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Energy-Efficient Wireless Body Area Networks for Healthcare

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Abstract: Recent developments and advancements in information and communication technology enhance several aspects of life. Significantly, the healthcare business has increasingly integrated information and communication technology-based services. One of the most crucial services is the monitoring of distant patients, which allows healthcare experts to watch, diagnose, and prescribe treatment without physical presence. The benefit of sensor technology downsizing allows for installation in, on, or off the patient's body, enabling the wireless transmission of physiological data to distant servers. This technology is referred to as a Wireless Body Area Network (WBAN). This article illustrates the architecture of WBAN, the communication technologies used in WBAN, as well as the problems and other factors associated with WBAN. This article delineates the architectural constraints of current WBAN communication systems. azure Moreover, implementation specifications are delineated in accordance with the IEEE 802.15.6 standard. Ultimately, this serves as a motivational impetus for the future advancement of research integrating Software Defined Networking (SDN), Energy Harvesting (EH), and Blockchain technology into Wireless Body Area Networks (WBAN).

Keywords: *WBAN, IEEE 802.15.6, M2M, SDN, Blockchain*

Introduction

The advancement of wireless communication technology has influenced our daily lives in every facet.

In the age of the Internet of Things (IoT) and Big Data, the impact of technological innovation on the healthcare industry is unavoidable. Contemporary advancements in communication technology enable electronic health monitoring, fitness tracking, calorie assessment, online consultations with professionals, diagnostics, and remote healthcare. Among the most promising communication technologies for monitoring human health data and post-processing, WBAN is regarded as the foremost choice. This connection, characterized by the exchange of substantial sensory data among participating nodes, may be classified as a kind of machine-to-machine (M2M) communication within the healthcare sector [5].

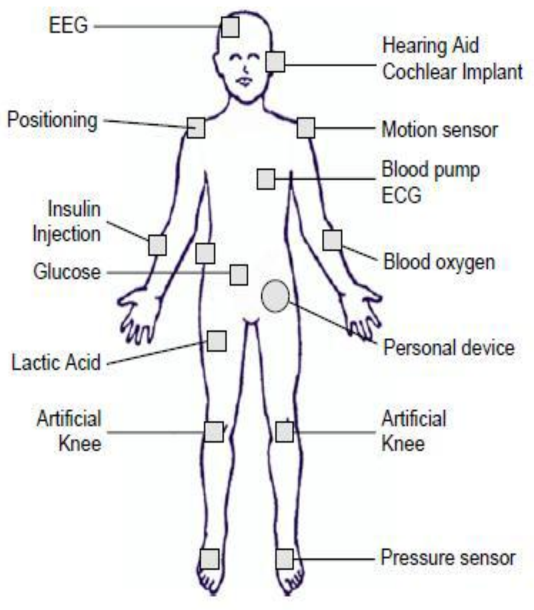

Fig. 1 : Example of patient monitoring in a Wireless Body Area Network.

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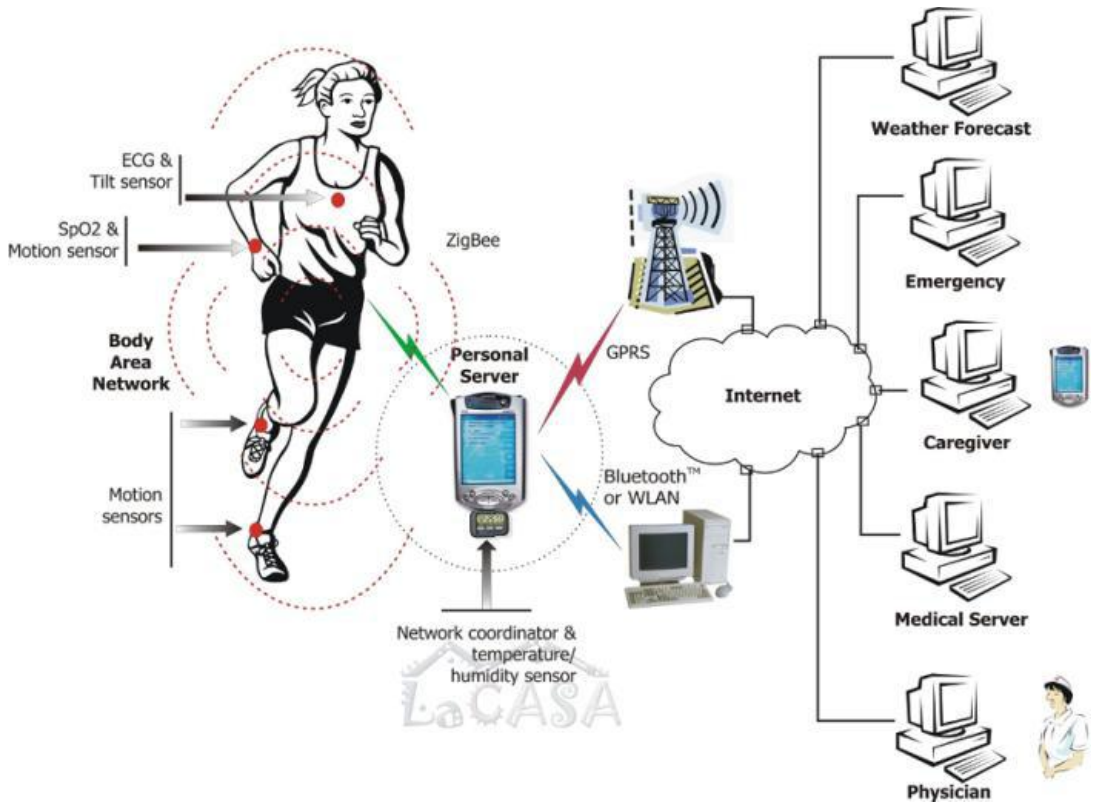

Fig 2 : Proposed Physical Network Architecture

The M2M communication system encompasses several application domains, including automotive, healthcare, energy, security and surveillance, smart metering, and transportation. The use of M2M technology in the healthcare industry is anticipated to be a significant market catalyst in the future [6]. Owing to advancements in the healthcare industry, people with various chronic conditions, including cardiovascular illnesses and strokes, exhibit enhanced physical mobility and are no longer need to remain hospitalized for ongoing monitoring. The need for hospitalization has significantly diminished owing to advancements in the healthcare industry. The healthcare system is now augmented with computerized procedures and communication, referred to as eHealth. Moreover, healthcare services are transitioning to mobile formats, therefore referred to as mobile health (mHealth) [8]. Within the framework of telemedicine and mHealth, a nascent and innovative technology is WBAN. In a Wireless Body Area Network (WBAN), health-related sensors are positioned proximate to the patient's body, affixed to the body, or, in some instances, implanted. Sensors are linked by short-range wireless technologies, including ZigBee, WiFi, and Bluetooth. Consequently establishing WBAN. Devices including mobile phones, Personal Digital Assistants (PDAs), or other similar devices can function as gateways, collecting data from sensors and transmitting this information to a remote online server for processing and analysis using medical software applications. Telecommunication networks, including WLAN, WiMax, LTE, LTE-A, and Satellite, may serve as communication links between gateways.

Related Works

In the last five years, literature studies have sought to emphasize the principal findings related to the design, problems, and implementation concerns of WBAN. Several extensively referenced survey papers [10, 11, 12, 13, 14, 15, 16, 17, 18] on WBAN encompass a diverse array of subjects, including WBAN communication architecture, potential technologies, applications in both medical and non-medical domains, security concerns related to WBAN, propagation modeling, and implementation prerequisites. Movassaghi et al. [17] identified the use of WBAN in both medical and non-medical domains, providing a comprehensive analysis of the PHY and MAC layers. The study also included significant insights on different routing protocols and security, as well as other technical issues related to implementations. Alam et al. [15] introduced a distinctive use of WBAN wearable devices pertinent to safety and vital operations in hazardous areas, including the oil and gas sectors, refineries, and other petrochemical industries.

This approach involves inter-WBAN interactions, whereby the WBAN coordinator functions as a resourceful device that wirelessly connects body sensors to external network infrastructure via WiFi or broadband cellular networks, including GSM, GPRS, 3G, and LTE. A comparative review of many WBAN technologies and their design problems is presented in [16]. The research focuses on radio channel modeling, energy consumption reduction, and coexistence challenges in WBAN, while presenting many case studies derived from real-world implementations and simulations. In [18], analogous arguments derived from a prior literature review are offered, concentrating only on certain medical applications and associated technologies for WBAN. The examination of coexistence challenges and interference reduction strategies in WBAN technology is detailed in [11]. Additionally, the mathematical depiction of coexistence challenges among IEEE 802.15.6, IEEE 802.15.4, and low-power WiFi technologies, together with simulation results, are analyzed and compared. The study further emphasizes interference mitigation strategies using a system model and definition. The connection between WBAN and cognitive radio technology is shown in [19]. The analysis of context awareness at the MAC layer, application layer, and associated problems is presented in [12]. Specific concerns regarding security and privacy in Wireless Body Area Networks for healthcare applications are addressed in [14]. A study about the home environment of WBAN-based electronic healthcare (e-healthcare) systems is presented in [10], which delineates the architecture of the e-healthcare system within a residential context and highlights the use of smartphone-based healthcare applications. The most recent review study [13] on WBAN presents programming frameworks for WBAN and emphasizes energy-efficient routing techniques. The document also highlights the use of virtual reality (VR) as a forward-looking perspective on WBAN and the integration of WBAN with cognitive radio technology for enhanced energy efficiency. Nevertheless, all these current surveys confine their discussions to communication architecture, applications, and a limited number of issues. None of the studies address the shortcomings of existing designs in managing complexity, security, dependability, and related issues. Furthermore, we see no substantial future trajectory for research aimed at enhancing communication architecture concerning management complexity, dependability, security, and privacy. Consequently, our survey report seeks to address this research gap.

Methodology

This section delineates our concept of a wireless body area network with nodes that exhibit heterogeneity in their initial energy levels. We specifically introduce the environment, the energy model, and the methodology for calculating the ideal number of clusters. Let us consider a scenario in which a portion of the patient node population has more energy resources than the other nodes.

Let \(f \) represent the proportion of the entire number of patient nodes that has α times more energy than the rest. We designate these potent nodes as advanced nodes, whereas the others are classified as standard patient nodes. We assume that all nodes are evenly dispersed over the wireless field. Our primary goal is to propose and implement a cluster-based energy-efficient and stable routing mechanism for wireless body area networks, wherein cluster heads are determined by energy ratios and random head selection probabilities are established through integer linear programming to facilitate efficient inter-cluster and intra-cluster communication for data transmission to a central monitoring authority.

The indoor hospital BAN communication devices are classified into three categories according on their accessible energy sources. Class 1 equipment are directly linked to the power supply, such as the Nursing Station Coordinator (NSC). Class 2 devices use consumable batteries, such as Medical Display Coordinators (MDCs). BAN Coordinators (BANCs) with restricted energy availability are classified as Class 3 devices. Class 1 and Class 2 devices use two channels. 802.15.4 is used for communication with the BANC, whereas 802.11 is employed for Wi-Fi connectivity. The table below presents a summary of the courses. The NSC database contains the information of all BANCs and MDCs under the BAN peering architecture. BANCs first does a search and thereafter connects to the NSC. Each BANC obtains information on its corresponding peer from the NSC and thereafter initiates the transmission of real-time BAN data to its designated peer MDC for visualization.

Table no. 1 parameter settings of summary of the classes in WBAN

Device Class	Device name	Power Source	Number of Channels	MAC protocol	Mobility
1	NSC	Directly Connected	2	802.15.4 802.11	No
2	MDC	Replaceable batteries	2	802.15.4 802.11	Yes
3	BANC	Limited energy available	1	802.15.4	Yes

Hierarchically Clustered Model for Communication

We assume a hierarchically clustered wireless body area network. Our suggested technique preserves the clustering hierarchy. In our approach, the clusters are reconstituted in each "round." In each cycle, new cluster leaders are chosen, resulting in a well-distributed and balanced load across the network nodes.

Wireless Body Area Network (WBAN)

WBAN comprises a series of sensors affixed to or implanted into the body, used to monitor several physiological data, including body temperature, blood glucose levels, heart rate, pulse rate, respiratory metrics, and caloric expenditure post-exercise. WBAN is used not just in medical applications but also in multimedia and gaming contexts. Sensor nodes may be configured in many topologies, including star, mesh, or tree formations. Nonetheless, it is contingent upon the sorts of applications, and in most instances, it adheres to a star topology whereby the nodes are linked to a central coordinator.

Figure 2 illustrates a comprehensive design of WBAN, as referenced in [20], with three tiers. In level 1, several body sensors are affixed to the human body, which then transmit data to an aggregator, where traffic classification occurs. Subsequent to the classification at level 2, a network coordinator engages with the base station. Level 3 comprises many base stations that retain patients' physiological data, enabling healthcare service providers to provide essential diagnostic suggestions based on this information.

WBAN employs many technologies for data transmission, including Wireless Medical Telemetry Services (WMTS), unlicensed Industrial, Scientific, and Medical (ISM) bands (2.4-2.4835 GHz), Ultra-wideband (UWB), and Medical Implant Communication Services (MICS). These technologies are used according on the kind of services, since some applications may need high data rates, while others are content with low data rates. For instance, limited WMTS (14 MHz) is unable of supporting video or speech transmission. The 2.4 GHz ISM band may be used instead. However, it induces neighboring channel interference since Bluetooth, ZigBee, and Wi-Fi all operate inside this frequency range. The designated frequency band for implant sensor applications is MICS (402-405 MHz).

Limitations of existing WBAN Architectures

The design of WBAN and M2M for mHealth situations seems logical; nonetheless, several difficulties remain. A multitude of studies have been undertaken to address prevalent difficulties associated with wireless sensor networks (WSN). Nonetheless, a research gap persists owing to the constraints of current WBAN design. A significant drawback of the existing design is its reliance on suppliers. Body sensors from manufacturers are compatible just with their specific platforms. Consequently, a WBAN consisting of sensors from several suppliers is challenging to maintain and run due to its lack of interoperability. It generates managerial and operational complications and also results in the challenge of network reconfigurability. Installing sensor nodes from other suppliers, apart from the current ones, will impede the network's seamlessness, which is detrimental to a strong network. A real-life example is shown in [25]. At Nagoa City University Hospital, a distinct network was established, and any modifications to the network settings resulted in a complete network failure, necessitating _xing. This led to increased managerial complexity and required significant effort.

The static characteristics of WBAN design necessitate a protracted procedure for updates due to the strong coupling of the application and infrastructure [26]. Furthermore, mobility is a critical concern in WBAN, necessitating that patients have the ability to move freely at all times. This mobility results in increased packet loss and error rates [27], which remains a tough problem to address efficiently within the architecture of WBAN. The integration of the existing architecture of WBAN with the cloud is both economically and technically challenging and intricate. Furthermore, the sensors' data transfer rate fluctuates significantly owing to their capacity to detect both normal and pathological events. Variations in data volume over time result in load imbalance in data storage and processing at backend servers [28].

The current architecture of WBAN does not use resources efficiently. Because of the inherent control circuitry in hardware, dynamic regulation of resource usage is not feasible [26]. As a result, sensors communicate superfluous measurements even when the data is useless. This results in superfluous bandwidth use and, most importantly, diminishes the system's energy efficiency.

Security and privacy are critical considerations in WBAN due to the involvement of a patient's sensitive health information. Managing extensive data may be complex, rendering the system susceptible to cybercrime [29, 30]. A rigorous and scalable system remains a significant worry for WBANs regarding data confidentiality, authenticity, integrity, and effective network administration.

Challenges In WBAN

WBAN is an emerging technology that encounters several hurdles throughout the deployment phase. The problems include technological, ethical, and non-technical aspects. The following delineates some significant issues.

Heterogeneous Devices and Track

WBAN exhibits heterogeneity. A variety of sensors and actuators are present inside the network. Consequently, the measurements and data types are likewise distinct. Certain applications need real-time data, whilst others are content with periodic observations. Additionally, there exists priority and non-priority data. Consequently, WBAN should include data formats including real-time audio, video material, and continuous signals such as ECG and EMG.

MAC protocols for WBAN should assume a significant role in this scenario. Various actions, including movement, body position, and environmental alterations, result in an abrupt shift in the data context. Consequently, the dynamic resource allocation approach must be underpinned by the MAC protocol. The MAC protocol of WBAN with fixed slot allocation does not meet the requirements of diverse and dynamic traffic in WBAN. Efforts have been made to address context-aware WBAN. An alert is available for emergency response in [90], however it functions just when no other node is designated for data transmission. The wake-up signal or wake-up radio is used in [91] to transition the node from a sleep state to an active one.

The incorporation of a wake-up circuit complicates and increases the cost of hardware design. In [92], another effort to facilitate context-aware WBAN is made, although it again lacks the computing capacity to assess the situation. A recent study on the simulation-based WBAN MAC is presented in [93], which advocates for the use of hybrid MAC protocols in emergency data scenarios. However, this poses challenges when used in diverse applications.

Energy Efficiency

A significant problem in the implementation of WBAN is the issue of energy efficiency. Given that WBAN sensors rely on tiny batteries, the battery's lifespan is a critical consideration. WBAN devices, including wearable sensors, are readily replaceable. However, with implanted sensors, replacing the battery may need significant surgery, hence incurring substantial costs. Enhancing energy-efficient Wireless Body Area Networks (WBAN) may be achievable by the optimization of PHY and MAC layer designs, the implementation of an efficient hopping system (single hop or multihop), or the adoption of an adaptive duty cycle. A TDMA-based MAC protocol for a multi-tier architecture in WBAN has been suggested in [94]. This concept comprises sensor nodes in the primary layer, a collection of master nodes in the secondary tier, and an observation station in the tertiary tier. Master nodes aggregate data from sensor nodes and transmit it to the monitoring station. The shortcoming of this concept is that it relies on a stationary network.

Challenges persist while the patient is in motion, resulting in varying distances between sensor nodes and master nodes. As a result, nodes modify the transmission power, hence reducing the system's energy efficiency. The authors in [95] examined energy efficiency via a developed route loss model about the human body. Single-hop communication in WBAN is shown to be ineffective because to the considerable distance of nodes from the sink. The question of line of sight versus non-line of sight persists. When the transmitter is positioned at the rear and the receiver at the front, it experiences increased path loss. In some instances, multichip WBAN is superior than single hop.

Due to the varying standards used in WBAN, energy efficiency differs correspondingly. IEEE 802.15.6 exhibits higher energy consumption than IEEE 802.15.4. In the IEEE802.15.6 protocol, the carrier monitors the channel, and the back-off counter reduces its count depending on the sensing results. In IEEE 802.15.4, the back-off counter value resets to zero after just two sensing phases. Notwithstanding this drawback in IEEE 802.15.6, the rate of successful packet transmission surpasses that of IEEE 802.15.4. Ultimately, we are presented with two options: dependability or energy efficiency.

Literature [96] discusses sources of energy inefficiency, including collisions, overhearing, idle listening, and resource allocation approaches. Energy efficiency via appropriate resource allocation has been examined in [97]. The suggested technique utilizes the Global Energy Minimization (GEM) strategy for optimization. The energy efficiency issue is formulated by assigning appropriate time and resources. The comparison has been made between network lifespan maximization, GEM systems, and uniform time allocation (UTA). In this suggestion, energy usage during node inactivity has been disregarded because to its little impact.

A TDMA-based MAC technique called BODYMAC is suggested in [98], with the primary objective of minimizing packet collisions via radio state switching. It used flexible bandwidth management via its super frame structure, whereby a synchronization beacon in the downlink segment is designated for transmission from the coordinator, while the uplink segment is utilized for packet transmission from nodes to the coordinator. The uplink segment is divided into two components: the Contention Access Part (CAP) and the Contention Free Part (CFP). In CAP, nodes notify the coordinator of their bandwidth requirements, whereas in the CFP segment, the coordinator allocates time slots for node transmission. To enhance BODYMAC, an effective sleep mode strategy is also given. The sleep mode is activated by deactivating the radio transmitter, after which the coordinator addresses the sleep request during the Contention Access Period (CAP).

Hardware Design

Designing appropriate hardware for WBAN is a critical challenge. The design of the sensor node, which is affixed or implanted into the human body. Consequently, the node's design must align with the characteristics of human biological tissue. The antenna's design is very important. The design of an implanted antenna is contingent upon the specific location and organ, imposing constraints on the designer. The antenna's dimensions, composition, and configuration must be compatible with human tissue and the radio frequency environment. The issues of antenna design, including antenna gain, polarization, sensitivity, and the capacity to connect with the access point in non-line-of-sight conditions, are critically significant. Currently, UWB technologies have garnered considerable attention from academics because of their ability to enhance SNR levels at the receiver.

WBAN Communication Technologies

WBAN utilizes many short-range technologies for communication with the gateway, including Bluetooth, Bluetooth Low Energy, ZigBee, and IEEE 802.15.6. All of these short-range communication technologies exhibit diverse properties and provide various operating frequencies and networking topologies. Table 6 presents an overview of the features of the wireless technologies used in WBAN. The gateway for server communication employs long-range communication technologies like WiMax, LTE, and LTE-Advanced. This section concentrates on many short-range potential technologies only for WBAN. Furthermore, we provide an implementation guidance for WBAN in accordance with the newest IEEE 802.15.6 standard.

Positioning Wbans

The field of Wireless Body Area Networks is in its nascent phase of development and investigation. Protocols for WBANs provide communication between sensors and the body node, which is linked to data networks and the Internet. To provide clarity, we will first define intra-body communication and extra-body communication. Information management between body sensors and personal devices is conducted first and subsequently, ensuring connectivity with external networks and the personal device. Consequently, patient data is either reviewed by a physician or saved in a medical server database. This work is executed in three stages. Step 1 entails intra-body communication, step 2 encompasses extra-body communication between the personal device and the Internet, and step 3 illustrates extra-body communication between the Internet and the medical server.

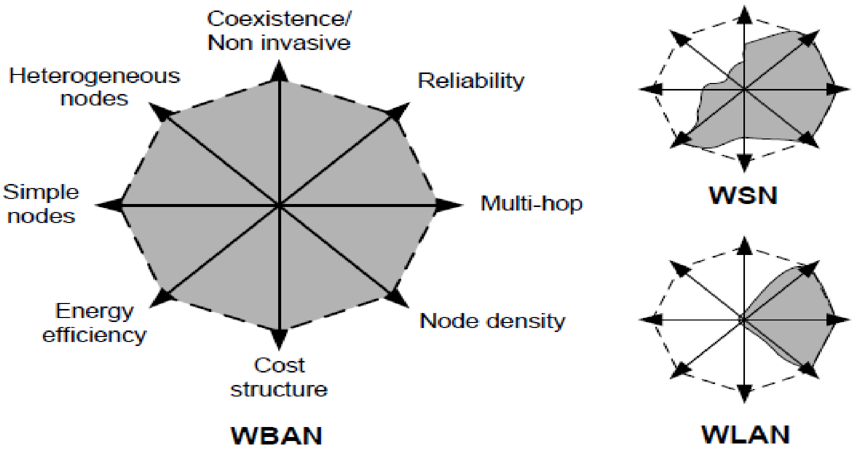

Fig. 3. Characteristics of WBAN compared with WSN and WLAN [4]

A Wireless Body Area Network operates in proximity to the human body, often achieving a communication range of around 1 to 2 meters.

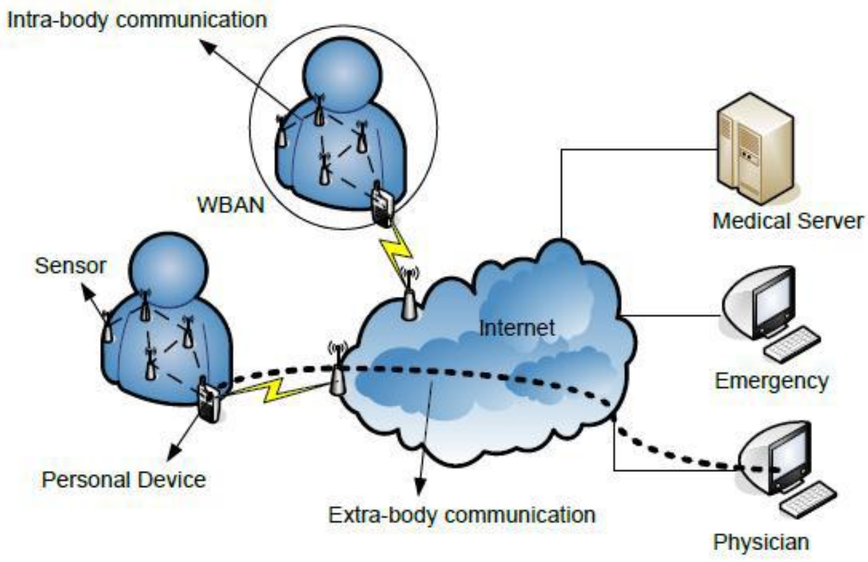

Fig. 4. Example of intra-body communication and extra-body communication in WBANs [4]

A Wireless Personal Area Network (WPAN) is a network that surrounds an individual, whereas a Wireless Body Area Network (WBAN) refers to the connectivity of personal wearable devices. The communication range may vary depending on whether the data rate is low or high. Wireless Body Area Networks are sometimes referred to as Wireless Sensor Networks (WSN) or Wireless Sensor Actuator Networks (WSAN) depending on specific needs. The human body comprises a complicated system that interacts with the external environment. The human body has a limited range and necessitates distinct obstacles for monitoring frequency in wireless sensor networks (WSNs). The monitored medical data emphasizes dependability. These sensors contribute to energy efficiency by optimizing battery and antenna performance.

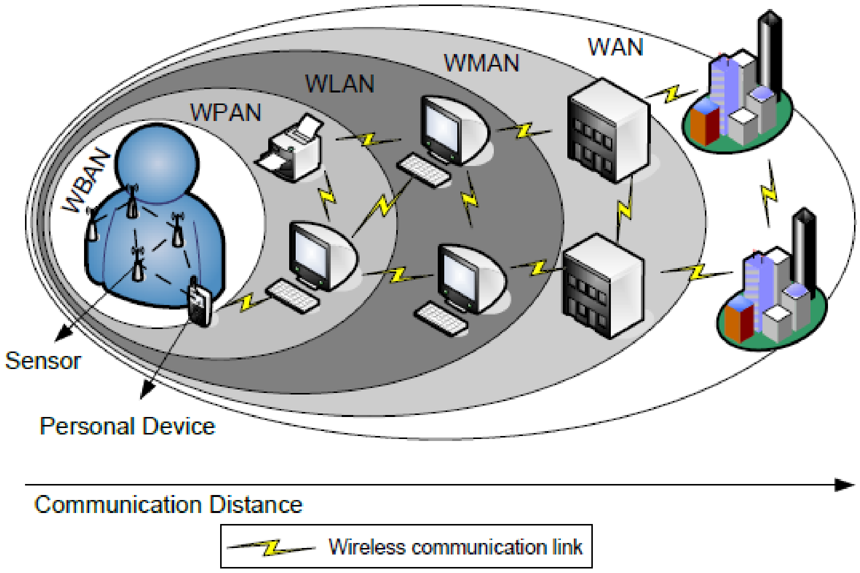

Fig. 5. The positioning of WBAN in the realm of wireless networks [4]

The sensor nodes may relocate throughout the human body, as those positioned in the wrist can traverse towards those situated on the hip. Wireless body area networks (WBANs) resemble wireless sensor networks (WSNs). These possess inherent distinctions.

Conclusion

WBAN is an emerging field of study within the healthcare arena. This study presents an overview of current research in WBANs and contemporary literature on various research difficulties. This document highlights the major differences between Wireless Sensor Networks (WSN) and Wireless Body Area Networks (WBAN). The constraints of conventional WBAN design are detailed. In this setting, it is crucial to comprehend the current architectures and constraints to tackle the difficulties effectively. This study emphasizes the uses of WBAN in both medical and non-medical domains. Additionally, a classification of medical and non-medical uses is presented with relevant citations. A thorough examination of many potential technologies for WBAN is conducted, emphasizing the attributes of each technology. This study focuses on the implementation recommendations of WBAN according to the newest standard IEEE 802.15.6, which will assist future investigators, experts, and researchers. We assert that the effective application of WBAN will undoubtedly enhance the quality of life in both medical and non-medical dimensions. It will save healthcare expenditures for patients and facilitate the early diagnosis of anomalies. Ultimately, the integration of emerging technologies like as SDN, EH, and blockchain with WBAN will catalyze transformative advancements in the healthcare industry. SDN and blockchain are anticipated to address the majority of the critical difficulties faced by WBAN.

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