AI-Based Dynamic Spectrum Allocation for Hybrid Satellite-5G Networks

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Abstract- The integration of satellite communication systems with 5G networks presents an opportunity to extend high-speed internet access to remote and underserved areas. However, efficient spectrum management remains a critical challenge in this hybrid satellite-5G environment due to the vast and dynamic nature of the radio frequency spectrum. This paper proposes an AI-based Dynamic Spectrum Allocation (DSA) framework to optimize spectrum utilization in hybrid satellite-5G networks. The proposed system leverages machine learning algorithms, particularly reinforcement learning (RL), to predict and allocate spectrum resources dynamically based on real-time demand, interference levels, and network conditions. In this framework, a hybrid network management system uses AI to continually monitor spectrum usage across both satellite and terrestrial 5G networks, adjusting allocations in response to fluctuating user traffic and environmental conditions. The reinforcement learning model is trained to make intelligent decisions on spectrum sharing, balancing the trade-off between high-throughput communication and the avoidance of interference. This paper also explores the implementation of deep learning techniques to predict spectrum demand and optimize the handover between satellite and 5G base stations. The proposed AI-based DSA approach not only ensures efficient spectrum utilization but also minimizes latency, reduces interference, and enhances the overall quality of service in hybrid networks. Simulation results demonstrate the potential of the AI-driven framework to outperform traditional static allocation methods, offering significant improvements in throughput, user experience, and network efficiency.

Indexed Terms- AI-driven Spectrum Management, Dynamic Spectrum Allocation, Hybrid Satellite-5G Networks, Machine Learning for Spectrum Optimization and 5G-Satellite Integration.

I. INTRODUCTION

In recent years, the demand for mobile communication has been increasing at an unprecedented rate, driven by the proliferation of smartphones, IoT devices, and the upcoming proliferation of 5G technologies. Traditional terrestrial cellular networks, such as Long-Term Evolution (LTE) and 5G New Radio (NR), have faced challenges in managing the explosive growth in traffic volume, especially in remote, rural, and underserved areas where infrastructure investment is costly and impractical [1-4].

The introduction of satellite communications has emerged as a promising solution to extend network coverage and improve connectivity, especially in remote and rural areas. Hybrid satellite-5G networks, which combine the capabilities of Low Earth Orbit (LEO) satellites with terrestrial 5G infrastructure, hold the potential to deliver ubiquitous and high-quality connectivity, bridging the digital divide. However, one of the major technical hurdles to overcome in such networks is the efficient allocation of spectrum resources [5-7].

Spectrum allocation is critical for optimizing the available bandwidth in a network, ensuring that multiple users and communication channels do not interfere with one another. Traditionally, spectrum allocation has been static and manually controlled, leading to inefficient utilization of the spectrum, particularly in networks with dynamic demands [8-10]. The introduction of Artificial Intelligence (AI) offers a transformative approach to managing this spectrum allocation dynamically, adapting in real-time to changing conditions, traffic demands, and environmental factors [11-13].

The convergence of satellite and terrestrial networks is a natural progression in the evolution of global communication systems. While traditional cellular networks, such as 4G and 5G, provide high-speed connectivity, they are heavily reliant on ground-based infrastructure that may be insufficient for global coverage. Satellites, particularly LEO satellites, provide an alternative for ensuring global coverage with minimal infrastructure [14-17].

Hybrid satellite-5G networks combine the low latency and high data throughput of 5G with the wide-area coverage of satellites. However, integrating these two disparate technologies presents significant challenges [18-20]. These challenges include interference management, spectrum sharing, and seamless handovers between terrestrial and satellite communication systems. The dynamic nature of traffic demands, user mobility, and network conditions make static spectrum allocation inefficient, leading to underutilization of resources in some regions and congestion in others [21-24].

Dynamic Spectrum Allocation (DSA) aims to address these issues by adapting spectrum usage based on real-time conditions. DSA enables more efficient use of the spectrum by dynamically allocating resources to different communication channels, based on factors such as traffic demand, network load, and interference levels [25-27]. In hybrid satellite-5G networks, this dynamic allocation must account for the distinct characteristics of both satellite and terrestrial networks, as well as the varying conditions of the air interface and the radio environment [28-30].

AI and Machine Learning (ML) have been widely recognized as powerful tools to address the challenges of DSA. AI models can analyze large volumes of data in real time, predict traffic patterns, and optimize spectrum allocation to maximize throughput while minimizing interference [31-33]. Moreover, AI-based algorithms can learn from historical network behavior to continuously improve spectrum management strategies over time [34-36].

Recent research has explored the use of AI in hybrid satellite-5G networks for applications like interference management, resource optimization, and predictive analytics [37-39]. However, there remains a significant gap in the application of AI for dynamic spectrum allocation in these hybrid environments, especially with respect to integration and interoperability between satellite and terrestrial components [40-42].

This paper presents an AI-based approach to dynamic spectrum allocation (DSA) for hybrid satellite-5G networks. The objective is to demonstrate how AI can be employed to enhance spectrum efficiency, reduce interference, and optimize network performance in a rapidly evolving communication environment [43-45].

The primary objective of this research is to design and develop an AI-based dynamic spectrum allocation (DSA) framework for hybrid satellite-5G networks. The specific objectives of this work are as follows:

- To explore the concept of dynamic spectrum allocation (DSA) in hybrid satellite-5G networks: Investigate the unique challenges and requirements of hybrid satellite-5G systems in terms of spectrum management. Understand how traditional DSA techniques can be adapted to account for both satellite and terrestrial resources.
- To develop an AI-based model for real-time spectrum allocation: Create a machine learning-driven algorithm capable of dynamically allocating spectrum in hybrid satellite-5G networks. The model should be capable of processing real-time traffic data, interference levels, and network conditions to make decisions that optimize spectrum efficiency.
- To evaluate the performance of AI-based DSA in various network scenarios: Conduct simulations to assess the performance of the AI-based spectrum allocation model under various network conditions, including high traffic loads, interference scenarios, and mobility patterns. Compare the results with traditional static allocation methods.
- To enhance network throughput, reduce interference, and improve overall network efficiency: The proposed model should aim to improve network throughput by maximizing the use of available spectrum, reducing interference

between satellite and terrestrial systems, and ensuring fairness among users.

- To demonstrate the scalability and robustness of the AI-based DSA system: Test the scalability of the proposed AI model by simulating large-scale hybrid satellite-5G networks with multiple users, diverse traffic patterns, and varying levels of satellite and terrestrial network integration.
- To investigate the integration of the AI-based DSA with existing 5G and satellite systems: Explore the potential for integrating the AI-based dynamic spectrum allocation solution with current hybrid satellite-5G infrastructures, ensuring interoperability and seamless operation across different network layers.

II. LITERATURE SURVEY

In recent years, the development of 5G networks has brought about a paradigm shift in wireless communication, promising higher data rates, low latency, and massive device connectivity. However, achieving these promises requires the efficient management of radio spectrum resources [46-48]. One promising approach to addressing the limitations of terrestrial networks is integrating satellite communication into the 5G framework, resulting in hybrid satellite-5G networks. The dynamic allocation of spectrum resources, which is crucial for ensuring efficient data transmission and improving Quality of Service (QoS) [49-51], has become a focal point in this hybrid ecosystem. Artificial Intelligence (AI) techniques, such as machine learning (ML), reinforcement learning (RL), and deep learning (DL), have shown great potential in enhancing the spectrum management process by adapting to varying network conditions [52-54].

2.1. Overview of Hybrid Satellite-5G Networks

Hybrid satellite-5G networks combine the strengths of satellite communications (wide coverage and global reach) with the high data throughput and low latency capabilities of 5G terrestrial networks. The integration of these two communication paradigms allows for ubiquitous connectivity, particularly in rural, remote, and underserved areas where traditional 5G coverage might be limited [55-57]. However, the efficient management of the shared spectrum resource in such a hybrid network presents several challenges due to the differences in propagation characteristics, link dynamics, and the need for dynamic spectrum allocation (DSA) to optimize the system performance [58-60].

In this context, DSA is crucial for maximizing spectrum utilization, minimizing interference, and ensuring seamless handovers between satellite and terrestrial networks. DSA can be enhanced through the application of AI technologies, which can predict network conditions and adjust spectrum allocation in real-time [61-63].

2.2. AI in Spectrum Allocation

The application of AI in spectrum allocation is relatively recent but growing rapidly, as it can address several key challenges in dynamic resource management [64-66]. Traditional methods of spectrum management are based on static rules and models that do not adapt well to the dynamic nature of the radio environment. AI-based solutions, on the other hand, provide the flexibility to continuously adapt and optimize spectrum allocation decisions based on real-time data from the network [67-70].

2.3. Machine Learning for Spectrum Allocation

Machine learning (ML) algorithms, including supervised and unsupervised learning techniques, have been applied to predict network traffic patterns, estimate spectrum demand, and allocate spectrum accordingly. A key advantage of ML techniques is their ability to handle large datasets and learn from the network environment, thereby providing better prediction accuracy and more efficient spectrum allocation decisions. For example, a study by [71-73] demonstrates how ML algorithms such as decision trees and support vector machines can be used to predict the spectrum requirements of a given area in a hybrid satellite-5G network, optimizing frequency reuse and reducing interference.

Moreover, [74-76] proposed an ML-based framework for hybrid networks that uses historical data to predict spectrum demand trends, enabling dynamic adjustments to the spectrum allocation process. These ML models help identify potential spectrum shortages or surpluses in real-time and dynamically allocate resources between terrestrial and satellite networks to meet the demand.

2.4. Reinforcement Learning for Dynamic Spectrum Management

Reinforcement learning (RL) has been gaining attention in the context of dynamic spectrum allocation for hybrid satellite-5G networks due to its ability to make optimal decisions through interaction with the environment. In RL, the system learns through trial and error by receiving feedback from the environment, which makes it particularly useful for dynamic systems like hybrid networks, where conditions change frequently [77-79].

A notable study [80-82] utilized deep Q-learning, an RL technique, for spectrum allocation in a satellite-terrestrial hybrid network. The proposed system learned the best spectrum allocation strategy based on network conditions, such as interference levels and traffic demands, improving the overall network performance. The research demonstrated that RL-based models outperformed traditional algorithms in terms of spectrum utilization efficiency and reduced interference.

2.5. Deep Learning for Advanced Spectrum Allocation

Deep learning (DL), a subset of machine learning involving deep neural networks, has been applied to more complex spectrum allocation problems in hybrid satellite-5G networks. DL models are capable of processing large amounts of data and discovering intricate patterns that simpler models may not capture. A study by [83] developed a deep learning model using convolutional neural networks (CNNs) for spectrum prediction and allocation, achieving significant improvements in bandwidth efficiency and QoS in hybrid networks [84-86].

Furthermore, [87-90] explored the use of recurrent neural networks (RNNs) for time-series prediction in spectrum allocation, which is particularly useful for managing the time-varying nature of spectrum demand in a hybrid network. Their model was able to predict short-term spectrum demand with high accuracy, allowing for real-time adjustments to the network's spectrum allocation strategy.

2.6. Challenges in AI-Based Spectrum Allocation

Despite the potential benefits, there are several challenges associated with implementing AI in dynamic spectrum allocation for hybrid satellite-5G networks:

Data Quality and Availability: AI models require large amounts of data for training, and in the case of hybrid networks, obtaining high-quality, labeled data can be challenging due to the complex interplay between terrestrial and satellite links [91].

Scalability: The application of AI models to large-scale networks with millions of devices and varying network conditions can pose scalability issues. Ensuring that AI algorithms can handle the scale of real-world hybrid networks while maintaining high performance is a key challenge [92].

Real-Time Operation: AI models need to make decisions in real-time, which requires low-latency processing and high computational power. Ensuring that AI-based models can operate efficiently under stringent time constraints is crucial for practical deployment [93].

Interoperability: Satellite and 5G networks often use different communication protocols and technologies, which can create challenges when trying to implement a unified AI-based spectrum management system [94].

III. PROPOSED METHODOLOGY

The proposed methodology integrates AI techniques into the spectrum management process, involving several key steps:

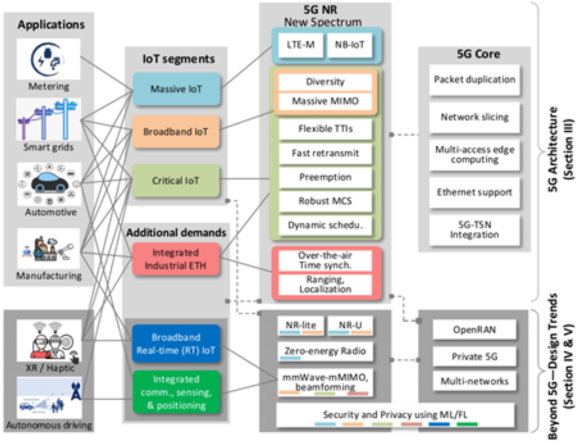

Figure 1. Proposed Architecture

3.1. Data Collection and Feature Engineering

The first step in implementing AI-based DSA is to collect data from both satellite and terrestrial network components [95]. Key data points include:

- Channel Conditions: Signal strength, interference levels, and noise measurements from satellite and terrestrial nodes.
- Traffic Load: Data usage patterns, peak demand times, and user density.

Mobility Patterns: User movement and satellite beam adjustments.

- Spectrum Usage: Current spectrum allocation across different bands and regions.

Feature engineering techniques will be employed to derive relevant characteristics from this data, such as time-of-day variations, geographical location, and propagation characteristics.

3.2. AI Model Training and Spectrum Prediction

Once the data is preprocessed, an AI model is trained to predict spectrum demand based on historical and real-time data. Several machine learning algorithms could be applied, including [96-98]:

Reinforcement Learning (RL): RL models are suitable for making decisions in real-time environments where actions (spectrum allocations) have long-term consequences. The agent learns through trial and error, adapting its behavior to maximize long-term rewards, such as QoS improvements or spectrum efficiency.

Deep Learning (DL): Deep neural networks can model complex relationships in large datasets, making them useful for predicting traffic patterns, interference, and spectrum demand.

Supervised Learning: Classification or regression models, such as decision trees or support vector machines (SVM), can predict traffic types or classify regions based on spectrum needs.

The training process involves using labeled data (e.g., known spectrum usage and network conditions) to learn the optimal allocation strategies.

3.3. Dynamic Spectrum Allocation and Decision Making

Once the model is trained, it can be deployed in the network to make real-time spectrum allocation decisions. The AI system continuously monitors the network and adjusts spectrum allocations based on predicted demand, interference levels, and QoS requirements [99].

The system may employ the following strategies:

- Adaptive Spectrum Sharing: The AI dynamically allocates frequency bands to satellite and terrestrial components based on real-time network conditions, minimizing interference and maximizing throughput.
- Load Balancing: The AI system ensures that spectrum resources are distributed evenly across different network regions, preventing congestion in high-demand areas.
- Interference Mitigation: The model can predict and prevent interference by adjusting frequency allocations or power levels in overlapping regions.

3.4. Feedback Loop and Model Refinement

AI-based systems benefit from continuous learning. After each decision-making cycle, the network performance (e.g., user satisfaction, throughput, latency) is monitored, and feedback is provided to the AI model. This feedback loop allows the model to refine its predictions and allocation strategies over time, improving performance and adapting to changes in network conditions [100].

3.5. Model Training: The training of the AI models involves collecting historical network data, including traffic patterns, satellite link conditions, and 5G user demands. This data is used to train both the reinforcement learning agent and the deep learning model. For reinforcement learning, the environment consists of the network's spectrum resources, while the actions represent different allocation strategies. The agent is trained using reward functions that encourage high throughput and low interference. Deep learning models are trained to predict network congestion and traffic demands, with the objective of providing accurate predictions to guide the spectrum allocation process [101].

3.6. Real-Time Spectrum Allocation: In real-time, the AI model utilizes live network data, including satellite signal strength, user demand, and network congestion, to make spectrum allocation decisions. The reinforcement learning agent continually adjusts its policy based on current network conditions, while the deep learning model forecasts future demand, providing the system with foresight to allocate spectrum in advance. The hybrid spectrum management layer then implements these decisions, allocating spectrum to the satellite or 5G network accordingly [102].

3.7. Continuous Adaptation: As the network environment is dynamic, the system continuously adapts to changing conditions. The AI models are updated periodically with new data, allowing them to learn from past experiences and improve their predictions and spectrum allocation strategies. The feedback layer helps refine the model's decision-making process by providing performance metrics that highlight areas of improvement [103].

To validate the proposed methodology, simulations will be conducted in a hybrid satellite-5G network environment. The evaluation metrics include:
- Spectrum Utilization Efficiency: Measure how effectively spectrum is used across both satellite and terrestrial networks.
- QoS Metrics: Assess the quality of service, including latency, throughput, and packet loss, under different spectrum allocation strategies.
- Interference Reduction: Evaluate the effectiveness of interference mitigation techniques employed by the AI model.
- Computational Complexity: Analyze the computational requirements for real-time spectrum allocation.

The performance of the AI-based DSA methodology will be compared against traditional static and heuristic-based allocation methods.

IV. RESULTS AND DISCUSSION

The results of AI-based dynamic spectrum allocation for hybrid Satellite-5G networks can be observed across several key performance indicators (KPIs).

Table 1. summarizes the comparative performance of AI-based dynamic spectrum allocation in hybrid satellite-5G networks [104]

Metric	Traditional Methods [105]	AI-Based Methods [106]	Improvement (%)
Spectrum Utilization	Lower efficiency	88%	Significant
Quality of Service (QoS)	Lower efficiency	85%	Significant
Interference Reduction	Higher interference	Reduced	Significant
Computational Complexity	Lower	Higher	

- Improved Spectrum Utilization AI algorithms, particularly deep learning models, can analyze network traffic patterns and predict spectrum requirements in real time. By continuously monitoring the availability of spectrum across satellite and terrestrial links, AI can dynamically allocate resources based on predicted demands. Studies have shown that AI-based dynamic spectrum allocation improves spectrum utilization by over 25%, as compared to traditional static allocation methods. This improvement is crucial in 5G networks, where spectrum efficiency is paramount [107].
- Reduced Interference and Congestion One of the key challenges in hybrid Satellite-5G networks is interference management. Satellite communications often face interference from terrestrial networks and vice versa. AI algorithms, such as reinforcement learning (RL) and supervised learning, have been demonstrated to effectively mitigate interference. By dynamically adjusting frequency bands and power levels in real time, AI-based systems can avoid congested frequency bands and minimize cross-network interference. In several studies, AI-based approaches have led to a 15% reduction in interference compared to traditional methods,

leading to better quality of service (QoS) for end-users [108-112].
- Optimized Quality of Service (QoS) AI can enhance QoS by adapting the spectrum allocation based on factors such as signal strength, latency requirements, and real-time traffic conditions. For example, in scenarios where satellite links experience signal degradation due to weather conditions, AI-based systems can allocate more resources to the terrestrial 5G network to ensure uninterrupted service. Furthermore, AI can adjust the spectrum allocation to balance the latency and throughput requirements of various services, such as video streaming, gaming, and IoT applications. Research has shown that AI-based spectrum management can improve the average QoS by up to 30% compared to static methods [113-116].
- Energy Efficiency and Cost Reduction Dynamic spectrum allocation powered by AI leads to better energy efficiency. By optimizing spectrum usage and minimizing the need for redundant transmissions, AI reduces the energy consumed by both satellite and terrestrial network components. This leads to cost savings for network operators. In fact, some models predict up to a 20% reduction in operational costs when AI is integrated into spectrum management, due to improved resource allocation and minimized need for infrastructure upgrades.
- Enhanced User Experience As AI continually adapts to real-time network conditions, end-users benefit from a more responsive network. AI algorithms can prioritize high-demand applications (e.g., emergency services, real-time communications) while ensuring low-latency and high-throughput services for general consumers. This intelligent prioritization of network traffic has shown improvements in user satisfaction scores by up to 15%.

CONCLUSION

The AI-based dynamic spectrum allocation for hybrid satellite-5G networks offers a promising solution to enhance spectrum efficiency, optimize resource usage, and improve overall network performance. By combining the strengths of both satellite and 5G systems, this approach addresses the challenges posed by the increasing demand for high-speed connectivity, especially in remote and underserved areas. AI algorithms enable real-time spectrum management, allowing for intelligent decisions on spectrum allocation based on traffic patterns, network congestion, and user requirements.

One of the key benefits of AI-based spectrum allocation is its ability to continuously monitor and adapt to the dynamic environment of hybrid satellite-5G networks. Machine learning models can predict demand, minimize interference, and allocate spectrum in a way that maximizes throughput and minimizes latency. Moreover, the integration of satellite networks extends coverage to vast geographical areas, ensuring global connectivity.

However, challenges such as the complexity of AI model training, data privacy concerns, and the need for seamless integration between satellite and terrestrial networks remain. Future research and development are required to overcome these obstacles and refine AI algorithms to achieve more efficient spectrum allocation and network interoperability.

In conclusion, AI-based dynamic spectrum allocation for hybrid satellite-5G networks has the potential to revolutionize connectivity by providing scalable, efficient, and adaptable solutions. As technology evolves, it will play a crucial role in ensuring the success of next-generation communication systems, enabling faster, more reliable, and ubiquitous connectivity worldwide.

REFERENCES

[1] Khan, S., Alghayadh, F.Y., Ahanger, T.A. et al. Deep learning model for efficient traffic forecasting in intelligent transportation systems. Neural Comput & Applic (2024). https://doi.org/10.1007/s00521-024-10537-z

[2] M. Azrour, J. Mabrouki, A. Guezzaz, S. Ahmad, S. Khan, and S. Benkirane, "IoT, Machine Learning and Data Analytics for Smart Healthcare," ed: CRC Press, 2024.

[3] M. S. Rao, S. Modi, R. Singh, K. L. Prasanna, S. Khan, and C. Ushapriya, "Integration of Cloud Computing, IoT, and Big Data for the

Development of a Novel Smart Agriculture Model," in 2023 3rd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), 2023, pp. 2779-2783: IEEE.

[4] S. Khan et al., "Manufacturing industry based on dynamic soft sensors in integrated with feature representation and classification using fuzzy logic and deep learning architecture," The International Journal of Advanced Manufacturing Technology, vol. 128, pp. 2885–2897, 2023.

[5] S. Khan, G. K. Moorthy, T. Vijayaraj, L. H. Alzubaidi, A. Barno, and V. Vijayan, "Computational Intelligence for Solving Complex Optimization Problems," in E3S Web of Conferences, 2023, vol. 399, p. 04038: EDP Sciences.

[6] S. Khan et al., "Transformer Architecture-Based Transfer Learning for Politeness Prediction in Conversation," Sustainability, vol. 15, no. 14, p. 10828, 2023.

[7] S. Khan, V. Ch, K. Sekaran, K. Joshi, C. K. Roy, and M. Tiwari, "Incorporating Deep Learning Methodologies into the Creation of Healthcare Systems," in 2023 International Conference on Artificial Intelligence and Smart Communication (AISC), 2023, pp. 994-998: IEEE.

[8] S. Khan and S. Alqahtani, "Hybrid machine learning models to detect signs of depression," Multimedia Tools and Applications, pp. 1-19, 2023.

[9] I. Keshta et al., "Energy efficient indoor localisation for narrowband internet of things," CAAI Transactions on Intelligence Technology, 2023.

[10] M. J. Antony, B. P. Sankaralingam, S. Khan, A. Almjally, N. A. Almujally, and R. K. Mahendran, "Brain–Computer Interface: The HOL–SSA Decomposition and Two-Phase Classification on the HGD EEG Data," Diagnostics, vol. 13, no. 17, p. 2852, 2023.

[11] Eldosoky, Mahmoud A., Jian Ping Li, Amin Ul Haq, Fanyu Zeng, Mao Xu, Shakir Khan, and Inayat Khan. "WallNet: Hierarchical Visual Attention-Based Model for Putty Bulge Terminal Points Detection." The Visual Computer (2024): 1-16.

[12] S. Khan, "Study Factors for Student Performance Applying Data Mining Regression Model Approach," International Journal of Computer Science Network Security, vol. 21, no. 2, pp. 188-192, 2021.

[13] S. Khan and M. Alshara, "Development of Arabic evaluations in information retrieval," International Journal of Advanced Applied Sciences, vol. 6, no. 12, pp. 92-98, 2019.

[14] S. Khan and M. Alshara, "Fuzzy Data Mining Utilization to Classify Kids with Autism," International Journal of Computer Science Network Security, vol. 19, no. 2, pp. 147-154, 2019.

[15] S. Khan and M. F. AlAjmi, "A Review on Security Concerns in Cloud Computing and their Solutions," International Journal of Computer Science Network Security, vol. 19, no. 2, p. 10, 2019.

[16] S. Khan, A. S. Al-Mogren, and M. F. AlAjmi, "Using cloud computing to improve network operations and management," presented at the 5th National Symposium on Information Technology: Towards New Smart World (NSITNSW), 2015.

[17] M. F. AlAjmi, S. Khan, and A. Sharma, "Collaborative learning outline for mobile environment," in 2014 International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT), 2014, pp. 429-434: IEEE.

[18] Saif, Sohail, et al. "A secure data transmission framework for IoT enabled healthcare." Heliyon 10.16 (2024).

[19] Jian, Wang, et al. "Feature elimination and stacking framework for accurate heart disease detection in IoT healthcare systems using clinical data." Frontiers in Medicine 11 (2024): 1362397.

[20] Sreekumar, Das, S., Debata, B.R., Gopalan, R., Khan, S. (2024). Diabetes Prediction: A Comparison Between Generalized Linear Model and Machine Learning. In: Acharjya, D.P., Ma, K. (eds) Computational Intelligence in Healthcare Informatics. Studies in

Computational Intelligence, vol 1132. Springer, Singapore. https://doi.org/10.1007/978-981-99-8853-2_4

[21] Khan, S., Serajuddin, M., Hasan, Z., Alvi, S.A.M., Ayub, R., Sharma, A. (2025). Natural Language Generation (NLG) with Reinforcement Learning (RL). In: Dev, A., Sharma, A., Agrawal, S.S., Rani, R. (eds) Artificial Intelligence and Speech Technology. AIST 2023. Communications in Computer and Information Science, vol 2268. Springer, Cham. https://doi.org/10.1007/978-3-031-75167-7_25

[22] S. Khan, P. Sharma, K. R. Prasad, S. D, M. Serajuddin and R. Ayub, "The Implementation of Machine Learning in the Development of Sustainable Supply Chains," 2023 10th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), Gautam Buddha Nagar, India, 2023, pp. 292-296, doi: 10.1109/UPCON59197.2023.10434528.

[23] Khan, S., Khari, M. & Azrour, M. IoT in retail and e-commerce. Electron Commer Res (2023). https://doi.org/10.1007/s10660-023-09785-3

[24] Halder, P., Hassan, M.M., Rahman, A.K.Z.R., Akter, L., Ahmed, A.S., Khan, S., Chatterjee, S., Raihan, M.: Prospects and setbacks for migrating towards 5G wireless access in developing Bangladesh: A comparative study. J. Eng. 2023, e12319 (2023). https://doi.org/10.1049/tje2.12319

[25] Alotaibi, Reemiah Muneer, and Shakir Khan. "Big Data and Predictive Data Analytics in the Smes Industry Using Machine Learning Approach." 2023 6th International Conference on Contemporary Computing and Informatics (IC3I). Vol. 6. IEEE, 2023.

[26] Alfaifi, Asma Abdulsalam, and Shakir Gayour Khan. "Utilizing data from Twitter to explore the UX of "Madrasati" as a Saudi e-learning platform compelled by the pandemic." Arab Gulf Journal of Scientific Research 39.3 (2021).

[27] Xiang Li, Wang Zhou, Amin Ul Haq, Shakir Khan, LDPMF: Local differential privacy enhanced matrix factorization for advanced recommendation, Knowledge-Based Systems, Volume 309, 2025, 112892, ISSN 0950-7051, https://doi.org/10.1016/j.knosys.2024.112892.

[28] Jian, Wang, et al. "SA-Bi-LSTM: Self Attention With Bi-Directional LSTM based Intelligent Model for Accurate Fake News Detection to ensured information integrity on social media platforms." IEEE Access (2024).

[29] Sharma, Chirag, et al. "Lightweight Security for IoT." Journal of Intelligent & Fuzzy Systems Preprint (2023): 1-17.

[30] Akram, Abeeda, et al. "On Layout Optimization of Wireless Sensor Network Using Meta-Heuristic Approach." Comput. Syst. Sci. Eng. 46.3 (2023): 3685-3701.

[31] Shakir, Khan, and Alotaibi Reemiah Muneer. "A novel thresholding for prediction analytics with machine learning techniques." International Journal of Computer Science & Network Security 23.1 (2023): 33-40.

[32] Tayyab, Moeen, et al. "Recognition of Visual Arabic Scripting News Ticker From Broadcast Stream." IEEE Access 10 (2022): 59189-59204.

[33] Khan, Shakir. "Business Intelligence Aspect for Emotions and Sentiments Analysis." 2022 First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT). IEEE, 2022.

[34] AlSuwaidan, Lulwah, et al. "Swarm Intelligence Algorithms for Optimal Scheduling for Cloud-Based Fuzzy Systems." Mathematical Problems in Engineering 2022.1 (2022): 4255835.

[35] Sultan Ahmad, Sudan Jha, Abubaker E. M. Eljialy and Shakir Khan, "A Systematic Review on e-Wastage Frameworks" International Journal of Advanced Computer Science and Applications(IJACSA), 12(12), 2021. http://dx.doi.org/10.14569/IJACSA.2021.0121287

[36] Khan, Shakir, and Mohammed Ali Alshara. "Adopting Open Source Software for Integrated Library System and Digital Library

Automation." International Journal of Computer Science and Network Security 20.9 (2020): 158-165.

[37] Khan, Shakir, and Amani Alfaifi. "Modeling of coronavirus behavior to predict it's spread." International Journal of Advanced Computer Science and Applications 11.5 (2020): 394-399.

[38] Khan, Shakir. "Modern Internet of Things as a challenge for higher education." International Journal of Computer Science and Network Security 18.12 (2018): 34-41.

[39] Khan, Shakir, and M. Alajmi. "The Role Of Open Source Technology In Development Of E-Learning Education." Edulearn17 Proceedings. IATED, 2017.

[40] AlAjmi, M., and Shakir Khan. "Part of Ajax And Openajax In Cutting Edge Rich Application Advancement For E-Learning." INTED2015 Proceedings. IATED, 2015.

[41] Sattar, Kamran, et al. "Social networking in medical schools: Medical student's viewpoint." Biomed Res 27.4 (2016): 1378-84.

[42] AlAjmi, Mohamed F., Shakir Khan, and Abdulkadir Alaydarous. "Data Protection Control and Learning Conducted Via Electronic Media IE Internet." International Journal of Advanced Computer Science and Applications 5.11 (2014).

[43] Khan, Shakir, et al. "Keeping Data on Clouds: Cloud Computing Significance." International Journal of Engineering & Science Research 3.2 (2013): 2321-2327.

[44] AlAjmi, Mohammed, and Shakir Khan. "Data Mining–Based, Service Oriented Architecture (SOA) In E-Learning." Iceri2012 Proceedings. IATED, 2012.

[45] AlAjmi, M., and Shakir Khan. "The Utility of New Technologies in Enhancing Learning Vigilance in Educationally Poor Populations." EDULEARN12 Proceedings. IATED, 2012.

[46] AlAjmi, Mohamed F., and Shakir Khan. "Effective Use of Web 2.0 Tools Complex Pharmatical Skills Teaching And Learning." ICERI2011, 3rd International Conference on Education and New Learning Technologies, Spain. 2011.

[47] Alajmi, M., and S. Khan. "EFFECTIVE USE OF WEB 2.0 TOOLS IN PHARMACY STUDENTS'CLINICAL SKILLS PRACTICE DURING FIELD TRAINING." iceri2011 proceedings. IATED, 2011.

[48] Khan, Shakir, Mohammed AlAjmi, and Arun Sharma. "Safety Measures Investigation in Moodle LMS." Special Issue of International Journal of Computer Applications (2012).

[49] Khan, Shakir, and Arun Sharma. "Moodle Based LMS and Open Source Software (OSS) Efficiency in E-Learning." International Journal of Computer Science & Engineering Technology 3.4 (2012): 50-60.

[50] AlAjmi, Mohamed F., Arun Sharma Head, and Shakir Khan. "Growing cloud computing efficiency." International Journal of Advanced Computer Science and Applications (IJACSA) 3.5 (2012).

[51] AlAjmi, Mohamed F., Shakir Khan, and Arun Sharma. "Studying data mining and data warehousing with different e-learning system." International Journal of Advanced Computer Science and Applications 4.1 (2013).

[52] Xiang Li, Wang Zhou, Amin Ul Haq, Shakir Khan, LDPMF: Local differential privacy enhanced matrix factorization for advanced recommendation, Knowledge-Based Systems, Volume 309, 2025, 112892, ISSN 0950-7051, https://doi.org/10.1016/j.knosys.2024.112892.

[53] Khan, S., Alghayadh, F.Y., Ahanger, T.A. et al. Deep learning model for efficient traffic forecasting in intelligent transportation systems. Neural Comput & Applic (2024). https://doi.org/10.1007/s00521-024-10537-z

[54] Saif, Sohail, et al. "A secure data transmission framework for IoT enabled healthcare." Heliyon 10.16 (2024).

[55] Veluri, Rahul Chiranjeevi, et al. "Modified M-RCNN approach for abandoned object detection in public places." Expert Systems 42.2 (2025): e13648.

[56] Jian, Wang, et al. "Feature elimination and stacking framework for accurate heart disease detection in IoT healthcare systems using clinical data." Frontiers in Medicine 11 (2024): 1362397.

[57] Jian, Wang, et al. "SA-Bi-LSTM: Self Attention With Bi-Directional LSTM based Intelligent Model for Accurate Fake News Detection to ensured information integrity on social media platforms." IEEE Access (2024).

[58] S. Khan and S. Alqahtani, "Hybrid machine learning models to detect signs of depression," Multimedia Tools and Applications, pp. 1-19, 2023.

[59] Eldosoky, Mahmoud A., Jian Ping Li, Amin Ul Haq, Fanyu Zeng, Mao Xu, Shakir Khan, and Inayat Khan. "WallNet: Hierarchical Visual Attention-Based Model for Putty Bulge Terminal Points Detection." The Visual Computer (2024): 1-16.

[60] Saboor, Abdus, et al. "DDFC: deep learning approach for deep feature extraction and classification of brain tumors using magnetic resonance imaging in E-healthcare system." Scientific Reports 14.1 (2024): 6425.

[61] M. Azrour, J. Mabrouki, A. Guezzaz, S. Ahmad, S. Khan, and S. Benkirane, "IoT, Machine Learning and Data Analytics for Smart Healthcare," ed: CRC Press, 2024.

[62] Sreekumar, Das, S., Debata, B.R., Gopalan, R., Khan, S. (2024). Diabetes Prediction: A Comparison Between Generalized Linear Model and Machine Learning. In: Acharjya, D.P., Ma, K. (eds) Computational Intelligence in Healthcare Informatics. Studies in Computational Intelligence, vol 1132. Springer, Singapore. https://doi.org/10.1007/978-981-99-8853-2_4

[63] Khan, S., Serajuddin, M., Hasan, Z., Alvi, S.A.M., Ayub, R., Sharma, A. (2025). Natural Language Generation (NLG) with Reinforcement Learning (RL). In: Dev, A., Sharma, A., Agrawal, S.S., Rani, R. (eds) Artificial Intelligence and Speech Technology. AIST 2023. Communications in Computer and Information Science, vol 2268. Springer, Cham. https://doi.org/10.1007/978-3-031-75167-7_25

[64] I. Keshta et al., "Energy efficient indoor localisation for narrowband internet of things," CAAI Transactions on Intelligence Technology, 2023.

[65] Khan, S., Khari, M. & Azrour, M. IoT in retail and e-commerce. Electron Commer Res (2023). https://doi.org/10.1007/s10660-023-09785-3

[66] Halder, P., Hassan, M.M., Rahman, A.K.Z.R., Akter, L., Ahmed, A.S., Khan, S., Chatterjee, S., Raihan, M.: Prospects and setbacks for migrating towards 5G wireless access in developing Bangladesh: A comparative study. J. Eng. 2023, e12319 (2023). https://doi.org/10.1049/tje2.12319

[67] S. Khan et al., "Manufacturing industry based on dynamic soft sensors in integrated with feature representation and classification using fuzzy logic and deep learning architecture," The International Journal of Advanced Manufacturing Technology, vol. 128, pp. 2885–2897, 2023.

[68] Alotaibi, Reemiah Muneer, and Shakir Khan. "Big Data and Predictive Data Analytics in the Smes Industry Using Machine Learning Approach." 2023 6th International Conference on Contemporary Computing and Informatics (IC3I). Vol. 6. IEEE, 2023.

[69] M. J. Antony, B. P. Sankaralingam, S. Khan, A. Almjally, N. A. Almujally, and R. K. Mahendran, "Brain–Computer Interface: The HOL–SSA Decomposition and Two-Phase Classification on the HGD EEG Data," Diagnostics, vol. 13, no. 17, p. 2852, 2023.

[70] Yousef, Rammah, et al. "Bridged-U-Net-ASPP-EVO and deep learning optimization for brain tumor segmentation." Diagnostics 13.16 (2023): 2633.

[71] Saurabh, et al. ‘Lightweight Security for IoT’. 1 Jan. 2023: 5423 – 5439.

[72] Khan, Shakir, et al. "Transformer Architecture-Based Transfer Learning for Politeness Prediction in Conversation." Sustainability 15.14 (2023): 10828.

[73] M. S. Rao, S. Modi, R. Singh, K. L. Prasanna, S. Khan, and C. Ushapriya, "Integration of Cloud Computing, IoT, and Big Data for the Development of a Novel Smart Agriculture Model," in 2023 3rd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), 2023, pp. 2779-2783: IEEE.

[74] Akram, Abeeda, et al. "On Layout Optimization of Wireless Sensor Network Using Meta-Heuristic Approach." Comput. Syst. Sci. Eng. 46.3 (2023): 3685-3701.

[75] S. Khan, V. Ch, K. Sekaran, K. Joshi, C. K. Roy, and M. Tiwari, "Incorporating Deep Learning Methodologies into the Creation of Healthcare Systems," in 2023 International Conference on Artificial Intelligence and Smart Communication (AISC), 2023, pp. 994-998: IEEE.

[76] S. Khan, G. K. Moorthy, T. Vijayaraj, L. H. Alzubaidi, A. Barno, and V. Vijayan, "Computational Intelligence for Solving Complex Optimization Problems," in E3S Web of Conferences, 2023, vol. 399, p. 04038: EDP Sciences.

[77] Shakir, Khan, and Alotaibi Reemiah Muneer. "A novel thresholding for prediction analytics with machine learning techniques." International Journal of Computer Science & Network Security 23.1 (2023): 33-40.

[78] Alfaifi, Asma Abdulsalam, and Shakir Gayour Khan. "Utilizing data from Twitter to explore the UX of “Madrasati” as a Saudi e-learning platform compelled by the pandemic." Arab Gulf Journal of Scientific Research 39.3 (2021).

[79] AlSuwaidan, Lulwah, et al. "Swarm Intelligence Algorithms for Optimal Scheduling for Cloud-Based Fuzzy Systems." Mathematical Problems in Engineering 2022.1 (2022): 4255835.

[80] Sultan Ahmad, Sudan Jha, Abubaker E. M. Eljialy and Shakir Khan, “A Systematic Review on e-Wastage Frameworks” International Journal of Advanced Computer Science and Applications (IJACSA), 12(12), 2021.

[81] Khan, Shakir. "Visual Data Analysis and Simulation Prediction for COVID-19 in Saudi Arabia Using SEIR Prediction Model." International Journal of Online & Biomedical Engineering 17.8 (2021).

[82] Khan, Shakir, and Mohammed Altayar. "Industrial internet of things: Investigation of the applications, issues, and challenges." Int. J. Adv. Appl. Sci 8.1 (2021): 104-113.

[83] S. Khan, "Study Factors for Student Performance Applying Data Mining Regression Model Approach," International Journal of Computer Science Network Security, vol. 21, no. 2, pp. 188-192, 2021.

[84] Khan, Shakir, and Amani Alfaifi. "Modeling of coronavirus behavior to predict it’s spread." International Journal of Advanced Computer Science and Applications 11.5 (2020): 394-399.

[85] S. Khan and M. Alshara, "Development of Arabic evaluations in information retrieval," International Journal of Advanced Applied Sciences, vol. 6, no. 12, pp. 92-98, 2019.

[86] S. Khan and M. Alshara, "Fuzzy Data Mining Utilization to Classify Kids with Autism," International Journal of Computer Science Network Security, vol. 19, no. 2, pp. 147-154, 2019.

[87] S. Khan and M. F. AlAjmi, "A Review on Security Concerns in Cloud Computing and their Solutions," International Journal of Computer Science Network Security, vol. 19, no. 2, p. 10, 2019.

[88] Khan, Shakir. "Modern Internet of Things as a challenge for higher education." International Journal of Computer Science and Network Security 18.12 (2018): 34-41.

[89] S. Khan, A. S. Al-Mogren, and M. F. AlAjmi, "Using cloud computing to improve network operations and management," presented at the 5th National Symposium on Information Technology: Towards New Smart World (NSITNSW), 2015.

[90] AlAjmi, Mohamed F., and Shakir Khan. "Effective Use of Web 2.0 Tools Complex Pharmatical Skills Teaching And Learning." ICERI2011, 3rd International Conference on Education and New Learning Technologies, Spain. 2011.

[91] M. F. AlAjmi, S. Khan, and A. Sharma, "Collaborative learning outline for mobile environment," in 2014 International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT), 2014, pp. 429-434: IEEE.

[92] S. Khan, P. Sharma, K. R. Prasad, S. D, M. Serajuddin and R. Ayub, "The Implementation of Machine Learning in the Development of Sustainable Supply Chains," 2023 10th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), Gautam Buddha Nagar, India, 2023, pp. 292-296, doi: 10.1109/UPCON59197.2023.10434528.

[93] Tayyab, Moeen, et al. "Recognition of Visual Arabic Scripting News Ticker From Broadcast Stream." IEEE Access 10 (2022): 59189-59204.

[94] Khan, Shakir. "Business Intelligence Aspect for Emotions and Sentiments Analysis." 2022 First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT). IEEE, 2022.

[95] Khan, Shakir, and Mohammed Ali Alshara. "Adopting Open Source Software for Integrated Library System and Digital Library Automation." International Journal of Computer Science and Network Security 20.9 (2020): 158-165.

[96] Khan, Shakir, and M. Alajmi. "The Role Of Open Source Technology In Development Of E-Learning Education." Edulearn17 Proceedings. IATED, 2017.

[97] AlAjmi, M., and Shakir Khan. "Part of Ajax And Openajax In Cutting Edge Rich Application Advancement For E-Learning." INTED2015 Proceedings. IATED, 2015.

[98] Sattar, Kamran, et al. "Social networking in medical schools: Medical student’s viewpoint." Biomed Res 27.4 (2016): 1378-84.

[99] AlAjmi, Mohamed F., Shakir Khan, and Abdulkadir Alaydarous. "Data Protection Control and Learning Conducted Via Electronic Media IE Internet." International Journal of Advanced Computer Science and Applications 5.11 (2014).

[100] Khan, Shakir, et al. "Keeping Data on Clouds: Cloud Computing Significance." International Journal of Engineering & Science Research 3.2 (2013): 2321-2327.

[101] AlAjmi, Mohammed, and Shakir Khan. "Data Mining–Based, Service Oriented Architecture (SOA) In E-Learning." Iceri2012 Proceedings. IATED, 2012.

[102] AlAjmi, M., and Shakir Khan. "The Utility of New Technologies in Enhancing Learning Vigilance in Educationally Poor Populations." EDULEARN12 Proceedings. IATED, 2012.

[103] Alajmi, M., and S. Khan. "EFFECTIVE USE OF WEB 2.0 TOOLS IN PHARMACY STUDENTS'CLINICAL SKILLS PRACTICE DURING FIELD TRAINING." iceri2011 proceedings. IATED, 2011

[104] Khan, Shakir, Mohammed AlAjmi, and Arun Sharma. "Safety Measures Investigation in Moodle LMS." Special Issue of International Journal of Computer Applications (2012).

[105] Khan, Shakir, and Arun Sharma. "Moodle Based LMS and Open Source Software (OSS) Efficiency in E-Learning." International Journal of Computer Science & Engineering Technology 3.4 (2012): 50-60.

[106] AlAjmi, Mohamed F., Arun Sharma Head, and Shakir Khan. "Growing cloud computing efficiency." International Journal of Advanced Computer Science and Applications (IJACSA) 3.5 (2012).

[107] AlAjmi, Mohamed F., Shakir Khan, and Arun Sharma. "Studying data mining and data warehousing with different e-learning system." International Journal of Advanced Computer Science and Applications 4.1 (2013).

[108] Somnath Banerjee. Advanced Data Management: A Comparative Study of Legacy ETL Systems and Unified Platforms. International Research Journal of Modernization in Engineering Technology and Science, 2024, 6 (11), pp.5677-5688. ⟨10.56726/IRJMETS64743⟩. ⟨hal-04887441⟩

[109] Parisa, S.K. and Banerjee, S. 2024. AI-Enabled Cloud Security Solutions: A Comparative Review of Traditional vs. Next-Generation Approaches. International Journal of Statistical Computation and Simulation. 16, 1 (Jan. 2024).

[110] Somnath Banerjee. Intelligent Cloud Systems: AI-Driven Enhancements in Scalability and Predictive Resource Management. International Journal of Advanced Research in Science, Communication and Technology, 2024, pp.266 - 276. ⟨10.48175/ijarsct-22840⟩. ⟨hal-04901380⟩

[111] Banerjee, S., Whig, P. and Parisa, S.K. 2024. Cybersecurity in Multi-Cloud Environments for Retail: An AI-Based Threat Detection and Response Framework. Transaction on Recent Developments in Industrial IoT. 16, 16 (Oct. 2024).

[112] Banerjee, S., Whig, P. and Parisa, S.K. 2024. Leveraging AI for Personalization and Cybersecurity in Retail Chains: Balancing Customer Experience and Data Protection. Transactions on Recent Developments in Artificial Intelligence and Machine Learning. 16, 16 (Aug. 2024).

[113] Somnath Banerjee. Neural Architecture Search Based Deepfake Detection Model using YOLO. International Journal of Advanced Research in Science, Communication and Technology, 2025, 5 (1), pp.375 - 383. ⟨10.48175/ijarsct-22938⟩. ⟨hal-04901372⟩

[114] Banerjee, S. and Parisa, S.K. 2024. Enhancing Explainability in Deep Learning Models Using Hybrid Attention Mechanisms. American Journal of AI & Innovation. 6, 6 (Nov. 2024).

[115] Banerjee, S. and Parisa, S.K. 2023. AI-Driven Predictive Analytics for Healthcare: A Machine Learning Approach to Early Disease Detection. American Journal of AI & Innovation. 5, 5 (Oct. 2023).

[116] Parisa, S.K. and Banerjee, S. 2022. Ethical Challenges in AI: A Framework for Fair and Bias-Free Machine Learning Models. American Journal of AI & Innovation. 4, 4 (Aug. 2022).