UtilitasMathematica

ISSN 0315-3681 Volume 122, 2025

INTEGRATION OF WIRELESS BODY AREA NETWORKS TO IMPROVE HEALTHCARE MONITORING

[1]Ravi, [2]Dr. Mridul Chawla

[1]Ph.D Scholar, Electronics and Communication Engineering Department, Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana, India. antilravi6519@gmail.com

[2]Professor, Electronics and Communication Engineering Department, Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana, India. mridulchawla.ece@dcrustm.org

ABSTRACT: Internet of Things (IoT)-enabled devices are paired with Wireless Body Area Network (WBAN) technology to facilitate seamless data collection, transmission, and analysis from multiple sensors placed on or near the body. The integration of IoT and WBANs transforms healthcare monitoring, addressing the challenges of traditional methods in providing timely and efficient patient care. As the global population ages and chronic diseases become more prevalent, the need for continuous and real-time health monitoring has intensified. Multiple solar-powered wearable sensor nodes use ZigBee transmission to create an efficient WBAN. The system facilitates the monitoring of vital signs and emergency conditions through various sensors, including accelerometers and ECG sensors, which communicate data to a smartphone application. This paper includes a comparative analysis of IoT-only, WBAN-only, and integrated IoT-WBAN systems, highlighting significant improvements in performance metrics such as data transmission latency, energy consumption, signal coverage, and system reliability. It indicates that the integrated system not only enhances real-time data collection and transmission but also provides scalable and inexpensive remote patient monitoring. The seamless exchange of information between healthcare professionals and patients, this integrated approach enhances healthcare delivery, promoting better patient outcomes and overall system efficiency.

KEYWORDS: Devices, Healthcare, IoT, Medical, Monitoring, Sensors, WBAN, Wearable Technology.

1. INTRODUCTION

The integration of the Internet of Things (IoT) and Wireless Body Area Networks (WBANs) signifies a transformative advancement in healthcare monitoring, enabling continuous and real-time tracking of patients' vital signs and overall health conditions [1]. With an aging global population and a rising prevalence of chronic diseases, traditional healthcare monitoring methods often fall short in delivering timely and efficient care. IoT-enabled devices, paired with WBAN technology, facilitate seamless data collection, transmission, and analysis from multiple sensors placed on or near the body. This innovative approach enhances monitoring accuracy and equips healthcare providers with the ability to make informed decisions swiftly, ultimately improving patient outcomes [2]. Healthcare is a critical aspect of human life, necessitating timely diagnosis and prevention of health issues. Traditionally, healthcare professionals have been required to be physically present to monitor patients' medical parameters, leading to prolonged hospital stays connected to wired biomedical instruments. The advent of modern healthcare monitoring systems, featuring wireless body sensors, allows for medical parameter monitoring anytime affordably and patient-friendly. An IoT framework enables access to patient health data both locally and remotely

[3-4]. WBAN systems offer crucial healthcare services, including emergency communication with healthcare providers through SMS or GPRS [5].

Multiple solar-powered wearable sensor nodes using ZigBee transmission form a WBAN. These sensor nodes are integral to the WBAN and include devices such as accelerometers, temperature sensors, pressure sensors, plug-in PPG sensors, and ECG sensors, all integrated onto a flexible solar panel [6]. Various nodes can be positioned on the body to monitor temperature distribution, measure heartbeat, and detect falls. Multiple power point tracking powers sensor nodes in the flexible solar energy harvester. These sensors' data and fall notifications will be sent to a web-based smartphone app via the monitoring system's ZigBee module. Wearable sensors can improve emergency detection in at-risk patients through continuous health monitoring [7-8]. By employing a wake-sleep mode for sensor nodes, we can achieve 24-hour operation powered by solar energy. The development of wearable sensors, low-power integrated circuits, and advanced wireless communication technologies positions WBANs as a pivotal research area worldwide [9]. The IoT encompasses a network of interconnected devices, including smartphones, home automation systems, and wearable technologies [10-11]. This paradigm shift in healthcare applications facilitates low-cost, real-time monitoring of patients' health, enabling connections between patients and specialists globally. In healthcare, IoT technologies allow for the monitoring of glucose levels, heart rates, and other vital measurements. Key issues addressed by IoT in healthcare include critical treatment situations, routine check-ups, and data transfer through cloud services for comprehensive patient care. The integration of smart devices plays a crucial role in connecting physicians and patients, enabling seamless data upload and analysis through big data technologies. Communication protocols are vital for the effective operation of IoT devices, with ZigBee networks employing both proactive and reactive routing. Thus, IoT-based healthcare focusses on relies on interconnected device networks, allowing secure data processing through a dedicated service layer. Wearable gadgets, doctors, and systems, necessitate secure transmission systems to facilitate information exchange [12]. Telemonitoring systems enable patients to receive care from home, allowing flexibility and comfort during treatment while avoiding hospital visits [13]. The healthcare industry stands to undergo significant transformations through innovations aimed at improving the transfer of electronic health records. Connected medical devices, increasingly integral to the healthcare system, are supported by 5G communication technology, which enhance IoT applications in healthcare. This next generation offers significantly higher bandwidth while optimizing energy consumption and data storage through big data analytics. Wireless communication can accommodate trillions of devices, enhancing user-controlled privacy and addressing the limitations of wired monitoring systems that restrict patient movement and increase the risk of hospital-acquired infections. Medical Body Area Networks (MBANs) enable low-cost monitoring solutions, as the Federal Communications Commission (FCC) has authorized specific wireless frequency bands (2360–2400 MHz) for the healthcare capabilities of MBAN devices [14].

1.1 Integration of IoT and WBAN

WBAN technology used WPAN to communicate on, near, and around the body in 1995, making a breakthrough. To describe to systems in which communication takes place fully Within, on, and near a human body, a new term known as "BAN" was established approximately six years later. Wireless communication, MEMS technology, and integrated circuits have enabled low-power, intelligent, miniaturized, invasive/non-invasive, micro and nanotechnology sensor nodes to be strategically placed in or around the body for many applications, including personal health monitoring [15]. These advancements. It is also possible for BAN to interface with other wireless technologies such as wireless sensor networks (WSNs), radio frequency identification (RFID) technology, Bluetooth, Bluetooth Low Energy (previously known as WiBree), Zigbee, wireless personal area networks (WPAN), video surveillance systems, wireless local area networks (WLAN), internet, and cellular networks [16]. BAN interactions include those between the master node and smartphones, tablets, notebooks, PCs, home service robots, etc. Beyond-BAN connects the device to the Internet [17-18]. IoT and WBAN are shown to be integrated in figure 1, which exhibits this integration. End unit may be IoT data processing or healthcare facilitator WBAN. Both networks could become interconnected, sophisticated, and smart wireless sensor networks.

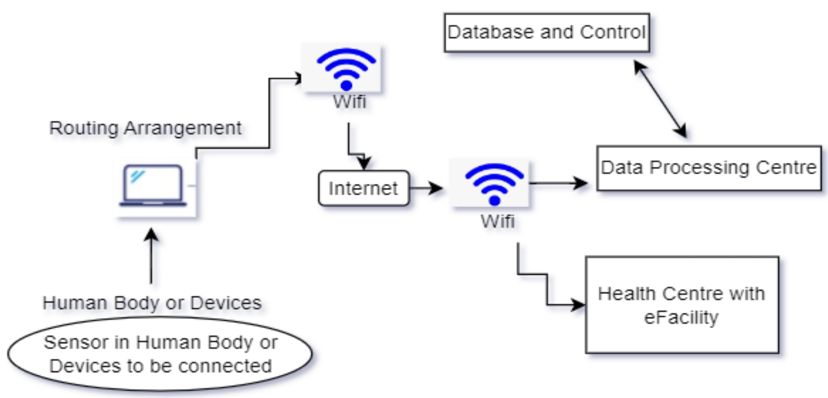

Figure 1: Integration of IoT and WBAN

As time progresses, the number of individuals and objects that coexist in BAN and IoT is rapidly increasing, which is directly proportional to the anticipated increase in the number of users. In this context, dependable communication is especially important in situations involving healthcare. Wireless BBNs, also known as things-to-things networks are implemented when there is a cohabitation between BAN and IoT. This is because of the possibility for inter-network communication and collaboration between the two types of networks [19]. The most important goal for the future is to find solutions to the problems of cohabitation and to improve overall performance. Providing a cost-effective solution for the process of remote monitoring of a group of patients or items, for example, can be accomplished by this form of integrated network through the relaying of sensor data in the event that the network infrastructure is located outside of its range [20].

2. LITERATURE REVIEW

The end unit may be IoT data processing or health care facilitator WBAN network and technologies has emerged as a transformative approach to improve healthcare monitoring. According to studies, IoT-enabled WBANs can increase health assessment accuracy and speed, improving patient outcomes and healthcare system efficiency.

Javaid, S., et al. [21], discussed sensor technology has enhanced our health, comfort, and lifestyle in recent decades. Technological developments reduced medical sensor size and cost, expanding their use. Medical sensors are useful for surgeries, therapy, rehabilitation, and remote health monitoring, among other healthcare services. The medical sensors focus on their use in healthcare. IoT technology improves healthcare sensor technologies, according to the review. It also evaluates contemporary integrated architectures that smoothly combine heterogeneous medical sensors with edge, MCC, fog, and cloud computing technologies. Challenges to maximize medical sensor technology's robust, scalable, dependable, and cost-effective healthcare potential.

Liu, Q., et al. [22], analyzed wireless body area network difficulties, applications, findings, and performance challenges. WBAN signal processing, network reliability, spectrum management, security, and healthcare tech integration. Microelectronic technology and commercialization enhance the availability, miniaturization, and communication of devices. WBANs' operational, standardization, and security challenges hamper privacy, safety, and performance. Healthcare will increasingly use WBAN for medical and non-medical uses as internet connectivity increases. Despite WBAN's benefits in remote health monitoring, more research is needed to optimize performance.

Mahmoud, N., et al. [23], studied chronic disease limits a patient's life due to recurrent illness and degeneration. It demands ongoing patient-physician collaboration in an integrated health care system. Modern technologies make patient monitoring efficient. Nobody offers end-to-end data extraction, transport, analysis, storage, and integration solutions. A complete model links WBAN, cloud, fog, semantic ontology, and CDSS. Physicians can help chronic disease patients make the correct decisions by monitoring them in real time. In addition, patients can live normally. Finally, patients don't need hospital stays, saving money WBAN data will be linked into the patient's EHR using semantic interoperability challenge. The revolutionary structure is viable and should improve patient quality of life and cut healthcare costs.

Elhayatmy, G., et al. [24], examined IoT-based wireless body area networks in healthcare replaced hospital visits and constant observation. IoT measures, processes, and communicates biological and physical characteristics. Smart devices connect doctors, patients, and nurses, who can wander freely. The transforming healthcare by cutting costs and Improve patient care by boosting efficiency. The record and analyse life-critical data in real time using powerful algorithms and intelligent systems to better research, management, and critical care.

Wu, T., et al. [25], descried IoT is a new technology that connects devices from different industries via the Internet. Wearable devices make WBAN appealing for IoT-connected healthcare. Wearable sensor node with solar energy collection and Bluetooth low energy transmission for autonomous WBAN. Sensor nodes on bodily parts measure heartbeat, temperature, and falls. Wearable sensor nodes combine flexible solar energy harvesters with output-based maximum power point tracking for extended life. The solar energy harvester effectively powers the wearable sensor node. Experimental results enable 24-hour autonomy. The proposed solar energy harvesting system illustrates that WBAN can be utilised for long-term medical monitoring if the subject spends a little time outside per day.

Shaji, et al. [26], studied Internet of Things (IoT) is a network of devices, vehicles, monitoring appliances, and other objects containing electronics, software, sensors, actuators, and network connectivity that can communicate. Monitoring healthcare uses wireless body area networks. An autonomous sensor network links medical sensors and gadgets in the body. The several wearable sensor nodes with ZigBee transmission and solar energy harvesting for WBAN. Nodes in various body parts measure temperature, pressure, heart rate, ECG, and fall detection. Smartphone webapps display sensor data. Adaptable solar harvester with maximum power point tracking extends sensor life. Wearable sensor nodes perform well with solar energy harvesters. With a solar energy harvester and ZigBee, the suggested system can monitor heath 24/7 using WBAN.

Chatterjee, et al. [27], described modern advances in sensors, miniaturization, and wireless networking made wireless sensor networks capable of monitoring and regulating the environment. Sensor networks use tiny wireless sensors strategically positioned on the body to build a wireless body area network (WBAN) that can administer critical implications and provide real-time feedback to users and medical staff. In the future, the Internet of Things (IoT) will facilitate communication and machine-to-machine learning. Therefore, IoT links everyone and everything.

Next, in Table 1, we have summarized the literature review based on their focus, approaches, and key findings.

Table 1: Summary of the Literature Review

Author(s)	**Year**	**Focus**	**Approaches**	**Key Findings**
Javaid, S., et al.	2022	Medical sensor IoT integration in healthcare	Overview of sensor architectures and technologies	Medical sensors improve healthcare delivery, but integration with IoT and other technologies is difficult. These systems must be optimized for robust, reliable, and cost-effective treatment.
Liu, Q., Mkongwa et al.	2021	Issues and performance challenges in WBAN	WBAN performance, signal processing, security, and integration	WBANs face operational, standardization, and security issues; increasing dependency on WBAN for healthcare; need for further studies on performance optimization and future research directions.
Mahmoud, N., El-Sappagh et al.	2020	Integration of WBAN, cloud, and semantic ontology for chronic disease management	The framework for patient monitoring using WBAN and clinical decision support systems (CDSS)	A comprehensive model can enhance real-time monitoring of chronic diseases, improve patient quality of life, and reduce healthcare costs; emphasizes semantic interoperability in EHR integration.

Elhayatmy, G., et al.	2018	IoT-based WBAN in healthcare and its impact on patient monitoring	Overview of IoT functionalities and its application in healthcare	IoT improves healthcare efficiency by enabling real-time data collection and analysis; highlights the need for intelligent systems to enhance patient care through reduced costs and improved management.
Wu, T., et al.	2017	Development of an autonomous WBAN with solar energy harvesting for continuous health monitoring	Creation of a wearable, solar-powered sensor node with low-power Bluetooth connectivity	Successful implementation of a wearable sensor node for 24-hour operation; demonstrates the viability of using WBAN to capture solar energy for long-term medical monitoring.
Shaji, J. E., et al.	2017	Implementation of WBAN for healthcare monitoring using solar energy harvesting	Multiple solar-powered ZigBee-connected wearable sensor nodes.	Continuous healthcare monitoring is feasible with solar energy-powered wearable sensor nodes; effective for measuring vital signs and fall detection.
Chatterjee, S., et al.	2020	Study on integrated IoT and WBAN for health monitoring.	Investigation of IoT-WBAN integration	Highlights the potential of IoT and WBAN integration for real-time health monitoring and data feedback; emphasizes the importance of miniaturized sensor technology for effective healthcare applications.

3. RESEARCH METHODOLOGY

The research methodology for this study focuses on evaluating the integration of IoT and WBANs to enhance healthcare monitoring. The approach involves a comparative analysis of IoT-only, WBAN-only, and integrated IoT-WBAN systems based on key performance metrics. The systems are test and evaluate under simulate healthcare environments with varying conditions, including patient mobility, energy constraints, and network coverage. The methodology incorporates both quantitative measurements of system performance and qualitative analysis of patient support and system scalability. For each configuration—IoT-only, WBAN-only, and the integrated system—a set of performance metrics collected, including data transmission latency, energy consumption, signal coverage, packet loss rate, system reliability, and sensor response time. Emphasis was placed on critical healthcare requirements, such as low latency for real-time monitoring, energy efficiency to prolong battery life of wearable sensors, and high system reliability to ensure continuous patient data collection. Table 2 shows the performance metrics for IoT, WBAN only, and integrated IoT-WBAN system. This table illustrates the relative performance of the three systems, showcasing the improvements achieved by integrating IoT and WBAN technologies. The integrated system significantly reduces data transmission latency and energy consumption while increasing signal coverage and throughput. The data presented in the table was collected through experimental trials and simulations, ensuring accuracy in reflecting real-world performance.

Table 2: Performance Metrics of IoT and WBAN-based Healthcare Monitoring System

Metric	**IoT-Only System**	**WBAN-Only System**	**Integrated IoT-WBAN System**
Data Transmission Latency	120	80	35
Energy Consumption	2.5	1.8	1.2
Signal Coverage	50	15	60
Packet Loss Rate	2.1	3	0.8
Patient Mobility Support	1	0.5	1.8
System Reliability	91	85	98
Sensor Response Time	150	100	50
Throughput	2.5	1.5	4
Cost per Patient	40	25	30
System Scalability	1000	250	2000

The integrated system demonstrates superior performance across most metrics, suggesting its potential as a more effective solution for healthcare monitoring than standalone IoT or WBAN systems.

- **Data Transmission Latency:** The integrated system has the lowest latency due to optimized communication protocols.
- **Energy Consumption:** The integrated system consumes less energy, making it efficient for continuous monitoring.
- **Signal Coverage:** Integration improves coverage, extending the range to monitor patients across larger areas.
- **Packet Loss Rate:** The integrated system offers better data transmission with minimal packet loss. Patient Mobility Support: Higher mobility support enables real-time monitoring of patients in motion.
- **System Reliability:** The integrated approach provides the highest reliability for data transmission and monitoring.
- **Sensor Response Time:** Faster response time in the integrated system enhances real-time data collection.
- **Throughput:** Data transmission is more efficient in the integrated system.
- **Cost per Patient:** The integrated system balances cost-effectiveness and performance.
- **System Scalability:** The integrated system supports a larger number of devices, facilitating scalability.

4. RESULTS AND DISCUSSION

The results of the integration of IoT and WBANs for healthcare monitoring demonstrate significant improvements in real-time patient data collection and transmission. In Figures 1 and 2 described as terms of data transmission latency, the IoT-only system exhibits higher latency, reflecting slower data transfer, whereas the WBAN-only system demonstrates lower latency, which is more efficient for real-time monitoring. Energy consumption is also higher for IoT systems, as they require more resources to maintain communication and processing, while the WBAN system consumes significantly less energy, making it more suitable for long-term patient monitoring. The signal coverage for IoT systems extends further than WBAN, which is expected as IoT systems typically operate on larger, more expansive networks. However, the packet loss rate is considerably lower in the WBAN system, indicating better communication reliability within short-range environments. The patient mobility support is slightly better in IoT systems, likely due to their broader network capabilities, but WBAN shows better results in system reliability and sensor response time, which are critical for ensuring accurate and timely data collection in healthcare settings. On throughput, the IoT-only system offers higher bandwidth, though at a higher operational cost. This is reflected in the cost per patient, where IoT systems are more expensive than WBAN systems. Finally, in terms of system scalability, IoT systems significantly outperform WBAN, being more adaptable to larger-scale deployments, whereas WBAN is more optimized for smaller, more controlled environments. Overall, the figure illustrates that while IoT systems offer advantages in scalability and network reach, WBAN systems exhibit higher energy efficiency and dependability, and cost-effectiveness, making them more suitable for personalized healthcare applications

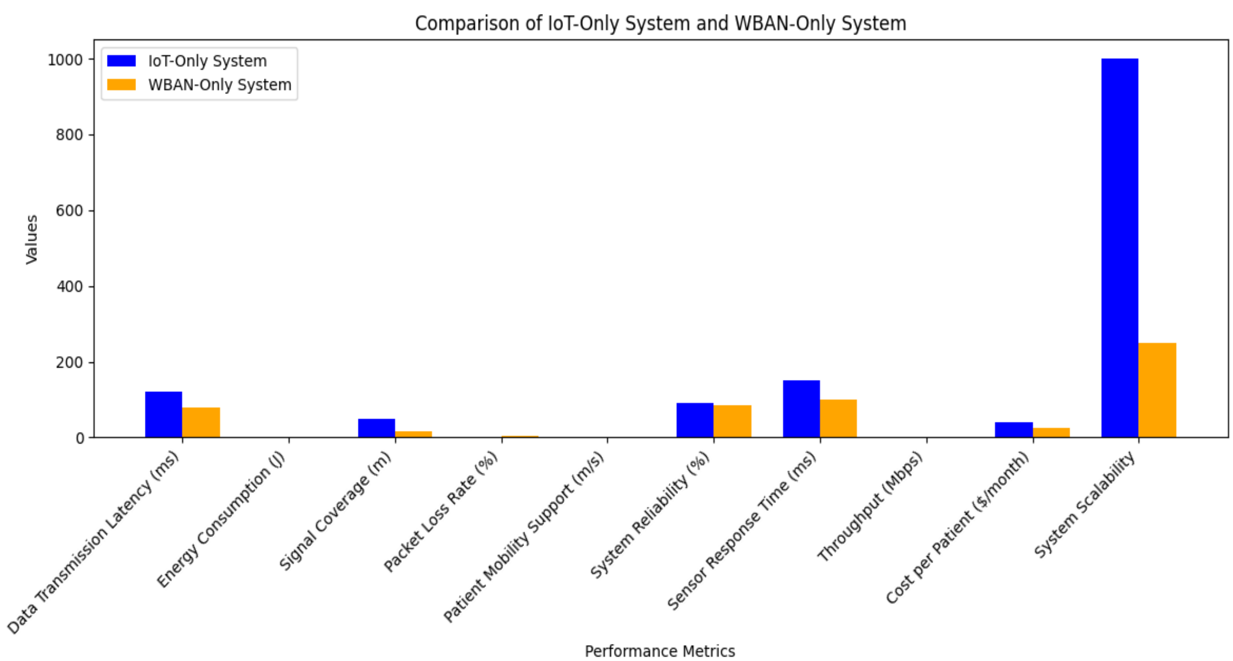

Figure 2: Comparison of IoT-System and WBAN-Only System

In Figure 2, a comparative analysis of two healthcare monitoring systems is presented: IoT-Only and WBAN-Only. The comparison is made across several performance metrics such as data transmission latency, energy consumption, signal coverage, packet loss rate, patient mobility support, system reliability, sensor response time, throughput, cost per patient, and system scalability.

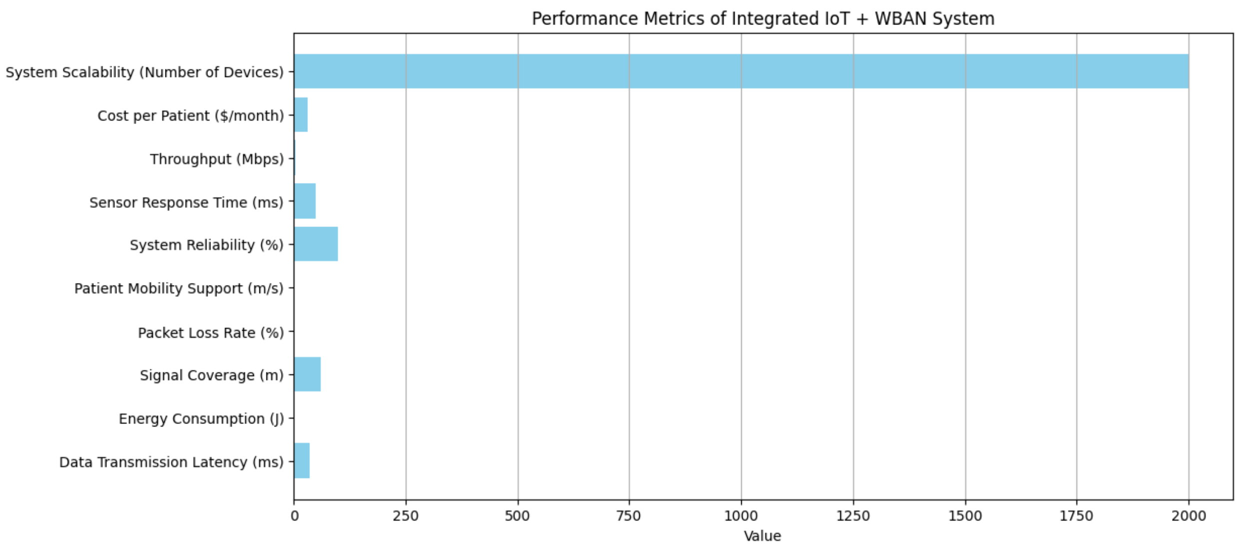

Figure 3: Performance Metrics of Integration IOT-WBAN System

In Figure 3 illustrates the performance metrics of an integrated IoT and WBAN system, which are critical in assessing the system's efficiency and effectiveness in healthcare monitoring.

4.1 DISCUSSION

The integration of IoT with WBANs has brought transformative changes to healthcare monitoring by enabling real-time, continuous, and remote monitoring of patients. This research aimed to evaluate the performance and potential of IoT and WBAN-based healthcare systems, focusing on the improvements they offer in terms of patient monitoring, early disease detection, and overall healthcare efficiency.

- The integration of IoT and WBAN has significantly improved healthcare monitoring by offering seamless data collection from sensors placed on the patient's body. An IoT-enabled WBAN system can monitor heart rate, blood pressure, glucose, and body temperature. The ability to remotely monitor patients using IoT also alleviates the burden on healthcare facilities, especially during high-demand situations such as pandemics or natural disasters. It has the potential to decentralize healthcare services by bringing monitoring and diagnosis into patients' homes, thus making healthcare more accessible.
- The performance metrics of IoT and WBAN-based systems were compared across several factors, such as latency, data transmission rates, power consumption, security, and reliability. While IoT networks provide the backbone for communication between sensors, gateways, and cloud storage, WBANs offer an energy-efficient solution for short-range communication of health data.
- Despite their benefits, WBAN and IoT integration for healthcare monitoring are not without obstacles. The transmission of sensitive patient data over IoT networks exposes it to potential security threats, including data breaches and unauthorized access. Encryption and secure communication protocols must be employed to protect patient data.

- Interoperability between different IoT devices and WBAN systems is another challenge. Since IoT devices come from different manufacturers, standardization is frequently absent in communication protocols, which can lead to compatibility issues.
- The future of IoT and WBAN integration in healthcare lies in addressing these technical and ethical challenges. Additionally, the adoption of 5G networks will likely improve the speed and reliability of data transmission in IoT systems, thereby reducing latency and enabling more responsive healthcare applications.

5. CONCLUSION

In conclusion, IoT and WBANs improve healthcare monitoring, offering a transformative approach to patient care. This study has demonstrated that combining these technologies enables continuous and real-time tracking of vital health parameters, significantly improving monitoring and detect health issues early. The comparative analysis of IoT-only, WBAN-only, and integrated systems highlights the superior performance of the integrated solution, characterized by reduced data transmission latency, lower energy consumption, and enhanced system reliability. Moreover, the integration facilitates greater scalability, making it suitable for widespread healthcare applications while ensuring effective remote monitoring capabilities. The shift towards decentralized healthcare services, particularly during high-demand situations, emphasizes the importance of these technologies in enhancing accessibility and efficiency in patient care. To maximize IoT and WBAN integration, data security, privacy, and interoperability must be addressed. As healthcare technology evolves, future advancements—especially with the adoption of 5G networks—are likely to further enhance the capabilities of IoT and WBAN systems. Addressing the existing challenges and leveraging emerging technologies will be essential to optimize patient outcomes and ensure the effective use of integrated healthcare monitoring systems. In conclusion, the convergence of IoT and WBAN not only reshapes healthcare monitoring but also holds the promise of improving overall health management, making healthcare more connected and efficient.

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