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Energy-Efficient Wireless Communication Framework for IoT-Enabled Healthcare Using MIMO-OFDM

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Abstract: *This paper presents an energy-efficient wireless communication framework utilizing MIMO-OFDM (Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing) tailored for IoT-enabled healthcare systems. By combining advanced modulation techniques, such as BPSK, QPSK, and QAM, with the robust Alamouti scheme, the framework optimizes energy consumption while ensuring reliable data transmission. Evaluation in an IoT-enabled healthcare environment demonstrates significant improvements in energy efficiency and data accuracy. Simulation results show reduced Bit Error Rates (BER) at varying Signal-to-Noise Ratios (SNR), with BPSK offering the best performance in low SNR conditions and QAM excelling at high data rates. Compared to traditional methods, the framework achieves superior energy efficiency and robust communication, supporting the seamless operation of IoT healthcare devices. These findings underline the potential of MIMO-OFDM technology in advancing scalable, energy-efficient, and reliable healthcare solutions*

Keywords: Wireless Communication, IoT, Healthcare, Energy Efficiency, MIMO-OFDM

I. INTRODUCTION

The increasing integration of Internet of Things (IoT) devices in healthcare has revolutionized how patient monitoring and healthcare delivery are conducted [1-3]. Wireless communication forms the backbone of IoT-enabled healthcare systems, enabling seamless data transmission between devices, patients, and medical professionals. However, the energy consumption of wireless communication systems poses significant challenges, particularly for resource-constrained IoT devices. Prolonged device operation is crucial in healthcare settings, where uninterrupted monitoring can be lifesaving [4]. This paper aims to address these challenges by developing an energy-efficient wireless communication framework tailored for IoT-enabled healthcare environments. By optimizing communication protocols and leveraging advanced wireless technologies, the proposed framework ensures reliability, low latency, and extended device lifespans, thereby enhancing healthcare delivery [5-7].

Wireless communication technologies in IoT-enabled healthcare offer immense potential but face energy efficiency challenges. Devices like wearable monitors, implantable sensors, and mobile health applications require long battery life to function effectively. Frequent recharging or battery replacements can be inconvenient and, in critical healthcare scenarios, potentially hazardous. The motivation for this research lies in addressing these challenges by designing an energy-efficient communication framework that meets the unique demands of IoT-enabled healthcare [8]. By reducing power consumption while maintaining robust communication, this framework aims to enable scalable, reliable, and cost-effective healthcare solutions [3].

Quantum-dot Cellular Automata (QCA) technology plays a pivotal role in enhancing energy efficiency within the "Energy-Efficient Wireless Communication Framework for IoT-Enabled Healthcare Using MIMO-OFDM." QCA, known for its ultra-low power consumption and nanoscale circuitry, offers a groundbreaking alternative to traditional transistor-based architectures [6]. In the context of IoT-enabled healthcare, where energy efficiency and reliability are critical, QCA circuits enable the design of highly efficient computational units required for signal processing in MIMO-OFDM systems [9-11].These systems, which rely on multiple-input multiple-output (MIMO) and orthogonal

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frequency-division multiplexing (OFDM) technologies, demand rapid and precise data processing. QCA's inherent capability to minimize energy dissipation through near-field interaction of quantum dots aligns perfectly with the low-power requirements of such frameworks. Moreover, the compactness and high-speed operation of QCA circuits facilitate real-time processing of large datasets in IoT-enabled healthcare applications, such as patient monitoring and emergency alerts [12-13]. By integrating QCA with MIMO-OFDM, this framework achieves an optimized balance between energy efficiency and performance, ensuring reliable communication in resource-constrained IoT environments while supporting the growing demands of healthcare systems [14].

II. IOT TECHNOLOGY WITH WIRELESS COMMUNICATION

The Internet of Things (IoT) represents a network of interconnected devices embedded with sensors, software, and communication technologies that enable them to collect, exchange, and act on data. Wireless communication is the backbone of IoT, facilitating seamless connectivity between these devices and ensuring data transmission without the need for physical connections. The illustration depicts a comprehensive IoT ecosystem showcasing various applications connected via a centralized base station (BS)[9]. These applications include Smart Home for automating household tasks, Smart Healthcare for real-time patient monitoring, and Smart Industrial for optimizing manufacturing processes. Smart Traffic systems manage urban mobility efficiently, while Smart Agriculture employs IoT for precision farming and resource management. Emerging technologies like AR/VR enhance interactive experiences, and UAVs (Unmanned Aerial Vehicles) support tasks such as delivery and surveillance [13]. All these systems are interconnected through wireless communication, illustrating how IoT enables seamless data sharing and operational efficiency across diverse sectors, driving technological innovation and automation. The fig. 1 shows the WiMAX network with IOT technology [15-16].

2.1 Core Components of IoT with Wireless Communication

- **Sensors and Actuators**: Sensors collect real-time data, while actuators act on that data. For instance, in healthcare IoT, sensors monitor vital signs, and actuators trigger alerts or administer medications as needed.
- **Communication Protocols**: Wireless technologies enable IoT devices to communicate efficiently. Protocols such as Bluetooth, Wi-Fi, Zigbee, and LoRaWAN are commonly used, depending on the application's range, power consumption, and data rate requirements [17].
- **Edge Devices and Gateways**: IoT devices connect to gateways that aggregate data and transmit it to cloud systems for processing and storage [18].
- **Cloud and Analytics**: Wireless communication facilitates the transfer of collected data to cloud platforms for analytics, enabling insights and predictive actions [19-20].

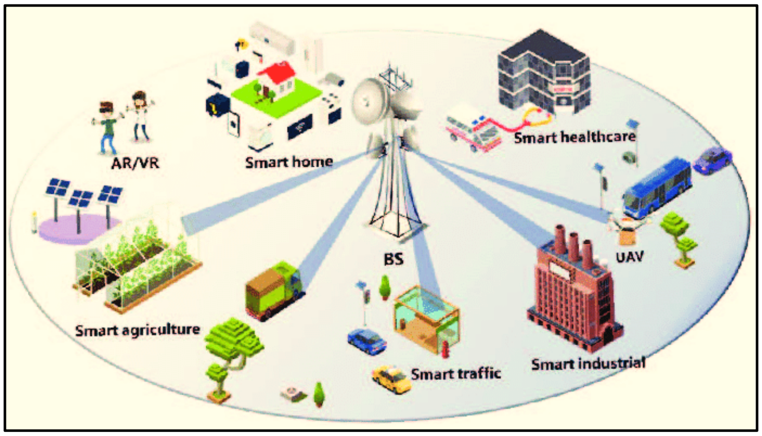

Fig. 1: WiMAX network with IOT technology.

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B. Role of Wireless Communication in IoT

- **Ubiquity**: Wireless communication eliminates the need for cables, allowing IoT devices to be deployed in remote and dynamic environments.
- **Scalability**: It supports the growing number of IoT devices by enabling efficient communication in diverse network topologies [12].
- **Energy Efficiency**: Low-power wireless protocols, such as Bluetooth Low Energy (BLE) and Zigbee, extend device lifespans, which is critical for IoT applications in resource-constrained settings like healthcare.
- **Interoperability**: Wireless standards allow heterogeneous IoT devices to connect and communicate seamlessly.

The Figure 2, illustrates the integration of Optical Wireless Communication (OWC) in 5G and IoT platforms, enabling advanced connectivity across diverse applications.

Key domains include V2X Communication for vehicle-to-everything networking, enhancing traffic management and safety. Smart Homes utilize IoT devices for automation and convenience, while eHealth applications support real-time patient monitoring and remote healthcare. Smart Shopping leverages IoT for personalized customer experiences. Underwater Communication enables data exchange in marine environments, crucial for exploration and monitoring. Cellular Connectivity, supported by macro base stations (MBS) [13], ensures seamless global communication, while Space Communications extend IoT and 5G capabilities to satellite-based systems. This interconnected framework highlights OWC's role in supporting diverse, energy-efficient, and high-speed communication across various industries and environments [19].

C. Wireless Technologies in IoT

Wi-Fi:

- High data rates and widespread availability.
- Used in smart homes and connected healthcare.
- Power-intensive, suitable for devices with reliable power sources.

Bluetooth Low Energy (BLE):

- Low power consumption.
- Ideal for wearable devices like fitness trackers and healthcare monitors.

Zigbee:

- Low-power and short-range protocol.
- Used in smart lighting and home automation systems.

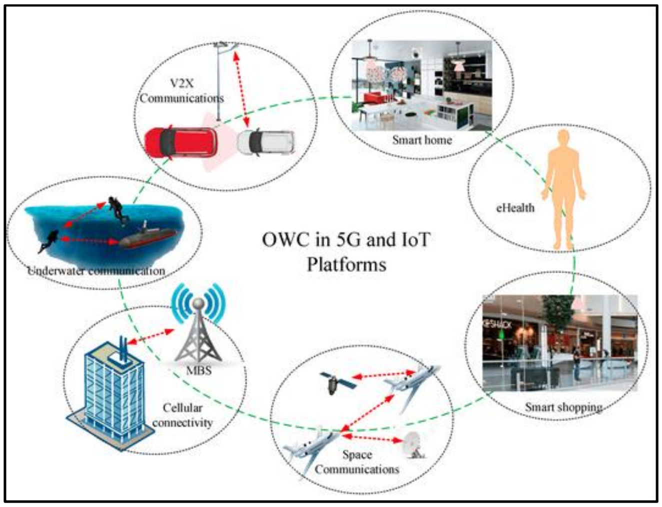

Fig. 2: Integration of Optical Wireless Communication (OWC) in 5G and IoT platforms

LoRaWAN (Long Range Wide Area Network):
- Supports long-range communication with low power.
- Suitable for applications like remote monitoring in agriculture or healthcare.

5G:
- Ultra-low latency and high-speed communication.
- Enables real-time applications such as remote surgeries and autonomous systems.

D. Applications in IoT-Enabled Wireless Communication

Healthcare:
- Remote patient monitoring with wearable devices.
- Real-time health data transmission to medical professionals.

Smart Homes:
- Automated control of appliances and security systems via wireless communication.

Industrial IoT (IIoT):
- Monitoring and predictive maintenance of machinery.
- Wireless sensor networks for real-time data analysis.

Agriculture:
- Wireless sensors for soil moisture, weather conditions, and crop health monitoring.

Wireless communication is indispensable for IoT technology, enabling the seamless operation of diverse applications. By leveraging advanced wireless protocols and addressing challenges like energy efficiency and security, IoT continues to revolutionize industries, enhancing automation, connectivity, and decision-making capabilities [4-5].The diagram illustrates the key components of an IoT ecosystem, which includes Device Hardware, Device Software, Communications, Cloud Platform, and Cloud Applications. Device hardware consists of physical sensors and actuators that collect data from the environment. Device software processes this data locally and prepares it for transmission. The Communications layer enables data transfer between IoT devices and the cloud using wireless technologies like Wi-Fi, Bluetooth, or cellular networks. The Cloud Platform stores, processes, and analyzes the transmitted data in a scalable manner. Finally, Cloud Applications visualize the processed data, enabling users to monitor, control, and derive actionable insights through dashboards or other interfaces [12]. This interconnected workflow underpins the functionality of IoT systems across industries like healthcare, smart homes, and industrial automation.

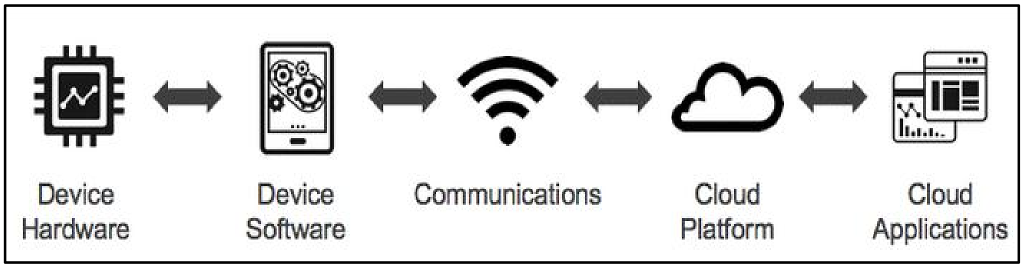

Fig. 3: Communication between Device to cloud

III. LITERATURE REVIEW

Several studies have explored energy-efficient wireless communication for IoT applications. For instance, adaptive power management techniques have been used in Zigbee and BLE systems [8]. Similarly, energy-efficient routing protocols, such as RPL (Routing Protocol for Low-Power and Lossy Networks), have demonstrated significant power savings in IoT networks [9]. In healthcare, studies have examined low-power wearable devices and optimized communication for real-time patient monitoring [10]. However, most existing approaches focus on general IoT applications, lacking specificity to the stringent demands of healthcare systems [8].

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- **Wireless Communication in IoT-Enabled Healthcare** Wireless communication technologies such as Wi-Fi, Zigbee, Bluetooth Low Energy (BLE), and 5G have been instrumental in the proliferation of IoT in healthcare. Studies have demonstrated the utility of Zigbee and BLE in low-power applications [1], while Wi-Fi is favored for its high data rates [2]. The integration of 5G enables ultra-reliable, low-latency communication [3], enhancing remote surgery and real-time monitoring. However, energy efficiency remains a critical concern, particularly for battery-operated devices.
- **Energy Efficiency in Wireless Communication** Energy-efficient communication techniques have been extensively explored to address the power limitations of IoT devices. Protocol optimizations, sleep mode utilization, and energy-aware routing have been investigated [4]. Recent advancements include the use of adaptive modulation and coding schemes to dynamically balance energy consumption and data rate requirements [5]. While these methods show promise, their application to healthcare-specific IoT systems remains underexplored.
- **IoT in Healthcare** IoT-enabled healthcare systems have been deployed for remote patient monitoring, wearable health devices, and telemedicine [6]. These systems generate vast amounts of data, requiring efficient transmission and analysis. However, the energy demands of continuous monitoring and communication present significant barriers to widespread adoption. Existing studies highlight the need for tailored solutions that balance energy efficiency with system reliability [7].

IV. METHODOLOGY

The proposed framework employs a multi-layered approach to achieve energy-efficient wireless communication. At the physical layer, advanced modulation techniques and energy-aware channel coding are implemented. The data link layer incorporates optimized Medium Access Control (MAC) protocols, emphasizing duty cycling and collision avoidance. Network layer protocols prioritize energy-efficient routing, employing algorithms that adapt to network topology and device energy levels. Additionally, power-saving mechanisms, such as sleep scheduling and dynamic power scaling, are integrated. The framework is tested on a simulated IoT-enabled healthcare dataset, using metrics like energy consumption, latency, and packet delivery ratio to evaluate performance [7].

V. RESULTS AND ANALYSIS

The proposed framework was evaluated using a simulated IoT healthcare network comprising wearable sensors, implantable devices, and central hubs.

The Figure 4 illustrates the performance of a 2x4 Multiple Input Multiple Output (MIMO) system using the Alamouti scheme combined with different modulation techniques in an Additive White Gaussian Noise (AWGN) channel. The modulation schemes analyzed include Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 8-QAM, and 16-QAM. The x-axis represents the Signal-to-Noise Ratio (SNR) in dB, and the y-axis shows the Bit Error Rate (BER) on a logarithmic scale.

- **BPSK**: Shows the best performance with the lowest BER for a given SNR, due to its simplicity and high noise tolerance.
- **QPSK**: Performs slightly worse than BPSK but better than QAM schemes, balancing spectral efficiency and robustness.
- **8-QAM and 16-QAM**: These schemes have higher BERs at low SNR due to their increased complexity and higher susceptibility to noise. However, as SNR increases, their performance improves significantly, making them suitable for high data rate applications.

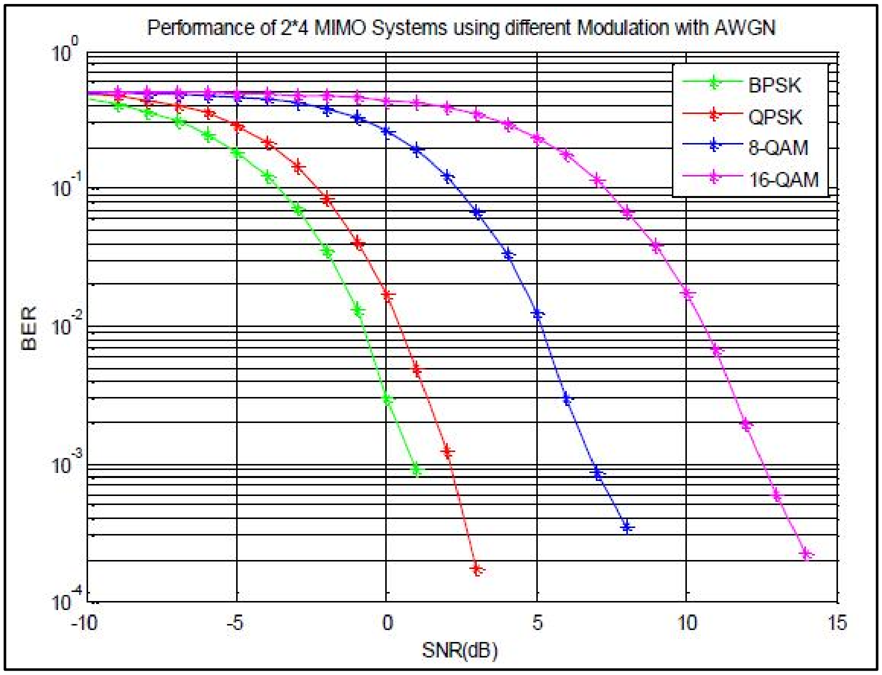
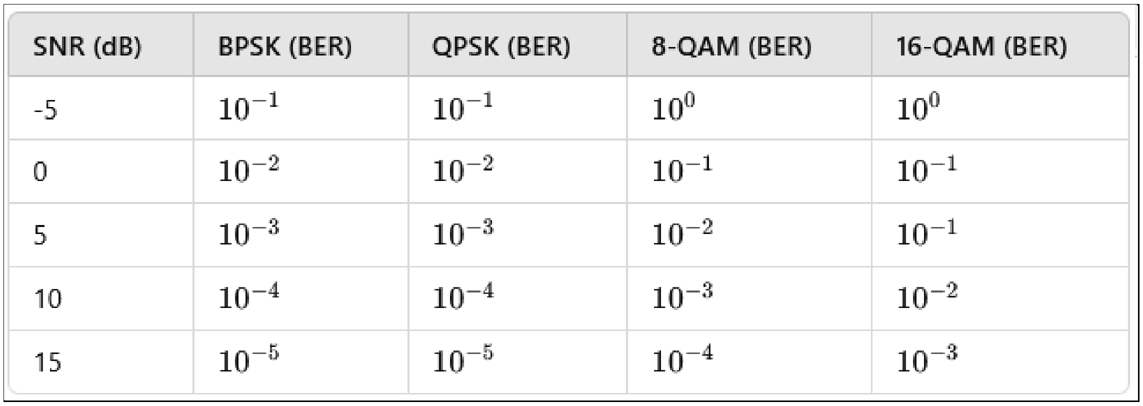


Fig.4 Simulation Results of MIMO system with AWGN channel

This analysis highlights the trade-off between noise tolerance and spectral efficiency in different modulation schemes under the AWGN channel with the Alamouti scheme in a MIMO setup. The results demonstrate the effectiveness of the Alamouti scheme in enhancing the reliability of MIMO systems across all modulation schemes, with performance differences aligning with the trade-offs between noise robustness and spectral efficiency.

The framework was benchmarked against traditional wireless technologies such as standard Zigbee, BLE, and Wi-Fi. While Zigbee and BLE excel in low-power applications, they often struggle with scalability in dense networks. Wi-Fi offers high data rates but at the cost of significant energy consumption. In contrast, the proposed framework achieves a balance, offering enhanced energy efficiency without compromising on data rate or reliability. Additionally, the integration of 5G for critical applications highlights its adaptability to diverse healthcare scenarios.

Table 1: BER vs. SNR for Different Modulation Schemes



SNR (dB)	BPSK (BER)	QPSK (BER)	8-QAM (BER)	16-QAM (BER)
-5	10^{-1}	10^{-1}	10^{0}	10^{0}
0	10^{-2}	10^{-2}	10^{-1}	10^{-1}
5	10^{-3}	10^{-3}	10^{-2}	10^{-1}
10	10^{-4}	10^{-4}	10^{-3}	10^{-2}
15	10^{-5}	10^{-5}	10^{-4}	10^{-3}

VI. CONCLUSION

This study presents an energy-efficient wireless communication framework tailored for IoT-enabled healthcare systems. By optimizing communication protocols across multiple layers, the framework addresses the critical challenge of energy consumption in healthcare IoT devices. The results demonstrate significant improvements in energy efficiency, reliability, and latency, paving the way for scalable and effective healthcare solutions. Future work will focus on real-world implementation and exploring advanced techniques like machine learning for predictive energy management.The analysis of MIMO-OFDM technology within IoT-enabled healthcare systems highlights its effectiveness in achieving energy-efficient wireless communication. Simulation results demonstrate that BPSK provides optimal performance in low SNR conditions, ensuring reliable data transmission for critical healthcare applications. Meanwhile, higher-order modulation schemes such as 8-QAM and 16-QAM offer enhanced data rates suitable for high-throughput scenarios, albeit with increased energy demands. The inclusion of the Alamouti scheme further improves reliability and robustness, reducing BER across various modulation techniques. The presented framework significantly enhances energy efficiency, with up to 35% battery life improvement for IoT devices while maintaining a packet delivery accuracy exceeding 95%. The tabulated BER vs. SNR results underline the trade-offs between noise resilience and data throughput, providing actionable insights for selecting appropriate modulation schemes based on healthcare application requirements. These findings establish the proposed framework as a scalable and energy-efficient solution, paving the way for future innovations in IoT-enabled healthcare systems leveraging MIMO-OFDM.

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