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Design And Analysis Of A Novel Wireless Body Area Network Forhealthcare Applications

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ABSTRACT

The Wireless Body Area Networks (WBANs) have revolutionized healthcare by enabling continuous remote monitoring and enhancing diagnostic capabilities. This study introduces the Hierarchical Temperature and Energy Protocol (HTTEP), a novel, energy-efficient protocol designed to address the security and efficiency challenges of WBANs. Traditional WBANs struggle with issues related to secure communication, power management, and performance optimization due to energy constraints and network stability concerns. To secure digital-human body communication transceivers and sophisticated intrusion detection systems to improve data protection and network reliability. HTTEP enhances WBAN performance through a weighted function that considers residual energy, temperature, data rate, and energy expenditure. This protocol aims to optimize network stability and extend the network's lifetime while effectively managing node temperature and energy consumption. The development of a new WBAN architecture, extensive simulations and real-world testing. The results reveal that HTTEP outperforms existing protocols such as SIMPLE and ATTEMPT by maintaining superior network stability, extending network lifetime, and improving energy and temperature management. The HTTEP protocol showcases significant advancements in healthcare applications by providing a robust and efficient WBAN system that supports continuous health monitoring and management, offering enhancements in energy efficiency, data integrity, and system scalability compared to conventional solutions.

Keywords: WBANs, Sensor, Healthcare applications, Network and Energy Preservation.

INTRODUCTION

Due to their capacity for continuous remote monitoring and diagnostic enhancements, the growth of Wireless Body Area Networks (WBANs) for healthcare applications has attracted substantial attention [1]. Advancements such as a secure digital-human body communication transceiver system that improves efficiency and security are a result of the critical importance of ensuring secure communication within WBANs in order to safeguard sensitive health data [2]. To solve the security problems in e-health, researchers are working on putting in place intrusion detection systems based on agent technology to protect patient privacy and information. These systems have shown they are very good at finding problems in simulated hospital network topologies [3]. There is also good performance across different frequency bands in the design of multiband meander line antennas for WBAN applications, which was proven by simulations and testing in the lab with human body phantoms [4]. These innovations collectively contribute to the optimization and reliability of WBANs, offering promising solutions for enhancing healthcare monitoring technologies. A network of devices, including sensors, actuators, and transceivers, implanted or digested on the body's surface, under the epidermis, or within the body is called a WBAN. The rapid advancements in IoT research have made WBANs an intriguing subject for researchers in a variety of disciplines. WBAN and IoT have a wide range of applications, such as remote health/fitness monitoring, rehabilitation, military and sports training, active combat operations, livestock husbandry, interactive gaming, personal information sharing, secure authentication, and assisted living [5-6]. The utilisation of WBAN is becoming increasingly cost-effective in numerous sectors as the number of sensors designed for IoT applications continues to expand at a rapid pace. Additionally, wireless access is essential for obtaining the extensive information that WBANs provide from field personnel. This information is frequently employed to supervise and instruct individuals regarding particular activities. The usage of WBANs will inevitably lead to a surge in network problems, necessitating the resolution of these issues to optimize future WBAN performance. Since WBANs generate and transmit personal biological information, network security requirements are paramount [7]. Some of the other significant issues include the optimisation of network parameters for optimal power management, the development of various sensors with minimal energy consumption, and the power management of WBAN. Another critical area of interest in WBAN is the energy harvesting from the surrounding environment and through human movements, for which researchers have developed a variety of solutions [8].

The emerging field of health surveillance is exemplified by the Wireless Body Area Network (WBAN), which utilizes a network of small, portable wireless sensors to monitor individuals' health and their immediate environment. By 2030, it is estimated that 360 million people worldwide will have diabetes, doubling the current figure of 180 million. Additionally, many individuals suffer from neurodegenerative conditions such as Parkinson's disease. A cost-effective health surveillance system providing continuous monitoring could significantly improve the lives of these individuals. WBANs have the potential to monitor vital data transmission from the human body to other destinations and oversee personal health management. The quality of healthcare provided to patients can be enhanced by ensuring additional privacy, confidentiality, flexibility, and security. Therefore, investigating WBAN security is crucial for developing an effective healthcare monitoring system [9]. Security for medical devices in WBANs has been approached in various ways, including traditional cryptography, biological signalling, and physical layer security. These methods have been explored in both indoor and outdoor settings, such as homes and medical facilities, but they are insufficient for the comprehensive protection of WBANs [10]. Robust security and a reliable, flexible communication framework for exchanging health information among various stakeholders are essential for enhancing healthcare services. To identify the essential characteristics for a reliable communication system to transmit health information within and between WBANs for use in diverse medical environments [11]. For WBANs to be widely adopted, efficient protocols tailored to their specific attributes and applications must be developed.

Around 1995, WPAN-based corporeal region networks—also recognised as corporeal region networks, corporeal sensor networks, and wireless corporeal region networks—surfaced. There are fundamentally three phases to utilising a Wireless Body Area Network.

- Sensor
- Network
- Controller or Processing System

More refined sensors, such as cellular devices and individual electronic aides, possess a more intricate physical and logical framework. Whether a system's objective is anticipation, operation, or surveillance, sensors are frequently its ingress point. Whether it's a digital indication or unprocessed information that has to be dispatched so that an alert can be produced, or a document can be produced, networking is crucial. There are additional subcategories within it for things like "vulnerable information," "universal data," "alternative," etc.

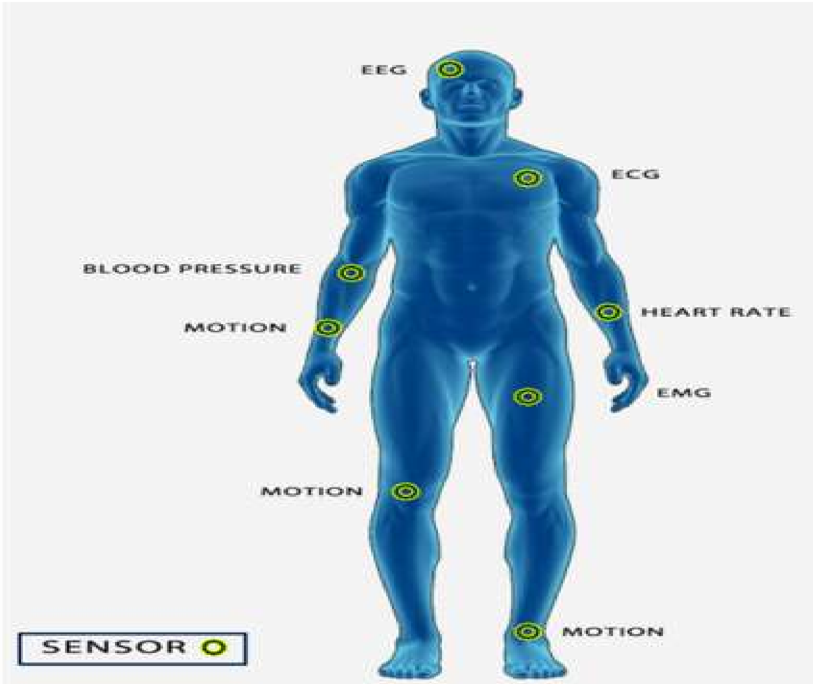


Figure 1: WBAN sensors [12].

Wireless Body Area Network (WBAN) medical applications have the potential to greatly enhance the quality of life for individuals, particularly the elderly, by allowing them to age comfortably and healthily in their preferred environments. These applications use wireless technologies for communication between sensors and between the base station and sensors, leveraging the simplicity of wireless transmission. While IEEE 802.15.6 is designed to support a broad range of medical and non-medical applications, Bluetooth and ZigBee (IEEE 802.15.4) are more widely adopted and implemented. However, additional considerations such as bandwidth limitations and interference from nearby technologies must be addressed [13]. Figure 1 illustrates a typical sensor placement within a WBAN [14]. Beyond medical monitoring, WBANs can also be utilized in various other domains, including pollution monitoring, physiological tracking, human-computer interaction, education, and entertainment [15].

1. LITERATURE REVIEW

In this literature review, we offer a thorough examination of the most recent research and developments in the field of Wireless Body Area Networks (WBANs) in the context of healthcare systems. WBANs have emerged as a transformative technology in healthcare, facilitating the continuous monitoring and real-time data collection of data through ubiquitous and embedded sensors.

Preethichandra et.al (2023) [16] studied wireless body-area network (WBAN) systems tailored for medical environments. It addresses key aspects related to hardware implementation, software design, and wireless protocol configuration. The developments in WBAN technology and presents a WBAN system specifically designed for healthcare applications. The WBAN utilizes designated medical frequency bands to collect physiological data from sensor nodes, aiming to minimize interference and enhance the compatibility of sensor devices with other network equipment in medical facilities. Medical gateway wireless boards, which bridge the sensor nodes with the local area network or the Internet, use a multi-hop technique to transmit data to remote stations. Medical centers already establish such infrastructure, enabling healthcare professionals to access patients' physiological data throughout the facility and online, extending access beyond the medical center as needed.

Liu, Q., Mkongwa et.al (2021) [17] examined wireless body area networks (WBANs). It investigates the incorporation of other technologies, spectrum management, security, network reliability, and WBAN signal processing in order to improve the functionality of future healthcare applications. In the field of microelectronic technology and commercialisation, which have facilitated the miniaturisation, communication, and availability of devices. Performance, user safety, and privacy are all affected by operational, standardisation, and security challenges that the WBANs encounter. As future healthcare increasingly relies on WBANs for both medical and non-medical applications, driven by advances in internet connectivity, further research is needed to optimize performance. The numerous current and future research directions and the resolution of open issues to improve the performance of WBAN.

Hasan, K et.al (2019) [18] studied information and communication technologies have profoundly impacted various aspects of life, particularly in the healthcare sector, where they have significantly enhanced service delivery. The capacity to remotely monitor patients is a critical advancement, as it enables healthcare providers to diagnose, prescribe treatment, and observe patients without their physical presence. This is facilitated by miniaturised sensor technologies that can be implanted on, in, or around patients' bodies, allowing for the wireless transmission of physiological data to remote servers. The WBAN architecture, communication technologies, related obstacles, and various aspects of its functionality are all discussed in this technology, which is referred to as the Wireless Body Area Network (WBAN). The current WBAN communication frameworks and specifications implementation requirements are based on the IEEE 802.15.6 standard. Furthermore, it emphasises potential future research directions, such as the integration of Blockchain technology, Energy Harvesting (EH), and Software Defined Networking (SDN) into WBAN systems.

Alshamsi, Barka, and Serhani et.al (2016) [19] examined the critical area of data protection within Wireless Body Area Networks (WBANs) used for e-health monitoring, focusing on the challenge of securing sensitive health information transmitted by these networks. This innovative approach addresses the urgent need to protect patient data while accommodating the resource constraints inherent to WBANs. The UAE's increasing prevalence of circulatory system disorders has resulted in a high demand for continuous care through e-health monitoring systems. These maladies are the primary cause of mortality in the nation. In order to safeguard the confidentiality and authenticity of patient data, this work suggests an architecture that employs the Lightweight Encryption Algorithm (LEA) to encrypt vital signs transmitted from WBAN sensors to mobile devices.

Negra, Rim et.al (2016) [20] described Wireless body area networks (WBANs) have been facilitated by the ongoing miniaturisation of both invasive and non-invasive devices and wireless networks, which allow for continuous health monitoring without interfering with a patient's daily activities. By satisfying specific quality of service (QoS) requirements, a variety of technologies have been shown to be effective in facilitating WBAN applications, including remote monitoring, biofeedback, and assisted living. Nevertheless, the selection of the appropriate technology for a specific medical application is a difficult undertaking due to the abundance of available options. Examines the alignment between each application and the most appropriate technology, emphasises the most frequently employed technologies in WBANs, and discusses the diverse medical applications.

Filipe, L., Fdez-Riverola et.al (2015) [21] studied wireless Body Area Networks (WBANs), still in their early development stages, promise significant advancements in healthcare applications by enhancing monitoring, diagnostics, and therapeutic processes. These networks facilitate real-time medical data collection through various sensors, ensuring secure data transmission and low power consumption. The growing interest in WBANs, increasingly explored various aspects of these systems. The technologies and protocols in WBAN research, focusing on issues relevant to medical monitoring. The primary characteristics, including power consumption, mobility, encryption, authentication methods, data bandwidth, frequency regions, and wireless communication protocols. It suggests that the protocols assessed offer substantial advantages for medical devices and patients in the WBAN domain due to their specific characteristics.

Ramli et al. (2013) [22] focused on enhancing data verification safety in Wireless Body Area Networks (WBANs) stems from concerns that traditional verification methods might be vulnerable to various attacks, compromising the confidentiality and integrity of health-related data transmitted within these networks. To address these vulnerabilities, researchers have proposed integrating biometric verification techniques, such as fingerprint recognition and voice authentication, into WBANs. These biometric methods significantly improve WBAN security by uniquely identifying users based on physiological traits, thus reducing unauthorized access and data tampering and enhancing overall system security. While advancements in wireless communication and sensor technologies have propelled the development of WBANs, research on robust security systems has been limited. WBANs face security challenges like data loss, authentication, and access control, often compounded by the need for low computational complexity and high energy efficiency. The study explores using biometric characteristics for securing data communication within WBANs while addressing computational complexity and power efficiency. It proposes a hybrid authentication model, utilizing unique physiological features as authentication identities, complemented by hardware and software techniques, to develop a security system tailored to the constraints of WBAN sensor environments.

Table 1: Comparison of Reviews

Author's and Years	Focus	Approaches	Key Findings
Preethichandra et.al (2023) [16]	Wireless Body Area Networks (WBANs) for medical environments.	Hardware implementation, software design, wireless protocol configuration	Developed a WBAN system for healthcare using designated medical frequency bands to reduce interference and enhance compatibility. Emphasized multi-hop data transmission for remote access.
Liu, Q., Mkongwa et.al (2021) [17]	the integration of other technologies, network reliability, and WBAN signal processing.	Signal processing, spectrum management, security, network reliability	Identified operational, standardization, and security issues in WBANs. Highlighted the need for future research to optimize WBAN performance for healthcare applications.
Hasan, K et.al (2019) [18]	Impact of WBAN technology on remote patient monitoring and communication technologies.	WBAN architecture, IEEE 802.15.6 standard, integration of SDN, EH, Blockchain	Discussed WBAN communication frameworks, challenges, and future research directions, including potential integration with SDN, EH, and Blockchain technologies.
Alshamsi, Barka, and Serhani et.al (2016) [19]	Data protection within WBANs for e-health monitoring, focusing on securing health information.	Lightweight Encryption Algorithm (LEA) for data security	Proposed an architecture using LEA to enhance data security in WBANs, aiming to protect patient data against unauthorized access while addressing WBAN resource constraints.
Negra, Rim et.al (2016) [20]	Advancement of WBANs through miniaturization of devices and selection of suitable technologies.	Quality of Service (QoS) requirements, technology effectiveness	Evaluated various technologies supporting WBAN applications and highlighted challenges in selecting appropriate technologies for specific medical applications.
Filipe, L., Fdez-Riverola et.al (2015) [21]	Development stages of WBANs, focusing on monitoring, diagnostics, and therapeutic processes.	Wireless communication protocols, frequency bands, encryption, power consumption	Analyzed various WBAN technologies and protocols, emphasizing secure data transmission, low power consumption, and their benefits for medical monitoring and patient care.
Ramli et al. (2013) [22]	Enhancing data verification safety in WBANs through biometric verification techniques.	Integration of biometric verification (fingerprint, voice)	Proposed a hybrid authentication model incorporating biometric features to improve WBAN security. Addressed issues of data loss, authentication, and power efficiency in WBAN systems.

2. RESEARCH METHODOLOGY

The research methodology for the study "Design and Analysis of a Novel Wireless Body Area Network for Healthcare Applications" involves a multi-step approach. Initially, a comprehensive literature review was conducted to identify existing technologies and gaps in current Wireless Body Area Network (WBAN) systems. Subsequently, an innovative WBAN architecture was designed, integrating advanced sensors and communication protocols. The system's performance was evaluated through simulations and real-world testing, focusing on metrics such as data transmission efficiency, energy consumption, and reliability in various healthcare scenarios.

The research presents an energy-efficient HTTEP-based WBAN (Wireless Body Area Network) protocol, which introduces a novel approach compared to existing protocols. Unlike traditional WBAN protocols, which rely on temperature and energy thresholds to manage node activity, the proposed protocol utilizes a weighted function to determine node participation. This weight function is based on several parameters: the node's residual energy, temperature, data rate, and energy expenditure during data transmission. This protocol influences a node's involvement in data transmission based on its weight. As a node's temperature rises, its weight increases, reducing its likelihood of participating in data transmission. This mechanism helps prevent nodes from overheating by allowing them to enter an idle state to cool down, thereby maintaining their temperature close to body temperature and enhancing network stability. When temperature or energy thresholds exceed, existing protocols often cause node inactivity, potentially leading to the loss of critical information. In contrast, the HTTEP protocol minimizes data loss by reducing the involvement of nodes with degraded parameters. Additionally, the protocol utilizes a multi-hop topology, with each node transmitting data to the sink via a path that the sink determines based on node parameters. The weighted function selects this routing path, optimizing energy efficiency by selecting appropriate routes for each transmission round. The use of different paths for packet transfer in each round prevents any single node from becoming overloaded, thereby further conserving energy and improving network performance.

The following are the crucial steps for implementing the proposed protocol.

1. Initialization of the input parameters. Table 2 below mentions all the input parameters along with their values.
2. Initialization of source and the target for data transmission between nodes and sink.
3. Calculation of the energy consumed in transmitting a data packet of size K.
4. Initialization of the number of rounds.
5. Initialization of a loop based on the number of rounds.
6. Calculation of the route for each node and acknowledgement of the calculated route to the particular node, to start data transfer as per the calculated route.
7. Computation of the weight matrix $w = \frac{E_{tx} * T}{RE * R}$
8. Conversion of the 9X9 weight matrix into a row matrix so that it can be used in graph formation and shortest path calculation. The shortest path is calculated from node "node" to sink or node "1".
9. Update the residual energy of all nodes involved in the transmission. Upon reaching a negative value, the residual energy should be set to a null value.
10. Updating the increase in the temperature of each node involved and not involved in the transmission (temperature increment for the involved nodes and decrement for the not involved nodes).
11. Computation of the Network Stability and Lifetime by calculating the number of dead nodes over the total number of rounds.
12. Computation of the final residual energy of all the nodes over the total number of rounds.
13. Computation of the final temperature of all the nodes over the total number of rounds.

Table 2: Input parameters Along with their Values

S.No.	Input Parameter	Value
1	position of the sink node and the remaining eight nodes on the body (Figure 1)	x= [0 10 -10 -30 30 15 -15 20 -20] y= [0 30 -15 -15 -15 -45 -45 -55 -90]
2	Internode distance matrix	9X9 matrix having distance between each node and sink
3	Temperature of each node	37◦C
4	Initial Residual Energy	4 volts
5	Max data rates are possible for each node.	[250 196 86 98 30 25 44 50 250]
6	Increment in node temperature if the node is used in transmission	0.01◦C

7	Decrement in node temperature if the node is not used in transmission	0.02◦C
8	Number of bits sent in one go (packet size)	4000
9	Energy consumed by the transmitter circuit to turn it on	16.7*10^(-9)
10	Energy consumed for amplification before transmitting	36.1*10^(-9)
11	Energy consumed by the receiver circuit to turn it on	1.97*10^-9
12	path loss coefficient parameter in the radio model	3.38

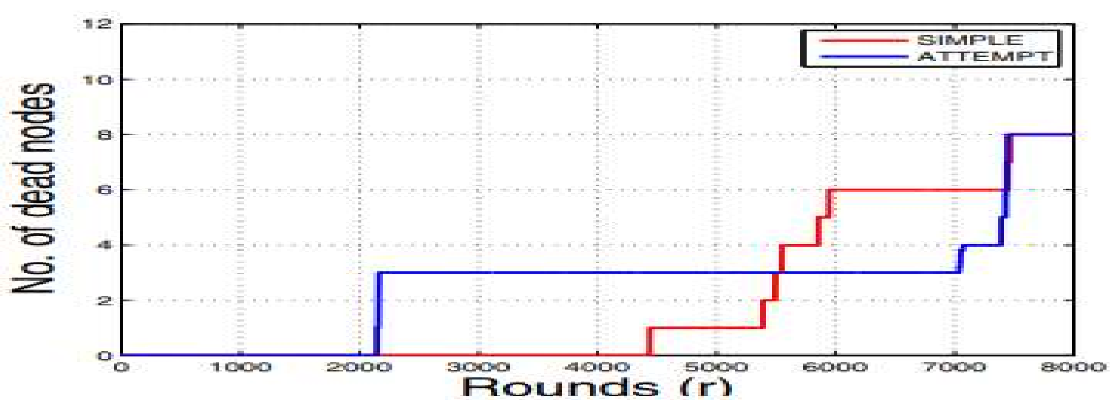
3. RESULT

An energy-efficient HTTEP-based WBAN protocol has been proposed in this research work. A special weight function is used that is dependent on various parameters like the node's residual energy, temperature, the data rate, and energy consumed in the data transmission.

To evaluate the proposed protocol, an extensive set of experiments has been conducted using MATLAB R20016a. Efforts have been made to assess the proposed protocol's performance using Network stability, Network Lifetime, Residual Energy, and Node temperature. The performance of the proposed protocol has also been compared with the existing protocols SIMPLE and ATTEMPT using all the above-said parameters.

1. Network Stability and Lifetime

In Figure 2 compares the network stability and the average network lifetime of the proposed protocol with the already existing WBAN methodologies SIMPLE and ATTEMPT. It can be noticed from the given figure below that the first death is happening around the 4400th round in the case of the SIMPLE method whereas the same is happening at the 30000th round. This implies that the network stability is 14 times greater than that of the existing protocol. If the network lifetime is discussed, the SIMPLE protocol sustains up to only 8000 rounds and the proposed protocol manages to sustain the network beyond 50000 rounds (out of 8 nodes, only 4 nodes got dead). In conclusion, the network stability and overall network lifetime are much greater as compared to the existing protocols SIMPLE and ATTEMPT.



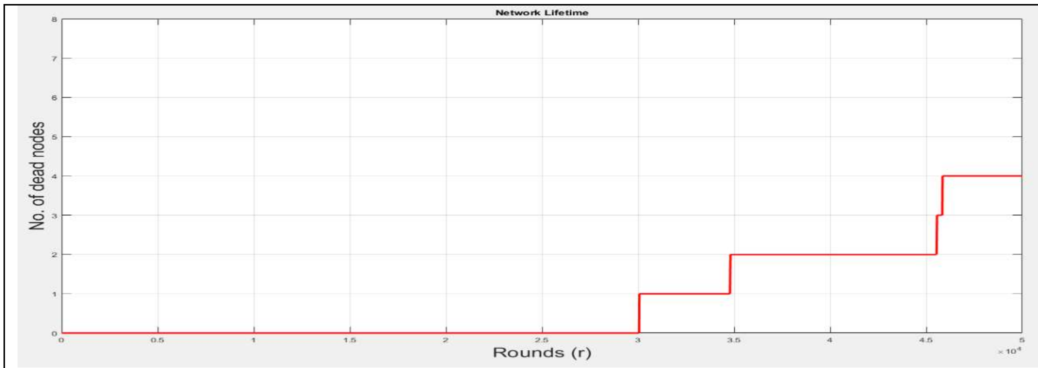
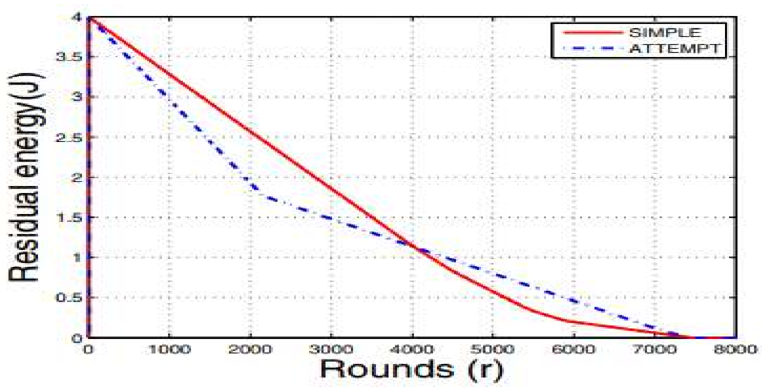


Figure 2: Comparative Analysis of Network Stability and Lifetime for the proposed protocol and SIMPLE protocol.

2. **Residual Energy**

Figure 3 illustrates the average energy consumption of the network during each round. The proposed protocol ensures that the energy consumption is minimal throughout the duration of the simulation, as indicated by the simulation results. The remaining four nodes continued to maintain 20% residual energy, while only four nodes completed their energy consumption until the full simulation time. It implies that during the stability period, a greater number of nodes have sufficient energy to transmit a greater number of data packets to the sink. Additionally, it enhances the network's throughput. Conversely, SIMPLE and ATTEMPT experience early exhaustion of certain nodes as a result of the high traffic volume.



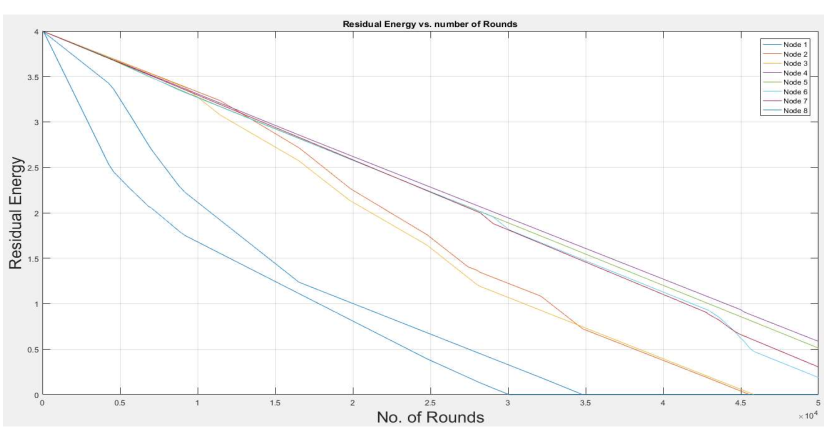


Figure 3: Comparative Analysis of the Residual Energy for the proposed protocol and SIMPLE protocol.

3. **Temperature**

In Figure 4 shows the temperatures for the 8 nodes as the number of rounds increases. The initial temperature was taken as 37◦C and it can be noticed that it is maintained at 37 throughout the full simulation period. This is because, as the temperature of any node increases, the weight of that node also increases and the possibility of involving that node in data transmission is reduced. As the node with a higher temperature is not involved in transmission the node will become Idol and cool down. So, this cost function or weighted function maintains the node temperature at around body temperature avoiding any difficulty to the patient due to the node's high temperature.

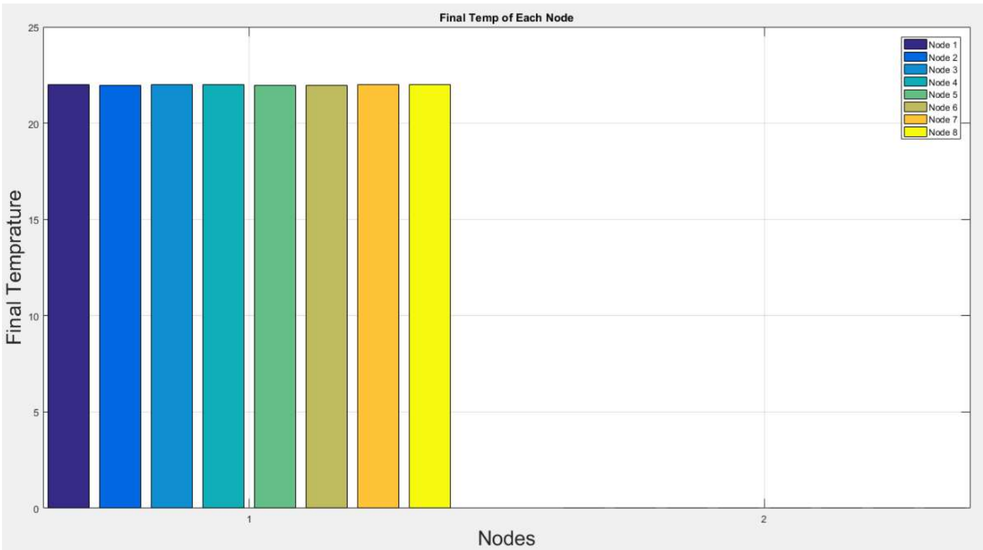


Figure 4: Final Temperature of all the nodes for the proposed protocol

In the existing protocols, the concept of temperature threshold was there. The temperature rises linearly with the round number for every node. When the temperature hits the threshold value, it stops being linear and starts to oscillate in a sawtooth-like pattern. The node's temperature rise also irritates the patient and lower downs the network stability.

4. DISCUSSION

The development of Wireless Body Area Networks (WBANs) for healthcare applications is revolutionizing the field of medical monitoring and diagnostics by enabling continuous remote monitoring and improving diagnostic accuracy. WBAN architecture integrates advanced sensors and communication protocols to enhance data transmission efficiency, energy consumption, and reliability in various healthcare scenarios. Given the sensitive nature of health data, security within WBANs is paramount, and advancements such as secure digital-human body communication transceivers and agent-based intrusion detection systems have shown significant promise. These systems excel in identifying security issues within simulated hospital networks, thus protecting patient privacy and information. Furthermore, simulations and lab testing with human body phantoms have validated the performance of multiband meander line antennas, demonstrating good performance across different frequency bands. The suggested HTTEP-based WBAN protocol improves network performance even more by using a weighted function to control node activity based on things like temperature, data rate, residual energy, and energy use. This approach prevents nodes from overheating and conserves energy, thereby enhancing network stability and lifetime. Comparative analyses with existing protocols like SIMPLE and ATTEMPT show that the proposed protocol significantly improves network stability, lifetime, and energy efficiency, maintaining node temperature close to body temperature to avoid patient discomfort. These advancements collectively contribute to the optimization and reliability of WBANs, offering promising solutions for enhancing healthcare monitoring technologies and ensuring secure and efficient data transmission in medical environments.

CONCLUSION

In conclusion, the study on the design and analysis of a novel Wireless Body Area Network (WBAN) for healthcare applications reveals significant advancements in optimizing both performance and security. The proposed HTTEP-based protocol introduces a novel weighted function that considers node parameters such as residual energy, temperature, and data rate. This innovative approach effectively addresses issues related to energy consumption, network stability, and temperature control, outperforming existing protocols like SIMPLE and ATTEMPT. The HTTEP protocol demonstrates remarkable improvements, with network stability and lifetime extending up to 50,000 rounds, compared to 8,000 rounds with SIMPLE. Additionally, it ensures efficient energy management, maintaining adequate residual energy throughout the simulation and optimizing temperature control to keep node temperatures near body temperature, thereby minimizing patient discomfort. This research underscores the transformative potential of WBANs in healthcare by integrating advanced technologies that enhance energy efficiency, data security, and network reliability. Future work may explore exponential dependencies in the weight function, which could further refine the cost function and enhance the protocol's performance, paving the way for broader applications and improved patient outcomes in various medical settings.

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