Research Article

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Performance analysis of a hybrid OFDM-MIMO multiresonator system: synchronization, CFO estimation, and return loss evaluation

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Abstract
The dynamic landscape of wireless communication technologies demands innovative solutions to overcome synchronization challenges, carrier frequency offset (CFO)-induced interference, and impedance mismatches. This research presented a novel approach by developing a hybrid orthogonal frequency-division multiplexing-multiple-input, multiple-output (OFDM-MIMO) multiresonator system. Recent studies indicate the critical importance of addressing synchronization errors and CFO-induced interference in communication systems. Although OFDM and MIMO techniques enhance data transmission, challenges arising from CFO and synchronization discrepancies can affect system performance. This research aims to contribute a comprehensive solution integrating OFDM, MIMO, and multiresonator frameworks to tackle signal degradation and reduced transmission efficiency. CFO-induced interference is a significant challenge, negatively impacting transmitted signal quality, and timing discrepancies can lead to synchronization errors, detrimentally affecting overall performance. Impedance mismatches pose a risk of signal reflections, contributing to decreased transmission efficiency. The motivation for this research arises from the need for robust communication systems in the face of these challenges. Our objectives include analyzing CFO's impact, developing synchronization methods, and evaluating return loss and impedance matching to enhance overall system efficiency.

Keywords
OFDM-MIMO, Multiresonator system, Synchronization errors, CFO-induced interference, Impedance matching.

1.Introduction
The ever-evolving landscape of wireless communication technologies demands innovative solutions to address synchronization challenges, carrier frequency offset (CFO) issues, and impedance mismatches. In this context, our research focuses on advancing the field through the development of a hybrid orthogonal frequency-division multiplexing-multiple-input, multiple-output (OFDM-MIMO) multiresonator system. Recent studies in wireless communication technologies have underscored the critical importance of addressing synchronization errors, CFO-induced interference, and impedance mismatches in communication systems [1–4]. The advent of OFDM and MIMO techniques has significantly enhanced data transmission capabilities [5–9]. However, the complexities arising from CFO and synchronization discrepancies can compromise the overall performance of such systems [10–14].

Recognizing the significance of these challenges, our research aims to contribute a comprehensive solution that integrates OFDM, MIMO, and multiresonator frameworks. These challenges can lead to signal degradation, reduced transmission efficiency, and compromised overall system reliability [15, 16]. CFO-induced interference stands as a notable example, exerting a substantial adverse impact on the quality of transmitted signals [15–18]. Similarly, timing discrepancies have the potential to precipitate synchronization errors, thereby detrimentally affecting the overall performance of the communication system [19–21]. Furthermore, impedance mismatches pose a risk of signal reflections, contributing to a decrease in transmission efficiency [20–22].

The motivation behind this research stems from the pressing need for robust and efficient communication systems. Existing studies have highlighted the detrimental effects of CFO-induced interference, timing issues, and impedance mismatches on signal

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fidelity and transmission efficiency. These challenges motivate us to design a hybrid OFDM-MIMO multiresonator system that not only identifies and mitigates these issues but also serves as a foundational step toward advancing the reliability and efficiency of wireless communication.

Our research objectives are threefold:

- To scrutinize the impact of CFO on the performance of an OFDM system within a multiresonator framework: Our goal is to conduct a comprehensive analysis of CFO's influence within the context of our hybrid OFDM-MIMO multiresonator system.
- To formulate and implement synchronization methods to rectify timing issues in the system: Our objective is to devise effective synchronization methods tailored to the intricacies of the multiresonator framework.
- To assess return loss and optimize impedance matching to augment signal fidelity and transmission efficiency: We aim to evaluate return loss and institute measures to refine impedance matching, thereby elevating signal fidelity and bolstering overall system efficiency.

This paper implemented a hybrid OFDM-MIMO multiresonator system designed to tackle synchronization errors, CFO-induced interference, and impedance mismatches.

This paper is structured as follows: Section 2 provides a literature review, discussing relevant prior research. In Section 3, the methods and steps involved in the development of the system are explored. Section 4 elaborates on the results and discussion. Finally, Section 5 presents the conclusion of the study.

2.Related work

This section explores the related work considering the method, result, advantages, and limitations.

In 2022, Sakhnini et al. [23] investigated the problem of direction estimation in OFDM MIMO radar systems. The study focused on estimating departure and arrival direction under frequency-interleaved MIMO multiplexing. Bistatic and collocated antenna systems were considered, revealing range-angle coupling. Two compensation methods were presented, with quantified performance loss when ignoring this coupling.

In 2022, Adnan [24] conducted simulations on a visible light communication (VLC) network with 9 user equipment's (UEs) employing non-orthogonal multiple access (NOMA), OFDM, and a 3×3 MIMO configuration. The study analyzed the impact of signal-to-noise ratio (SNR) variation and interference from light emitting diode (LED) neighbors on the BER performance of the main LED (T×A). A power ratio of 1:2:4 for successful NOMA of UE1:UE2: UE3 by T×A was found to maintain bit error rate (BER) below the limit. Additionally, considering interference from LED neighbors (T×B and T×C), the minimum SNR of the LED transmitted signal needed to be over 25 dB at 0% and 1% interference level, over 27 dB at 2% and 3% interference level; otherwise, the BER performance exceeded the forward error correction (FEC) value of 3.8×10^(-3).

In 2022, DN and Eshwarappa [25] proposed a novel peak-to-average power ratio (PAPR) reduction method for MIMO-OFDM, combining dynamic audio power management (DAPM) and discrete wavelet transform (DWT). Achieving lower PAPR and BER compared to other techniques, their 2×2 long term evolution (LTE)-MIMO configuration demonstrated 3.433 PAPR at 10^{-1} complementary cumulative distribution function (CCDF) and 0.4006 BER at 20 dB SNR.

In 2022, Nadiger et al. [26] explored OFDM as a modulation technique, emphasizing its spectrum efficiency compared to frequency division multiple access (FDMA). They employed field programmable gate arrays (FPGA) for a reconfigurable architecture, focusing on MIMO systems for maximum data rate. The project aimed to design a baseband OFDM transmitter and receiver, incorporating quadrature phase shift keying (QPSK) mapping, scrambling, encoding, interleaving, and cyclic prefix insertion modules. A 64-point fast Fourier transform (FFT) or inverse (IFFT) was utilized, along with the zero-force precoding technique to reduce inter-user interference. The design was simulated using Xilinx 14.5 and verified with MATLAB 7.1.

In 2022, Nguyen et al. [27] assessed channel estimation techniques for the 5G new radio (NR) physical uplink control channel (PUCCH). Examining LS, discrete Fourier transform (DFT)-based LS, moving-average least squares (LS), and minimum mean square error (MMSE) algorithms with different receive antennas, they found MMSE performed best, while moving-average LS offered a favorable performance-complexity trade-off. Using

32Rx instead of 2Rx significantly increased system energy efficiency by 12–14 dB. The study provides valuable insights for designing 5G NR systems.

In 2022, Phan et al. [28] introduced a simplified approach to enhance the decoding performance of the PUCCH format 2 in 5G NR, achieving improved decoding simplicity and significant reduction in acknowledge missed detection probability (PACK). Experimental validation demonstrated practical suitability and compliance with technical requirements.

In 2023, Toland et al. [29] investigated the recovery of mixed signals transmitted by multiple users through OFDM modulation over a doubly-dispersive channel. The study considered QPSK signal blocks from collocated and non-collocated users on a shared OFDM frequency band. A modified OFDM receiver architecture, utilizing a Least Square equalizer, was proposed to separate and recover signals at the base station, addressing challenges like additive white Gaussian noise (AWGN) and inter-symbol interference. Channel state information was estimated using pilots, establishing a baseline performance for the proposed multi-user OFDM receiver.

In 2023, Zakavi et al. [30] proposed a multiuser (MU) VLC system using massive multiple-input multiple-output (mMIMO) orthogonal frequency-division multiplexing (OFDM) to address the limited modulation bandwidth challenge. The system utilizes an array of LEDs for illumination, enabling high data rates. They investigated three linear precoding methods (maximum ratio transmission (MRT), MMSE, zero forcing (ZF)) for intensity-modulation and direct-detection links in the proposed MU-mMIMO-OFDM VLC system. The study evaluated spectral efficiency, total downlink optical power, and derived a closed-form expression for the lower bound on average achievable sum-rate, confirming improved performance compared to previous works. Results indicated the effectiveness of the proposed method, with ZF and MMSE outperforming MRT in scenarios with a large LED-to-user ratio and vice versa.

In 2023, Bishe et al. [31] introduced a genetic algorithm (GA)-based subcarrier allocation method for OFDM in hybrid beamforming(BB) multi-user massive multiple-input multiple-output (MU-mMIMO) systems. Their objective was to maximize system sum-rate capacity within a total transmit power constraint by optimally selecting users for each subcarrier. The proposed algorithm, involving radio frequency (RF), BB precoding, GA-based subcarrier allocation, and power allocation, outperformed random and greedy schemes in terms of achieved sum-rate, as demonstrated in illustrative results.

In 2023, Feng et al. [32] introduced Deep Learning-based detection for compressed sensing-aided multi-dimensional index modulation (CS-MIM). Their approach achieves near-capacity performance with reduced complexity, eliminating the need for Channel Estimation in blind detection for improved transmission rates.

In 2023, Cunha and Linnartz [33] addressed the challenges in LED-based optical wireless communication (OWC) using distributed MIMO (D-MIMO) and OFDM. They introduced power-loading strategies for enhanced throughput, considering LED constraints and eye-safety regulations. The study evaluated and compared performance and computational costs, offering practical choices for system designers.

The reviewed literature covers diverse aspects of communication systems. Studies address direction estimation in OFDM MIMO radar, VLC network simulations, PAPR reduction in MIMO-OFDM, FPGA-based OFDM modulation, 5G NR channel estimation, simplified decoding in 5G NR, and more, showcasing advancements in wireless communication technologies.

3.Method

In this paper a hybrid OFDM-MIMO was been developed for the correlation system to estimate performance using BER across diverse system specifications. The initial step involves constructing a system model with varying configurations, encompassing 2mod, 3mod, 4mod, 5mod, and 6mod transmit and receive antennas. The operational mechanism is delineated in *Figure 1.* During the data stream selection phase, an AWGN channel was utilized, with a set number of 2000 iterations to enhance confidence and ensure robust estimation. The subsequent phase involves the selection and identification of channels. This stage initiates with the selection of subcarriers spanning from 8 to 1024. The code length is determined, accommodating variable timing jitters. Subsequently, subcarrier distances are computed using both Euclidean and Manhattan distances to identify the nearest jitters. The considered channels encompass AWGN and

Rayleigh, while modulation techniques include quadrature amplitude modulation (QAM).

The process of establishing a comprehensive system employing both OFDM and MIMO techniques involves several crucial steps. Initially, the system undergoes an initialization phase, laying the groundwork for subsequent operations. This foundational step is pivotal for the seamless integration of OFDM and MIMO processes.

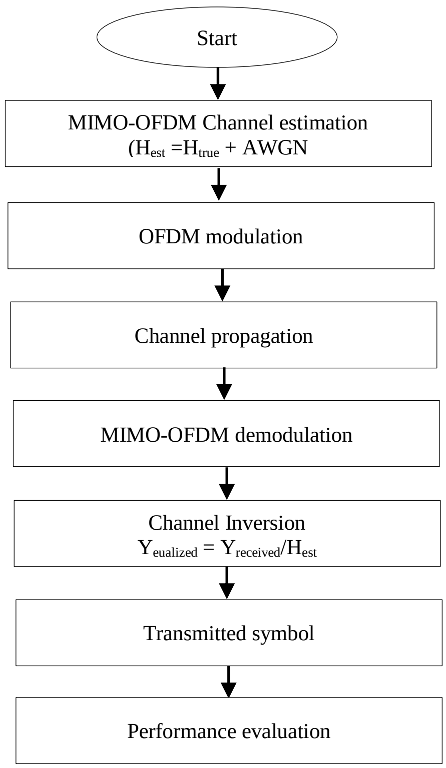

Figure 1 MIMO-OFDM channel estimation and performance evaluation

The parameters for the OFDM component are then carefully defined, with a particular focus on subcarrier spacing. These parameters play a critical role in shaping the spectral characteristics and temporal aspects of the OFDM signal, thereby influencing its overall performance. Following this, the MIMO system parameters are set, with a close consideration of the number of transmit and receive antennas. These parameters significantly impact the spatial diversity and multiplexing capabilities of the MIMO system, thereby influencing its overall capacity and reliability.

The next stage involves applying frequency modulation to the OFDM signal to modulate the carrier frequency. The frequency modulation factor becomes instrumental in determining the extent of this modulation, affecting crucial signal characteristics such as bandwidth and frequency stability. Simultaneously, phase modulation was applied into the OFDM signal, altering the phase of the carrier wave. The phase modulation factor governs the degree of phase variation, influencing the signal's resilience to phase distortions and the overall quality of communication. Subsequently, MIMO processing was implemented on the modulated signal to manipulate the transmitted signal across multiple antennas. This step harnesses spatial diversity and spatial multiplexing, thereby enhancing communication reliability and throughput. To account for the complexities introduced by the propagation medium, scattering effects in the channel are simulated. Scattering coefficients are carefully evaluated to characterize the impact of scattering on the received signal.

Furthermore, the insertion loss is assessed to quantify the signal power loss during transmission. This factor is important for the efficiency and fidelity of signal propagation through the entire system. In essence, this algorithm provides a series of steps encompassing initialization, modulation, processing, and evaluation of a communication system employing OFDM and MIMO techniques. Each parameter and modulation process carries distinct implications for the system's performance, for the design and analysis of the communication systems.

Step 1: System Initialization
Step 2: Set up parameters for Orthogonal Frequency Division Multiplexing (OFDM)
Subcarrier spacing: Δf Hz
Number of subcarriers: N_{sub}
OFDM symbol duration: T_{OFDM} seconds
Step 3: Configure parameters for multiple input multiple output (MIMO) system.
Number of transmit antennas: N_{tx}
Number of receive antennas: N_{rx}
Step 4: Apply frequency modulation to the signal in the OFDM system.
Frequency modulation factor: Δf_{mod} Hz
Step 5: Introduce phase modulation to the signal in the OFDM system.
Phase modulation factor: $\Delta \phi_{mod}$ radians
Step 6: Implement MIMO processing on the modulated signal.
MIMO channel matrix: H
Step 7: Simulate the received signal considering scattering effects in the channel.

Scattering coefficients: $\alpha_{scatter}$
Step 8: Assess the insertion loss in the system.
Insertion loss factor: IL_{factor}
Step 8: Evaluate the impact of frequency modulation on the received signal.
Step 9: Examine the influence of phase modulation on the received signal.
Step 10: Assess the characteristics of the signal after passing through the MIMO channel and encountering scattering.
Step 11: Quantify the insertion loss in the system.

4.Results and discussion

Table 1 shows the parameters used for the simulations

Table 1 Parameters used in the experimentation

S.No.	Parameter	Ranges
1	System model	AWGN/Rayleigh
2	Bandwidth estimation	5-10MHZ
3	Iteration	2000
4	MIMO-OFDM	Iterative approach
5	Time slot	Jitter
6	Modulation	QPSK and ICI

In the first phase synchronization errors was considered, specifically, CFO, within MIMO-OFDM multiresonator system. CFO can lead to inter carrier interference (ICI), causing frequency distortion in both transmitter and receiver oscillators. The absence of synchronization between the local oscillator signal and the carrier signal in the received signal can degrade OFDM performance. This paper investigated the impact of CFO on OFDM system performance, exploring various CFO estimation. The results indicate that the increasing the channel helps reduce CFO-induced noise.

Return loss (RL) has been determined to find the disparity between the power of a transmitted signal and the power of signal reflections caused by variations in connection and channel impedance. It illustrates the degree to which the impedance of the connection and channel aligns with its rated impedance across a range of frequencies. Higher return loss values indicate a close impedance match, resulting in greater separation between the powers of transmitted and reflected signals. Conversely, increasing voltage standing wave ratio (VSWR) serves to minimize return loss. The result indicates that in the case of our system it minimizes the loss rate.

A complete list of abbreviations is summarised in *Appendix I.*

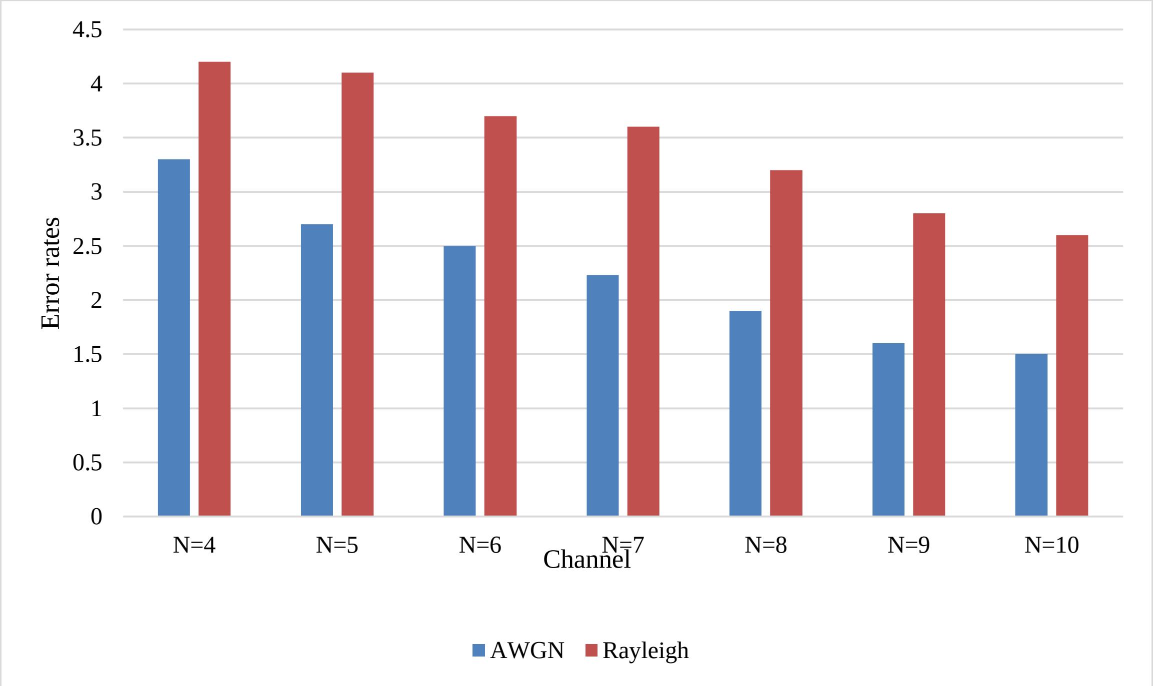

Figure 2 Carrier sub frequency estimation considering N=4 to N=10

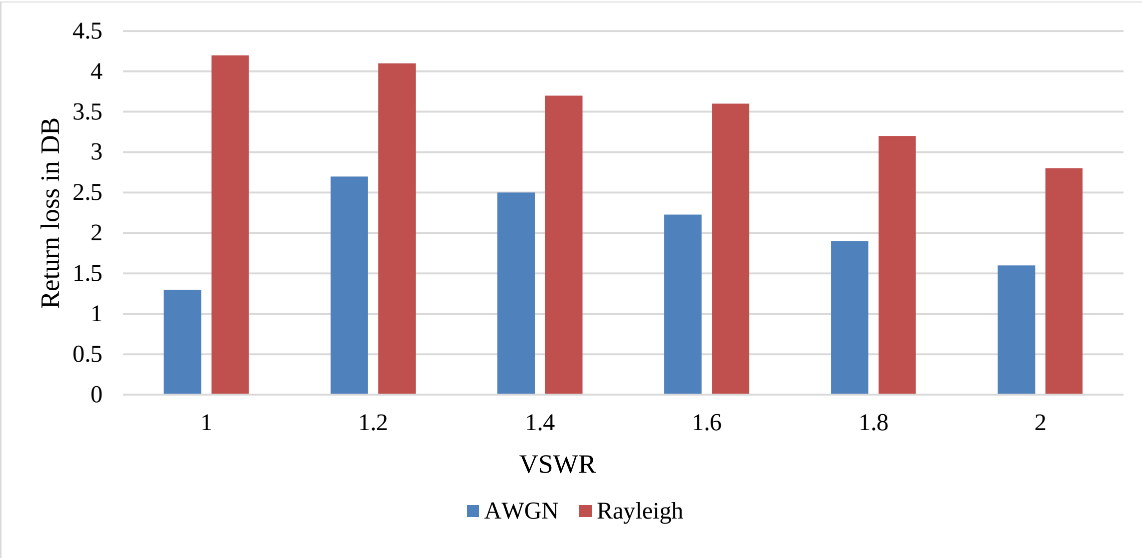

Figure 3 Carrier sub frequency estimation considering N=4 to N=10

5.Conclusion

This paper introduced a hybrid OFDM-MIMO multiresonator system designed to address synchronization errors, CFO-induced interference, and impedance mismatches. The comprehensive analysis and experimental results presented in this study contribute to advancing the reliability and efficiency of wireless communication systems. The system's robustness in handling synchronization challenges, CFO-induced interference, and impedance mismatches has been demonstrated. Through systematic evaluation and optimization of key parameters, such as subcarrier spacing and the number of antennas, the proposed system exhibits enhanced signal fidelity and transmission efficiency. The research provides valuable insights into the impact of CFO on system performance, offering effective synchronization methods and impedance matching strategies. The hybrid OFDM-MIMO multiresonator system presented in this paper stands as a significant step forward in addressing critical challenges in wireless communication technologies.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

References

[1] Sameer Babu TP, Ameer PM, David Koilpillai R. Synchronization techniques for underwater acoustic communications. International Journal of Communication Systems. 2023; 36(15):e5563.

[2] Pourtahmasi Roshandeh K, Mohammadkarimi M, Ardakani M. Joint method of moments (JMoM) and successive moment cancellation (SMC) multiuser time synchronization for ZP-OFDM-based waveforms applicable to joint communication and sensing. Sensors. 2023; 23(7):3660.

[3] Sakhnini A, De Bast S, Guenach M, Bourdoux A, Sahli H, Pollin S. Near-field coherent radar sensing using a massive MIMO communication testbed. IEEE Transactions on Wireless Communications. 2022; 21(8):6256-70.

[4] Kojima S, Goto Y, Maruta K, Sugiura S, Ahn CJ. Timing Synchronization Based on Supervised Learning of Spectrogram for OFDM Systems. IEEE Transactions on Cognitive Communications and Networking. 2023.

[5] Paul P, Roy B, Bhattacharjee AK. A novel Block Bi-diagonalization based pre-coding scheme for bit error reduction in mutiple input multiple output-orthogonal frequency division multiplexing. International Journal of Communication Systems. 2023; 36(8):e5469.

[6] Tuninato R, Riviello DG, Garello R, Melis B, Fantini R. A comprehensive study on the synchronization procedure in 5G NR with 3GPP-compliant link-level simulator. EURASIP Journal on Wireless Communications and Networking. 2023; 2023(1):111.

[7] Geetha MN, Mahadevaswamy UB. Crest dwindling and interposing for PAPR reduction in OFDM signal with sustainable spectral efficiency. Wireless Personal Communications. 2022; 125(3):2799-818.

[8] Shi VT, Nhg DR. Channel estimation optimization model in internet of things based on MIMO/OFDM with Deep Extended Kalman Filter. Advances in Engineering and Intelligence Systems. 2022; 1(02).

[9] Wei P, Lu R, Ye G, Xie S, Wang R. Channel synchronization based on deep learning. Transactions

on Emerging Telecommunications Technologies. 2023; 34(1):e4656.

[10] Holtom J, Herschfelt A, Lenz I, Ma O, Yu H, Bliss DW. Wiscanet: a rapid development platform for beyond 5g and 6g radio system prototyping. Signals. 2022; 3(4):682-707.

[11] Arora M, Chawla P. A hybrid optimization-based technique for channel estimation in OFDM system: a parametric approach. Wireless Personal Communications. 2023; 128(4):2571-87.

[12] Cortés JA, Cañete FJ, Díez L. Channel estimation for OFDM-based indoor broadband power line communication systems. Journal of Communications and Networks. 2023; 25(2): 151-166.

[13] Cheng NH, Chen CC, Wang YF, Chen YF. Adaptive carrier frequency offset estimation in interference environments for OFDMA uplink systems. IEEJ Transactions on Electrical and Electronic Engineering. 2023; 18(10):1664-72.

[14] You YH, Jung YA, Lee SH, Hwang I. Complexity-efficient coherent physical cell identity detection method for cellular IoT systems. Mathematics. 2022; 10(16):3024.

[15] Wang F, Cheng Z, Li H, Zhu D. A software and hardware cooperation method for full nyquist rate transmission symbol synchronization at E-band wireless communication. Sensors. 2022; 22(22):8924.

[16] Petroni A, Scarano G, Cusani R, Biagi M. On the effect of channel knowledge in underwater acoustic communications: estimation, prediction and protocol. Electronics. 2023; 12(7):1552.

[17] Ghafoor U, Ali M, Khan HZ, Siddiqui AM, Naeem M. NOMA and future 5G & B5G wireless networks: a paradigm. Journal of Network and Computer Applications. 2022; 204:103413.

[18] Ishibashi K, Hara T, Uchimura S, Iye T, Fujii Y, Murakami T, et al. User-centric design of millimeter wave communications for beyond 5G and 6G. IEICE Transactions on Communications. 2022; 105(10):1117-29.

[19] Zhang X, Chen L, Feng M, Jiang T. Toward reliable non-line-of-sight localization using multipath reflections. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies. 2022; 6(1):1-25.

[20] Singh P, Tiwari S, Budhiraja R. Low-complexity LMMSE receiver design for practical-pulse-shaped MIMO-OTFS systems. IEEE Transactions on Communications. 2022; 70(12):8383-99.

[21] Tyler JH, Fadul MK, Reising DR. Considerations, advances, and challenges associated with the use of specific emitter identification in the security of internet of things deployments: a survey. Information. 2023; 14(9):479.

[22] Hassan ES. Reduced-complexity selective mapping for improving wireless communication in smart irrigation systems. Wireless Personal Communications. 2023; 129(4):2653-67.

[23] Sakhnini A, Bourdoux A, Guenach M, Sahli H, Pollin S. Range-angle coupling compensation in frequency domain interleaved OFDM MIMO systems. In 19th European radar conference (EuRAD) 2022 (pp. 153-6). IEEE.

[24] Adnan Y. NOMA implementation in OFDM-MIMO-VLC network serving 9 user equipments. In 2022 5th international seminar on research of information technology and intelligent systems (ISRITI) 2022 (pp. 130-4). IEEE.

[25] DN PK, Eshwarappa MN. Analysis of PAPR and BER in MIMO OFDM 5G systems with different modulation and transform techniques. In 2nd international conference on mobile networks and wireless communications (ICMNWC) 2022 (pp. 1-5). IEEE.

[26] Nadiger DK, Aravinda K, Akilesh K, Raj G, Harshitha K, Sandeep GS. MIMO-OFDM implementation using VLSI. In international conference on computer communication and informatics (ICCCI) 2022 (pp. 1-5). IEEE.

[27] Nguyen TP, Nguyen H, Khuc B. Performance evaluation of channel estimation methods for 5G NR uplink control channel in the scenario of low signal-to-noise ratios. In international conference on advanced technologies for communications (ATC) 2022 (pp. 18-22). IEEE.

[28] Phan DM, Hao LX, Tien NT, Van Hoan D. A simplified judgment to enhance decoding performance of 5G NR physical uplink control channel format 2 with reed-muller code. In international conference on advanced technologies for communications (ATC) 2022 (pp. 177-81). IEEE.

[29] Toland K, Taiwo P, Cole-Rhodes A. Towards equalization of mixed multi-user OFDM signals over a doubly-dispersive channel. In 57th annual conference on information sciences and systems (CISS) 2023 (pp. 1-5). IEEE.

[30] Zakavi MJ, Nezamalhosseini SA, Chen LR. Multiuser massive MIMO-OFDM for visible light communication systems. IEEE Access. 2023; 11:2259-73.

[31] Bishe F, Koc A, Le-Ngoc T. Intelligent subcarrier allocation in hybrid beamforming multi-user mMIMO-OFDM systems. In 97th vehicular technology conference (VTC2023-Spring) 2023 (pp. 1-5). IEEE.

[32] Feng X, Mohammed EH, Xu C, Hanzo L. Deep learning-based soft iterative-detection of channel-coded compressed sensing-aided multi-dimensional index modulation. IEEE Transactions on Vehicular Technology. 2023; 72(6):7530-44.

[33] Cunha TE, Linnartz JP. OFDM bitloading in distributed MIMO OWC using power-constrained LEDs. IEEE Access. 2023.

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Appendix I

S. No.	Abbreviation	Description
1	AWGN	Additive White Gaussian Noise
2	BB	Beamforming
3	CFO	Carrier Frequency Offset
4	CCDF	Complementary Cumulative Distribution Function
5	CS-MIM	Compressed Sensing-Aided Multi-Dimensional Index Modulation
6	DAPM	Dynamic Audio Power Management
7	DWT	Discrete Wavelet Transform
8	FDMA	Frequency Division Multiple Access
9	FFT	Fast Fourier Transform
10	FPGA	Field Programmable Gate Arrays
11	GA	Genetic Algorithm
12	IFFT	Inverse Fast Fourier Transform
13	ICI	Inter Carrier Interference
14	LED	Light Emitting Diode
15	LS	Least Squares
16	LTE	Long Term Evolution
17	MIMO	Multiple Input Multiple Output
18	MRT	Maximum Ratio Transmission
19	MU	Multiuser
20	MMSE	Minimum Mean Square Error
21	NOMA	Non-Orthogonal Multiple Access
22	NR	New Radio
23	OFDM-MIMO	Orthogonal Frequency-Division Multiplexing-Multiple-Input, Multiple-Output
24	PUCCH	Physical Uplink Control Channel
25	QAM	Quadrature Amplitude Modulation
26	QPSK	Quadrature Phase Shift Keying
27	RF	Radio Frequency
28	SNR	Signal-to-Noise Ratio
29	ZF	Zero Forcing
30	UEs	User Equipment's
31	VLC	Visible Light Communication
32	VSWR	Voltage Standing Wave Ratio