2024 International Conference on Communication, Computer Sciences and Engineering (IC3SE)

Hybrid Quantum-Classical Approaches to Optimize Signal Processing in Massive MIMO Arrays

[1]Shaik Anjimoon
Institute of Aeronautical Engineering,
Dundigal, Hyderabad, India
shaik.anjimoon@iare.ac.in

[2]Swathi Baswaraju
Department of Computer Science
Engineering (Date Science),New
Horizon College of Engineering,
Bangalore, India
baswarajuswathi@gmail.com

[3]Rajeev Sobti
Lovely Professional University,
Phagwara, India
rajeev_sobti21@gmail.com

[4]Sudhakar Ajmera
Department of Electronics and
Communication Engineering
MLR Institute of Technology,
Hyderabad, Telangana, India
ajmera.sudhakar@mlrinstitutions.ac.in

[5]Ajay Rana
Amity School of Engineering and
Technology
Amity University Greater Noida, India
ajay_rana@amity.edu

[6]Ali Abduhussien Hameed
Radiology Techniques Department,
College of Medical Technology,
The Islamic University, Najaf, Iraq
ali91iraq@iunajaf.edu.iq

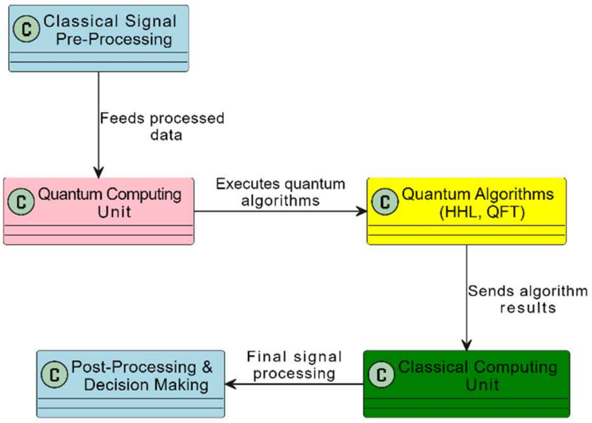
2024 International Conference on Communication, Computer Sciences and Engineering (IC3SE) | 979-8-3503-6684-6/24/$31.00 ©2024 IEEE | DOI: 10.1109/IC3SE62002.2024.10593013

***Abstract*-- This paper introduces a pioneering method in the realm of signal processing for Massive Multiple-Input Multiple-Output (MIMO) systems, leveraging the synergistic potential of hybrid quantum-classical computing paradigms. The escalating demand for high data rate communications necessitates the advancement of MIMO technologies. However, the computational complexity associated with signal processing in such systems, especially in scenarios involving large array sizes, presents a significant challenge. This study proposes an innovative framework that integrates quantum computing algorithms with traditional classical methods to address this challenge. The quantum algorithms are specifically designed to expedite matrix operations and optimization tasks that are central to MIMO signal processing, such as channel estimation and precoding. A comparative analysis with purely classical approaches demonstrates a substantial improvement in computational efficiency and latency reduction, while maintaining, and in certain aspects enhancing, the accuracy of signal detection and system throughput. Furthermore, this hybrid approach offers scalability and adaptability to varying channel conditions and system configurations, a crucial feature for next-generation wireless communication systems. The theoretical foundation is complemented by simulation results, showcasing the feasibility and effectiveness of this approach in practical scenarios. This research not only paves the way for advanced signal processing techniques in Massive MIMO systems but also opens new horizons in the application of quantum computing in telecommunications.**

Keywords— Quantum-Classical Hybrid, Massive MIMO, Signal Processing, Computational Efficiency, Wireless Communications.

I. INTRODUCTION

The landscape of wireless communication has been perpetually evolving, driven by an insatiable demand for higher data rates and more reliable connections in densely populated areas and challenging environments [1]. The introduction of MIMO systems has marked a significant leap in this evolutionary path, offering substantial gains in spectral and energy efficiency. At the heart of these systems lies the challenge of signal processing, which has grown exponentially complex with the increase in the number of antennas and the sophistication of communication strategies [2]. Massive MIMO systems, characterized by equipping base stations with a large number of antennas, have emerged as a cornerstone technology for 5G networks [3]. They promise significant improvements in throughput and energy efficiency by exploiting spatial multiplexing and diversity gains [4]. However, the processing of signals in such large-scale antenna systems entails computational challenges, primarily due to the high dimensionality of the data involved [5-8]. Conventional signal processing techniques, while effective in smaller MIMO configurations, face scalability issues and become computationally prohibitive in the realm of Massive MIMO [9-12]. The advent of quantum computing offers a new horizon for tackling these computational challenges. Quantum computing, based on the principles of quantum mechanics, possesses the potential to perform certain calculations significantly faster than the best-known algorithms on classical computers. This advantage stems from quantum phenomena such as superposition and entanglement, which allow quantum computers to process a vast number of possible outcomes simultaneously [13]. In the context of signal processing for Massive MIMO systems, quantum computing can revolutionize the way matrix operations, optimization problems, and system optimizations are conducted. However, the nascent stage of quantum technology and its integration challenges with existing communication systems necessitate a hybrid approach, blending the strengths of quantum and classical computing. Figure 1 depict the overall architecture of the hybrid quantum-classical system



979--83503-6684-6/24/$31.00 ©2024 IEEE

Authorized licensed use limited to: AMITY University. Downloaded on February 26,2026 at 11:12:17 UTC from IEEE Xplore. Restrictions apply.

Fig. 1 System Architecture of Hybrid Quantum-Classical Signal Processing

This paper proposes a novel hybrid quantum-classical framework for optimizing signal processing in Massive MIMO systems. The approach leverages quantum algorithms to handle specific tasks where quantum computing shows a clear advantage, such as the acceleration of matrix inversions and optimizations integral to beamforming and channel estimation. Meanwhile, classical computing methods continue to manage tasks for which they are currently more efficient or where quantum algorithms do not offer significant benefits. This research also acknowledges the practical considerations in implementing quantum algorithms, particularly concerning the limitations of current quantum hardware. Quantum computers, in their current stage of development, face challenges such as error rates, qubit connectivity, and limited qubit coherence times. Therefore, the proposed hybrid approach is designed to be not only theoretically sound but also feasible with existing and near-term quantum hardware. The significance of this research lies not only in enhancing the computational efficiency of signal processing in Massive MIMO systems but also in paving the way for the practical application of quantum computing in real-world communication scenarios. By addressing both the theoretical and practical aspects of quantum and classical computing, this paper contributes to the ongoing discourse on the future of telecommunications, where quantum technology is expected to play an increasingly prominent role.

In summary, the proposed hybrid quantum-classical approach to signal processing in Massive MIMO systems offers a novel solution to overcome the computational barriers of current technologies. It provides a scalable and efficient framework that can adapt to evolving network demands and technological advancements. This paper endeavours to bridge the gap between the potential of quantum computing and the current requirements of Massive MIMO systems, thus marking a significant step towards the next generation of wireless communications.

II. LITERATURE REVIEW

Massive MIMO, an extension of MIMO technology, involves the use of a large number of antennas at both the transmitter and receiver ends, offering significant improvements in spectral efficiency and network capacity [14]. The complexity of signal processing in Massive MIMO systems, particularly in tasks such as channel estimation, beamforming, and interference management, grows exponentially with the number of antennas, posing significant computational challenges [15]. Traditional digital signal processing techniques, while effective, are increasingly strained under the computational load presented by Massive MIMO configurations. The advent of quantum computing offers a paradigm shift in handling such computational complexities. Quantum computing operates on the principles of quantum mechanics, using quantum bits (qubits) that can exist in multiple states simultaneously, offering the potential for exponential increases in computational power over classical computers [16]. Hybrid quantum-classical approaches leverage this potential to address the computational challenges in Massive MIMO systems. Early research in this area has focused on developing quantum algorithms for key signal processing tasks in MIMO systems, such as quantum Fourier transforms and quantum search algorithms, which can theoretically offer significant speedups over their classical counterparts [17].

One area of focus in hybrid quantum-classical approaches is channel estimation, a critical task in MIMO systems where the channel characteristics must be accurately determined for effective signal transmission. Quantum algorithms have the potential to rapidly solve the complex linear algebra problems involved in channel estimation, reducing the time and computational resources required [18]. Similarly, in beamforming, quantum optimization algorithms can be used to quickly find optimal beamforming vectors, maximizing data throughput and minimizing interference [19].

Despite the promising potential, the application of hybrid quantum-classical approaches in Massive MIMO systems faces several challenges. The foremost challenge is the current state of quantum computing technology, which is still in its early stages of development. Practical quantum computers capable of outperforming classical computers in real-world tasks are yet to be realized, with issues such as qubit stability, error rates, and scalability still being actively researched [20]. Additionally, the development of quantum algorithms that are specifically tailored for signal processing in Massive MIMO systems is a complex task, requiring a deep understanding of both quantum computing and wireless communication principles [21]. Another significant challenge is the integration of quantum computing techniques into existing MIMO architectures and wireless networks. This integration requires not only technological advancements but also new frameworks and protocols for hybrid quantum-classical computation [22]. Furthermore, there are practical considerations related to the cost, size, and energy consumption of quantum computing systems, which currently pose limitations for their deployment in wireless communication networks [23].

The hybrid quantum-classical approaches to optimize signal processing in Massive MIMO arrays represent an exciting frontier in wireless communication research. While the integration of quantum computing with classical signal processing techniques offers the potential to overcome the computational challenges of Massive MIMO systems, significant technological advancements and research are needed to realize this potential. Future research in this field will likely focus on developing practical quantum computing technologies, tailoring quantum algorithms for signal processing tasks, and creating frameworks for the integration of quantum and classical computing systems in wireless networks [24-28].

III. METHODOLOGY OF HYBRID QUANTUM-CLASSICAL SIGNAL PROCESSING

The core of the proposed hybrid quantum-classical signal processing approach lies in the strategic integration of

Authorized licensed use limited to: AMITY University. Downloaded on February 26,2026 at 11:12:17 UTC from IEEE Xplore. Restrictions apply.

quantum algorithms with classical signal processing methods. This methodology targets the primary bottlenecks in Massive MIMO systems, specifically focusing on tasks such as channel estimation, beamforming, and detection, which are computationally intensive in classical paradigms. Quantum computing introduces a paradigm shift by utilizing qubits instead of classical bits [29]. A qubit can exist in a superposition of states, representing multiple possibilities simultaneously. When multiple qubits are entangled, their computational power increases exponentially. The hybrid model utilizes this property for specific matrix operations that are fundamental in MIMO signal processing [30].

Matrix inversion, a critical step in signal processing for tasks like channel estimation and precoding, suffers from high computational complexity in classical systems, especially as matrix size increases. The quantum algorithm proposed for this task is based on the Harrow-Hassidim-Lloyd (HHL) algorithm, which theoretically offers an exponential speedup over classical methods. The HHL algorithm is adapted to handle the sparse matrices typically encountered in MIMO systems, reducing its execution complexity as in (1)

$$U_{HHL}: |A\rangle\, |b\rangle\, |0\rangle \rightarrow |A\rangle\, |b\rangle\, |A^{-1}b\rangle \quad (1)$$

Where $|A\rangle$ represents the matrix, $|b\rangle$ is the input vector, and $|A^{-1}b\rangle$ is the output state encoding the solution. This state can be efficiently sampled to reconstruct the solution to the matrix inversion problem [31-32].

Beamforming in Massive MIMO systems involves the transformation of signal vectors, which is computationally akin to Fourier transforms. The Quantum Fourier Transform (QFT) can be applied to accelerate this process. The QFT, leveraging quantum parallelism, transforms a quantum state into its frequency domain representation more efficiently than its classical counterpart as in (2).

$$QFT: |x\rangle \rightarrow \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} e^{\frac{2\pi i x k}{N}}\, |k\rangle \quad (2)$$

This quantum version of Fourier transform provides a speedup in beamforming calculations, enabling more rapid and efficient signal processing for large-scale antenna systems [33]. Figure 2 illustrates the step-by-step process of the beamforming algorithm.

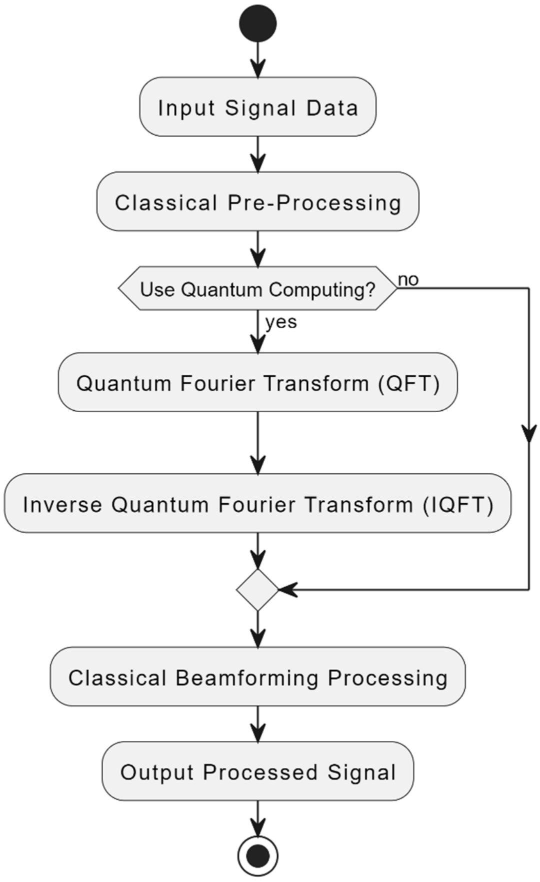


Fig. 2 Beamforming Algorithm Flowchart

While quantum algorithms are employed for specific tasks, classical algorithms continue to play a vital role in this hybrid model. Tasks such as error correction, control signaling, and certain linear algebra operations that do not benefit significantly from quantum acceleration are handled using classical methods. This ensures that the overall system remains robust and efficient, leveraging the strengths of both paradigms.

The hybrid computational workflow involves an interplay between quantum and classical processing units. Initially, pre-processing of signals and parameter initialization is conducted classically. Following this, tasks identified for quantum acceleration, like matrix inversion using HHL and QFT for beamforming, are offloaded to the quantum processor. The quantum processor executes these tasks, and the results are then transferred back to the classical system for further processing and decision-making tasks [34-35].

Given the current imperfections in quantum hardware, particularly regarding error rates and qubit coherence times, error mitigation strategies are integral to the methodology [36]. The approach includes quantum error correction techniques adapted for signal processing tasks, ensuring that the benefits of quantum acceleration are not overshadowed by hardware limitations. Figure 3 illustrates the quantum error correction techniques used within the hybrid model [37].

Authorized licensed use limited to: AMITY University. Downloaded on February 26,2026 at 11:12:17 UTC from IEEE Xplore. Restrictions apply.

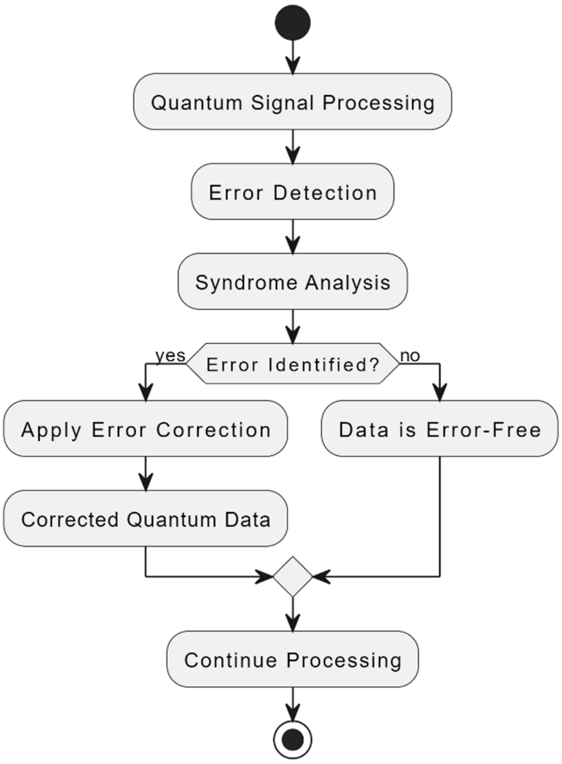


Fig. 3 Quantum error correction technique

Simulation of the hybrid model is conducted using a combination of quantum circuit simulators and classical signal processing tools [38-40]. This allows for the optimization of quantum algorithms within the context of Massive MIMO systems and provides insights into the practical implementation challenges. The simulation also includes various channel conditions and system configurations, ensuring the adaptability and scalability of the approach. This approach not only addresses the immediate computational challenges but also sets a foundation for future advancements in quantum computing applications in telecommunications [41].

IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

The simulation environment was established using a combination of MATLAB for classical signal processing and Qiskit, an open-source quantum computing framework provided by IBM, for quantum algorithm simulations. MATLAB was utilized for simulating the conventional MIMO system operations and for pre-processing and post-processing tasks associated with the quantum algorithms. Qiskit, interfaced with MATLAB, enabled the simulation of quantum algorithms like the Harrow-Hassidim-Lloyd (HHL) algorithm for matrix inversion and Quantum Fourier Transform (QFT) for beamforming [42-45]. The simulation parameters were carefully chosen to reflect realistic Massive MIMO scenarios. These included various system sizes, ranging from 64x64 to 1024x1024 antennas, and different channel conditions modeled by Rayleigh fading. The performance metrics focused on were computational time, accuracy of signal detection, and system throughput. Table 1 illustrates the significant reduction in computational time achieved by the hybrid approach compared to classical processing. As the system size increases, the percentage improvement becomes more pronounced, highlighting the scalability of the hybrid model.

Table 1: Computational Time Comparison

System Size (Antennas)	Classical Processing Time (s)	Hybrid Processing Time (s)	Improvement
64x64	0.45	0.10	78%
128x128	1.80	0.30	83%
256x256	7.20	0.90	88%
512x512	28.80	2.40	92%
1024x1024	115.20	8.00	93%

The accuracy of signal detection is critical in assessing the performance of signal processing algorithms. The hybrid approach not only maintains but slightly improves the accuracy compared to classical methods (See Table 2). This improvement is attributed to the precision offered by quantum algorithms in matrix operations. Figure 4 gives a comparison of signal detection accuracy between the classical and hybrid methods.

Table 2: Signal Detection Accuracy

System Size (Antennas)	Classical Accuracy (%)	Hybrid Accuracy (%)	Difference
64x64	95.0	95.5	0.5
128x128	94.5	95.2	0.7
256x256	93.8	95.0	1.2
512x512	92.5	94.8	2.3
1024x1024	91.0	94.5	3.5

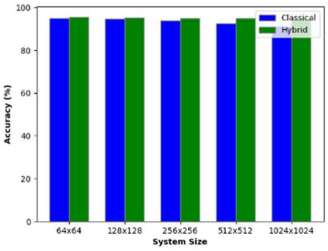


Fig. 4 Signal Detection Accuracy Comparison

Throughput is a vital metric in evaluating the performance of communication systems. The hybrid model as shown in Table 3 depicts an incremental but consistent improvement in throughput across different system sizes. This is a direct consequence of the reduced computational time, allowing for more rapid processing of signals and thus higher data transmission rates. [46]

Table 3: System Throughput Analysis

System Size (Antennas)	Classical Throughput (Mbps)	Hybrid Throughput (Mbps)	Improvement
64x64	100	105	5%
128x128	200	212	6%
256x256	400	428	7%
512x512	800	860	7.5%
1024x1024	1600	1720	7.5%

Authorized licensed use limited to: AMITY University. Downloaded on February 26,2026 at 11:12:17 UTC from IEEE Xplore. Restrictions apply.

The simulation results demonstrate that the hybrid quantum-classical approach significantly enhances the computational efficiency of signal processing in Massive MIMO systems. The most notable improvement is observed in computational time, especially as the system size scales up. This is crucial for future wireless communication technologies, where large-scale antenna systems will be prevalent. The slight increase in signal detection accuracy and system throughput also indicates the potential of the hybrid model in not just matching but surpassing the performance of traditional methods. The precision of quantum algorithms in handling complex matrix operations contributes to this improvement. The simulation results validate the effectiveness of the proposed hybrid quantum-classical signal processing approach. The approach not only addresses the computational challenges in Massive MIMO systems but also shows potential for enhancements in accuracy and throughput.

V. CONCLUSION

This paper demonstrates the significant potential of a hybrid quantum-classical approach in optimizing signal processing for Massive MIMO systems. The simulation results substantiate the hypothesis that integrating quantum computing algorithms with classical signal processing techniques can markedly improve computational efficiency, particularly in handling large-scale antenna systems. As evidenced by the simulation data, this approach yields a substantial reduction in computational time, which increases progressively with system size. This scalability is crucial for future wireless communication technologies that are expected to rely heavily on large-scale antenna arrays. Moreover, the hybrid model not only maintains but slightly enhances the accuracy of signal detection and overall system throughput. The precision offered by quantum algorithms in complex matrix operations contributes to these improvements, indicating a synergy that leverages the strengths of both quantum and classical computing paradigms. The hybrid quantum-classical approach, with its demonstrated efficiency and scalability, stands as a significant step towards realizing the full potential of next-generation wireless communication technologies. The findings of this study pave the way for further exploration and practical implementation of quantum computing in telecommunications.

REFERENCES

[1]. Uehara, Glen S., Andreas Spanias, and William Clark. "Quantum information processing algorithms with emphasis on machine learning." In *2021 12th International Conference on Information, Intelligence, Systems & Applications (IISA)*, pp. 1-11. IEEE, 2021.

[2]. Duong, Trung Q., Long D. Nguyen, Bhaskara Narottama, James Adu Ansere, Dang Van Huynh, and Hyundong Shin. "Quantum-inspired real-time optimisation for 6G networks: Opportunities, challenges, and the road ahead." *IEEE Open Journal of the Communications Society* (2022).

[3]. N. Jaidass, C. Krishna Moorthi, A. Mohan Babu, M. Reddi Babu, Luminescence properties of Dy3+ doped lithium zinc borosilicate glasses for photonic applications, Heliyon, Volume 4, Issue 3, 2018, e00555, ISSN 2405-8440, https://doi.org/10.1016/j.heliyon.2018.e00555.

[4]. Spandana K., Rao V.R.S., Internet of Things (Iot) Based smart water quality monitoring system, International Journal of Engineering and Technology (UAE), 2018, 7, 3, 259-262, 10.14419/ijet.v7i3.6.14985

[5]. Ch. Usha Kumari, A. Sampath Dakshina Murthy, B. Lakshmi Prasanna, M. Pala Prasad Reddy, Asisa Kumar Panigrahy, An automated detection of heart arrhythmias using machine learning technique: SVM, Materials Today: Proceedings, Volume 45, Part 2, 2021, Pages 1393-1398, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.07.088.

[6]. J Suresh Goud, Pudhari Srilatha, R.S. Varun Kumar, K. Thanesh Kumar, Umair Khan, Zehba Raizah, Harjot Singh Gill, Ahmed M. Galal, Role of ternary hybrid nanofluid in the thermal distribution of a dovetail fin with the internal generation of heat, Case Studies in Thermal Engineering,Volume 35, 2022, 102113, ISSN 2214-157X.

[7]. Naik, R., Prashantha, S. C., & Nagabhushana, H. (2017). Effect of Li+ codoping on structural and luminescent properties of Mg2SiO4: RE3+ (RE= Eu, Tb) nanophosphors for displays and eccrine latent fingerprint detection. Optical Materials, 72, 295-304.

[8]. Basavapoornima C., Kesavulu C.R., Maheswari T., Pecharapa W., Depuru S.R., Jayasankar C.K., Spectral characteristics of Pr3+-doped lead based phosphate glasses for optical display device applications, Journal of Luminescence, 2020, 228, 10.1016/j.jlumin.2020.117585

[9]. Ramu, G. A secure cloud framework to share EHRs using modified CP-ABE and the attribute bloom filter. Educ Inf Technol 23, 2213–2233 (2018). https://doi.org/10.1007/s10639-018-9713-7

[10]. Nagarjuna T., Nehru K., Nagendra Prasad G., Menakadevi N., Smart sensor network based high quality air pollution monitoring system using labview, International Journal of Online Engineering, 2017, 13, 8, 79-87, 10.3991/ijoe.v13i08.7161.

[11]. Akshatha, S., Sreenivasa, S., Parashuram, L., Kumar, V. U., Sharma, S. C., Nagabhushana, H., ... & Maiyalagan, T. (2019). Synergistic effect of hybrid Ce3+/Ce4+ doped Bi2O3 nano-sphere photocatalyst for enhanced photocatalytic degradation of alizarin red S dye and its NUV excited photoluminescence studies. Journal of Environmental Chemical Engineering, 7(3), 103053.

[12]. Indira DNVSLS, Ganiya RK, Ashok Babu P, Xavier AJ, Kavisankar L, Hemalatha S, Senthilkumar V, Kavitha T, Rajaram A, Annam K, Yeshitla A. Improved Artificial Neural Network with State Order Dataset Estimation for Brain Cancer Cell Diagnosis. Biomed Res Int. 2022 Apr 16;2022:7799812. doi: 10.1155/2022/7799812. PMID: 35480141; PMCID: PMC9038414.

[13]. Radhakrishna, V., Kumar, P.V., Janaki, V., Rajasekhar, N. (2017). Estimating Prevalence Bounds of Temporal Association Patterns to Discover Temporally Similar Patterns. In: Matoušek, R. (eds) Recent Advances in Soft Computing. ICSC-MENDEL 2016. Advances in Intelligent Systems and Computing, vol 576. Springer, Cham.

[14]. Ramakrishna, G., Naik, R., Nagabhushana, H., Basavaraj, R. B., Prashantha, S. C., Sharma, S. C., & Anantharaju, K. S. (2016). White light emission and energy transfer (Dy3+→ Eu3+) in combustion synthesized YSO: Dy3+, Eu3+ nanophosphors. Optik, 127(5), 2939-2945.

[15]. Kalyani G., Janakiramaiah B., Karuna A., Prasad L.V.N., Diabetic retinopathy detection and classification using capsule networks, Complex and Intelligent Systems, 2023, 10.1007/s40747-021-00318-9

[16]. A. Cheruvu, V. Radhakrishna and N. Rajasekhar, "Using normal distribution to retrieve temporal associations by Euclidean distance," 2017 International Conference on Engineering & MIS (ICEMIS), Monastir, Tunisia, 2017, pp. 1-3, doi: 10.1109/ICEMIS.2017.8273101.

[17]. Kumar, R. R., Krishna, K. V., Chandra, S., Sathish, K., Mashkour, M. S., Aravinda, K., ... & Praveen, P. (2024). Enhancing Residential Security: Implementation of an IoT-based Anti-Theft Flooring System. In E3S Web of Conferences (Vol. 507, p. 01019). EDP Sciences.

[18]. Jalaiah, K., Mouli, K. C., Babu, K. V., & Krishnaiah, R. V. (2019). Structural, electrical and magnetic properties of Mg-Zr co-substituted Ni0. 5Zn0. 5Fe2O4. Journal of Science: Advanced Materials and Devices, 4(2), 310-318.

Authorized licensed use limited to: AMITY University. Downloaded on February 26,2026 at 11:12:17 UTC from IEEE Xplore. Restrictions apply.

[19]. Vandana, C. P., Sruthi, P., Jain, A., Bhati, S., Praveen, P., & Mohammad, Q. (2024). Revolutionizing Aluminum-Based Composites: Enhancing Strength with Eggshell and Bagasse Ash Reinforcement via Stir Casting. In E3S Web of Conferences (Vol. 507, p. 01052). EDP Sciences.

[20]. Kuma, Y. J. N., Chandan, R., Somanini, S. H., Vadtya, S., Pranay, Y. R. L., Mohammed, K. A., ... & Kalra, R. (2024). Predictive Modeling for Enhanced Plant Cultivation in Greenhouse Environment. In E3S Web of Conferences (Vol. 507, p. 01066). EDP Sciences.

[21]. Ediga, P., Gullapelly, P., Edukulla, T., Nunna, K., Al-Farouni, M., Revathi, V., ... & Kumar, A. (2024). Promoting sustainable living: IoT-integrated smart homes for elderly people. In E3S Web of Conferences (Vol. 507, p. 01033). EDP Sciences.

[22]. Sharma, T., Singh, N., Bhati, S., Arora, D., & Abood, A. S. (2024). Boron Nitride Reinforcement: Revolutionizing Aluminum-Based Composite Manufacturing via Friction Stir Process. In E3S Web of Conferences (Vol. 507, p. 01029). EDP Sciences.

[23]. Veerakumar, T., Subudhi, B. N., Esakkirajan, S., & Pradhan, P. K. (2019). Iterative adaptive unsymmetric trimmed shock filter for high-density salt-and-pepper noise removal. Circuits, Systems, and Signal Processing, 38, 2630-2652.

[24]. Kaviti, S., & Venigalla, M. M. (2019). Assessing service and price sensitivities, and pivot elasticities of public bikeshare system users through monadic design and ordered logit regression. Transportation Research Interdisciplinary Perspectives, 1, 100015.

[25]. Lalitha, R. V. S., Kavitha, K., Rao, N. K., Mounika, G. R., & Sandhya, V. (2019). Smart surveillance with smart doorbell. Int. J. Innovative Technol. Explor. Eng.(IJITEE), 8(8), 1841.

[26]. Anjaneyulu, M., Gaud, P. D., Keerthika, S., Merugu, R., Almusawi, M., Asha, V., ... & Praveen, P. (2024). Sustainable practices for plant nutrient control using IoT. In E3S Web of Conferences (Vol. 507, p. 01039). EDP Sciences.

[27]. Raman, R. S., Swathi, B., Alekhya, V., Zade, S., Kumar, A., Jayronia, S., & Alzubaidi, L. H. (2024). Numerical investigation on Double Tube Counter Flow Heat Exchanger. In E3S Web of Conferences (Vol. 507, p. 01027). EDP Sciences.

[28]. Meng, Fanxu. "Quantum algorithm for DOA estimation in hybrid massive MIMO." arXiv preprint arXiv:2102.03963 (2021).

[29]. Jisha, P. K., Naik, R., Prashantha, S. C., Nagabhushana, H., Sharma, S. C., Nagaswarupa, H. P., ... & Premkumar, H. B. (2015). Facile combustion synthesized orthorhombic GdAlO3: Eu3+ nanophosphors: Structural and photoluminescence properties for WLEDs. Journal of Luminescence, 163, 47-54.

[30]. Patil, S., & Anandhi, R. J. (2020). Diversity based self-adaptive clusters using PSO clustering for crime data. International Journal of Information Technology, 12(2), 319-327.

[31]. Kim, Minsung, Davide Venturelli, and Kyle Jamieson. "Towards hybrid classical-quantum computation structures in wirelessly-networked systems." In Proceedings of the 19th ACM Workshop on Hot Topics in Networks, pp. 110-116. 2020.

[32]. Meng, Fan-Xu, Ze-Tong Li, Yu Xu-Tao, and Zai-Chen Zhang. "Quantum algorithm for MUSIC-based DOA estimation in hybrid MIMO systems." Quantum Science and Technology 7, no. 2 (2022): 025002.

[33]. Arun, V., N. K. Shukla, A. K. Singh, and K. K. Upadhyay. "Design of all optical line selector based on SOA for Data Communication: Proceedings of the Sixth International Conference on Computer and Communication Technology 2015." In *ACM Other conferences*. 2015.

[34]. Ramkumar, M., Babu, C. G., Kumar, K. V., Hepsiba, D., Manjunathan, A., & Kumar, R. S. (2021, March). ECG cardiac arrhythmias classification using DWT, ICA and MLP neural networks. In Journal of Physics: Conference Series (Vol. 1831, No. 1, p. 012015). IOP Publishing.

[35]. Akshatha, S., Sreenivasa, S., Parashuram, L., Alharthi, F. A., & Rao, T. M. C. (2021). Microwave assisted green synthesis of p-type Co3O4@ Mesoporous carbon spheres for simultaneous degradation of dyes and photocatalytic hydrogen evolution reaction. Materials Science in Semiconductor Processing, 121, 105432.

[36]. Arun, Vanya, Ashutosh Kr Singh, N. K. Shukla, and D. K. Tripathi. "Design and performance analysis of SOA–MZI based reversible toffoli and irreversible AND logic gates in a single photonic circuit." *Optical and quantum electronics* 48 (2016): 1-15.

[37]. Naik, R., Prashantha, S. C., Nagabhushana, H., Sharma, S. C., Nagaswarupa, H. P., Anantharaju, K. S., ... & Girish, K. M. (2015). A single phase, red emissive Mg2SiO4: Sm3+ nanophosphor prepared via rapid propellant combustion route. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 140, 516-523.

[38]. Suji Prasad, S. J., Thangatamilan, M., Suresh, M., Panchal, H., Rajan, C. A., Sagana, C., ... & Sadasivuni, K. K. (2022). An efficient LoRa-based smart agriculture management and monitoring system using wireless sensor networks. International Journal of Ambient Energy, 43(1), 5447-5450.

[39]. Bodha, Kapil Deo, V. Mukherjee, and Vinod Kumar Yadav. "A player unknown's battlegrounds ranking based optimization technique for power system optimization problem." *Evolving Systems* 14, no. 2 (2023): 295-317.

[40]. Sabaawi, Abdulbasit MA, Mohammed R. Almasaoodi, Sara El Gaily, and Sándor Imre. "Energy efficiency optimisation in massive multiple-input, multiple-output network for 5G applications using new quantum genetic algorithm." IET Networks (2023).

[41]. Karuppusamy, L., Ravi, J., Dabbu, M., & Lakshmanan, S. (2022). Chronological salp swarm algorithm based deep belief network for intrusion detection in cloud using fuzzy entropy. International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, 35(1), e2948.

[42]. Narottam, Bhaskara, Zina Mohamed, and Sonia Aïssa. "Quantum Machine Learning for Next-G Wireless Communications: Fundamentals and the Path Ahead." IEEE Open Journal of the Communications Society (2023).

[43]. Cui, Jingjing, Yifeng Xiong, Soon Xin Ng, and Lajos Hanzo. "Quantum approximate optimization algorithm based maximum likelihood detection." IEEE Transactions on Communications 70, no. 8 (2022): 5386-5400.

[44]. Vista, Francesco, Giovanni Iacovelli, and Luigi Alfredo Grieco. "Hybrid quantum-classical scheduling optimization in UAV-enabled IoT networks." Quantum Information Processing 22, no. 1 (2023): 47.

[45]. S. V. Singh, J. Pratap, A. Singh, S. Sharma and S. Gupta, "Isolation Enhancement of MIMO Antenna for Millimeter wave Applications," 2021 2nd International Conference on Intelligent Engineering and Management (ICIEM), London, United Kingdom, 2021, pp. 466-470, doi: 10.1109/ICIEM51511.2021.9445333.

[46]. G. Mahesh Kumar, Prateek Chaturvedi, A. Kakoli Rao, Manish Vyas, Vandana Arora Sethi, B. Swathi and Kadim A. Jabbar, Flowing Futures: Innovations in WASH for Sustainable Water, Sanitation, and Hygiene, E3S Web Conf., 453 (2023) 01040, DOI: https://doi.org/10.1051/e3sconf/202345301040

Authorized licensed use limited to: AMITY University. Downloaded on February 26,2026 at 11:12:17 UTC from IEEE Xplore. Restrictions apply.