International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

A Systematic Survey of AI-Enabled Secure and Energy-Efficient WBANs for 6G Smart Healthcare Systems

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Abstract - Wireless Body Area Networks (WBANs) have emerged as an key enabling technology for next generation smart healthcare systems by enabling continuous monitoring of physiological parameters using wearable and implantable sensors. The convergence of Artificial Intelligence (AI), Internet of Things (IoT) and sixth generation (6G) communication technologies is significantly transforming healthcare services by enabling real-time patient monitoring, remote diagnosis, intelligent decision making and personalised healthcare delivery.

However, WBAN-based healthcare systems still face critical challenges, including data security and privacy vulnerabilities, communication reliability issues, latency in real-time applications, and limited energy of wearable sensor nodes. To overcome these limitations, recent research has increasingly focused on advanced approaches, such as machine learning techniques , federated learning, edge computing, blockchain technology and intrusion detection systems.

This study presents a systematic survey of AI-driven secure and energy-efficient WBAN architectures for 6G-enabled smart healthcare systems. It comprehensively reviews WBAN communication models, healthcare applications, AI and IoT integration frameworks, security and privacy mechanisms, and energy-efficient optimisation methods. Moreover, the paper presents recent advances on edge intelligence, lightweight AI models and energy-aware communication protocols. However, there is still a lack of a unified analysis in the existing literature that combines AI techniques, security mechanisms, energy efficiency and 6G- enabled WBAN-based systems.The paper ends by highlighting the major research gaps and future directions for the design and development of scalable, secure, low latency, and energy-efficient intelligent healthcare systems in the emerging 6G environments.

Keywords - Wireless Body Area Networks (WBANs), Smart Healthcare, Artificial Intelligence (AI), Internet of Things (IoT), 6G Communication, Energy Efficiency, Security and Privacy, Machine Learning, Federated Learning, Remote Patient Monitoring, Edge Computing.

1.INTRODUCTION

The modern healthcare systems are changing with the rapid evolution of communication technologies and intelligent computing paradigms. The growing demand for continuous health monitoring, early diagnosis of disease and remote medical services has greatly accelerated the development of smart healthcare solutions.Emerging technologies such as Wireless Body Area Networks (WBANs), Artificial Intelligence (AI), Internet of Things (IoT), and sixth-generation (6G) communication systems are increasingly becoming an integral part of next-generation healthcare infrastructures. These technologies, collectively, improve healthcare delivery by allowing real-time monitoring, better diagnostic accuracy, reduced response time and personalised medical services.
Wireless Body Area Networks (WBANs) are a key enabling technology of smart healthcare systems, where wearable and implantable sensors are used to monitor physiological signals such as heart rate, blood pressure, body temperature, oxygen saturation and electrocardiogram (ECG). The sensors transmit the data wirelessly to healthcare servers for analysis, thus enabling applications in elderly care, chronic disease management, rehabilitation, fitness tracking and emergency healthcare services.
In recent years, the inclusion of Internet of Things (IoT) has greatly improved the connectivity and interoperability of healthcare devices. Moreover, Artificial Intelligence (AI) such as machine learning and deep learning techniques are the key in the analysis of large-scale healthcare data, abnormality detection, disease prediction and clinical decision making. Further, intelligent data processing, anomaly detection, adaptive routing, intrusion detection and energy optimisation techniques are used to improve the WBAN system using AI based methods which improve system reliability and efficiency.
The sixth generation (6G) communication technology is expected to transform healthcare systems with ultra-low latency, high data rates, massive connectivity and highly reliable communication. Existing communication technologies are often insufficient to meet the stringent requirements of advanced healthcare applications such as remote surgery, real-time telemedicine, and continuous patient monitoring. Meanwhile, 6G networks will enable seamless and efficient connectivity between wearable devices, healthcare infrastructure, and medical professionals.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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However, there are several critical challenges for WBAN based healthcare systems. Transfer of sensitive medical data poses serious security and privacy concerns and makes systems susceptible to cyber attacks, unauthorised access, and data breaches. Moreover, the major limitation is still the energy efficiency due to the limited battery lifetime of the wearable sensor nodes. These problems need efficient communication protocols, light weight security mechanisms and energy aware routing strategies. Although there is a lot of work in this domain, most of the available literature has focused on the individual aspects of AI techniques, security mechanisms, energy efficiency or communication technologies in isolation. Very limited work has been carried out to provide a unified framework that integrates AI-driven security mechanisms, energy-efficient communication protocols, IoT connectivity, and 6G-enabled WBAN architectures. Furthermore, issues related to scalability, computational complexity, privacy preservation, and real-time reliability remain insufficiently addressed.

Related Work The existing works mainly focus on AI technologies, security mechanisms, or energy efficiency. There is very little research in the literature that provides a unified framework that integrates AI-driven security, energy-efficient communication and 6G enabled WBAN architectures in a holistic manner.

In contrast to existing surveys, this study presents a holistic and integrated review of AI-driven secure and energy-efficient WBANs for 6G-enabled smart healthcare systems. This paper analyses WBAN architectures, communication models, healthcare applications, integration of AI and IoT, security mechanisms, and energy optimisation techniques systematically in a unified framework. It also identifies key research gaps and discusses future research directions for developing scalable, secure, low-latency and energy-efficient intelligent healthcare systems in emerging 6G environments. The main objective of this survey is to provide a systematic analysis of the integration of AI, security, energy efficiency, and 6G technologies in WBAN-based healthcare systems. The key contributions of this review are summarised as follows:

Survey on Artificial Intelligence Based WBAN Architectures and Its Applications in Healthcare.

To explore the integration of AI, IoT, and 6G technologies into intelligent healthcare systems.

To study the security and privacy issues and the existing mitigation techniques in WBAN environments.

The aim is to review energy-efficient communication protocols and optimisation techniques that can be used to improve network performance and device lifetime.

To provide an overview of the current challenges, recent developments, and future research directions for the development of secure, intelligent, and sustainable healthcare systems.

Moreover, this study also addresses the future trends like edge computing, federated learning, blockchain technology, intrusion detection systems and lightweight AI models for healthcare applications. This paper presents a detailed study on AI-enabled secure and energy-efficient WBANs for 6G-enabled healthcare systems in terms of architecture, applications, challenges, and future directions for next generation intelligent healthcare environments.

1.1 Research Methodology

This review adopts a structured literature review approach to examine recent advances in Artificial Intelligence (AI)-enabled Wireless Body Area Networks (WBANs) for secure and energy-efficient smart healthcare systems. Relevant publications were collected from five well-known scientific databases, namely IEEE Xplore, ScienceDirect, SpringerLink, MDPI, and Google Scholar, to ensure comprehensive coverage of high-quality peer-reviewed researchA systematic search was performed using combinations of keywords such as "Wireless Body Area Networks (WBAN)", "Artificial Intelligence", "Machine Learning", "Deep Learning", "Internet of Medical Things (IoMT)", "Smart Healthcare", "6G", "Energy Efficiency", "Security and Privacy", "Blockchain", "Federated Learning", and "Edge Computing". Boolean operators (AND and OR) were applied to combine these keywords and retrieve the most relevant studies.

Initial searches in the databases yielded 150 research records. Of these, 125 unique publications remained after 25 duplicates were removed. A first screening of the title and abstract led to the exclusion of 10 studies that did not fit the scope of this review, leaving 115 records for detail . After this step, 63 publications were excluded because they were not directly related to AI-enabled WBANs or did not meet the pre-defined inclusion criteria. Thus, 52 full-text articles were assessed for eligibility . The reasons for exclusion

International Journal of Engineering Research & Technology (IJERT)
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of the 17 studies after full-text evaluation were insufficient technical content, limited relevance or inadequate methodological information. Finally, 35 studies were included for qualitative analysis and synthesis.

To maintain the quality and relevance of the review, only peer-reviewed journal articles and conference papers published in English between 2022 and 2025 were considered. Studies focusing on AI-enabled WBANs, IoMT-based healthcare systems, security and privacy mechanisms, energy-efficient communication, intelligent healthcare applications, and 6G-enabled healthcare networks were included.Editorials, book chapters, patents, theses, duplicate publications, non-English articles, and studies not relevant to the scope of AI-driven WBAN-based healthcare were excluded.

The selected studies were grouped into six major themes: WBAN architecture and healthcare applications, AI and IoT integration, security and privacy mechanisms, energy-efficient communication techniques, 6G-enabled smart healthcare, and future research directions. A comparative analysis of previous survey studies was also carried out to identify existing research gaps and highlight the contribution of the present review.

The overall study selection process followed the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to improve transparency and reproducibility. .

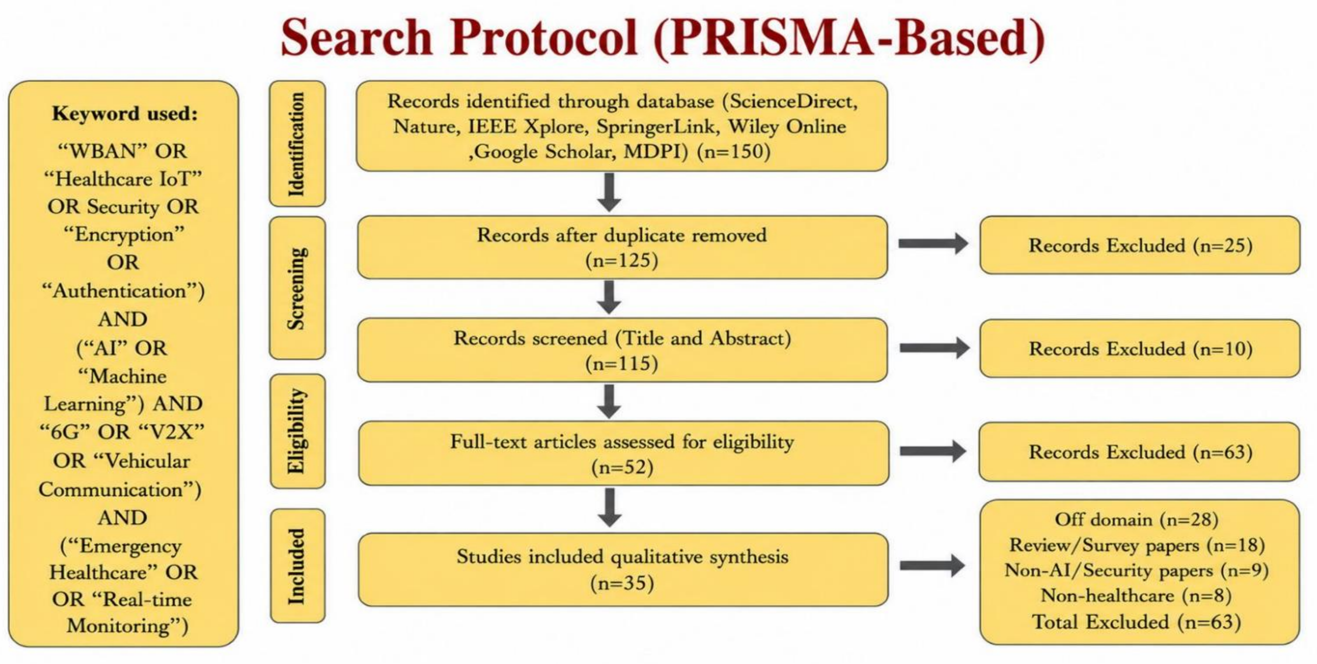

Fig. 1 shows the full workflow including identification, screening, eligibility assessment and final study selection.

2. WIRELESS BODY AREA NETWORKS (WBANS)

Wireless Body Area Networks (WBANs) are a subset of wireless sensor networks consisting of sensor nodes placed on or in the human body to monitor various physiological parameters such as blood pressure, body temperature, heart rate and blood glucose levels for continuous and remote health monitoring of a patient. The primary objective of WBAN is to monitor a patient health continuously by deploying biosensors on or around the human body and generate alerts for abnormal or critical situations.

2.1 WBAN Architecture

WBAN contains a control unit and many sensor nodes that can be implanted inside the body or wearable, body-worn or body-patched devices that can monitor vital physiological parameters such as body temperature, blood pressure, respiration rate, blood glucose level, heart rate, oxygen saturation and electrocardiogram (ECG).

2.2 Communication Types in WBAN

The communication layer is divided into three types: in-body, on-body, and off-body. In-body communication refers to the data exchange between implanted sensors and external devices. On-body communication takes place between sensors placed on human

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

body. Off-body communication connects WBAN system to external network such as hospital servers, cloud platforms, or healthcare monitoring systems.

2.3 Application of WBAN

WBAN has many applications including healthcare monitoring, rehabilitation, sports performance analysis and military operations . One of the most promising applications of WBAN technology is in health care sector. Biosensors deployed on or inside the human body allow continuous monitoring of physiological parameters and provide remote access to patient information by physicians, caregivers and diagnostic centres.

WBAN can improve the quality of life with devices such as hearing aids and medical implants. Athletes and sports personnel can use continuous monitoring of parameters like SpO2, heart rate, blood pressure and glucose levels for improving their performance and health management. WBAN technology is also beneficial in military environments where it can provide real-time monitoring of soldiers' physiological conditions and enhance operational efficiency.

However, despite the several advantages in healthcare and other application domains, WBAN technology is still facing a number of challenges. Limited battery capacity, communication reliability, data security, privacy protection and interoperability among heterogeneous devices are still critical issues. Hence, WBANs are increasingly being integrated with advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT) and next generation communication systems to enhance their efficiency, reliability, security and overall performance.

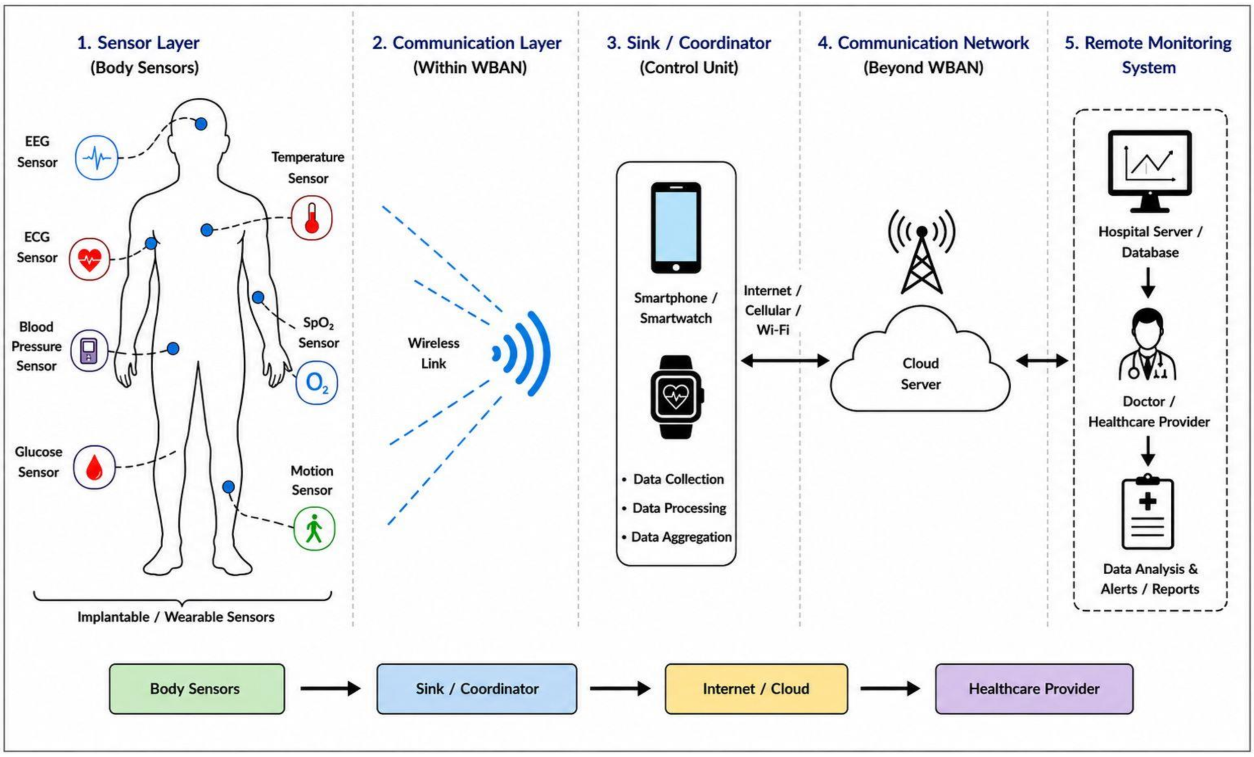

Fig.2 Shows General Architecture of Wireless Body Area Network (WBAN) for Healthcare Monitoring System.

3. ARTIFICIAL INTELLIGENCE AND IOT INTEGRATION IN SMART HEALTHCARE SYSTEMS

AI and IoT are widely used to connect available medical resources and provide reliable and efficient smart healthcare. As the adoption of wearable devices is growing, the use of healthcare applications such as remote patient monitoring, activity tracking, emergency alerts, and fitness management is increasing. The Internet of Medical Things (IoMT) includes connected wearable sensors that constantly monitor physiological parameters such as blood pressure, heart rate and oxygen saturation. The data collected are sent via wireless communication networks for further analysis and healthcare decision making.

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3.1 Machine Learning and Deep Learning in Healthcare

Underlying a multitude of AI applications in this domain is a fundamental concept: once data are collected, Machine Learning (ML) and Deep Learning (DL) methods process and provide predictive analytics. Healthcare modeling with predictive analytics is processing and analyzing large volume of data to show patterns, detect anomalies, make dynamic predictions, and guide decision making. AI enables knowledge discovery from structured and unstructured healthcare data and extract data from a range of sources such as patient records, genetic data, and environmental influences to find patterns and trends. In medical image recognition, CNNs have significant potential. RNNs (including LSTMs) are suitable for time series data such as electrocardiograms and medical notes.

3.2 Remote Patient Monitoring and Tele-monitoring

IoT wearable devices have several sensors that constantly check signals, detect anomalies, provide quicker response time, and prevent serious health problems. Remote patient monitoring, which uses wearable devices and remote monitoring tools to monitor vital signs, is used to check heart rate, blood pressure, and oxygen saturation in real time. They constantly collect data and alert healthcare providers if they detect abnormal patterns, reducing unnecessary visits to medical professionals, hospital stays, re-admission and medical care costs. Tele-monitoring applications connect the patient to doctors and domain experts through cloud-based data offerings using sensors and a residential hub. This is done in real time with the use of machine learning, cloud computing, and big data. Vital healthcare services employ these technologies.

3.3 Deep Learning Models for ECG Classification and Arrhythmia Detection

Scrugli et al. investigated the application of convolutional neural networks (CNNs) to implement a cognitive data analysis algorithm for ECG waveform classification directly on resource constrained. Microcontroller based computing platforms that allow lightweight models to be used to process cardiovascular data in real time, eliminating the need for large power resources and large deployment in remote health monitoring scenarios. Deep learning models implemented at the edge are applied to improve real-time arrhythmia detection and classification. Their results showed that the CNN-LSTM architecture with an attention layer outperforms the other architectures in most relevant metrics and is well suited to run on edge resource-constrained devices such as wearable devices.

3.4 Edge Computing in WBAN Healthcare Systems

Edge computing refers to the processing of data at or near the site of data generation. Edge computing offers lower latency and bandwidth consumption compared to cloud computing. Latency reduction is one of the key advantages of edge computing for latency-sensitive healthcare applications. AI models deployed at the edge, near patient, can provide real-time decision making and personalization of healthcare using monitoring data to predict health problems. Local data processing also enhances privacy and security because sensitive healthcare data does not have to be sent to centralized cloud servers.

3.5 Federated Learning for Privacy and Security in IoMT/WBAN

Federated Learning helps to preserve privacy and security in the context of IoT. Federated Learning ensures that learning is local to IoMT. FL trains the data in parallel learning models that are distributed to multiple local sites for learning. DFL enables multiple agents to learn a shared prediction model simultaneously with the assurance that the training data stay secure. The raw data collected by IoMT sensor are not shared with other nodes; therefore, FL protects the privacy of EHR in the IoMT domain. Patient data can be protected with federated learning and differential privacy. FL is a training approach that trains AI models on multiple decentralized devices or servers without sending the raw data.

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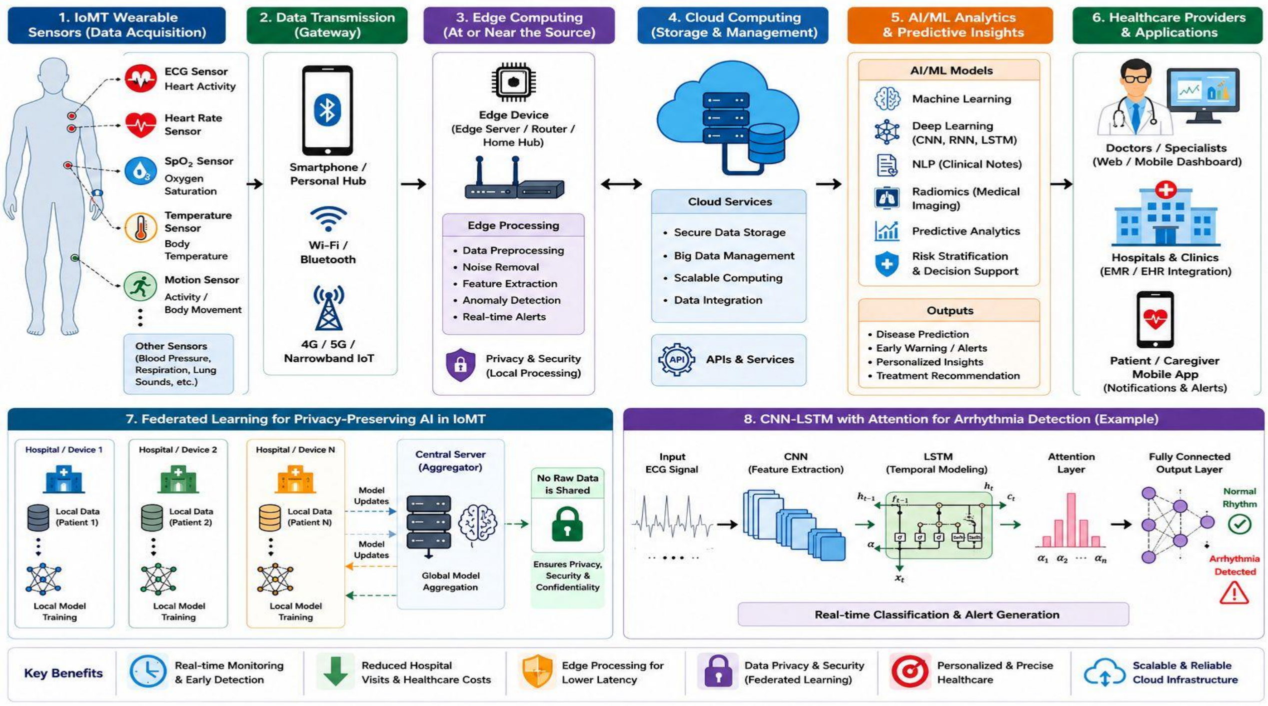

Fig.2 Illustrate AI-enabled IoMT framework for smart healthcare monitoring and intelligent decision support**.**

4. SECURITY AND PRIVACY IN WBAN

Since WBANs hold sensitive and private medical information, security is a key issue that can not be overlooked. In BAN-based healthcare systems, data protection and privacy are two prominent issues, and medical data should be protected both in storage and transmission. Sensor nodes capture the crucial information and send it to medical server for analysis, which make data security a serious challenge in WBAN. Due to ubiquitous availability of wireless media in WBAN, malicious tapping or tampering attacks can easily happen. If the medical records are altered, information is used for treatment. Thus, WBAN must satisfy two critical criteria for providing trustworthy services: data security and privacy.

4.1 Authentication and Secure Communication Protocols

WBAN security and privacy protocols are essential for authenticating sensitive health-related data transmitted through WBAN. Proposed schemes include several security schemes such as AES, SHA, ECC, blockchain, and lightweight authentication protocols such as TLS and DTLS; ECDSA authentication and blockchain based identity management systems.

4.2 Intrusion Detection Systems and Machine Learning Approaches

Intrusion Detection Systems (IDS) are a security mechanism used to detect intrusions and abnormal activity. Wireless intrusion can be detected with intrusion detection systems, machine learning techniques and wireless network intrusion detection system have been employed successfully. Federated learning is a model training approach that trains a model locally on the device for privacy. Deep learning can automatically extract features from large data sets without requiring domain knowledge, and deep learning has also performed better than traditional machine learning methods in cybersecurity applications. In the proposed federated intrusion detection approach, incoming network traffic is labeled as either normal or abnormal. IDS based on machine learning can detect and mitigate malicious activities in IoT networks in real time.

4.3 Blockchain-Based Security in WBAN and IoT Networks

The blockchain, as a decentralized, immutable, and transparent ledger, offers a potential platform for securing IoT systems. Blockchain ensures the integrity of data and reduces the potential for tampering as data is stored in blocks. Mitigation of attacks in IoT networks can be achieved via a decentralized, tamper-resistant ledger, which is characterized by the three key properties of decentralization: immutability, transparency and the integrity of data.

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4.4 Advance Anomaly Detection Techniques

Some of the anomaly detection methods being explored can be applied to securing IoMT-Blockchain and IoT systems. The healthcare IoT data is secured and distributed using IPFS blockchain technology. Artificial intelligence models are applied, and blockchain is utilized for secure medical data distribution with edge-based computing to reduce latency and bandwidth requirements in IoT environments and smart contracts to mitigate insider attacks and ensure data integrity. Blockchain guarantees the integrity of the systems log, and deep learning provides accurate anomaly detection in real-time environments.

4.5 Challenges and Future Directions

Existing IoT anomaly detection techniques usually have high false alarm rates and ineffective real time threat categorization. Centralized security framework also introduces a single point of failure to IoT networks.

Distributed IoT security with autonomous real-time threat responses can be achieved using blockchain based smart contracts. Future work will focus on lightweight DNN architecture and federated learning to improve scalability and preserve data privacy.

5. ENERGY EFFICIENCY TECHNIQUES IN WBANS

In WBANs, the sensor nodes are battery powered and are intended to operate for extended periods of time, making energy efficiency a major concern. Energy efficiency is important in WBANs because batteries are expected to operate for months or years, rather than days. The sensors are typically small and lightweight, battery operated and have limited energy capacity. Also transmission of data requires more energy than other operations, and is therefore the dominant source of energy consumption in WBAN nodes.

5.1 Energy-Efficiency MAC Protocols

A number of studies have been conducted to minimize unnecessary energy consumption in WBANs. Energy wastage in WBANs mainly occurs due to idle listening, packet collision , overhearing and retransmission. Collision, overhearing and traffic retransmission can be reduced by using energy aware MAC protocols that reduce idle listening and optimize duty cycling to improve energy efficiency. TDMA based protocols which allocate fixed time slots to nodes, enabling long sleep periods and reducing unnecessary energy consumption. SMAC based protocols saves energy by periodically switching nodes between sleep and wake states, and thereby reducing idle listening.

5.2 Energy Efficient Routing Protocols

Routing protocols plays an important role in improving energy efficiency of wireless sensor nodes. Energy efficient routing protocols optimize data transmission and network longevity with power consumption. Cluster based routing protocols further optimize energy efficiency by grouping nodes into clusters and minimizing direct transmission to the sink.

5.3 Optimization and Scheduling Techniques

Other proposed optimization techniques include different approaches to extend the network lifetime. TPC is a mechanism to achieve energy efficiency without sacrificing communication reliability, while adaptive scheduling protocols dynamically adjust node sleep schedules based on traffic patterns to avoid wasting energy. The proposed threshold based system reduces energy consumption by reducing unnecessary sensor transmissions and when the sensor node power threshold is met, the node schedules itself to sleep to conserve energy.

5.4 Data Processing and Energy Harvesting Techniques

Other methods used to facilitate efficient operation of WBAN include data processing and energy harvesting techniques. As energy efficient data processing techniques such as data aggregation, fusion and compression reduce transmitted data volume and communication related energy costs. Energy harvesting using solar, thermal and kinetic sources can extend sensor lifespan and reduce battery dependency.

6. 6G-ENABLED INTELLIGENT HEALTHCARE SYSTEM

6G Connectivity for AI-Driven Healthcare

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6G connectivity will be the enabler to AI-driven healthcare and will enhance quality of life and healthcare services. Current communication technologies are not adequate to satisfy the complex and diverse requirements of a variety of healthcare applications. Thus, 6G communication technology is predicted to provide a key infrastructure to future intelligent healthcare systems.

6.1 Requirements and Applications of 6G in healthcare

The services offered by 5G are not adequate to address the rising demand of healthcare, such as security and privacy for remote healthcare, communication for ultra-dense IoMT devices, and extremely low latency and reliable communication. To make 6G connectivity available to future intelligent healthcare, the requirements are high data rate(>=1Tbps), low end-to-end delay(<=1ms), high reliability, and high operating frequency. Telesurgery will depend on real-time communication, and holographic communication and virtual reality will help develop intelligent healthcare systems. IoMT technologies (such as wearable devices and wireless body area networks [WBAN]) will be employed to remotely check health. The reliable and efficient processing of data using AI coupled with high-speed and low-latency data transmission via 6G will provide a robust platform for advanced healthcare.

Table 1 : Comparison of 5G and 6G for healthcare applications

Parameters	5G	6G
Data Rate	Up to 20Gbps	Up to 1 Tbps
Latency	About 1 ms	Less than 1ms
Connectivity	Supports many connected devices	Supports a much larger number of healthcare and IoMT devices.
AI usage	AI can assist network management	AI is expected to play a central role in network operation.
Healthcare use	Telemedicine, remote monitoring , wearable healthcare devices	Tele surgery, digital twins, smart ambulances, immersive healthcare services.
Reliability	Reliable communication for healthcare monitoring	More reliable communication for time-critical healthcare applications.

6.2 Telesurgery and Real-Time Healthcare Monitoring

Low latency and high reliability are two of the key characteristics of 6G that are essential for applications such as remote surgery and real-time monitoring of patients. High bandwidth and URLLC efficiency networks are necessary for telesurgery to avoid latency or data loss during surgery. 6G-enabled ambulances will start treating patients before they even get to the hospital.

6.3 Future Scope of 6G in Intelligent Healthcare

The 6G communication technology will bring revolution in intelligent healthcare and increase the dependence on communication technologies. The holographic communication will make possible the global healthcare connectivity.

Table2 : Comparative Analysis of Existing Literature on AI-Enabled Secure and Energy-Efficient WBANs for Smart Healthcare

References	Year	Main Focus	AI Techniques	Security Method	Energy Efficiency	6G Consideration	WBAN Focus	Limitations
[1]	2022	WBAN Architecture, Technologies and Challenges	Not used	Discussed Security Challenges	Included energy related issues	Not considered	Strong	Limited focus on AI-driven Healthcare solutions
[3]	2024	Reliability,Robustness and Energy Efficiency in WBANs	Machine Learning (Limited)	Reliability and Robustness method	High focus on energy efficiency	Not considered	Strong	Security and 6G aspects not explored

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[4]	2024	Security and Privacy in WBAN-based Healthcare Systems	Not used	Comprehensive security analysis	Not discussed	Not considered	Strong	Energy-efficient communication aspects were not explored
[6]	2024	6G-Enabled Intelligent Healthcare	AI-supported healthcare applications discussed	Basic security discussion	Limited discussion	Core focus of the study	Moderate	Detailed WBAN-specific analysis was limited
[7]	2024	SDN-enabled Fog Computing for WBAN	Machine Learning based SDN-framework	Partial security integration	Moderate	Not considered	Moderate	Limited focus on AI security
[8]	2024	AI and 6G-Based Healthcare Analytics	Deep Learning +AI analytics	Basic security	Moderate	Core focus	Moderate	WBAN-specific analysis limited
[10]	2024	Edge Computing in Smart Healthcare	AI-assisted Edge Computing	Security challenges discussed	Moderate	Future 6G perspective	Moderate	Detailed WBAN communication mechanisms were not explored.
[11]	2023	AI-Enabled Wearable Medical IoT Systems	Deep Learning(wearable IoT)	Privacy concerns highlighted	Limited attention	Not considered	Strong	Integration with future 6G Healthcare environments was not investigated
[13]	2023	Federated Learning for IoMT	Federated Learning	Strong privacy preservation	Indirectly addressed	Not considered	Moderate	Energy Efficiency not explored in detail
[17]	2025	Energy-Efficient Strategies in WBANs	Not used	Not a primary focus	Comprehensive analysis	Not considered	Strong	Security and intelligent healthcare aspects were outside the scope
[19]	2022	Energy-Efficient WBAN Framework	Not used	Not focus	Comprehensive	Not considered	Strong	AI and 6G integration not considered
[20]	2025	Security and Energy-Efficient WBAN Healthcare Systems	Limited AI	Security and Energy combined	High	Not considered	Strong	Future 6G healthcare aspects not explored
[21]	2025	IoMT Technologies, Security and Explainability	Explainable AI (XAI)	Comprehensive security and privacy analysis	Limited discussion	Future research directions discussed	Moderate	WBAN-specific energy optimisation and 6G integration were not

								fully addressed.
[26]	2022	Security Issues in Heterogeneous WBANs	Not used	Comprehensive security analysis	Limited discussion	Not considered	Strong	AI-based healthcare applications were not considered.
[27]	2022	WBAN Health Monitoring: Technologies and Challenges	Not used	Security challenges discussed	Moderate	Not considered	Strong	AI and 6G integration were beyond the survey scope.
[31]	2023	IoT Healthcare Standards and WBAN Architectures	AI-assisted Healthcare	Basic security overview	Moderate	Not considered	Strong	AI-driven security and 6G support require further study.
[32]	2023	Smart Sensors for Intelligent Healthcare Systems	Intelligent sensing	Privacy concerns discussed	Limited attention	Not considered	Moderate	WBAN communication and energy management were limited.
[33]	2025	IoMT Challenges and Future Research Trends	AI-enabled IoMT	Strong security discussion	Limited coverage	Future perspective provided	Moderate	Integrated AI-enabled WBAN frameworks were not discussed.
[34]	2024	Cloud–Edge AI for Wearable Healthcare Monitoring	Cloud–Edge AI	Moderate security discussion	Indirectly discussed	Limited discussion	Moderate	WBAN routing and secure 6G communication need further investigation.
[35]	2023	Internet of Medical Things: A Systematic Review	Artificial Intelligence	Strong security discussion	Limited discussion	Future directions discussed	Moderate	WBAN-specific AI and energy optimisation received limited attention.

7. DISCUSSION

The healthcare industry has been transformed by the rapid development of Wireless Body Area Networks (WBANs), Artificial Intelligence (AI), Internet of Things (IoT) and next generation communication technologies. The studies reviewed show that WBAN-based healthcare systems can provide continuous patient monitoring, early disease detection and personalised medical services. With the capability of collecting and transmitting physiological data in real-time, WBANs have been an indispensable component of modern smart healthcare systems. AI techniques have also improved the capabilities of healthcare systems by improving data analysis, predictive modelling, and clinical decision-making.

Machine learning and deep learning approaches have provided promising results in disease diagnosis, anomaly detection and patient health assessment. Similarly, emerging technologies such as edge computing and federated learning have addressed several

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challenges associated with latency, bandwidth utilisation, and data privacy. These trends show that intelligent healthcare systems are gradually transitioning from reactive treatment models to proactive and preventive healthcare approaches.

However, the literature indicates that security and privacy remain among the most important concerns in WBAN-enabled healthcare environments. Medical information is highly sensitive and unauthorised access, data manipulation and cyberattacks can compromise patient safety and system reliability. Although many authentication mechanisms, encryption techniques, intrusion detection systems and blockchain based solutions have been proposed, it is difficult to attain comprehensive security while maintaining computational efficiency. Another important observation is the persistent problem of energy consumption in WBAN systems. The operation of wearable and implantable sensors is limited by the battery power and therefore, long-term operation without frequent battery replacement remains a challenge.

Existing studies have proposed energy-aware routing protocols, optimised communication mechanisms and energy harvesting approaches to enhance the network lifetime. However, achieving the energy efficiency while ensuring the communication reliability, data accuracy and security requirements is still an open research challenge. The advent of 6G communications technology is anticipated to open up new horizons in the future of smart healthcare. High-level features, such as ultra-low latency, massive connectivity, intelligent resource management and seamless integration of heterogeneous devices, can help to support advanced healthcare applications, such as remote patient monitoring, telesurgery and AI-driven healthcare services. However, challenges such as interoperability, scalability, deployment complexity and infrastructure requirements need to be addressed to unlock the full potential of 6G-enabled healthcare systems

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Overall, the literature reviewed suggests that convergence of WBANs, AI, IoT, security mechanisms, energy-efficient communication strategies, and 6G technologies can significantly enhance the quality, accessibility, and reliability of healthcare services. But there are a number of technical and operational issues to be sorted out. To address these challenges, collaborative research efforts are required to design secure, intelligent, scalable and energy-efficient healthcare frameworks to meet the increasing demands of future healthcare ecosystems.

8. FUTURE RESEARCH DIRECTIONS

While a lot of advancements have been achieved in AI-enabled WBAN healthcare systems in recent years, there are several challenges that need to be tackled. Intelligent healthcare systems still face challenges such as data privacy, energy consumption, network scalability and real-time communication which affect their performance.

Future work should focus on designing light-weight and energy efficient AI models that can be efficiently executed on wearable and resource constrained WBAN devices while maintaining the accuracy and reliability. Further research can be conducted on technologies such as federated learning, edge computing and blockchain for the improvement of patient data security, privacy preservation and decentralized healthcare management. Advanced approaches like Tiny ML and explainable artificial intelligence (XAI) may also help in creating more transparent, low power and intelligent healthcare systems. Furthermore, future 6G-enabled healthcare environments are expected to support advanced applications such as remote surgery, digital healthcare twins, smart ambulances and real-time emergency healthcare monitoring. Therefore, more research is required to design secure, scalable, low-latency and energy-efficient WBAN architecture capable of supporting future intelligent healthcare services in dynamic healthcare environments.

9. CONCLUSION

The Wireless Body Area Networks (WBANs) have become an essential part of future smart healthcare systems as they support continuous and real-time monitoring of physiological parameters with the help of wearable and implantable sensors. This paper presented a comprehensive review of AI- based secure and energy-efficient WBANs integrated with IoT and 6G communications for smart healthcare applications. This paper discussed the role of Artificial Intelligence, machine learning, edge computing, federated learning and blockchain in improving healthcare monitoring, decision making, communication reliability and patient data security.

The study also discussed the importance of 6G communication technology in providing ultra-low latency, high speed transmission and reliable connectivity for advanced healthcare services such as remote patient monitoring, telesurgery, and emergency healthcare support. In addition, different security mechanisms and energy efficient techniques were surveyed to tackle the main challenges of privacy protection, secure communication and limited battery power of wearable devices.

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Finally, the integration of AI, WABNs and 6G technologies gives a promising future for intelligent healthcare systems with better quality, efficiency and reliability. The integration of AI with WBAN and 6G technologies can improve the quality, efficiency and reliability of future intelligent healthcare systems.

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