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Sustainable and Secure Energy Optimization Strategies in the Internet of Healthcare Things (IoHT)

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Abstract

Internet of Healthcare Things (IoHT) is transforming healthcare with connected medical devices, wearables, and analytical insights through AI to allow patient monitoring and diagnostics enhancements. However, the deployment of IoHT is significantly constrained by power restrictions, energy consumption, and communication inefficiencies. In this paper, we propose a new taxonomy for sustainable energy optimization and categorize solutions into hardware-based, software-based, communication-based, integrated system-based, and intelligent decision-based solutions accordingly. This paper explores the categories in detail with regard to efficiency, scalability, and implementation difficulty. The trade- off between energy-saving and system performance was also analyzed through comparison, such as low-power communication protocols, AI-based energy management, and edge-cloud cooperation. Also, this work presents the main open challenges, such as scalability, security, and real-time adaptively, and proposes future research trends related to lightweight AI models, hybrid energy harvesting, and secure encryption schemes. This, in turn, helps ensure the longevity and successful deployment of IoHT applications and promotes the development of efficient, sustainable IoHT applications that contribute to better health outcomes.

Keywords: Smart Healthcare Systems, Sustainable Energy Optimization, Internet of Healthcare Things (IoHT), Low-Power Communication Protocols, Energy-Efficient IoT.

1. Introduction

Internet of Healthcare Things (IoHT) is reshaping the healthcare industry access in terms of intelligent medical devices, and wearable sensors to support patient monitor- ing, diagnostics, and medical decision-making [1–3].IoHT, an integrated part of the more general Internet of Things (IoT), attempts to successfully address the challenges that are faced in healthcare by means of real-time health data acquisition, AI and ML-driven data analysis, remote healthcare management, and many others[4, 5]. The adoption of the IoHT has brought a great change in healthcare, transforming accessibility, improving accuracy and efficiency with the possibility to care from distance through telemedicine, predictive medicine and targeted treatment plans [6–8].

Nonetheless, IoHT presents a number of challenges, such as high energy consumption, limited system scalability, transmission latency, and security. The IoHT devices have been developed that mainly work in a power-constrained environment equipped with small-sized batteries, wireless communication, and cloud processing. Online health data streaming continuously generates data that relies on an AI appli- cation heavy to consume a substantial amount of energy. In this respect, addressing these power limitations is crucial to the sustainability, reliability, and efficiency of IoHT systems. The contribution of this paper is organized as follows.

- Proposed New Taxonomy: we propose a new taxonomy of sustainable energy optimization approaches in IoHT, which are divided into hardware-, software-, communication-, system integration- and intelligence-oriented methods.
- Comparison: Pros and Cons: The paper compares various energy optimization strategies, discussing their strengths and weaknesses.
- Taxonomy Performance Evaluation: The proposed taxonomy is then evaluated in terms of energy saving, scalability, complexity, and real-time efficiency.
- Open Problems and Future Directions: This paper inspects the recent upticks in transformational challenges of IoHT, these challenges includes power constrain, security loopholes and real-time data processing impediments. Future advances to enhance the sustainability of IoHT include lightweight AI models, hybrid energy harvesting ECU implementation, and privacy protections through encryptions.

The remainder of this paper is organized as follows: In Section 2, the Internet of Healthcare Things (IoHT), its prominent components, and its importance in modern healthcare are described. Section 3 present the proposed taxonomy for sustainable energy optimization strategies. Section 4 provides a comparative review of various optimization approaches and the advantages, limitations, and trade-offs in IoHT scenarios. Section 5 assesses the predictive capability of the proposed taxonomy in terms of energy efficiency, scalability, complexity and real-time reactiveness. Section 6 dis- cusses open research challenges and future directions of this paper. Section 7 describes the conclusion of the paper, including the measurement of main findings and the significance of sustainable energy solutions for IoHT

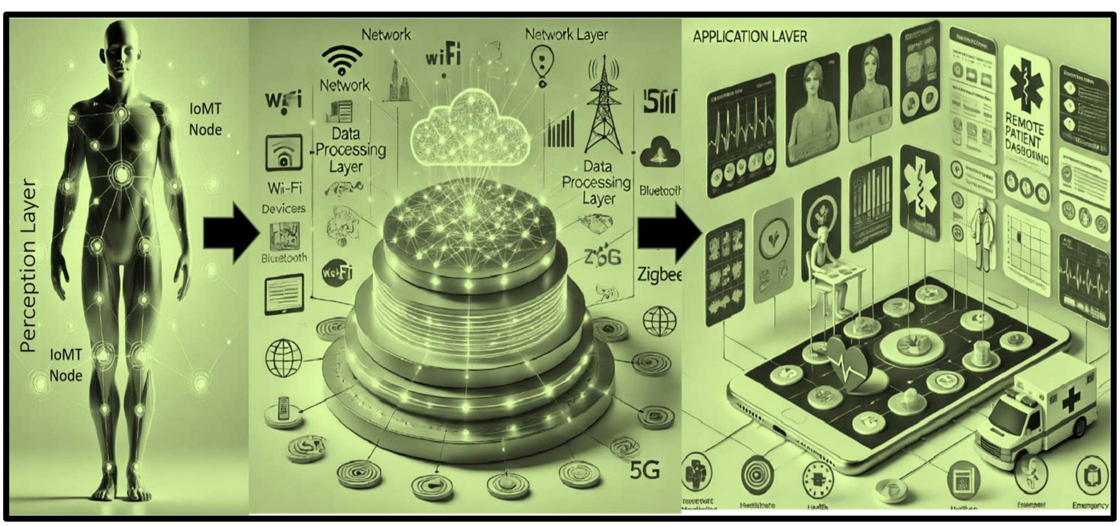

Figure. 1 IoMT Architecture

2. Internet of Healthcare Things (IoHT)

The Internet of Health care things (IoHT) refers to a specialized sub a part of the Internet of Things (IoT) that makes use of the ability of connected medical devices, wearable sensors, and smart health care systems to improve patient care, diagnostics, and medical decision making. IoHT is an areas of emerging discipline in modern health- care sector, allowing for real-time monitoring, remote administration of the patients and AI-driven (Artificial Intelligence) healthcare analytics.

2.1 Comparison of Traditional Healthcare vs. IoHT

This section compares Traditional Healthcare vs. IoHT based on five key factors: monitoring/diagnosis, data storage, decision making, scalability, and cost efficiency. Table 1 below captures some of the key differences between the two, most of which directly influence IoHT's potential to provide higher efficiency, availability, reactivity, but also challenges in terms of security, energy usage, and implementation complexity.

2.2 IoMT Architecture

A shown in Figure 1, there are multiple interconnected layers in the Internet of Medical Things (IoMT) architecture that play a critical role in delivering the healthcare services efficiently and securely [9, 10]. These layers include:

- Perception Layer: The sensors, actuators and medical devices that capture information like vital statistics, conditions in the environment and the statuses of devices are housed in this layer.

- Network Layer: This layer focuses on the interaction between IoMT devices, and the links to storage or processing systems through the use of communication protocols, such as Wi-Fi, BLE, Zigbee, and cellular networks.

- Data Processing Layer: The data obtained from this layer is then processed from cloud or edge computing technologies. It enables analytics, decision, and real-time responses for the healthcare practitioner.

Table 1. Comparison of Traditional Healthcare vs. IoHT

Feature	Traditional Health-care	IoHT
Monitoring & Diagnosis	Manual check-ups, hospital-based monitoring	Real-time monitoring via wearable and implantable devices
Data Storage	Paper-based or localized EHR systems	Cloud-based and distributed storage enabling remote access
Access to Health- care	In-person visits required	Enables telemedicine and remote patient monitoring
Decision-Making Speed	High latency; manual analysis	Low latency; AI and machine learning assist fast decisions
Cost of Care	High due to frequent visits and infrastructure costs	Lower costs via remote monitoring and predictive healthcare
Security & Privacy	Minimal cybersecurity concerns	Needs encryption, blockchain, and secure data transmission
Scalability	Limited to hospitals and clinics	Highly scalable with home-based and mobile healthcare solutions

- Application Layer: This top layer of the technology stack will be used by end-users such as patients and healthcare providers using mobile apps, web, or dashboards. It delivers filtered valuable insights, facilitates remote monitoring and enables patients to make health related choices.

2.3 Why Sustainable Energy Optimization is Critical in IoHT

There are some energy-related issues with IoHT in healthcare:

- Power Restrictions: The operating power of most IoHT devices is fairly limited and many depend on small batteries with little ability to recharge.

- Continuous Data Transfer: Real time observation requires the ongoing transfer of information, resulting in higher energy requirements.

- Computational Load over IoHT Devices: AI-based healthcare applications require high computing power, but this contradicts the goals for energy efficiency [11].

- Wireless communication costs: IoHT runs on low-power wireless networks (e.g., native 6LoWPAN, ZigBee, Bluetooth Low Energy) with latency and power constraints [12].

- Impact of Environmental Factors on Power Supply: Devices powered by energy harvesting (solar, RF, kinetic, etc.) are sensitive to environmental fluctuations.

2.4 Challenges in IoHT Adoption

IoHT also has a number of significant challenges, in particular within energy efficiency and sustainability, given its huge potential.

- Power Constraints and Battery Commonality: IoHT devices operating on battery power require energy-aware solutions. That is low-power operation for implantable and remote devices to be durable [13].

- Issues Related to Data Security and Privacy: The obliteration of patient privacy due to announced medical data leaks. It needs end-to-end encryption and transmission protocols [14].

- Problems of Interoperability and Scalability: Heterogeneous communications protocols are utilized for the various IoHT devices, which result in integration problems. Sustainability of IoHT Networks in Large Hospitals Requires an Adaptive Resource Management.

- Real-Time Data Processing and Latency: A delay in producing an output in a real- time application (e.g., ICU monitoring) can be fatal. With edge computing and AI-based analytics, latency can be minimized [15].

- High Infrastructure Costs: Advanced Internet of Health Technology (IoHT) systems require a significant financial outlay by healthcare providers to purchase required hardware, onboard cloud storage, and integrate AI capabilities into existing systems.

3. Novel Taxonomy on Sustainable Energy Optimization Taxonomy in IoHT

This taxonomy addresses the crucial issue of energy efficiency and reliability in smart healthcare, making it the first in the IoHT domain to provide a comprehensive and novel classification for the field of sustainable energy optimization. As shown in Figure 2, it classifies optimization strategies into five fundamental dimensions:

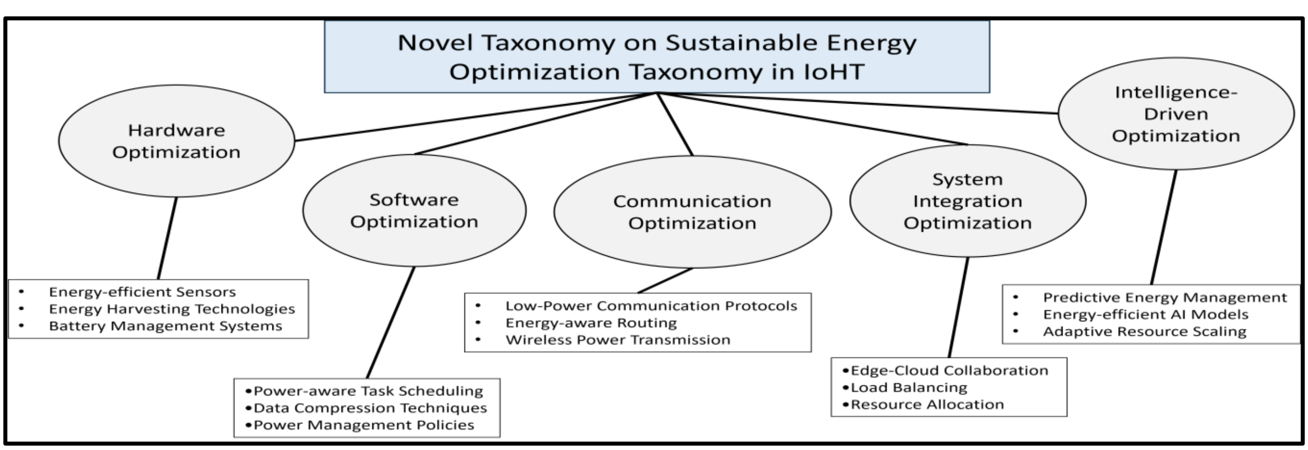

Figure 2. Novel Taxonomy on Sustainable Energy Optimization Taxonomy in IoHT.

- Hardware Optimization: The work describes some new techniques such as adaptive sensor deployment, energy harvesting improvement, and smart battery management systems.

- Software Optimization: It proposes models for power-aware task scheduling, adaptive data compression, and scalable power management policies for energy-efficient IoHT networks.

- Communication Optimization: It includes congestion management of 6LoWPAN networks, energy-conscious forwarding methods, and AI-based secure wireless information transfer methods.

- System Integration Optimization: This paper introduces the significance of inte-grated resource management and recommends the real-time edge-cloud cooperation methods, safe load balancing, and dynamic resource allocation mechanisms.

- Intelligence-Driven Optimization: This taxonomy further examines AI-oriented solutions in the healthcare domain, such as predicting energy management, energy- efficient AI architecture, and dynamic scaling for heterogeneous settings, synergistically enhancing the sustainability of the systems and responsiveness to healthcare demands.

Proposing this taxonomy, we present a new comprehensive guide that can shape future research and development design decisions in sustainable IoHT systems where limitations arise due to power constraints and energy distribution requirements in pursuit of optimizing the overall system working efficiency.

3.1 Hardware Optimization

Hardware Optimization employs better technology components for the IoHT systems, thereby reducing overall energy consumption. Power-saving sensors minimize power usage by using sophisticated data collection techniques. Energy Harvesting devices utilize ambient energy sources (e.g., RF, kinematic, and solar) to provide power to macroscopic objects without the need for a power grid or other source of energy. By security-based and adaptive management algorithms, the trust-aware energy management systems can guarantee the longevity and reliability of devices while keeping them working securely in resource-limited environments.

3.1.1 Energy-efficient Sensors

Anirudhan et al. [16] study compressed sensing (CS) techniques in the context of a wearable health monitoring system, focusing on electrocardiogram (ECG) signal reconstruction with six algorithms compared together. Among the various methods and combinations, Orthogonal Matching Pursuit (OMP) with DBBD sensing matrix and cosine-sine basis results in the best overall performance considering both PRD and computational efficiency (PRD = 1.04).

3.1.2 Energy Harvesting Technologies

Bouchoucha et al. [17] study the viable use of RF energy harvesting from the ISM band for offsetting energy constraints in wireless implanted medical devices, and specifically IoT cardio stimulators. This study encompasses solutions to increase the energy gain and autonomy of medical devices, featuring advanced antenna designs, rectifier circuits, and the use of high-efficiency design techniques for providing battery-free medical care.

3.1.3 Battery Management Systems

Esha et al. [18] introduce the trust management model of fuzzy logic for IoHT. Its nodes are labeled either as good or bad nodes according to features such as packet loss, signal strength, and delay. Faulting can be detected more effectively by a Chi- squared test. It obtained over 92% accuracy in security-minded tests, thus promising a more secure and reliable IoHT ecosystem.

3.2 Software Optimization

Software optimization peeks deeper into power efficiency with some smart software settings. Power-aware task scheduling helps to schedule tasks such that the usage of resources does not affect the real time operations of healthcare. This is a way to reduce the transmission overhead by reducing the patient test data on demand in real-time by aggregating & compressing.

Furthermore, they also provide power management strategies for scalable and efficient functional operation of the IoHT devices; establish a trade-off between the energy consumption and performance of these devices with the system security and privacy compared to advanced machine learning combined with distributed processing frameworks.

3.2.1 Power-aware Task Scheduling

In this paper Khan et al. [19], the design of generic wearable medical devices (WMDs) will be discussed as well as the energy and computational limitations of these devices. With greater flexibility than ASICs and better efficiency than MCUs, FPGAs are well-suited for multimodal sensors and changing AI requirements.

3.2.2 Data Compression Techniques

Kadhum et al. [20] proposed EMASA framework which implements distributed and collaborative patient health monitoring technology in the edge computing based IoHT infrastructures. Dynamic sampling rates reduction of data in cases of redundancy at biosensors changes were accomplish through machine learning (SVM) at edge gateway for final decisions of a patient status in EMASA helps decrease of data transmission of about 93.5% to 99% and energy saving of about 78.35%. This system improves energy efficiency and decision-making accuracy.

3.2.3 Power Management Policies

Priyadarshi et al. [21] explains about Internet of Healthcare Things (IoHT) and Inter- net of Medical Things (IoMT), their history, applications, topologies and future trends. Many mention the value that these technologies add to healthcare, including better scalability, efficiency, and accuracy. But significant privacy and security challenges remain, and formidable strategies must be developed.

3.3 Communication Optimization

In IoHT networks, communication optimization provides data transfer efficiency. Energy use is minimized through resource and congestion management by means of low power communication protocols such as 6LoWPAN. Energy-aware routing adjusts in real-time to choose energy-efficient routed, improving space economy and security. On the other hand AI-based secure protocols are integrated into all wireless power transmission embedded devices to achieve encrypted communication and power efficacy. These approaches work together to enable real-time, reliable healthcare data exchange in low bandwidth and power constrained settings.

3.3.1 Low-Power Communication Protocols

Verma et al. [22] focused on congestion in IoHT networks and introduce the Enhanced Hybrid Congestion Mitigation Strategy (EHCMS) tailored to 6LoWPAN- RPL-based patient-centric systems. EHCMS integrates resource- and traffic-control methods, applying Grey relational analysis and rate adaptation to achieve performance optimization.

3.3.2 Energy-aware Routing

Venkata et al. [23] provides an overview of energy-efficient and secure data routing in Internet of Medical Things (IoMT). It addresses device intrusion and high energy consumption challenges as well. To deal with these challenges a swarm intelligence based routing protocol is introduced.

3.3.3 Wireless Power Transmission

Wazid et al. [24] present ASCP-IoMT, an AI-based lightweight and secure communication protocol for IoMT. It makes encrypted data transfer and medical diagnosis (e.g., heart attack) better. ASCP-IoMT exceeds existing schemes in terms of end-to-end delay (0.01587 sec. as low), throughput and security. While SVM yields the highest accuracy (87.57%), decision tree is faster comparing both in AI-based analytics.

3.4 System Integration Optimization

System integration optimization enhances multiple layers harmonization of resources. Edge-cloud cooperation improves the performance of real-time data processing by task sharing between local servers and the cloud server dynamically. One of the functions of this research is to spread tasks among heterogeneous systems as well as to balance the performance and security of the data. Adaptive resource allocation strategies control computing resources adaptively, in order to reduce delays and improve the protection of privacy. Particularly, for large-scale deployments, these techniques can enable scalable and reliable IoHT healthcare solutions.

3.4.1 Edge-Cloud Collaboration

Tahir et al. [25] propose a collaborative edge-cloud caching scheme for IoHT-based real- time health monitoring as compared with existed IoHT caching strategies through the cache-assisted real-time detection (CARD). A greedy algorithm solves this NP-hard problem here, increasing cache hit ratios and speed.

3.4.2 Load Balancing

To address the above challenges, Lakhan et al. [26] proposed a secure offloading- efficient task scheduling (SEOS) framework for the workflow of the IoMT applications run on dispersed healthcare systems. To tackle challenges in the scenarios such as security heterogeneity and task heterogeneity, this architecture consists of application layer, management layer, and resource layer.

3.4.3 Resource Allocation

Wang et al. [27] proposes a computing resource allocation strategy to massive IoHT devices in a two-level 5G heterogeneous cloud-edge environment minimizing delay and improving privacy protection, thus addressing several challenges faced by IoHT. Based on network conditions, tasks are assigned dynamically between local and edge execution.

3.5 Intelligence-Driven Optimization

AI for sustainability optimization in IoHT Systems Real-time analytics enables predictive energy management, which anticipates and optimizes usage of power. Creating energy-efficient AI models for secure and privacy-aware healthcare monitoring lever- aging federated learning and encryption. One example of how cloud practitioners can take advantage of the data they have is through adaptive resource scaling, which dynamically allocates resources throughout edge-fog-cloud structures to meet real- time data requests. These strategies not only improve system efficacy and healthcare decision-making but also facilitate sustainable functioning in changing workloads.

3.5.1 Predictive Energy Management

Mishra et al. [28] proposed a sustainable lung cancer detection model by integrating the Internet of Health Things (IoHT) with computational intelligence. The algorithm for attribute selection by using Heuristic GBFS and classification by using Random Forest could achieve an accuracy of 98.8, specificity of 97.5 and sensitivity of 97.8.

3.5.2 Energy-efficient AI Models

Rahman et al. [29] proposed a framework for sustainable IoHT-enabled health care using 5G and deep learning. The model overcomes core concerns of data security & privacy and acceptance via private blockchain, federated learning, encrypted data sharing, and model explain ability.

3.5.3 Adaptive Resource Scaling

Yang et al. [30] proposed an intelligent end–edge–cloud structure on visual IoT-assisted healthcare (V-HIoT) to address the efficiency challenges of processing, caching, and transmission of data in heterogeneous healthcare IoT (HIoT) systems.

4. Comparison of Strengths and Weaknesses

This subsection presents an in-depth comparative analysis of different optimization schemes utilized in sustainable IoHT paradigms, along with their applications, device types, benefits, and drawbacks, as presented in Table 2. The goal is to provide a comparative analysis of each optimization category, highlighting key advantages, challenges, and areas for further improvement.

5. Discussion

This section provides a strengths and weaknesses analysis of the proposed optimization strategies in terms of effectiveness, scalability, implementation complexity and energy savings.

5.1 Energy Savings and Performance Improvement

As shown in Figure 3, we give numerical comparisons from prior work to help make recommendations for each optimization class.

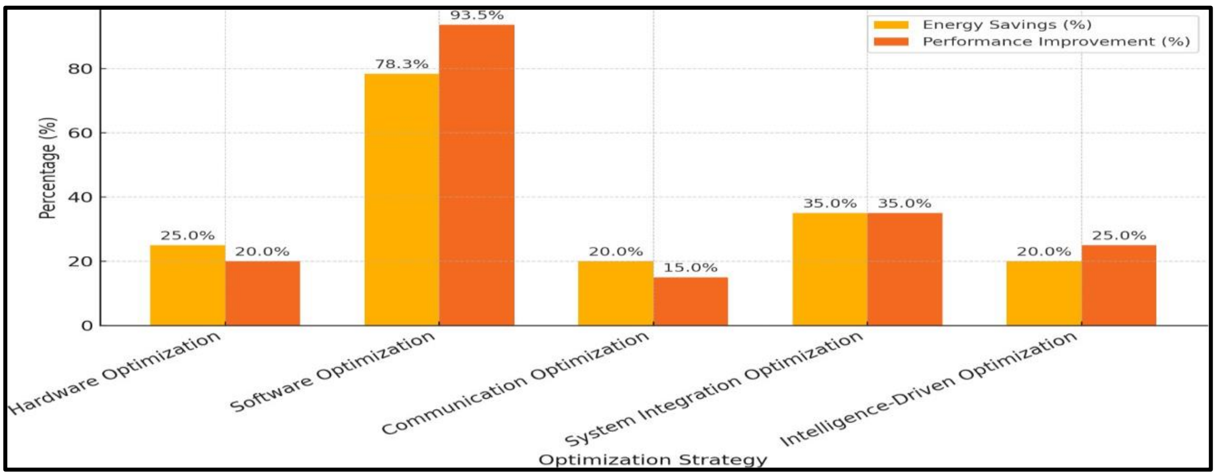

Figure 3. Comparison of Energy Savings and Performance Improvement.

• Hardware Optimization: Hardware solutions, like low-power sensors and energy harvesting, provide significant energy savings but have limits due to implementation costs. For instance, RF energy harvesting studies report that energy autonomy can be improved by 30% albeit efficiency relies on environmental settings. Battery management systems enhance the operational reliability zone at 25% and 40%, especially in resource-constrained IoHT environments.

Table 2. Comparison of Strengths and Limitations

Category of Optimization	Benefits	Shortcomings
Hardware Optimization	• Energy autonomy improvement by the energy harvesting technologies. • Fail-safe battery management strategies lead to better reliability.	• Advanced sensors and harvesting systems have high implementation costs. • Constrained by environmental dependence (e.g., solar or RF harvesting availability).

Software Optimization	• Improved energy efficiency by means of dynamic assignment of tasks and compression. • Instantaneous adaptation to dynamic workloads.	• Complex software algorithms may take more computational power. • Can use robust edge and cloud infrastructure already available in Software- based solutions.
Communication Optimization	• Designed to exchange health information based on low-power and real-time data transfer, with secure protocols. • Minimizes the bandwidth demands in healthcare IoT networks.	• Critical applications are often adversely affected by interruptions in communication. • Performance depends on the network topology and the scalability problems.
System Integration Optimization	• Efficient cooperation among edge, fog, and cloud infrastructures. • It reduce latency while improving resource allocation.	• Necessitates complex coordination primitives at different levels. • Security vulnerabilities of distributed systems/settings have some challenges.
Intelligence-Driven Optimization	• Enabling predictive power management and resource scaling by means of AI • Improves decision making by providing real time analytics.	• Initial high use-case development and training overhead for AI Models. • AI solutions must be continually updated to meet the changing demands and threats of healthcare.

• Software Optimization: Both power-aware scheduling and data compression are soft- ware approaches, hence they bring in flexibility and scalability. As an example, IoHT's adaptive data compression led to a 93.5%-99% data reduction and up to 78.35% reduced energy consumption. However, on the edge device, some sophisticated algorithms might require extra processing power and lead to 10-15 % more CPU utilization.

• Communication Optimization: This category is focused on the hardware-optimized architecture for low power consumption and real-time operation of communication protocols. The enhanced low-power propose the protocols such as 6LoWPAN consumes 20% less power and achieved higher throughput by 15%. They further minimized the communication delay by 30% (on average) in large IoHT deployments for energy-aware routing.

• System Integration Optimization: The integration approaches (e.g., edge and cloud coordination, load balancing) help to improve effective resource usage. Real-time operation of cache-assisted collaboration frameworks was achieved by 40%, and due to secure load balancing schemes a latency decrease of 35% was witnessed. But these measures require robust systems-level coordination.

• Intelligence-Driven Optimization: Proactive measures are made with the help of AI-based optimization methods. Energy Efficiency enhancement of 20%-30% with a diagnostic accuracy rate that can exceed 97 % for predictive energy management models. System resource scalability improved system responsiveness by 25%, but training and updating AI-based solutions is never done.

5.2 Complexity

In this section, we analyze the optimization strategies from the perspective of implementation complexity only, as listed on Table 3. Initial setup requirements, dependency on hardware/software, needs coordination, again needs to scale-up the system.

• Hardware Optimization: High complexibility is present in this category since a physical infrastructure like deploying a sensor and integrating with energy harvesting will be required. Customization of the battery and power management systems may also be necessary, prolonging the implementation process and increasing costs.

• Software Optimization: They are complex, but software strategies are inherently more flexible. Changes can be made remotely with less hardware dependence. How- ever, complex processes such as machine learning data compression needs specialized skills.

• Communication Optimization: Intermediate complexity is required for protocol changes such as the addition of low-power communication and routing strategies. In large-scale networks with diverse devices, the complexity increases exponentially, but it is negligible in small networks.

• System Integration Optimization: Integration strategies have high complexity as they need to synchronize across distributed systems. Dynamic load balancing and task allocation can complicate performance tuning and coordination.

• Intelligence-Driven Optimization: The complex nature of the resulting AI solution can make it difficult to implement, as systems typically require regular updating in terms of data acquisition, model training, and implementation of new models. To be able to handle these kinds of requirements you need a solid architecture that uses AI that can predict what kind of resources will be required and when.

Table 3. Comparison of Optimization Strategies Based on Implementation Complexity

Strategy	Level	Description
Hardware optimization	High	Energy-efficient sensors and energy harvesting technologies that require investment in specialized components. Dependencies on the environment add complexity.
Software Optimizations	Medium	Includes designing and incorporating sophisticated algorithms (e.g., power- aware scheduling and data compression). But compared to hardware, is more scalable, and adaptable.
Communication Optimization	Medium	This needs update of protocols (like 6LoWPAN) as well as secure communication routing strategies. The larger the network and the more heterogeneous the devices, the more complex the management.
System Integration Optimization	Moderate	Requires the intelligent coordination of resource allocation and load balancing across the edge, fog, and cloud layers. Usually custom architecture and management required.
Intelligence-Driven Optimization	High	This includes working on predictive handling and scaling modules, and managing AI constructs. Asks for data collection, training and updates to keep model accurate.

6. Open Issues and Future Directions

6.1 Open Issues

• Scalability and Interoperability: In response to these divergent devices and network protocols, current IoHT systems found difficulties in being scaled up as well as being integrated with the rest of the IoT network. More study will be needed to improve effective cross-platform provision.

• High Hardware cost: The complex systems, e.g., the high energy harvesting and sensor networks implementations, are usually hardware-based systems that have higher costs. This lack of efficiency cannot be scaled up when resources are limited.

• Security and Privacy of Data: Improved performance and better power management to handle data security issues using an AI-based solution (creating Issues especially with distributed healthcare data).

• Real-Time Adaptability: The existing optimization techniques may not be capable of effectively adapting to instantly change the healthcare urgency (which affects system response time in emergency healthcare situations).

• Energy-Aware AI Models: AI models for energy management have been difficult to model and were characterized by long training duration. The dilemma of efficiency and low power-consumption for predictive healthcare tasks is yet unresolved.

• Communication delays- Despite being efficient, the existing protocols, such as 6LoWPAN, are susceptible to bandwidth constraints and communication latency in large heterogeneous Internet of Health Things (IoHT) networks.

• Regulatory and Ethical Concerns: Specifically, most places lack established regulations covering this type of energy-efficient healthcare IoT solution, particularly in privacy, device certification, and cross-border data sharing.

6.2 Future Directions

• Developing lightweight AI models: Study the performance of lightweight AI methods that are tailored for IoHT devices with computational constraints. Methods such as federated learning and model pruning can reduce power consumption and execution time.

• New techniques to capture energy from the environment: It covers research on hybrid energy harvesting (solar, RF, and kinetic sources) for delivering a sustainable power supply that can adjust according to the surroundings of IoHT devices.

• Inter-tier design in integrated edge-cloud architectures: Fuzzy logic-based dynamic resource management for edge-fog-cloud collaboration. They also need to optimize the load splitting on near and far cloud sides, respectively, during the enhanced schemes to achieve extremely low-latency (also referred to as single-digit milliseconds) and critical power efficiency with various workloads.

• Better communication protocols: Building next-gen efficient low power protocols for providing enablement of high throughput, time-sensitive data transmissions with security assurance. Indeed, such congestion management has the potential to maximize data flow on large AI systems.

• Privacy Preservation with Energy Awareness: Wecus on the design of low-power encryption algorithms that can be adopted to securely communicate data over a network, while avoiding unwanted entities. There is value in investigating a blockchain-based and/or SMPC solution.

• The context-aware Optimization Frameworks: Build up the frameworks so as to adjust themselves according to the modus operandi from healthcare (e.g., emergency cases vs routine monitoring).

• Green IoHT Initiatives: Investigating Sustainable Development and Energy-Efficiency of IoHT in the Eco-System. This includes recycling, reduction of electronic waste, and minimizing carbon footprints.

• Cross-disciplinary Research: Collaboration between health care, artificial intelligence, engaging and enabling technology, and energy can cooperate in developing sustainable IoHT systems, which are not only suitable but also science-based.

7. Conclusion

The Internet of Healthcare Things (IoHT) refers to IoT-based devices in healthcare. However, high energy consumption, power constraints, and scalability issues remain major challenges. Accordingly, this article provides a novel taxonomy on sustainable energy optimization based on IoHT: hardware, software, and communication trade- offs, system integration, and intelligence. In this paper, we compare these methods side-by-side with an emphasis on their energy savings, complexity, and responsiveness to reveal some important energy trade-offs between them. These findings reveal the necessity for low-power communication protocols, AI-driven resource management, and edge-cloud cooperation at a lower energy cost with optimal performance. IoHT has been developed significantly, but still, there are some issues like interoperability, exposure to security breaches, and inability to process data in real time. Activities based on mixed energy harvesting techniques, lightweight AI methods, and secure encryption mechanisms can be researched as important aspects that might contribute toward accounting for a sustainable and reliable IoHT. By addressing these challenges in future IoHT systems, the next-generation IoHT systems can provide energy-efficient, scalable, and secure IoHT systems for a more intelligent and reachable healthcare.

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