Optimal thermo-QoS-aware routing protocol for WBAN communication

Pradeep Bedi[1,2], Sanjoy Das[1], S. B. Goyal[3], Manoj Kumar[4], Sunil Gupta[5]
[1]Regional Campus Manipur, Indira Gandhi National Tribal University, Amarkantak (M.P.), India
[2]School of Computer Science Engineering, Galgotias University, Greater Noida, India
[3]Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India
[4]School of Computer Science, University of Wollongong in Dubai, Dubai Knowledge Park, United Arab Emirates
[5]School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India

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ABSTRACT

Wireless body area network (WBAN) has emerged as a promising solution to address problems such as population aging, a lack of medical facilities, and different chronic ailments. WBANs have real-time applications, and there is an increasing demand for them. However, due to changing network structure, power supply limitations, and constrained computing capacity, energy constraints, it is difficult task to achieve quality of service (QoS). To mitigate these limitations, the paper proposed an optimal thermo-QoS-aware routing protocol (OTQRP) for WBAN communication. The result was investigated in terms of temperature rise, energy consumption and delay. The paper shows better energy efficiency with respect to existing works. Finally, OTQRP feature comparison is also presented with recent research in terms of features such as complexity, latency, and energy economy and observed that OTQRP shows best performance as compared to others.

Corresponding Author:

S. B. Goyal
Chitkara University Institute of Engineering and Technology, Chitkara University
Punjab, India
Email: drsbgoyal@gmail.com

1. INTRODUCTION

Wireless body area networks (WBAN) have emerged as a result of technological advancements, and they comprise of tiny wearable biosensors or implanted devices that gather physiological signals such as ECG data, temperatures and blood pressure, as presented in Figure 1. WBANs are utilised in healthcare, human contact applications, and disability assistance. WBANs are mostly used in the field of medicine, where a wireless sensing device collects and analyzes data on medical vital signs before communicating it to remote server for analysis. The physical layer optimises the wireless channel model while minimising route loss. The data connection layer is concerned with creating an efficient multiple access protocol that saves energy and increases network longevity [1]. Because of the unexpected movement of human body and the subsequent changes in the network's structure, the network layer focuses on determining a suitable topology for the WBAN. The goal of the network layer is to provide high data transmission dependability. Recent research has focused about wireless sensor network routing protocols (WSNs), but in WBANs, minimising power consumption is just one of many factors to consider, such as node energy consumption, valid bytes are sent and received through the wireless network, and minimising the number of devices worn by the patient [2].

In static networks, most WSN protocols assume homogenous sensors, but WBANs feature heterogeneous and mobile devices. WBAN communication must also adhere to the rigors of real-time limitations and take movement precision in millimeters into account. While WBANs and WSNs face similar issues, the former need more research owing to significant internal variations.

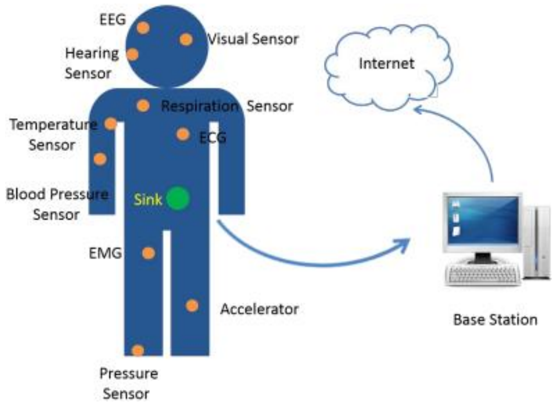

Figure 1. Wireless body area networks

WBANs leverage wireless communication and sensor technologies to monitor physiological data from the human body, structured into three layers for efficient data handling and transmission. The first tier consists of sensors placed on or inside the body for data collection. The second tier includes devices that receive this data and forward it to a terminal data center, represented by the third tier, where the data is processed and utilized for various applications. WBANs enable real-time monitoring and emergency response capabilities by facilitating immediate alerts in case of abnormal data detection. This technology integrates the human body into the communication network, making pervasive and continuous health monitoring services a reality [3].

Therefore, WBANs are essential for long-term human surveillance, relying heavily on energy-efficient operation due to their constrained resources. Research in this domain has explored various optimization techniques, including cooperative clustering, particle swarm optimization (PSO), QoS-aware routing protocols, and algorithms like LEACH. to enhance energy efficiency. However, challenges persist, such as the lack of support for network heterogeneity, mobility, multi-WBAN configurations, and the need for optimal parameters apart from energy for selection of more efficient routing protocol for WBAN communications. Additionally, balancing energy efficiency with performance metrics like latency remains a crucial area for improvement. Despite significant advancements, the field continues to seek solutions that can adapt to the dynamic and diverse requirements of WBANs, emphasizing the need for scalable, flexible, and performance-oriented protocols.

The researchers' contributions of routing protocols in WBANs highlight significant advancements in managing energy efficiency, reducing delay, and optimizing for specific conditions like posture and temperature [3]-[12]. Researchers have developed a range of protocols, from posture and temperature-based to cluster and quality of service (QoS) based, each addressing different aspects of WBAN routing challenges. While some protocols excel in energy efficiency or complexity management, others focus on minimizing delay or adapting to dynamic conditions. Despite these contributions, limitations persist, such as the trade-off between energy efficiency and delay, the high complexity of certain algorithms, and the need for greater adaptability and scalability [13]-[19]. Then the research directions include balancing energy and delay more effectively, simplifying complex protocols, enhancing adaptability to changing conditions, supporting network heterogeneity, and exploring cross-layer optimization strategies [20]-[32]. Addressing these limitations could lead to more robust, efficient WBAN routing solutions, improving the reliability and usability of these networks for health monitoring and other applications.

Therefore, motivated by this, the main contributions of this work are:

- First of all, the paper highlighted several key issues and potential directions in QoS-based routing for WBAN.
- Design of a routing protocol for WBAN communication taking temperature and QoS as contributing factors.
- The proposed OTQRP is efficient in showing low complexity, low delay, and high energy efficiency.

The rest of the paper is organized as: section 2 presents the introduction about WBAN, section 3 presents the literature review showing recent contribution of researchers in the field of WBAN routing. This section discussed different types of routing protocols based on posture, temperature, and energy-efficiency. Section 4 presents the proposed methodology with flowchart and algorithm. Section 5 presents the result analysis of the model with comparative state-of-art. Finally, in section 6 conclusion and future scope is presented.

2. WIRELESS BODY AREA NETWORK INTRODUCTION

WBANs are a type of body network that operates on a three-tier architecture. The network comprises of sensors that are either attached to or implanted within the body (tier-1), smart devices (tier-2), and remote servers that offer various applications (tier-3). Information about human physiological state is collected and transmitted to data center through internet services. Subsequently, the data center analyzes the collected data and responds dynamically by providing emergency transmission and raising alarms in the event of abnormal data. This innovative technology facilitates faster emergency processing and rescue operations. There are currently few applications for WBAN, but research is underway to expand this list. WBANs are widely used in the healthcare and medical industries, where they can be used for telehealth, remote patient monitoring, and emergency response. They can also be used for military, entertainment, and sports and fitness monitoring. However, further in-depth studies and developments are needed to expand the potential applications of WBANs to other industries. In healthcare monitoring, biofeedback is considered as one of the major application of WBANs. WBANs allow healthcare professionals to collect signals from body sensors for use in health assessment, medical diagnosis, and prescribing. By providing real-time feedback and rehabilitative health at home, WBANs can also help with rehabilitation. WBANs also allow for remote monitoring of the body using sensors, enabling the application of biofeedback to maintain and improve health. Finally, WBANs can be used in assisted living facilities to monitor the elderly and disabled in their homes, improving their quality of life and reducing healthcare costs. Security, interoperability, privacy, complexity of system components, sensor data validation, data consistency, interference, and data management are some of these difficulties. Effective WBAN operation requires ensuring patient data security, interoperability across many technology standards, privacy, and minimal system device complexity. Other significant problems that need to be resolved include controlling the consistency and validation of sensor data and managing enormous amounts of generated data. To improve coexistence with other network devices, interference should also be reduced.

3. RELATED WORK

3.1. Posture-based routing

Posture-based routing protocol is designed for such network in which topology is designed according to body posture. The regularity of human body motions can help enhance network topology. Limb motions have an impact on network architecture and create shadow effects, which can cause delays. Predicting the next action ahead of time aids in reducing delays and increasing data transmission speeds. Researchers have created several methods for raising the effectiveness and performance of WBAN systems. A variety of research studies have been conducted to improve the performance and efficiency of WBAN systems. Sun [1] created a data transmission technique based on a Bayesian network that demonstrated superior real-time performance. These include Gao *et al.* [2] development of a hierarchical recognition algorithm for human pose, Quwaider *et al.* [3] creation of a power control mechanism for optimal power assignments, and Alrashidi and Nasri [4] investigation into new wireless technologies. Liang *et al.* [5] presented a posture-oriented routing protocol whose main target is to reduce energy consumption of the nodes. Karmakar *et al.* [6] presented a fault-tolerant system with two sets of nodes that are exactly the same, while Samanta and Misra [7] introduced an optimal framework to minimize costs for opportunistic WBAN. In all cases, the experimental results showed significant improvement in network performance.

3.2. Temperature-based routing

The primary parameter for path selection in WBANs according to the temperature-based routing approach is the node's temperature. By choosing optimal pathways that avoid high-temperature nodes, it aims to prevent or lessen the rise in node temperature. This method was the first to be studied due to security concerns in WBANs, but its use has decreased in recent years with the focus shifting to energy efficiency. Boano *et al.* [8] created TempLab testbed whose main task is to control temperature control and show impact of temperature on network performance. Park [9] demonstrated a WSN-based device to reduce dew condensation in greenhouse conditions, while Nasipuri *et al.* [10] designed temp-aware routing protocol for substation monitoring. Recent research includes Ciani *et al.* [11] implementing smart farming tech to monitor conditions and soil parameters, Kadjouh *et al.* [12] simulating batteries using CupCarbon, and Alassery [13] proposing an efficient routing technique for WSNs. Tang *et al.* [14] addressed routing issues in implanted sensor networks using a thermal-aware routing protocol, and Khan *et al.* [15] proposed a stable network for wireless body area sensor networks. Bhangwar *et al.* [16] presented a routing protocol for WBANs with trust and thermal considerations, and Kim *et al.* [17] suggested a routing method that considers temperature. All proposed algorithms demonstrated better performance in simulations compared to other schemes, reducing hot spots, delivery delay, loss, drop ratio, throughput, and temperature under various traffic conditions.

3.3. Cross-layer routing

This routing protocol is designed with integration of several protocols and achieves low latency and high reliability by collaborating amongst several levels to deliver customized services for various sorts of data. It is more adaptive to dynamic WBANs, and energy efficiency. Experiments have shown the effectiveness of the cross-layer approach. Bai *et al.* [18] describe a cross-layer energy optimization approach (EOA) for WSNs that combines physical, medium access control (MAC), and routing layer optimization to improve energy efficiency. Saleem *et al.* [19] to find the best routes based on link quality, energy level, and velocity characteristics, we suggest an ant colony stimulated routing protocol that leverages cross-layer architecture. Singh and Verma [20] we provide a cross-layer routing protocol that combines proactive and reactive network techniques and is based on an adaptive threshold sensitive distributed routing protocol for heterogeneous networks. Overall, these studies show how cross-layer strategies can increase WSN energy efficiency and data transmission. Melodia *et al.* [21] discussed cross-layer routing protocol as optimization problem. Jaradat *et al.* [22] propose an energy-aware routing scheme that uses a fuzzy logic system controller to make next hop routing decisions based on parameters from different stack layers. Kaur and Kumar [23] suggest a multi-objective, cross-layer routing protocol with QoS considerations, which is shown to be more energy-efficient and have fewer delays from end to finish than with other approaches. Bahadur and Lakshmanan [24] present an overview of recent cross-layer QoS approaches in WSNs and recommend the use of the RAS classification for achieving QoS. Finally, Alrajeh *et al.* [25] designed a routing protocol dedicated on cross-layer concept along with coverage of security aspects.

3.4. Cluster-based routing

The clustering technique is extensively used in WBANs, and it is adopted from WSNs. Clustering routing protocols provide network connectivity, optimize energy consumption, adapt to changing topologies, and enhance network resilience. In this approach, nodes are grouped into clusters, with each cluster comprising multiple cluster nodes and a cluster head (CH) responsible for collecting and transmitting data within the cluster. The LEACH protocol is a well-known example of clustering routing in WSNs, and it has been demonstrated that clustering routing is more appropriate for WBANs. In an investigation by Singh and Sharma [26] outlined a classification of cluster-based routing techniques and supplied a comprehensive overview of clustering schemes. In another investigation, Singh *et al.* [27] focused on cluster-based hierarchical routing protocols for WSNs and found that much research had been done in areas such as low-power protocols, network design, protocol routing, and coverage issues. Tang *et al.* [28] developed a hybrid approach combining genetic optimization and particle swarm algorithms to optimize cluster leader (CH) selection and improve data transmission based on sink mobility. Yu *et al.* [29] suggested a routing technique called CCM that enhances performance by combining the benefits of LEACH and PEGASIS. Fanian and Rafsanjani [30] also designed a energy-constraint clustering protocol for WBAN. Maheshwari *et al.* [31] conducted a survey on WSN clustering techniques and divided them into four groups depending on their methodology. Sabet and Naji *et al.* [32] conducted a survey on WSN clustering techniques and divided them into four groups depending on their methodology. Lotf *et al.* [33] presented a decentralized hierarchical cluster-based routing technique that uses multi-hop routing and clustering simultaneously to cut down on control packets and increase network longevity. Ke *et al.* [34] suggested a hierarchical cluster-based routing protocol with energy awareness that reduces overall energy usage while guaranteeing equitable energy consumption amongst nodes. Sahooa *et al.* [35] A novel clustering algorithm based on sensors voting for their neighbors was given in the extending lifetime of cluster head (ELCH) routing protocol, which selects suitable CHs using this method. Evenly spaced clusters are the result of this.

3.5. QoS-based routing

As the WBANs operate in a resource-constrained environment, it is essential to consider QoS factors that ensure reliable and efficient data transmission. Othman and Yahya [36] proposed EQSR protocol that balances energy consumption across nodes while optimizing delay, throughput, and data redundancy, Liu *et al.* [37] designed a protocol based on software agents whose task is to monitor network topology changes and participate in routing. Fonoage *et al.* [38] proposed a geographic routing mechanism combined with QoS support, and Tan *et al.* [39] to save energy and increase network lifetime, the double-CH-based uneven clustering method is employed in the proposed QSDN-WISE protocol. Zhang and Xu [40] used PSO for optimizing multiple QoS metrics. Mahajan *et al.* [41] designed a routing protocol based on weightage of CH nodes for energy-efficiency. Sharma *et al.* [42] designed OS routing protocol designed on energy aspects. Kalnoor and Agarkhed [43] proposed an energy-efficient approach with secured routing protocols and intruder detection to achieve end-to-end delay. Maheshwari and Karthika [44] designed cluster-based routing protocol with intrusion detection approach to achieve better QoS. Additionally, Kumar and Thirukrishna [45] proposed the OREA algorithm, which aims to enhance energy dissipation and data transmission speed in WSN. They assessed its performance by contrasting its QoS metrics with those of other current methods like random and homogeneous selection. These metrics include traffic load and packet delivery ratio.

4. METHOD USED

The paper presented a proposed solution to address the issue of temperature rise as well as lower QoS in WBAN by considering as multi-objective optimization problem. For this gray wolf optimization (GWO) is used to minimize temperature rise and increase network life by uniformly distributing the load among sensor nodes. Therefore, this research aims to improve the performance of WBAN by efficiently handling multi-hop communication to ensure reliable and QoS aware data transmission with low temperature rise. Therefore, the methodology outlined for addressing temperature rise and QoS issues in WBANs through a multi-objective optimization approach, utilizing GWO. It clearly defines the objective to balance temperature management with network longevity by equitable load distribution among sensor nodes. The assumptions made are realistic and set a clear framework for the implementation of the optimal thermo-QoS-aware routing protocol (OTQRP), distinguishing between critical and routine data transmission modes to optimize for both efficiency and temperature rise. This approach capacities improvements in WBAN performance through efficient handling of multi-hop communication.

4.1. Assumptions

For implementation of OTQRP following assumptions are considered:

- In the network, each sensor node has a fixed position, communicates with a sink node, and has a fixed transmission power and range.
- The sink node has enough resources to provide energy continuously, and after startup, the locations of nearby nodes are known.
- Critical data is sent directly to the destination using single-hop communication, while routine data is sent using multi-hop communication with the forwarder node selected based on the stage of the temperature rise.

4.2. Proposed methodology

The OTQRP is designed to select optimal CH node for data aggregation and transmission using GWO algorithm which is inspired by grey wolf hunting behavior, as presented in Algorithm 1. The cluster routing technique involves three stages-cluster formation, CH selection, and data transmission, which operate in cycles. Therefore, the entire working of the proposed model is divided in three steps as presented in Figure 2. In Figure 3 represents the flowchart of working of proposed OTQRP.

- Node deployment and parameter initialization: in this phase, N nodes are deployed on each WBAN user. This will enable Inter-WBAN as well as Intra-WBAN communication. In intra-WBAN, there is a hub node (or CH) for the coordination of data. Similarly, inter-WBAN has a coordinator node for the coordination of data to a higher level. Intra-WBAN sensor nodes are considered to be non-rechargeable, heterogeneous, and unable to change topology. There exists a full-duplex transmission mode.
- Objective functions determination: sensor nodes in WBANs can increase surrounding tissue temperature and reduce network lifespan. The proposed OTQRP algorithm considers temperature and QoS parameter such as delay and energy impact during route initialization.

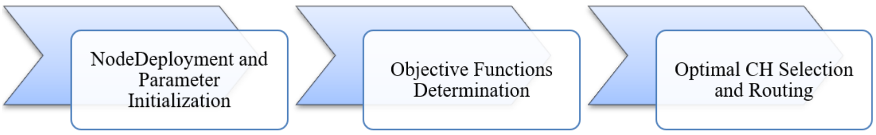

Figure 2. Working steps of proposed methodology

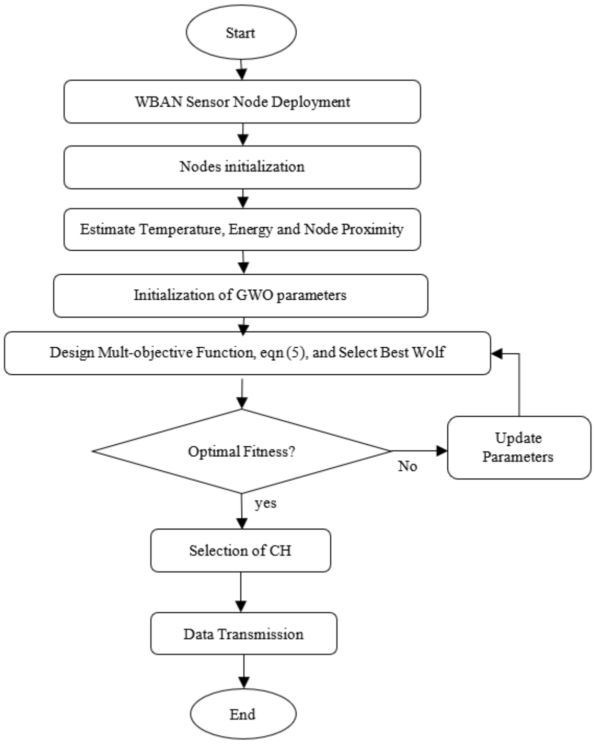

Figure 3. Flowchart of OTQRP

The thermal dissipation of nodes are also considered to select optimal CHs. The thermal model includes node temperature rise and heat absorption rate by human tissues. The temperature is equated as:

$$N_{temp} = Current_{temp} + N * AT_{rise} \quad (1)$$

here, N represents the number of packets transmitted and AT_{rise} represents the average temperature rise. The impact of temperature on human tissues is determined by the heat absorption rate of tissues, which is estimated by measuring the heat absorbed, HA, during RF wave exposure for a certain duration. This can be expressed as:

$$\text{HA} = \frac{\sigma(EMF)^2}{\rho} * \frac{t}{c} \quad (2)$$

conductivity rate and density of sensor is represented as σ and ρ respectively. EMF represents the electromagnetic field. Time interval and specific heat capacity is represented as t and c.

The distance or node's proximity is also a major QoS parameter which directly effect the energy consumption of nodes. Therefore, this needs to be minimized and is evaluated as:

$$N_{prox} = \min\{\frac{dist_{mean}^2}{rad_0^2}\} \quad (3)$$

where, $dist_{mean}^2$ is the mean distance among nearby nodes and radius of nodes is represented as rad_0^2. Another QoS objective function is residual energy E_{res} of nodes which needs to be maximized and is calculated as:

$$N_{energy} = max \sum_{i=1}^{N} E_{res}(N_i) \quad (4)$$

then these QoS parameters, such as temperature, delay, and energy, are fed into the multi-objective GWO algorithm to select optimal CH for data aggregation and transmission. For this objective function equation is equated as:

$$F_{obj} = N_{temp} + N_{prox} + N_{energy} \quad (5)$$
$$\text{Subject to } \min\{F_{obj}\}$$

– Optimal CH selection and routing: after determination of objective function, GWO algorithm is initialized for optimal CH selection and further data transmission. The use of the GWO algorithm for optimal CH selection and routing involves objective function determined in above step i.e., $F_{obj} = N_{temp} + N_{prox} + N_{energy}$. The GWO, inspired by grey wolves' social hierarchy and hunting behavior, is then employed to find the best CHs and establish efficient data transmission paths. This method efficiently addresses complex network optimization challenges, aiming for lower energy use, reduced transmission delays, and prolonged network lifetimes, thereby enhancing the overall performance and sustainability of WBAN communications.

Algorithm 1. Routing based on GWO

Initialize the generation counter t and the grey wolf population $X_i (i = 1, 2, ..., n)$
Compute the fitness of every wolf
X_α = The best wolf
X_β = The 2nd best wolf
X_δ = The 3rd best wolf
while (t is less than Max_iterations)
Select X_α, X_β, and X_δ according to fitness function
Update the latest wolf's location using $X_{(t+1)} = (X_\alpha + X_\beta + X_\delta)/3$
end for Update parameters
Determine the overall fitness of all wolves using F_{obj}
Update $X_\alpha, X_\beta, X_\delta$
Swap out the worst-fitting wolf with the best-fitting wolf.
$t = t + 1$;
end while;
return to X_α.

5. RESULT AND DISCUSSION

The suggested OTQRP algorithm is evaluated in this section using the simulation's results analysis. The simulation was conducted on the MATLAB platform using a Pentium Core I5-2430M CPU operating at 2.40 GHz, with 4GB of RAM, and a 64-bit OS.

5.1. Simulation parameters

The simulation environment consisted of a 30 m × 30 m area with 50 WBAN nodes. These nodes are deployed randomly in the network. The initial energy of the network is 30 Joules. The packet size for data transmission is also a variable ranging from 2000 to 4000. The network's initial level of energy can be adjusted to take on a variety of values because it is flexible. 16.7 nJ/bits of energy are lost throughout bit transmission when compared with 36.1 nJ/bits throughout bit reception. 1.98 nJ/bits of energy are lost via power in the amplification process.

5.2. Performance measures

The study assessed several factors to evaluate the algorithm's performance such as:

– Energy efficiency: it refers to the ability of a system or device to perform its functions while minimizing the consumption of energy. It is evaluated as:

$$Energy_{consumption} = \frac{(Total\ Energy - Energy\ remaining\ after\ transmitting\ n\text{-}bit\ data\ packets)}{Total\ Energy} * 100 \quad (6)$$

– Temperature rise: it represents the rise in temperature of nodes after transmission of n packets. It is mathematically represented as:

$$Temp_{rise} = (\frac{(T_c - T_p)}{T_p}) * 100 \quad (7)$$

where the temperature before transmission is represented as T_p and after transmission is represented as T_c.

5.3. Result analysis

In Figure 4, the recommended solution's energy use OTQRP at different rounds of operation are presented. The system consumes very little energy, with only 0.04% after 100 rounds and increasing gradually to 0.21% after 500 rounds. Figure 5 shows the temperature rise for different numbers of rounds. As the number of rounds increases, the temperature rise also increases. For example, in the first round, the temperature rise is 0.15%, while in the fifth round, the temperature rise is 0.89%. This suggests that as more data is transmitted, more heat is generated, leading to an increase in the temperature rise. Figure 6 shows the delay in seconds for different rounds during data transmission. The delay is measured for 100, 200, 300, 400, and 500 rounds. As the number of rounds increases, the delay also increases. For instance, in 100 rounds, the delay is 1.0657 sec, whereas in 500 rounds, the delay increases to 2.55974 sec.

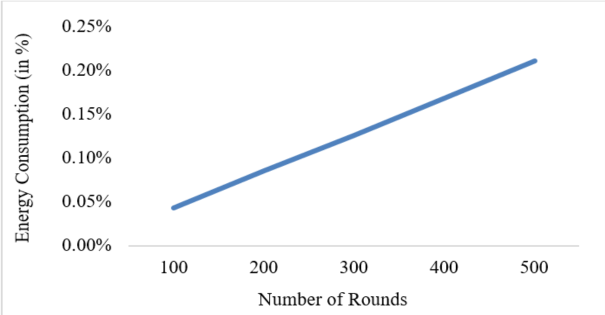

Figure 4. Energy consumption with respect to rounds

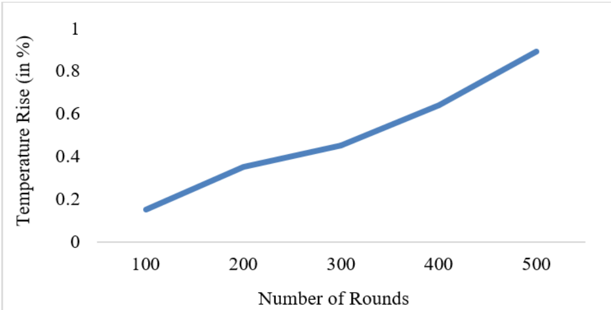

Figure 5. Temperature rise with respect to rounds

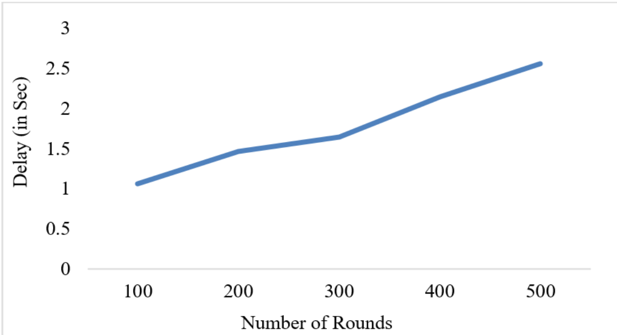

Figure 6. Delay with respect to rounds

Figure 7 shows a comparison of energy consumption with respect to node density for three different algorithms: TARA [46], EES-NOT [46], and proposed OTQRP. For this, 50 nodes are considered under multi-WBAN scenario. For 10 nodes, TARA and EES-NOT have the same energy consumption of 0.1%, while OTQRP has lower energy consumption of 0.006%. For 20 nodes, TARA and EES-NOT have slightly higher energy consumption of 0.16% and 0.15%, respectively, compared to OTQRP which has 0.011% energy consumption. For 30 nodes, TARA has the highest energy consumption of 0.3%, followed by EES-NOT with 0.2% and OTQRP with 0.014%. For 40 and 50 nodes, TARA and EES-NOT have significantly higher energy consumption compared to OTQRP. Therefore, OTQRP consistently achieves the lowest energy consumption across all node densities.

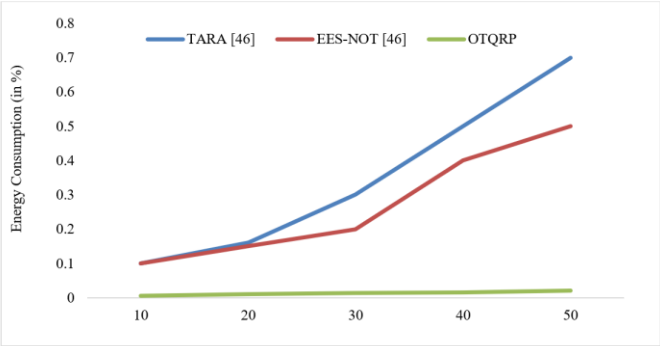

Figure 7. Energy consumption comparative state-of-art

In Table 1, the performance comparison of routing protocols is discussed. The table lists various protocols and categorizes them based on their approach. Each protocol is assigned a score based on its complexity, delay, and energy efficiency, with low, medium, and high values. The Bayesian network protocol, for example, is posture-based and has a low complexity but high delay and low energy efficiency. On the other hand, the optimal network management cost minimization algorithm is posture-based and has a high complexity, medium delay, and high energy efficiency. Therefore, the paper identifies several QoS-based routing issues and potential research directions in WBAN. These include improving energy efficiency, exploring service differentiation in scenarios with different QoS requirements, designing secure QoS-based routing protocols, investigating the scalability of QoS-based routing protocols, validating the protocols in real-world deployments, leveraging machine learning-based approaches to address challenges, and exploring hybrid approaches that combine different QoS-based routing protocols to improve efficiency in terms of energy use, service differentiation, security, and scalability. Addressing these challenges, the paper presented a hybrid approach using temperature-based and QoS-based routing protocols for WBAN. The proposed protocol, called OTQRP (ours), which is based on a Thermo-QoS-aware routing protocol achieves low complexity, low delay, and high energy efficiency as compared to existing state-of-the-art models.

Table 1. Performance comparison of routing protocols

Ref	Method used	Type of protocol	Complexity	Delay	Energy efficiency
[1]	Bayesian network	Posture based	Low	High	Low
[3]	Adaptive transmission power control (ATPC)	Posture based	Medium	Low	Low
[5]	Tree-based energy-efficient routing	Posture based	Low	High	Low
[7]	Optimal network management cost minimization algorithm	Posture based	High	Medium	High
[9]	Exterior gateway protocol (EGP)	Temperature based	Low	Low	Medium
[12]	Routing information protocol (RIP)	Temperature based	High	Medium	High
[20]	Adaptive threshold routing protocol	Cross-layer based	Low	High	Low
[22]	Multi-hop constraint-based network based on fuzzy logic	Cross-layer based	Low	Medium	High
[31]	Butterfly optimization algorithm and ant colony optimization	Cluster-based	High	Medium	Medium
[32]	Hierarchical cluster-based routing algorithm	Cluster-based	Low	Medium	High
[34]	Hierarchical cluster-based routing protocol that is energy conscious	Cluster-based	Low	High	Low
[37]	PSO algorithm	QoS based	High	Medium	Medium
[41]	Approach using cluster network weight metrics (CCWM)	QoS based	Low	Medium	High
[43]	Deer hunting optimization (DHO) algorithm	QoS based	Low	Medium	Medium
OTQRP (ours)		Thermo-QoS-aware based	Low	Low	High

6. DISCUSSION

The paper analyzed the routing protocols for WBANs presented with different strategies aimed at optimizing performance metrics such as complexity, delay, and energy efficiency. This critical discussion evaluates these protocols across various dimensions, emphasizing the trade-offs inherent in their design and the potential directions for future research to enhance WBAN routing protocols. Protocols like Bayesian network, ATPC, and tree-based routing demonstrate a focused attempt to address the dynamic nature of human posture but often at the expense of either energy efficiency or increased delay. EGP and RIP protocols adapt routing based on temperature variations, aiming to maintain operational efficiency. RIP's high complexity yet high energy efficiency suggests a potential for sophisticated algorithms to effectively manage resources, though possibly at the cost of increased system demands [47], [48]. adaptive threshold routing protocol and the fuzzy logic-based multi-hop network prioritize a holistic view of network operation, integrating various layers' considerations. Cluster-based protocols includes protocols employing optimization algorithms like the butterfly optimization and ant colony optimization, and hierarchical clustering. These approaches aim to manage energy consumption and delay through structured network organization, with varying success in balancing these metrics. Protocols leveraging PSO, CCWM, and DHO emphasize QoS, achieving a balance between operational demands and performance. The CCWM approach, in particular, highlights how low complexity does not preclude high performance in terms of energy efficiency and delay management.

The introduction of proposed OTQRP (hybrid protocol) protocol marks a significant advancement, purportedly overcoming many limitations identified in above approaches. Its low complexity, coupled with low delay and high energy efficiency, presents a promising solution that appears to reconcile the challenges of balancing performance metrics effectively. This protocol's hybrid approach, integrating temperature sensitivity with QoS considerations, suggests a novel pathway to address the demands of WBANs, particularly in terms of energy and efficient data transmission.

7. CONCLUSION AND FUTURE WORK

WBAN is a subset of WSN that has its own unique features and is limited in scope due to resource constraints and application focus. The paper presented the different WBAN routing designs that currently revolves around next hop selection methods, which involve both optimization and QoS delivery. Researchers have proposed various routing algorithms and techniques to address the challenges of energy efficiency, network lifetime, security, and data reliability. The article discussed various techniques before presenting an ideal thermal and QoS conscious routing protocol for WBAN. Then paper presented an OTQRP for WBAN communication and shows its efficiency with respect to existing works. In future this work will be integrated with congestion control mechanism with security aspects.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Pradeep Bedi	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Sanjoy Das		✓				✓	✓	✓		✓	✓	✓	✓	
S. B. Goyal	✓		✓	✓			✓			✓	✓		✓	
Manoj Kumar	✓		✓	✓			✓			✓	✓			
Sunil Gupta	✓		✓	✓			✓			✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SBG], upon reasonable request.

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BIOGRAPHIES OF AUTHORS

Pradeep Bedi is an accomplished professional with extensive experience in teaching and learning, administration, and research and development. He has received B.Tech. degree in computer science and engineering from Uttar Pradesh Technical University (UPTU), Lucknow, India, M.Tech. in computer science and engineering from Guru Gobind Singh Indraprastha University (GGSIPU), Delhi, India, and Ph.D. in computer science from IGNTU, Amarkantak (M.P.), India. He has also qualified UGC NET and GATE. Currently, he holds the position of associate professor in the department of computer science and engineering, Graphic Era Deemed to be University, Dehradun, Uttrakhand, India. He has authored/co-authored over 100 research papers published in national and international journals (SCI/SCOPUS indexed) and conferences and also published 14 patents in India and abroad. He is a member of reputed professional bodies such as IEEE and ACM. His research interests include applications of artificial intelligence, machine learning, deep learning and IoT in healthcare, and WBAN. He is having 30+ research collaborations with international academicians/researchers and serving as reviewer for various SCI indexed journals (Heliyon, applied ai, cybernetics and systems, scientific reports, intelligent and fuzzy systems, and wireless personal communications). He can be contacted at email: pradeep.kcu21@gmail.com.

Sanjoy Das currently serves as the professor and head of the Department of Computer Science at Indira Gandhi National Tribal University (a Central Government University) in Amarkantak, M.P. – Manipur Campus, India. He holds a Bachelor of Engineering (B.E.), a Master of Technology (M.Tech.), and a Doctorate (Ph.D.) in Computer Science. With over 20 years of experience in teaching and research, Dr. Das has held several academic positions at reputed institutions. Before joining IGNTU, he was an Associate Professor in the School of Computing Science and Engineering at Galgotias University, India, from July 2016 to September 2017, and an Assistant Professor at the same university from September 2012 to June 2016. He has also taught at G.B. Pant Engineering College in Uttarakhand and Assam University in Silchar between 2001 and 2008. Dr. Das has made significant contributions to academic research and the organization of variour international conferences. He has chaired sessions at multiple international conferences and played a key role in their organization. His current research interests include MANETs, VANETs, distributed systems, and IoT. He has published over 100 research papers in Scopus, Web of Science, and SCI-indexed international journals, as well as in conference proceedings and book chapters. Additionally, he has edited nine books and holds several national and international patents. He can be contacted at email: sanjoy.das@igntu.ac.in.

S. B. Goyal is a distinguished academician and researcher in the field of Computer Science and Engineering, with over two decades of experience spanning teaching, research, and academic leadership. He earned his Ph.D. from Banasthali University, Rajasthan, India, in 2012. Dr. Goyal has made significant contributions to the integration of Industry Revolution (IR) 4.0 technologies into higher education curricula, including quantum computing, big data, data science, ai, blockchain, and cloud computing, particularly across Malaysian universities. A seasoned speaker and thought leader, he has been invited to deliver keynote talks and serve as a panelist at several prestigious forums, including Bloconomic 2019 and the World AI Show 2021, as well as various academic and industry platforms focused on IR 4.0 advancements. Dr. Goyal is committed to building a future-ready, globally benchmarked academic ecosystem, equipping students with advanced technological competencies and preparing them for leadership in a rapidly evolving digital world. His career objective is to leverage his deep expertise to drive academic innovation, research excellence, and international accreditation in premier institutions. He can be contacted at email: drsbgoyal@gmail.com.

Manoj Kumar completed his Ph.D. from Northcap University and M.Sc. (Information Security and Digital Forensics) from Technological University Dublin, Ireland in 2013. Dr. Kumar has more than 15 years of research, teaching, and corporate experience. Currently, Dr. Kumar holds the position of Associate Professor at the University of Wollongong in Dubai. In addition, he serves as the Research Cluster Head for Network and Cyber Security @UOWD. Dr. Kumar is listed among the top 2% of computer scientists worldwide. He published over 280 research articles in international refereed journals and conferences. He published over 12 patents, completed 10 research-funded grants, and released 3 authored and 16+ edited books. Three students have successfully completed their Ph.D. research under Dr. Kumar's supervision, and four more are currently pursuing their doctoral studies under his guidance. He has organized six international conferences in collaboration with reputed publishers such as IEEE, Taylor & Francis, and Springer. He also delivered more than 20+ keynote talks at international conferences and has conducted several short-term courses and FDPs. In addition, he acts as an editor, associate editor, guest editor, and editorial board member for several scientific journals. Dr. Kumar is a member of numerous renowned professional bodies, including IEEE, ACM, IAENG, ISTS, and UACEE. Dr. Kumar received the Best Researcher Award in 2020, an Outstanding Scientist Award, and a Young Researcher Award in 2021 from recognized international professional bodies. His specializations are cyber security, intelligent systems, digital forensics, AI, image processing, IoT, and networks. He can be contacted at email: wss.manojkumar@gmail.com

Sunil Gupta is an alumnus of the prestigious NIT Jalandhar and NIT Hamirpur. He is an academic with a broad variety of research, development, industrial, and administrative expertise. Dr. Gupta has worked in both higher education and industry for more than a decade. He has played a key role in developing innovative curricula in cutting-edge technological fields at UPES and BMU as a professor. Dr. Gupta has always felt that education should extend beyond the classroom; therefore, have worked hard to instil ideals and provide students with a solid moral basis. Dr. Gupta has worked on formulating academic policies, innovating teaching-learning pedagogies, engaging students, educating about new technologies, consulting, conducting research, attending conferences, publishing journals, and building connections with the business world. He can be contacted at email: s.gupta@ddn.upes.ac.in.