International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Deep Overview of Body Area Sensor Network Technologies

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ABSTRACT:

Body Area Sensor Networks (BASNs) have emerged as a critical innovation in healthcare and wellness, offering real-time, continuous monitoring of physiological parameters through a network of wearable and implantable sensors. This literature review provides an extensive examination of the technological advancements, applications, challenges, and future directions of BASNs. The review explores the evolution of sensor technologies, wireless communication protocols, data processing techniques, and power management solutions integral to the functionality of BASNs. Additionally, it highlights the diverse applications of BASNs in healthcare monitoring, fitness and wellness, rehabilitation, and elderly care. Key challenges such as data security, interoperability, power consumption, and user comfort are analyzed, with a discussion on potential solutions and ongoing research efforts. The review concludes by identifying emerging trends and future research directions, including the development of advanced materials, integration with artificial intelligence and the Internet of Things, and the establishment of regulatory and ethical standards. This comprehensive review aims to provide a foundational understanding of BASNs, emphasizing their transformative potential and the critical areas requiring further exploration to enhance their adoption and efficacy.

KEYWORDS: BANSN, Applications, Security

INTRODUCTION:

In many nations, the rise of chronic illnesses including obesity, diabetes, and hypertension is creating several economic and social problems in addition to increasing the strain on publicly financed healthcare systems[1]. Chronic illnesses account for almost two-thirds of all fatalities globally, making them a significant contributor to human health hazards[2]. Numerous studies [3] have shown that chronic illnesses can be successfully avoided in their early stages, indicating the critical importance of early diagnosis and identification. Thus, achieving real-time human health monitoring through disease surveillance and health assessment is crucial and essential. An elderly population, a lack of healthcare facilities, the prevalence of chronic diseases, and other issues may be lessened or perhaps resolved by (WBANs), which are made possible by recent advancements in sensor and wireless communication technologies. A wearable body area network, or WBAN, links nodes with sensors inside, on, or near individuals to facilitate communication between people and objects[4].

Every node is in charge of gathering physiological statistics, including blood pressure (BP), heart rate variability (HRV), blood oxygen saturation (SpO2), electrocardiogram (ECG), and electroencephalogram (EEG). To compile all of the data from nodes and send it to the Internet, the terminal functions as an individual server. Additionally, patients can receive biofeedback from distant servers via the WBAN system. In addition to quickly processing data, the remote system's servers offer various services like continuous monitoring and health consultations that are beneficial for managing chronic illnesses.

RESEARCH BACKGROUND

Three levels of communication: intra, inter, and beyond WBAN can be differentiated in WBANs [5]. The intra-WBAN communication is made up of a number of sensors that are inserted into or applied to the human body. In this layer, sensors maintain star topology and are linked to a centralized node for the purpose of gathering and sending different human physiological information. This communication is limited to the sensors and the sink, and the function of it is to handle the data gathered and send it to next level via Bluetooth, Wi-Fi, ZigBee, or some other kind of short-distance transmission method. The inter-WBAN communication, which makes use of computers, smartphones, and other clever gadgets. In this layer, ad hoc architecture is dispersed and uses an unplanned topology for communication. By using WLAN, 3G, 4G, 5G, and other wireless connections, 2^{nd} level transmits the data that the sensor sends to 3^{rd} level (the terminal hub). In Level 3, which is beyond-WBAN communication, distant servers make up the majority of the terminal center. Its purpose is to record and examine incoming data so that it can be utilized for disease detection, diagnosis, and treatment. A rapid response and alarm can be set off, particularly if the received data are unusual, which helps to expedite emergency care. Every tier has unique requirements and technical challenges that must be overcome.

The challenges faced by WBANs have been outlined in a number of paper. However, these surveys, which concentrate on particular WBAN aspects, are only able to systematically describe WBANs and only make reference to a few technical points; they do not offer integrated circuit (IC)-based solution programs.

USES OF WBAN IN VARIOUS MEDICAL & NON-MEDICAL APPLICATIONS

WBAN software has significant economic and social benefits and is widely utilized in health surveillance, military service, entertainment, sports, aviation, and a variety of human-centered areas. WBANs could help safeguard personnel like firefighters, soldiers, deep-sea researchers, and space explorers who might be subjected to potentially fatal situations. A few instances include giving firefighters real-time health monitoring to determine the proper training intensity, monitoring specific environments like fire sites and areas with toxic gases, giving emergency early warnings to increase firefighter safety, and wirelessly transmitting critical military data to command centers or remotely commanding units. Real-time streaming, entertainment, and non-medical situations are some categories for the non-medical uses.

Table 1: Certain medical & non-medical applications

Reference	Focus	Key Contributions	Challenges Identified
Taleb H., Nasser A., Andrieux G., Charara N., Cruz E.M. (2021)[6]	Wireless technologies, medical applications, and future challenges in WBAN	Overview of WBAN technologies, medical applications, and future research directions	Security, energy efficiency, data management, and interoperability
Pan Q., Brulin D., Campo E.J.J.B.E. (2020)[7]	Sleep monitoring systems	Systematic review of current sleep monitoring technologies, their effectiveness, and areas for improvement	Accuracy, comfort, integration with existing medical systems
Joshi R., Constantinides C., Podilchak S.K., Soh P.J. (2018) [8]	Antenna design for military search and rescue operations	Dual-band folded-shorted patch antenna design for robust communication in challenging environments	Antenna performance in varying environmental conditions, miniaturization
Ullah S., Higgins H., Braem B., Latre B., Blondia C., Moerman I., Saleem S., Rahman Z., Kwak K.S. (2012)[9]	WBAN solutions on PHY, MAC, and network layers	Comprehensive survey of solutions at different layers of WBAN architecture, including protocols and algorithms	Scalability, energy efficiency, quality of service (QoS), and standardization
Chakraborty C., Gupta B., Ghosh S.K. (2013)[10]	Telemedicine-based WBAN framework for patient monitoring	Review of telemedicine applications using WBAN, emphasizing the framework for remote patient monitoring	Security, reliability, patient data privacy
Bouazizi A., Zaibi G., Samet M., Kachouri A. (2018)[11]	Miniaturized invasive antenna for medical applications	Study on miniaturized antennas for invasive medical applications, aiming to improve performance and patient comfort	Biocompatibility, long-term reliability, signal interference
Young D.J. (2020)[12]	Wireless inductive sensing for implantable glucose monitoring	In-vitro study of wireless inductive sensing and packaging for implantable glucose monitoring systems	Robust packaging, long-term stability, biocompatibility
Mahmood S.N., Ishak A.J., Saeidi T., Soh A.C., Jalal A., Imran M.A., Abbasi Q.H. (2021)[13]	Ultra-wideband wearable textile antenna for WBAN applications	Development of a full ground ultra-wideband textile antenna for wearable applications, particularly in breast cancer detection	Antenna performance, wearability, signal integrity in diverse environments
Chen D.R. (2018)[14]	Real-time streaming control for quality-of-service in coexisting WBANs	Proposed a real-time streaming control mechanism to enhance quality-of-service in WBANs	Real-time data processing, coexistence of multiple networks, QoS maintenance
Movassaghi S., Abolhasan M., Lipman J., Smith D., Jamalipour A. (2014)[15]	General survey of WBAN	Detailed survey on the state-of-the-art in WBAN technologies, protocols, and applications	Interference management, energy consumption, and security
Salayma M., Al-Dubai A., Romdhani I., Nasser Y. (2017)[16]	WBAN reliability, fault tolerance, and technology coexistence	Survey on reliability, fault tolerance, and coexistence strategies for WBANs	Fault tolerance, reliability, integration with other wireless technologies

SECURITY IN WBAN

Since human physiological characteristics are patient-specific and impact the outcome of clinical diagnoses, they are extremely sensitive and private information that WBANs collects or transmits. As Internet of Things technology advances, WBANs have a growing number of nodes, which causes the networks to transmit a rising amount of crucial data. Thus, the most important factors for BANs are security and privacy, which need to be strictly ensured to stop data leaks and manipulation. However, WBANs cannot use security mechanisms designed for other networks because of stringent resource limitations, including energy usage, communication rate, and processing power. Therefore, managing security in the WBAN context is an important area of research and presents new difficulties for WBAN implementation.

Table 2: Comparison of different security techniques in WBAN

Reference	Focus	Key Contributions	Challenges Identified
Bengag A., Bengag A., Moussaoui O. (2020)[17]	Detection of jamming attacks for WBAN-based healthcare monitoring systems	Proposed a robust method for detecting jamming attacks in WBAN, enhancing the reliability of healthcare monitoring systems	Real-time detection, accuracy, and false positives
Arya K., Gore R. (2020)[18]	Data security solutions for e-health applications	Intelligent data security solutions for WBAN in e-health IoT applications, focusing on encryption, access control, and secure data transmission	Scalability, integration with existing systems, computational overhead
Al Hayajneh A., Bhuiyan M.Z.A., McAndrew I. (2020)[19]	Broadcast authentication for cloud-enabled wireless medical sensor devices in 5G networks	Enhanced security of broadcast authentication in 5G-enabled wireless medical sensor devices, addressing issues in cloud-based WBANs	Authentication delays, computational complexity, and energy consumption
Thamilarasu G., Odesile A., Hoang A. (2020)[20]	Intrusion detection system for Internet of Medical Things (IoMT)	Developed an intrusion detection system for IoMT, improving security through anomaly detection and real-time monitoring	Scalability, real-time processing, and adaptability to new threats
Umar M., Wu Z., Liao X. (2020)[21]	Mutual authentication in body area networks using signal propagation characteristics	Proposed a mutual authentication technique utilizing signal propagation characteristics to enhance security in WBAN	Authentication accuracy, signal variability, and environmental factors
Suchithra M., Baskar M., Ramkumar J., Kalyanasundaram P., Amutha B. (2021)[22]	Low rate attack detection in multimedia networks for improved QoS	Developed a method using invariant packet features and network conditions to efficiently detect low rate attacks, improving QoS in multimedia WBANs	Detection accuracy, processing overhead, and adaptability
Rao J.D., Sridevi K. (2019)[23]	Security system for WBAN based on fuzzy logic and trust factor considering residual energy	Proposed a novel security system that employs fuzzy logic and trust factor, taking into account the residual energy of WBAN nodes	Energy efficiency, trust calculation accuracy, and adaptability to network changes

ENERGY EFFICIENCY IN WBASN

WBAN's energy usage varies more than that of traditional short-range wireless communication technologies like Zigbee and Bluetooth. Since WBANs touch human tissue, it is frequently required to restrict the component's size in order to make it wearable, resulting in increasing the battery power challenging. Furthermore, patients find regular battery changes to be quite inconvenient, particularly for implanted devices that can only be replaced surgically. A WBAN's usefulness and user satisfaction are directly impacted by its hardware dimensions and battery power constraints. Energy conservation is therefore crucial for a well-designed WBAN, and many studies now focus on optimizing energy usage as one of the main goals of WBANs. Studies on energy harvesting to increase the efficiency of energy including those that used thermal, vibrational, and solar energy [24].

Table 3: A comparison of different energy efficiency techniques in WBASN

Reference	Focus	Key Contributions	Challenges Identified
Taleb H., Nasser A., Andrieux G., Charara N., Cruz E.M. (2021)[6]	General overview of WBAN technologies	Identified energy efficiency as a key challenge and discussed various approaches, including duty cycling and energy-efficient protocols	Balancing energy efficiency with performance and reliability
Ullah S., Higgins H., Braem B., Latre B., Blondia C., Moerman I., Saleem S., Rahman Z., Kwak K.S. (2012)[9]	WBAN solutions on PHY, MAC, and network layers	Comprehensive survey of energy-efficient solutions at different layers of WBAN architecture, such as low-power MAC protocols and energy-aware routing algorithms	Scalability, real-time performance, and standardization
Chen D.R. (2018)[14]	Real-time streaming control for QoS in WBANs	Proposed a real-time streaming control mechanism that optimizes energy consumption while maintaining quality of service (QoS)	Managing energy consumption without compromising QoS
Movassaghi S., Abolhasan M., Lipman J., Smith D., Jamalipour A. (2014)[15]	General survey of WBAN technologies	Detailed survey highlighting various energy-efficient protocols and mechanisms for WBAN, including energy harvesting and energy-efficient communication protocols	Interference management, energy consumption, and security

Salayma M., Al-Dubai A., Romdhani I., Nasser Y. (2017)[16]	WBAN reliability and fault tolerance	Survey on strategies for enhancing reliability and fault tolerance in WBANs, emphasizing energy-efficient mechanisms	Fault tolerance, reliability, and integration with other wireless technologies
Pan Q., Brulin D., Campo E.J.J.B.E. (2020)[7]	Sleep monitoring systems	Review of sleep monitoring technologies focusing on energy-efficient designs to prolong the battery life of wearable devices	Comfort, accuracy, and integration with existing medical systems
Mahmood S.N., Ishak A.J., Saeidi T., Soh A.C., Jalal A., Imran M.A., Abbasi Q.H. (2021)[13]	Ultra-wideband wearable textile antenna for WBAN applications	Development of energy-efficient ultra-wideband textile antennas for wearable applications, aiming to reduce energy consumption while maintaining performance	Antenna performance, wearability, and signal integrity
Rao J.D., Sridevi K. (2019)[23]	Security system for WBAN based on fuzzy logic and trust factor considering residual energy	Proposed a security system that employs fuzzy logic and trust factor while considering residual energy to optimize the energy consumption of WBAN nodes	Energy efficiency, trust calculation accuracy, and adaptability to network changes

Key Findings:

1. **Applications in Disease Monitoring:**
- **Cardiovascular Monitoring:** WBANs are used to monitor heart rate, blood pressure, and ECG signals, providing critical data for early detection and management of cardiovascular diseases.
- **Diabetes Management:** Continuous glucose monitoring systems integrated with WBANs offer real-time data, enabling better glycemic control and reducing the risk of complications.
- **Neurological Disorders:** WBANs facilitate the monitoring of brain activity and seizure detection, aiding in the management of conditions such as epilepsy and Parkinson's disease.
- **Sleep Disorders:** Sleep monitoring systems using WBANs help diagnose and manage conditions like sleep apnea by tracking sleep patterns and breathing abnormalities.

2. **Technical Requirements and Challenges:**
- **Data Security and Privacy:** Ensuring the confidentiality and integrity of sensitive health data is paramount. Techniques such as encryption, authentication, and secure data transmission are essential but must be balanced with the constraints of low-power devices.
- **Energy Efficiency:** WBAN devices rely on battery power, making energy efficiency a critical concern. Techniques such as duty cycling, energy-efficient communication protocols, and energy harvesting are crucial for prolonging battery life while maintaining reliable performance.
- **Interoperability and Standardization:** The integration of WBANs with existing healthcare systems and other IoT devices requires standardized protocols and interfaces to ensure seamless data exchange and interoperability.
- **Reliability and Fault Tolerance:** The continuous and accurate monitoring of health parameters necessitates robust and fault-tolerant network designs that can handle node failures and ensure data reliability.

3. **Energy Efficiency Techniques:**
- **Duty Cycling:** Reducing the active time of sensors and communication modules to conserve energy.
- **Energy-Efficient Protocols:** Implementing low-power MAC protocols and energy-aware routing algorithms to optimize communication energy usage.
- **Energy Harvesting:** Utilizing ambient energy sources such as body heat, motion, and ambient light to extend battery life.
- **Low-Power Hardware Design:** Developing hardware components optimized for low energy consumption without compromising performance.

CONCLUSION :

WBANs hold significant potential in revolutionizing healthcare by enabling continuous, real-time monitoring of various health parameters. However, the successful implementation of WBANs in healthcare applications requires addressing technical challenges related to data security, energy efficiency, interoperability, and reliability. Advances in these areas will be crucial for the widespread adoption of WBANs, ultimately improving patient outcomes and enabling more effective disease management. The ongoing research and development in energy-efficient protocols, secure data transmission, and robust network architectures will play a pivotal role in overcoming these challenges and realizing the full potential of WBANs in healthcare.

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