with fewer antennas, such as 1x1 and 2x1, have elevated BER, indicating less efficacy in mitigating signal deterioration caused by fading. This underscores the trade-off between system complexity and performance.

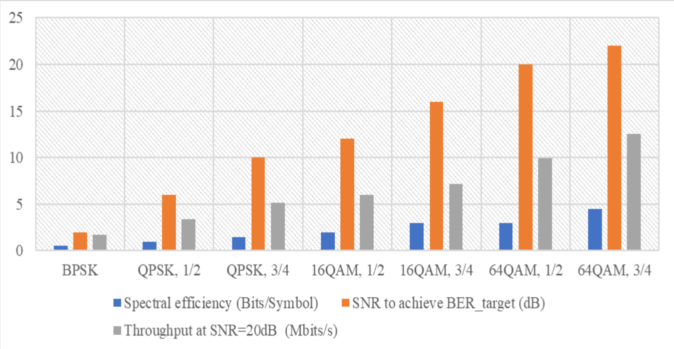

Fig. 4: Spectral efficiency and throughput analysis of various modulation schemes and code rates for PC-MIMO-AS in RFC

Fig. 4 illustrates the Spectral efficiency and throughput analysis of various modulation schemes and code rates for PC-MIMO-AS in RFC. Fig. 4 illustrates the correlation among modulation techniques, spectral efficiency, necessary SNR to meet the BER objective, and throughput for PC-MIMO-AS in an RFC context. Elevated modulation orders, such as 64-QAM, provide enhanced spectral efficiency (up to 4.5 bits/symbol) and throughput (up to 12.5 Mbits/s at 20 dB SNR). Nonetheless, they need elevated SNR levels (e.g., 22 dB for 64-QAM with a ¾ coding rate) to achieve the BER objective. Lower modulation methods, such as BPSK, exhibit reduced spectral efficiency and throughput; nevertheless, they demonstrate greater resilience to noise and need just 2 dB SNR to achieve BER objectives.

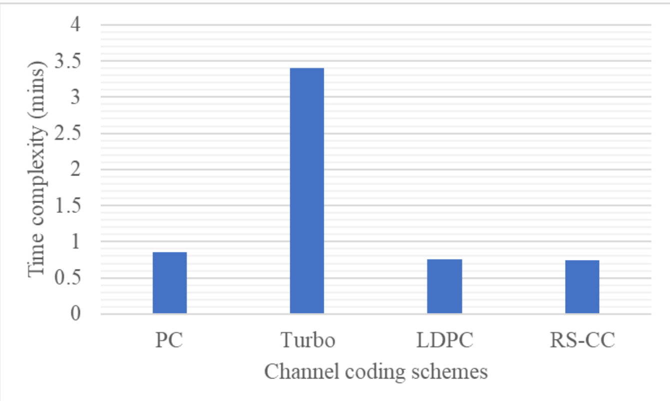

Fig. 5: Time complexity analysis of various channel coding schemes for MIMO-AS

Fig. 5 depicts the Time complexity analysis of various channel coding schemes for MIMO-AS. PC has a low temporal complexity of 0.86 minutes, making it efficient for real-time applications. Turbo coding has the maximum temporal complexity at 3.4 minutes, indicating increased processing requirements. LDPC (0.76 minutes) and RS-CC (0.74 minutes) have the least time complexity, indicating their appropriateness for expedited processing. This investigation underscores the trade-offs between complexity and performance in selecting coding schemes.

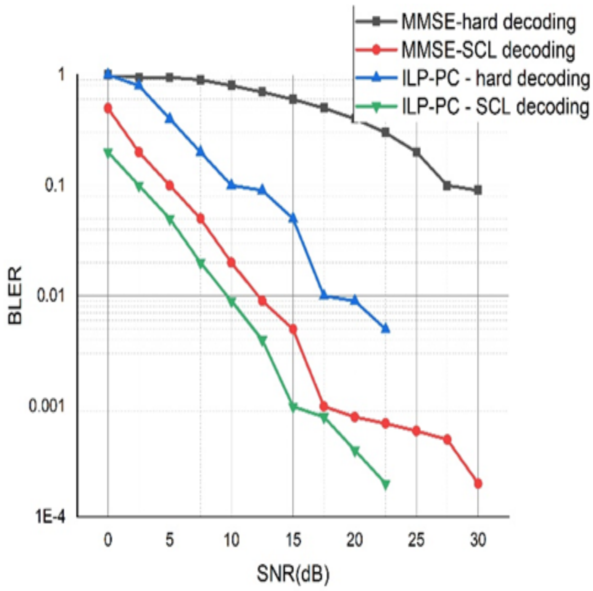

Fig. 6: Block error rate (BLER) versus SNR for various channel coding schemes with 2x2 MIMO-AS

Fig. 6 illustrates the Block error rate (BLER) versus SNR for various channel coding schemes with 2x2 MIMO-AS. PC gave the least BLER (green) with the lowest BLER of $1x10^{-3}$ at SNR of 15dB. LDPC (red) gave moderate BLER performance of $4x10^{-3}$ at an SNR of 15 dB. Turbo coding (blue) gave the least BLER of $4x10^{-2}$ at an SNR of 15 dB. PC gave 2dB and 7dB performance gain compared to LDPC and Turbo codes at BLER of 10^{-2}, respectively. Thus, PC gave improved coding gain with less complexity to be implemented in MIMO-AS under RFC.

Conclusion

A Polar-coded Multiple Input Multiple Output Antenna System (PC-MIMO-AS) has been proposed for operation over an RFC to improve resiliency and reduce complexity. An analysis of PC has been conducted during signal assessment and recognition to enhance resilience by converting the limitations of Galois field (GF) codes into a flexible signal system. Additionally, the PC has been included to enhance spectrum efficiency and computational efficacy for CDD in MIMO-AS. The efficacy of the suggested PC-MIMO-AS technique is assessed under various simulated settings. This work simulates MIMO-AS in MATLAB using four antenna configurations: (2x1), (2x2), (2x3), and (2x4), utilizing Alamouti's Space Time Block Codes (STBC). The antenna designs underwent further testing using two modulation schemes: 16-Quadrature Amplitude Modulation (16-QAM) and 64-QAM. PC has a low temporal complexity of 0.86 minutes, making it efficient for real-time applications. Higher diversity orders, such as 2x4 MIMO, clearly enhance performance with the lowest BER at a certain SNR, illustrating the advantages of spatial diversity. In contrast, systems with fewer antennas, such as 1x1 and 2x1, have elevated BER, indicating less efficacy in mitigating signal deterioration caused by RFC. PC gave 2dB and 7dB performance gain compared to LDPC and Turbo codes at BLER of 10^{-2}, respectively.

References

[1] Arikan, E. (2011). Systematic polar coding. *IEEE communications letters*, *15*(8), 860-862.

[2] Dai, J., Niu, K., & Lin, J. (2018). Polar-coded MIMO systems. *IEEE Transactions on Vehicular Technology*, *67*(7), 6170-6184.

[3] Muralidharan, J. "Optimization Techniques for Energy-Efficient RF Power Amplifiers in Wireless Communication Systems." SCCTS Journal of Embedded Systems Design and Applications 1.1 (2024): 1-5.

[4] Niu, K., & Li, Y. (2020). Polar codes for fast fading channel: Design based on polar spectrum. *IEEE transactions on vehicular technology*, *69*(9), 10103-10114.

[5] SUDHIR, MADUGURI, et al. "Untangling Pancard By Designing Optical Character Reader Tool Box By Correlating Alpha Numeric Character." International Journal of communication and computer Technologies 10.1 (2022): 7-10.

[6] Bharati, S., Podder, P., Gandhi, N., & Abraham, A. (2020). Realization of MIMO channel model for spatial diversity with capacity and SNR multiplexing gains. *arXiv preprint arXiv:2005.02124*.

[7] Mahmud, M. H., Hossain, M. M., Khan, A. A., Ahmed, S., Mahmud, M. A., & Islam, M. H. (2020, December). Performance analysis of OFDM, W-OFDM and F-OFDM under Rayleigh fading channel for 5G wireless communication. In *2020 3rd International Conference on Intelligent Sustainable Systems (ICISS)* (pp. 1172-1177). IEEE.

[8] Chen, W., Huang, Y., Cui, S., & Guo, L. (2022). Channel coding. In *5G NR and Enhancements* (pp. 361-411). Elsevier.

[9] Rahim, Robbi. "Quantum Computing in Communication Engineering: Potential and Practical Implementation." Progress in Electronics and Communication Engineering 1.1 (2024): 26-31.

[10] Bao, J., Qi, K., Liu, C., Jiang, B., & Wu, J. (2023). Polar-coded cooperation with optimized relay selection in multi-satellite and wireless integrated systems. *IEEE Internet of Things Journal*, *10*(23), 20429-20441.

[11] Uvarajan, K. P. "Advances in Quantum Computing: Implications for Engineering and Science." Innovative Reviews in Engineering and Science 1.1 (2024): 21-24.

[12] Zheng, H., Hashemi, S. A., Balatsoukas-Stimming, A., Cao, Z., Koonen, T., Cioffi, J. M., & Goldsmith, A. (2021). Threshold-based fast successive-cancellation decoding of polar codes. *IEEE transactions on communications*, *69*(6), 3541-3555.

[13] Soelistijanto, B., & Manoah, G. (2021). Network Size Estimation in Opportunistic Mobile Networks: The Mark-Recapture Method. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 12(3), 29-46.

[14] Umar, R., Yang, F., Xu, H., & Mughal, S. (2019). Distributed Polar Code Based on Plotkins Construction with MIMO Antennas in Frequency Selective Rayleigh Fading Channels. *Wireless Personal Communications*, *104*, 287-306.

[15] Tu, Z., Zhou, H., Li, K., & Li, G. (2019). DCTG: Degree Constrained Topology Generation Algorithm for Software-defined Satellite Network. Journal of Internet Services and Information Security, 9(4), 49-58.

[16] Li, Y., Chen, Z., Liu, G., Wu, Y. C., & Wong, K. K. (2021). Learning to construct nested polar codes: An attention-based set-to-element model. *IEEE Communications Letters*, *25*(12), 3898-3902.

[17] Mahdavifar, H. (2020). Polar coding for non-stationary channels. *IEEE Transactions on Information Theory*, *66*(11), 6920-6938.

[18] Zhou, H., Zheng, J., Yang, M., Gross, W. J., You, X., & Zhang, C. (2022). Low-complexity sphere decoding for polar-coded MIMO systems. *IEEE Transactions on Vehicular Technology*, *72*(5), 6810-6815.

[19] Han, S., Li, Y., Zhang, T., Bai, Y., Chen, Y., & Tellambura, C. (2024). Signal Detection Techniques in Social Internet of Vehicles: Review and Challenges. *IEEE Intelligent Transportation Systems Magazine*.

[20] Reza Fatemi Mofradi and Morteza Shahidi Nasab. (2017). Using of the Vernier frequencies method to resolve problem of the ambiguity in range of the pulsed radars. International Academic Journal of Innovative Research, 4(2), 10–21.