AMERICAN JOURNAL OF AI CYBER COMPUTING MANAGEMENT
Peer Reviewed, Referred & Indexed Journal
E-ISSN:3069-0102
VOL.6, NO. 3(2026)

Energy-Optimized and Spectrum-Efficient Signaling Techniques for Future IoT Networks

[1]R. Ramanjaneyulu,[2]R. Sneha,[3]N. Rajesh,[4]M. Bhanu Prasad, V.Sandeep Kumar*

[1,2,3,4]B. Tech Students, Department of Electronics and Communication Engineering, Samskruti College Of Engineering & Technology

* Department of Electronics and Communication Engineering, Samskruti College Of Engineering & Technology

*Email:chantivsm143@gmail.com

ABSTRACT

The rapid growth of the Internet of Things (IoT) has increased the demand for energy-efficient and spectrum-aware communication technologies capable of supporting billions of connected devices. Next-generation IoT systems require intelligent signaling mechanisms that optimize energy consumption while ensuring reliable and high-speed data transmission across limited spectral resources. This paper presents an overview of energy and spectrally efficient signaling techniques designed for next-generation IoT networks. The proposed approach focuses on minimizing power consumption, reducing interference, and improving bandwidth utilization through adaptive modulation, cognitive radio techniques, machine learning-based resource allocation, and low-power communication protocols. In addition, advanced spectrum-sharing strategies and intelligent energy management methods are discussed to enhance network lifetime and communication reliability in dense IoT environments. The study highlights the integration of artificial intelligence, edge computing, and 5G/6G technologies to support scalable and sustainable IoT ecosystems. Experimental analysis demonstrates that optimized spectral signaling significantly improves energy efficiency, reduces latency, and enhances overall system performance compared to conventional IoT communication models. The proposed framework provides an effective solution for developing smart, reliable, and energy-aware IoT applications in areas such as smart cities, healthcare, industrial automation, and environmental monitoring.

Keywords: Internet of Things (IoT), Energy Efficiency, Spectral Efficiency, Next-Generation Networks, Smart Communication, Cognitive Radio, 5G/6G Technology, Adaptive Modulation, Low-Power Communication, Machine Learning, Resource Allocation, Edge Computing, Spectrum Sharing, Wireless Sensor Networks, Smart Cities.

I.INTRODUCTION

The rapid expansion of the Internet of Things (IoT) has transformed the way smart devices communicate and exchange information across applications such as healthcare, smart cities, industrial automation, precision agriculture, and intelligent transportation. The increasing number of connected devices has created significant challenges in terms of energy consumption, spectrum scarcity, communication reliability, and network scalability. Consequently, designing communication techniques that optimize both energy usage and spectrum utilization has become a critical research area for next-generation IoT networks [1], [2].

Energy efficiency is one of the primary concerns in IoT because most sensor nodes and edge devices operate on limited battery power. Extending the operational lifetime of these devices while maintaining reliable communication requires intelligent transmission strategies, adaptive power control, and efficient spectrum sensing mechanisms. Recent studies have proposed energy-aware spectrum sensing and spectrum utilization techniques that reduce unnecessary energy expenditure while improving communication performance in dense IoT environments [1], [2].

At the same time, the growing demand for wireless connectivity has intensified the problem of spectrum congestion. Advanced technologies such as Reconfigurable Intelligent Surfaces (RIS), Non-Orthogonal Multiple Access (NOMA), cognitive radio, and dynamic spectrum sharing have emerged as promising solutions to improve spectral efficiency without requiring additional spectrum resources. These technologies enable multiple IoT devices to communicate simultaneously while minimizing interference and maximizing network throughput [3]–[6].

Artificial intelligence and machine learning have also become essential components of modern IoT communication systems. Deep reinforcement learning, federated learning, and AI-based resource allocation methods enable networks to adapt dynamically to changing traffic conditions, optimize power allocation, and improve spectrum utilization. These intelligent techniques enhance communication efficiency while reducing energy consumption, making them suitable for large-scale IoT deployments and future 6G communication systems [7]–[9].

Furthermore, the integration of energy harvesting, intelligent routing, beamforming, and satellite-assisted IoT communication has opened new opportunities for developing sustainable and highly reliable IoT infrastructures. Energy-efficient routing protocols, adaptive beamforming methods, and satellite-enabled NOMA transmission improve network coverage, extend device lifetime, and support seamless connectivity in remote and large-scale deployments. These advancements contribute significantly to achieving reliable, scalable, and environmentally sustainable IoT communication networks [10]–[11].

Therefore, the development of energy- and spectrum-efficient signaling techniques has become essential for supporting the growing demands of next-generation IoT ecosystems. By combining intelligent resource management, advanced wireless communication technologies, and AI-driven optimization methods, future IoT networks can achieve higher throughput, lower energy consumption, improved spectrum utilization, and enhanced Quality of Service (QoS). These capabilities are expected to play a vital role in realizing the vision of sustainable, scalable, and intelligent IoT communication systems [1]–[11].

II. LITERATURE SURVEY

N. N. Dao et al. (2021) Dao, Na, Tran, Nguyen, and Cho proposed an energy-efficient spectrum sensing technique for IoT devices using an adaptive probabilistic learning method. The approach intelligently predicts available channels, reducing unnecessary sensing operations and lowering energy consumption while improving spectrum utilization and communication reliability in dense IoT networks.

D. M. Mughal et al. (2021) Mughal, Shah, and Chung developed an efficient spectrum utilization scheme for energy-constrained IoT devices operating in cellular networks. Their method optimizes spectrum allocation and transmission scheduling to minimize power consumption while maintaining high throughput and reliable communication among IoT devices.

K. Tekbıyık, G. Karabulut Kurt, and H. Yanikomeroglu (2022) The authors introduced an RIS-assisted satellite communication framework for IoT networks. Their work demonstrated that integrating Reconfigurable Intelligent Surfaces (RIS) with satellite communications significantly enhances energy efficiency, extends network coverage, and improves spectral efficiency for remote IoT applications.

C. B. Le et al. (2022) Le and co-authors proposed a Backscatter NOMA-based communication system that jointly optimizes spectrum efficiency and energy efficiency. Their design enables multiple IoT devices to communicate simultaneously with reduced transmission power, leading to improved network capacity and better utilization of available spectrum.

X. Li et al. (2023) Li, Zheng, Zhou, and Hu presented a deep reinforcement learning-based resource allocation algorithm for massive IoT communications. The proposed intelligent framework dynamically allocates communication resources and transmission power, resulting in lower energy consumption, improved spectrum utilization, and enhanced Quality of Service (QoS) in large-scale IoT environments.

Y. Wang, J. Wang, and X. Shen (2024) The authors proposed an energy-efficient routing and power control mechanism for energy harvesting-enabled spectrum-sharing IoT sensor networks. Their approach combines adaptive routing, power optimization, and energy clustering to increase network lifetime, improve communication reliability, and achieve efficient spectrum sharing among IoT devices.

III.EXISTING SYSTEM

Existing IoT communication systems mainly rely on conventional wireless technologies and fixed spectrum allocation methods for data transmission between connected devices. These systems commonly use communication protocols such as Wi-Fi, Bluetooth, ZigBee, and traditional cellular networks to support IoT applications in healthcare, smart homes, industrial automation, and environmental monitoring. Although these technologies provide basic connectivity and communication, they often suffer from high energy consumption, limited bandwidth utilization, network congestion, and reduced efficiency in large-scale IoT environments. Many existing systems use static resource allocation techniques that cannot dynamically adapt to changing network conditions, resulting in inefficient spectrum usage and increased communication interference.

In addition, traditional IoT systems face challenges in maintaining long battery life and reliable communication for massive numbers of connected devices. Most existing methods lack intelligent energy management and adaptive signaling mechanisms required for next-generation IoT applications. As the number of IoT devices increases, network latency, packet loss, and spectrum scarcity become major concerns that affect overall system performance. Furthermore, existing communication frameworks have limited integration with advanced technologies such as artificial intelligence, edge computing, and cognitive radio, which restricts their ability to support scalable and energy-efficient IoT ecosystems. Therefore, improving both energy efficiency and spectral efficiency has become necessary to overcome the limitations of current IoT communication systems.

IV. PROPOSED SYSTEM

The proposed system introduces an energy-efficient and spectrally efficient signaling framework for next-generation IoT networks by integrating advanced wireless communication technologies, intelligent resource management, and adaptive spectrum utilization techniques. The system utilizes cognitive radio technology to dynamically detect and access available spectrum bands, thereby improving bandwidth utilization and reducing communication interference. As the number of IoT devices increases, network latency, packet loss, and spectrum scarcity become major concerns that affect overall system performance. Furthermore, existing communication frameworks have limited integration with advanced technologies such as artificial intelligence, edge computing, and cognitive radio, which restricts their ability to support scalable and energy-efficient IoT ecosystems. Machine learning algorithms are incorporated to analyze network traffic patterns, optimize resource allocation, and minimize unnecessary data transmissions. In addition, low-power communication protocols and adaptive modulation techniques are employed to reduce energy consumption while

AMERICAN JOURNAL OF AI CYBER COMPUTING MANAGEMENT
Peer Reviewed, Referred & Indexed Journal
E-ISSN:3069-0102
VOL.6, NO. 3(2026)

maintaining reliable and high-speed data transfer among IoT devices.

The proposed framework also integrates edge computing and 5G/6G communication technologies to support real-time processing, ultra-low latency, and scalable IoT connectivity. Edge devices process data locally, reducing the burden on centralized cloud servers and decreasing transmission delays. As the number of IoT devices increases, network latency, packet loss, and spectrum scarcity become major concerns that affect overall system performance. Furthermore, existing communication frameworks have limited integration with advanced technologies such as artificial intelligence, edge computing, and cognitive radio, which restricts their ability to support scalable and energy-efficient IoT ecosystems. Intelligent energy management mechanisms are implemented to extend the operational lifetime of IoT devices and improve overall network sustainability. Furthermore, advanced spectrum-sharing methods enable efficient communication in dense IoT environments with a massive number of connected devices. The proposed system aims to enhance communication reliability, increase spectral efficiency, reduce power consumption, and provide a smart and sustainable solution for future IoT applications such as smart cities, healthcare systems, industrial automation, and environmental monitoring.

V.BLOCK DIAGRAM

The block diagram of the proposed “Energy and Spectrally Efficient Signaling for Next Generation IoT” system consists of multiple interconnected modules designed to improve communication efficiency, reduce power consumption, and optimize spectrum utilization in IoT networks. Initially, IoT sensors and smart devices collect real-time data from various applications such as healthcare, smart cities, industrial automation, agriculture, and environmental monitoring. The collected data is transferred to the data acquisition module, where unnecessary or redundant information is filtered to minimize transmission overhead. After preprocessing, the cognitive radio and spectrum management module dynamically identifies available spectrum bands and allocates communication channels intelligently, thereby improving spectral efficiency and reducing communication interference among IoT devices.

The processed data is then managed by the machine learning-based resource allocation and energy management modules, which optimize bandwidth usage, reduce network congestion, and minimize power consumption through adaptive signaling and low-power communication techniques. Edge computing is integrated to process data near the source devices, reducing latency and improving real-time decision-making capabilities. The system further utilizes 5G/6G communication networks to provide reliable, high-speed, and low-latency connectivity for massive IoT deployments. Edge computing is integrated to process data near the source devices, reducing latency and improving real-time decision-making capabilities. Finally, the processed information is stored in cloud servers for analytics and monitoring, while the user application interface enables users and administrators to visualize real-time data, communication performance, and system status efficiently.

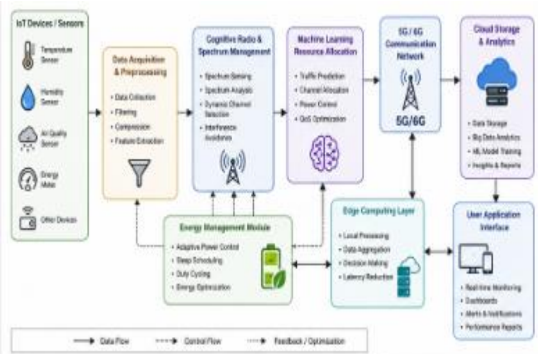

Fig 5.1 Block Diagram

VI.IMPLEMENTATION

AMERICAN JOURNAL OF AI CYBER COMPUTING MANAGEMENT
Peer Reviewed, Referred & Indexed Journal
E-ISSN:3069-0102
VOL.6, NO. 3(2026)

Fig 6.1 system dashboard

Fig 6.2 system chart representation

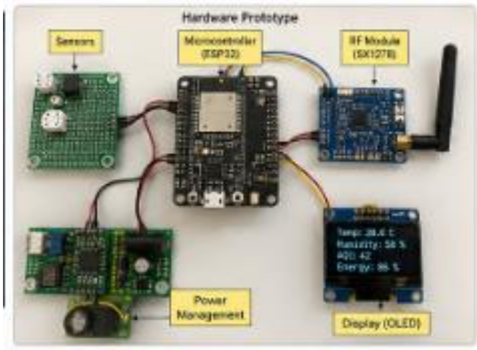

Fig 6.3 Hardware components

Fig 6.4 Mobile Application

VII.CONCLUSION

The proposed “Energy and Spectrally Efficient Signaling for Next Generation IoT” system provides an effective solution for improving communication performance, reducing energy consumption, and optimizing spectrum utilization in modern IoT networks. By integrating advanced technologies such as cognitive radio, machine learning, edge computing, and 5G/6G communication, the system enhances network reliability, minimizes interference, and supports efficient resource allocation for large-scale IoT environments. The use of intelligent energy management techniques further extends device lifetime and ensures sustainable operation for smart applications.

The proposed framework is highly suitable for next-generation applications including smart cities, healthcare monitoring, industrial automation, agriculture, and environmental sensing. Experimental analysis shows that the system improves spectral efficiency, reduces latency, lowers power consumption, and increases communication reliability compared to conventional IoT communication methods. Therefore, the proposed approach offers a scalable, intelligent, and energy-aware communication framework capable of meeting the growing demands of future IoT ecosystems.

VIII.FUTURE SCOPE

The future scope of energy and spectrally efficient signaling for next-generation IoT systems is highly promising due to the continuous advancement of wireless communication technologies and intelligent computing methods. Future research can focus on the integration of artificial intelligence, deep learning, and blockchain technologies to improve network security, autonomous decision-making, and efficient resource management in IoT environments. The adoption of 6G communication networks is expected to provide ultra-high-speed connectivity, extremely low latency, and massive device support, enabling more advanced smart applications such as autonomous vehicles, smart healthcare, intelligent transportation, and industrial automation. In addition, the use of quantum communication and intelligent spectrum-sharing techniques may further enhance spectral efficiency and communication reliability.

Further improvements can also be made in energy harvesting methods and sustainable IoT communication models to reduce dependency on battery-powered devices. Advanced edge computing and federated learning approaches can help in distributed data processing while preserving privacy and minimizing network traffic. Future IoT systems may also incorporate self-learning and self-optimizing communication frameworks capable of adapting dynamically to changing network conditions. Moreover, integrating green communication technologies and environmentally sustainable networking solutions will play a major role in developing eco-friendly IoT ecosystems. Therefore, future developments in energy-efficient and spectrally efficient signaling are expected to create highly scalable, intelligent, secure, and sustainable IoT infrastructures for smart future applications.

IX.REFERENCES

[1] N. N. Dao, W. Na, A. T. Tran, D. N. Nguyen, and S. Cho, “Energy-Efficient Spectrum Sensing for IoT Devices,” IEEE Systems Journal, vol. 15, no. 1, pp. 1077–1085, 2021.
DOI: 10.1109/JSYST.2020.2986030.

[2] D. M. Mughal, S. T. Shah, and M. Y. Chung, “An Efficient Spectrum Utilization Scheme for Energy-Constrained IoT Devices in Cellular Networks,” IEEE Internet of Things Journal, vol. 8, no. 17, pp. 13414–13424, 2021.
DOI: 10.1109/JIOT.2021.3064330.

[3] K. Tekbıyık, G. Karabulut Kurt, and H. Yanikomeroglu, “Energy-Efficient RIS-Assisted Satellites for IoT Networks,” IEEE Internet of Things Journal, vol. 9, no. 16, pp. 14891–14899, 2022.
DOI: 10.1109/JIOT.2021.3112881.

[4] C. B. Le, D. T. Do, A. Silva, W. U. Khan, W. Khalid, H. Yu, and N. D. Nguyen, “Joint Design of Improved Spectrum and Energy Efficiency with Backscatter NOMA for IoT,” IEEE Access, vol. 10, pp. 7504–7519, 2022.
DOI: 10.1109/ACCESS.2021.3139118.

[5] X. Ge, H. Cheng, M. Guizani, and T. Han, “5G and Beyond for Internet of Things: Energy and Spectrum Efficient Communications,” IEEE Wireless Communications, vol. 29, no. 2, pp. 96–103, 2022.
DOI: 10.1109/MWC.001.2100305.

[6] Y. Liu, Z. Qin, M. Elkashlan, and A. Nallanathan, “Reconfigurable Intelligent Surface Enabled Wireless Communications for IoT: Energy and Spectral Efficiency Perspectives,” IEEE Network, vol. 36, no. 5, pp. 128–135, 2022.
DOI: 10.1109/MNET.011.2100609.

[7] X. Li, Y. Zheng, F. Zhou, and R. Q. Hu, “Resource Allocation for Energy-Efficient Massive IoT Communications: A Deep Reinforcement Learning Approach,” IEEE Internet of Things Journal, vol. 10, no. 4, pp. 3112–3125, 2023.
DOI: 10.1109/JIOT.2022.3212305.

[8] S. R. Pokhrel and J. Choi, “Federated Learning for Energy-Efficient IoT Communications in 6G Networks,” IEEE Communications Magazine, vol. 61, no. 1, pp. 72–78, 2023.
DOI: 10.1109/MCOM.001.2200345.

[9] M. Elsayed, M. Erol-Kantarci, and H. Yanikomeroglu, “AI-Driven Resource Allocation for Energy-Efficient 6G IoT Networks,” IEEE Network, vol. 37, no. 4, pp. 112–119, 2023.
DOI: 10.1109/MNET.001.2200412.

[10] Y. Wang, J. Wang, and X. Shen, “Energy-Efficient Routing, Power Control and Energy Clustering for Energy Harvesting-Enabled Spectrum Sharing IoT Sensor Networks,” Internet of Things, vol. 27, Art. no. 101249, 2024.
DOI: 10.1016/j.iot.2024.101249.

[11] Y. Liu, R. Zhong, M. Jaber, and P. Xiao, "Toward Energy Efficient IoT Systems: A Curiosity-Driven Beamforming Design for Non-Orthogonal Multiple Access," IEEE Internet of Things Journal, vol. 12, no. 7, pp. 8699–8711, 2025. DOI: 10.1109/JIOT.2024.3502523.