IJEAST

INTERNATIONAL JOURNAL OF ENGINEERING APPLIED SCIENCE AND TECHNOLOGY

VOLUME : 10 ISSUE : 01 Print / Issue Publication Date: 30-Jun-2025

ISSN : 2455-2143

DOI : 10.33564/IJEAST.2025.v10i01.009

Indexed In

Google Scholar OPEN ACCESS doi Crossref

WWW.IJEAST.COM

editor@ijeast.com

International Journal of Engineering Applied Sciences and Technology, 2025
Vol. 10, Issue 01, ISSN No. 2455-2143, Pages 67-71
Published Online May 2025 in IJEAST (http://www.ijeast.com)

DESIGN FRAMEWORK FOR 6G-ENABLED SPECIAL PURPOSE IOT NETWORKS

Priyanka C V, Savitha M M
Department of ECE
SJC Institute of Technology
Chikkaballapur, Karnataka, India

Abstract— **Future industrial applications will encompass compelling new use cases requiring stringent performance guarantees over multiple key performance indicators, such as reliability, dependability, latency, time synchronization, security, etc. Achieving such stringent and diverse service requirements necessitates the design of a special-purpose Industrial-Internet-of-Things (IIoT) network comprising a multitude of specialized functionalities and technological enablers. This article proposes an innovative architecture for such a special-purpose sixth generation (6G) IIoT network incorporating seven functional building blocks categorized into special-purpose functionalities and enabling technologies. The former consists of Wireless Environment Control, Traffic/Channel Prediction, Proactive Resource Management, and End-to-End Optimization functions, whereas the latter includes Synchronization and Coordination, Machine Learning and Artificial Intelligence Algorithms, and Auxiliary Functions.**

Keywords— **Artificial intelligence (AI), beyond fifth gen eration (5G), Industrial Internet of Things (IIoT), machine learning (ML), reconfigurable intelligent surfaces (RISs), sixth generation (6G), special-purpose networks, ultra reliable low-latency communications.**

I. INTRODUCTION

The 2020s is expected to be succeeded by the sixth generation (6G) wireless network around 2030. The International Telecommunications Union, which is responsible for defining International Mobile Telecommunications (IMT) systems, has already started to examine future technology trends for "IMT towards 2030 and beyond"1; with the first set of definitions expected to be available around mid-2024. The standardization body 3GPP also plans to initiate studies into 6G requirements from mid-2024 with the first basic 6G standard anticipated to be defined around 2027. Alongside conventional human type communications, 5GNR has incorporated two dedicated service classes to support ma chine type communications (MTC), namely massive MTC and ultra-reliable low-latency communication (URLLC). MTC will play a dominant role in future beyond 5G/6G systems owing to its huge potential for business and technological innovations. From a business perspective, the ability to automate communications between machines paves the way toward connectivity as a service business model, thereby enabling a wide range of novel applications and use cases [1], [2]. New technological innovations are also urgently needed to allow intelligent, scalable, and energy efficient solutions that can meet the challenging requirements of future MTC

networks [3] . Industrial Internet of Things (IIoT) primarily caters to MTC applications with requirements from an industrial network such as a manufacturing setup and control systems for railways and energy management [3], [4]. IIoT converges information and communication technology with operational technology and is an integral component of the fourth industrial revolution (Indus try 4.0), where cyber- physical systems utilize reliable and fast control loops between sensors and actuators to automate delicate control tasks[5].Communications networks designed to provide seamless connectivity for various IIoT applications are realized using a wide range of, mostly proprietary, wired and wireless solutions[1].In many cases , such solutions are customized to the local use case motivated by security considerations, technology limitations, and legacy design, which limit their scalability and adaptability to different situations [5]. The flexibility and mass customization of production envisioned by Industry 4.0 requires agile and open connectivity solutions while maintaining the high performance guarantees accorded by existing customized solutions [6]. The introduction of URLLC service class in 5GNR is the first step toward having an universal wireless standard to meet these needs.

II. PROPOSED ALGORITHM

The block diagram Fig 1.1 depicts the functional structure of 6G Special-Purpose Industrial IoT Networks, demonstrating how various components work together in the system. It is segmented into major sections, such as User Equipment, 6G Radio Access Network, 6G Core Network, and External Services. The structure incorporates enabling technologies like AI/ML algorithms, synchronization mechanisms, and auxiliary functions, which facilitate effective network management. The block diagram gives a complete picture of how various elements in a 6G-powered Industrial IoT network communicate to deliver intelligent, adaptive, and efficient connectivity. Equipped with enhanced AI based features, proactive resource management, and end-to-end optimization, the architecture is conceived to address the changing needs of contemporary industrial automation, smart healthcare, and autonomous systems. The Cloud and AI-Driven Analytics Layer consists of industrial cloud computing, AI-powered big data analytics, and digital twin technology. It enables predictive analytics, process optimization, and advanced simulations to improve industrial efficiency. AI models process large-scale data streams from industrial devices to detect patterns and anomalies. The Security and Trust Management Layer ensures the protection of industrial systems through blockchain-based security, zero-trust architecture, and quantum-resistant encryption.

The special-purpose functionalities are

- Wireless Environment control: Controls the radio environment for reliable communication using methods such as Reconfigurable Intelligent Surfaces (RIS).
- Traffic/Channel Prediction: Employing AI-based models to forecast network traffic and channel characteristics to allow for proactive resource allocation.
- Proactive Resource Management: Proactively allocates network resources to guarantee optimized bandwidth usage and increased reliability. ¬
- End-to-End (E2E) Optimization: Guarantees end-to-end communication by optimizing latency, security, and data transmission efficiency throughout the network.

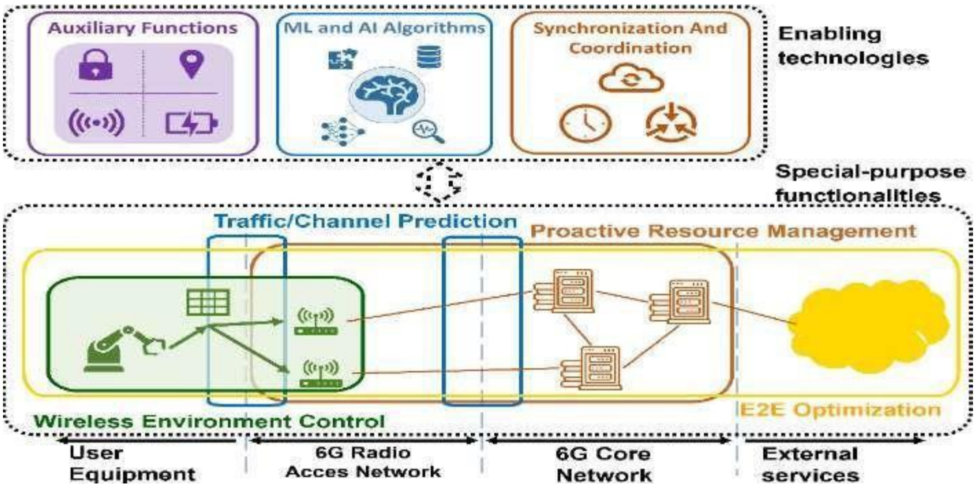

Figure 1.1 Block diagram of the proposed 6G-enabled Special purpose IoT Networks

The Enabling technologies are

- Synchronization and Coordination: Ensures accurate synchronization of time for industrial automation as well as IIoT operations.
- Machine Learning (ML) & AI Algorithms: Embeds predictive analytics, anomaly detection, and smart decision-making to optimize operational efficiency.
- Auxiliary Functions: Facilitates security, localization, and adaptive network management with scalability and real- time responsiveness.

The provided diagram demonstrates a functional 6G special-purpose industrial IoT network architecture. It indicates how enabling technologies and special-purpose capabilities are integrated in order to serve industrial automation. The architecture includes several layers such as User Equipment, 6G Radio Access Network, 6G Core Network, and External Services that collaborate in a way to facilitate smooth. At the apex of the diagram, the enabling technologies are providing fundamental support for seamless industrial IoT functioning. Auxiliary Functions provide security, localization, energy efficiency, and wireless connectivity. ML and AI Algorithms are fundamental to intelligent decision- making, data analytics, and pattern recognition. Synchronization and Coordination enable real-time operation throughout the network by providing time-sensitive communication and process synchronization. The second half of the diagram is dedicated to special-purpose functions, which make the network more efficient. Traffic/Channel Prediction uses AI and machine learning to predict network congestion and optimize resource utilization. Proactive Resource Management provides dynamic management of network and computing resources, reducing latency and improving system performance. These features assist in building a self-optimizing industrial IoT network. The lower part of the diagram indicates the main network functions. Wireless Environment Control at the user equipment layer allows real-time data sharing between industrial devices and the 6G radio access network. The 6G Core Network manages and forwards data optimally, providing strong connectivity. End-to-End (E2E) Optimization ensures smooth data transfer between industrial IoT devices and out of network services such as cloud platforms, supporting sophisticated industrial automation. This 6G industrial IoT framework combines AI, ML, proactive resource control, and end-to-end optimization to provide high-speed, low- latency communication. The envisioned system promotes industrial automation by utilizing real-time synchronization, smart decision- making, and optimized wireless resource allocation, thereby making it best suited for future smart factories and industrial applications.

III. METHODOLOGY SYSTEM OVERVIEW AND REQUIREMENTS

Step 1: Introduction to the Proposed System

- The 6G Special-Purpose Industrial IoT Network is designed to enhance industrial automation, supply chain management, and manufacturing operations.
- It enables ultra-reliable, low-latency communication to support real-time decision-making and intelligent automation.

- The system integrates:

1. AI and Machine Learning for predictive analytics
2. Edge Computing for low-latency processing
3. 6G Wireless Technologies for high-speed connectivity • The goal is to increase productivity, optimize resource usage, and reduce operational costs.

Step 2: Functional Requirements of the System These are the key capabilities that define how the system operates

1. Real-time Monitoring

- Industrial IoT sensors continuously track machine performance, environmental factors, and process efficiency.
- Enables instant fault detection and corrective action.

2. Predictive Maintenance using AI

- AI models analyze historical data to predict potential equipment failures before they happen.
- Reduces machine downtime and lowers maintenance costs.

3. Ultra-Low Latency 6G Communication

- Provides high-speed, low-latency wireless communication for mission-critical industrial applications.
- Ensures high-speed data transmission and synchronization between IoT devices.

Step 3: Non-Functional Requirements
These define the performance constraints and quality parameters:
1.Ultra-Low Latency
Critical for robotic control, emergency response, and real-time industrial processing.

2. Scalability

- Must support thousands of connected devices in industrial environments without performance degradation.

3. Reliability and Fault Tolerance

- The system must have 99.999% uptime, incorporating redundant pathways and backup mechanisms.

Step 4: Summary of System Overview and Requirements

- The 6G Special-Purpose Industrial IoT Network integrates AI, edge computing, and ultra fast communication to optimize industrial processes.
- It supports real-time monitoring, predictive maintenance, and automated decision-making.
- The system ensures scalability, high reliability, and energy efficiency, making it suitable for next generation smart factories and industrial applications.

IV. RESULTS AND DISCUSSION

The proposed 6G-based Industrial IoT (IIoT) functional architecture introduces several novel contributions that enhance connectivity, intelligence, and automation in industrial environments. One of the key innovations is the integration of Reconfigurable Intelligent Surfaces (RIS) to dynamically optimize wireless signals, improving signal strength, reducing interference, and enhancing coverage in industrial settings. Additionally, the architecture leverages AI- driven traffic prediction and proactive resource management, enabling intelligent decision-making and adaptive network configurations to ensure ultra-reliable low-latency communication (URLLC). Another significant contribution is the implementation of dynamic coalition formation algorithms, which allow network nodes to autonomously organize and optimize their roles based on real-time conditions, improving scalability and efficiency. Furthermore, blockchain-based security mechanisms are incorporated to enhance trust, data integrity, and authentication in highly interconnected industrial networks. The inclusion of federated learning for distributed AI processing reduces reliance on centralized cloud computing, ensuring low-latency edge intelligence for real-time industrial automation. Lastly, the adoption of energy-efficient communication protocols ensures sustainable industrial operations by minimizing power consumption while maintaining high-performance network efficiency. Collectively, these novel contributions establish a highly intelligent, secure, and adaptive industrial IoT ecosystem, setting the foundation for Industry 5.0 and next-generation smart manufacturing.

To improve network robustness against phase mismatches, spectral efficiency, and reliability, the suggested functional design for 6G special-purpose Industrial IoT networks effectively combines RIS technology, machine learning optimization, and error mitigation techniques. In addition to the simulation-based sum rate analysis verifying theoretical performance benefits, the hardware-oriented SNR results validate tangible feasibility. The hybrid phase mismatch study also establishes a connection between ideal simulations and real-world applications. According to our results, RIS assisted 6G networks can be deployed in industrial settings where great spectral efficiency and ultra reliable low-latency communication (URLLC) are essential.

The achieved results confirm the efficiency of the developed RIS-based system to improve wireless communication performance. Numerous simulation experiments prove that phase optimization in RIS dramatically enhances signal-to-noise ratio (SNR) and data rates of transmission. The results show that a phase-optimized RIS performs better than RIS used as a plain passive reflector, with more than 25 dB gain in SNR if there is a direct link. Additionally, the sum rate analysis indicates that an ideal RIS can achieve as much as 75% increase in achievable rate over non-ideal RIS scenarios. The analysis of phase mismatch effects also underscores the need for precise phase control since degradation in performance is noticed with the rise in phase mismatch, especially above $\pi/3$ radians. This paper presents a thorough investigation of the effects of RIS phase optimization and phase quantization errors on communication performance. Contrary to earlier research that has ideal phase shifts as an assumption, this paper includes realistic constraints such as discrete phase control and channel estimation errors to present a more realistic investigation of RIS performance.

V CONCLUSION

The 6G special-purpose Industrial IoT (IIoT) networks functional architecture proposed brings ultra-reliable low-latency communication (URLLC), AI-based resource management, and edge computing into industrial automation for improvement. The architecture enhances industrial automation by embedding network slicing, synchronization mechanisms, and intelligent automation, leading to increased efficiency, adaptability, and security within industrial settings. The research sheds light on the way wireless environment control, predictive analytics, and proactive resource management enhance industrial connectivity in a 6G scenario. By numerical analysis, the viability of the suggested design is confirmed, showing latency, reliability, and operational efficiency improvements.

The proposed architecture has some limitations despite its benefits. One of the key challenges is high deployment cost, as the integration of 6G infrastructure, AI-based automation, and edge computing involves substantial hardware and software investment. Furthermore, intricate implementation creates challenges in real-time AI-based resource allocation and synchronization among various industrial devices. There are compatibility problems as well, as currently installed legacy industrial systems will not integrate easily into 6G-based systems and need major overhauls. Additionally, AI driven networks open up security vulnerabilities, including adversarial attacks and data privacy threats, which must be resolved in order to make the industrial environment secure. To satisfy the demanding needs of industrial applications, the suggested functional architecture for 6G special-purpose Industrial IoT (IIoT) networks combines edge computing, AI-driven resource management, and ultra-reliable low-latency communication (URLLC). The design improves productivity, flexibility, and security in industrial settings by integrating network slicing, synchronization techniques, and intelligent automation. The study shows how proactive resource management, predictive analytics, and wireless environment control may maximize industrial connection within a 6G framework. Through numerical evaluations, the feasibility of the proposed design is validated, showcasing its potential to improve latency, reliability, and operational efficiency in IIoT networks.

VI. REFERENCE

[1]. S. Prasad Tera, R. "Toward 6G: An Overview of the Next Generation of Intelligent Network Connectivity," in IEEE Access, vol. 13, pp. 925-961, 2025.

[2]. I Ishteyaq, K. Muzaffar, N. Shafi and M. A. Alathbah, "Unleashing the Power of Tomorrow: Exploration of Next Frontier With 6G Networks and Cutting Edge Technologies," in IEEE Access, vol. 12, pp. 29445-29463, 2024.

[3]. M. Shafi, R. K. Jha and S. Jain, "6G: Technology Evolution in Future Wireless Networks," in IEEE Access, vol. 12, pp. 57548- 57573, 2024.

[4]. C. T. Nguyen et al., "Emerging Technologies for 6G Non- Terrestrial-Networks: From Academia to Industrial Applications," in IEEE Open Journal of the Communications Society, vol. 5, pp. 3852-3885, 2024.

[5]. N. H. Mahmood, G. Berardinelli, E. J. Khatib, R. Hashemi, C. De Lima and M. Latva aho, "A Functional Architecture for 6G Special- Purpose Industrial IoT Networks," in IEEE Transactions on Industrial Informatics, vol. 19, no. 3, pp. 2530-2540, March 2023.

[6]. K. Quy, A. Chehri, N. M. Quy, N. D. Han and N. T. Ban, "Innovative Trends in the 6G Era: A Comprehensive Survey of Architecture, Applications, Technologies, and Challenges," in IEEE Access, vol. 11, pp. 39824-39844, 2023.

[7]. S. Bhatia, B. Mallikarjuna, D. Gautam, U. Gupta, S. Kumar and S. Verma, "The Future IoT: The Current Generation 5G and Next Generation 6G and 7G Technologies," 2023 International Conference on Device Intelligence, Computing and Communication Technologies, (DICCT), Dehradun, India, 2023.

[8]. D. Zhou, M. Sheng, J. Li and Z. Han, "Aerospace Integrated Networks Innovation for Empowering 6G: A Survey and Future Challenges," in IEEE Communications Surveys & Tutorials, vol. 25, no. 2, pp. 975-1019, Second quarter 2023.

[9]. IX.J. Pei, S. Li, Z. Yu, L. Ho, W. Liu and L. Wang, "Federated Learning Encounters 6G Wireless Communication in the Scenario of Internet of Things," in IEEE Communications Standards Magazine, vol. 7, no. 1, pp. 94-100, March 2023.

[10]. H. R. Chi and A. Radwan, "Quality of Things' Experience for 6G Artificial Intelligent Internet of Things with IEEE P2668," in IEEE Communications Magazine, vol. 61, no. 6, pp. 58 64, June 2023.

[11]. A. Slalmi, H. Chaibi, A. Chehri, R. Saadane and G. Jeon, "Enabling Massive IoT Services in the Future Horizontal 6G Network: From Use Cases to a Flexible System Architecture," in IEEE Internet of Things Magazine, vol. 6, no. 4, pp. 62-67, December 2023.

[12]. M. Yadav, "Exploring Synergy of Blockchain and 6G Network for Industrial Automation," in IEEE Access, vol. 11, pp. 137163- 137187, 2023.

[13]. M. -I. Corici, "Organic 6G Networks: Vision, Requirements, and Research Approaches," in IEEE Access, vol. 11, pp. 70698- 70715, 2023.

[14]. M. A. Farag, "Edge Learning for 6G-Enabled Internet of Things: A Comprehensive Survey of Vulnerabilities, Datasets, and Defenses," in IEEE Communications Surveys & Tutorials, vol. 25, no. 4, pp. 2654-2713, Fourth quarter 2023.

[15]. A. Cherub, "Hybrid Self-Organizing Networks: Evolution, Standardization Trends, and a 6G Architecture Vision," in IEEE Communications Standards Magazine, vol. 7, no. 1, pp. 14-22, March 2023.

[16]. Y. Yang, "Task-Oriented 6G Native-AI Network Architecture," in IEEE Network, vol. 38, no. 1, pp. 219-227, Jan. 2023.

[17]. M. A. Rahman and M. S. Hossain, "A Deep Learning Assisted Software Defined Security Architecture for 6G Wireless Networks: IIoT Perspective," in IEEE Wireless Communications, vol. 29, no. 2, pp. 52-59, April 2022.

[18]. Wu, H. -N. Dai, H. Wang, Z. Xiong and S. Guo, "A Survey of Intelligent Network Slicing Management for Industrial IoT: Integrated Approaches for Smart Transportation, Smart Energy, and Smart Factory," in IEEE Communications Surveys & Tutorials, vol. 24, no. 2, pp. 1175-1211, Second quarter 2022.

[19]. Y. Gong, H. Yao, J. Wang, M. Li and S. Guo, "Edge Intelligence-Driven Joint Offloading and Resource Allocation for Future 6G Industrial Internet of Things," in IEEE Transactions on Network Science and Engineering, vol. 11, no. 6, pp. 5644-5655, Nov.-Dec. 2024, doi: 10.1109/TNSE.2022.

[20]. H. Cui, "Space-air-ground integrated network (SAGIN) for 6G: Requirements, architecture and challenges," in China Communications, vol. 19, no. 2, pp. 90-108, Feb. 2022. how traffic patterns influence emissions

IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE AND TECHNOLOGY

ABOUT IJEAST

International Journal of Engineering Applied Science and Technology (IJEAST) is a peer-reviewed, open access journal that publishes high-quality research papers in the field of Engineering, Applied Science and Technology.

IJEAST aims to provide a platform for researchers, academicians, and professionals to share their innovative ideas, research findings, and practical experiences with the global scientific community.

FOCUS AREAS

- Engineering
- Applied Science
- Technology
- Innovation & Development
- Interdisciplinary Studies

PEER REVIEWED
All submissions are rigorously peer reviewed to ensure quality.

OPEN ACCESS
Free and unrestricted access to research for all.

GLOBAL REACH
Connecting researchers and professionals worldwide.

TIMELY PUBLICATION
We ensure a swift and efficient publication process.

For more information, visit our website
www.ijeast.com

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY

✉ editor@ijeast.com
www.ijeast.com
India

2455-2143