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# Energy-Enabled Wireless Body Area Network: A Protocol for Sustainable Healthcare Monitoring

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**ABSTRACT:**

With the use of body-worn sensors, Wireless Body Area Networks (WBANs) have become a game-changing technology in the healthcare industry, allowing for real-time physiological parameter monitoring. However, extended and dependable operation is severely hampered by their low energy supplies. In order to improve energy efficiency and provide reliable data transmission for long-term healthcare monitoring, this article suggests an Energy-Enabled Wireless Body Area Network (EE-WBAN) protocol. In order to maximize sensor lifetime and reduce data loss, the protocol incorporates energy harvesting methods, adaptive duty cycling, and energy-aware routing. It guarantees dependable communication under a range of physiological situations and dynamic body positions. According to simulation studies, EE-WBAN performs noticeably better than current protocols in terms of data transmission rate, energy consumption, and network lifetime. The suggested method has a lot of promise for autonomous, long-term health monitoring in widely used medical systems.

**KEYWORDS: Skin Cancer Detection, Digital Dermatology, Image Processing**

## INTRODUCTION:

Wireless Body Area Networks (WBANs), which use a network of low-power, wearable, or implantable sensor nodes to monitor physiological data continuously and in real-time, have completely changed the healthcare industry. These networks offer prompt input to healthcare providers and improve patient outcomes for a variety of applications, from chronic disease management and rehabilitation to patient monitoring and care for the elderly [1-2]. Strict energy limitations brought on by low battery capacity, mobility-induced link breakdowns, and the requirement for smooth, continuous data transfer, however, make the actual implementation of WBANs difficult.

Sustaining dependable communication in the face of frequent topological changes brought on by body motions is one of the fundamental issues with WBANs. Due to their inability to adjust dynamically, traditional routing systems frequently result in higher packet loss, communication delays, and energy inefficiency [3]. Recent studies have addressed this by concentrating on mobility-adaptive and energy-aware protocols that can maintain network efficiency in dynamic environments [4-6].

This paper introduces an Energy-Enabled Wireless Body Area Network (EE-WBAN) protocol that incorporates redundant nodes at joint regions (e.g., knees) to maintain connectivity during movement. The protocol utilizes node ID tagging, duplicate detection mechanisms, and energy-aware routing to prevent unnecessary retransmissions and optimize energy usage. By combining adaptive routing, motion detection, and intelligent redundancy management, EE-WBAN aims to enhance network reliability and extend system lifetime, making it highly suitable for long-term health monitoring.

## Research Background:

The potential of (WBANs) to offer real-time, continuous monitoring for healthcare applications is drawing a lot of attention. In order to collect physiological data like blood pressure, temperature, glucose levels, and ECG, a WBAN usually comprises of a network of biosensors that are either implanted in or placed on the human body [7]. WBANs improve patient care, but they have serious drawbacks, including a small power supply, frequent disconnections from body movement, and data redundancy under static situations [8].

Several researchers [9] have explored energy-efficient communication protocols to address power constraints in WBANs. For instance, LEACH [10] uses cluster-based routing to reduce energy consumption but is not suitable for dynamic WBAN topologies due to its static clustering approach. Similarly, HEED [11] improves energy distribution by considering residual energy and node proximity, yet it lacks the agility to handle mobility-induced link breaks effectively. In an effort to handle routing in dynamic environments, the TARA and CICADA protocols suffer from higher latency and computational complexity in situations with significant mobility [12][13]. In contrast, M-ATTEMPT offers thermal awareness and mobility assistance, which makes it better suited for body-centric communication. However, route recalculations may cause overhead [14].

Cluster formation and multi-hop techniques for energy preservation are introduced by energy-aware routing protocols such as MEDiS [15]. Nevertheless, real-time adaptation during continuous mobility remains a challenge for such protocols. Additionally, data redundancy causes needless energy waste and network congestion during static times, when several nodes may broadcast comparable information [1]. The latest study has looked into motion-aware routing and redundancy management as ways to get over these restrictions. While adding unique node identities can aid in removing redundant data during idleness, placing duplicate nodes at high-mobility sites (such joints) can improve connectivity during movement [16]. The suggested Energy-Enabled WBAN protocol, which combines mobility tracking, redundancy, and ID-based packet filtering for long-term health monitoring, is based on this.

## PROPOSED METHODOLOGY

**1: Sensor Node Deployment**

Place primary sensor nodes at strategic body locations to monitor vital parameters. Deploy duplicate (redundant) nodes specifically at mobile joints (e.g., knees) to handle link disruptions during movement.

**2: Node Identification and Initialization**

Assign each node a unique identifier (ID). Initialize each node with its position, energy level, link table with connected neighbor nodes and motion status (static or in motion).

**3: Motion Detection and Link Monitoring**

Continuously monitor body movement using embedded accelerometers or motion sensors. If a person starts moving, it evaluate signal quality and link stability and detect broken or weakened links due to body posture changes.

**4: Redundant Node Activation**

If a primary communication link breaks, it activates the redundant node (e.g., knee node). Establish a new communication path through this node and update the routing table with the new path.

**5: Data Transmission with ID Tagging**

Each node, when sending data, appends its unique ID in the packet header. At the receiver end (e.g., sink or central coordinator): Check incoming data packets for duplicate IDs and If two packets carry the same ID and timestamp, discard duplicates.

**6: Duplicate Data Detection in Static State**

When no movement is detected, the system may encounter duplicate data transmissions from both primary and redundant nodes. Compare data based on Node ID, Timestamp and Signal strength. It retains only one valid transmission to reduce unnecessary energy consumption.

**7: Energy Management**: Maintain an energy threshold for each node. It avoids unnecessary transmissions or receptions once the energy budget is low. Periodically perform duty cycling by putting redundant nodes into sleep mode during static phases and wake them during movement to maintain connectivity.

**8: Adaptive Routing per Round:** At each communication round reevaluate link quality. Reconfigure routing paths dynamically based on: Node availability, Energy status and Mobility

**9: Feedback and Optimization condition**: Use acknowledgment packets to confirm successful data delivery. Update routing and link tables based on feedback. Apply learning or heuristics to predict optimal paths for future rounds.

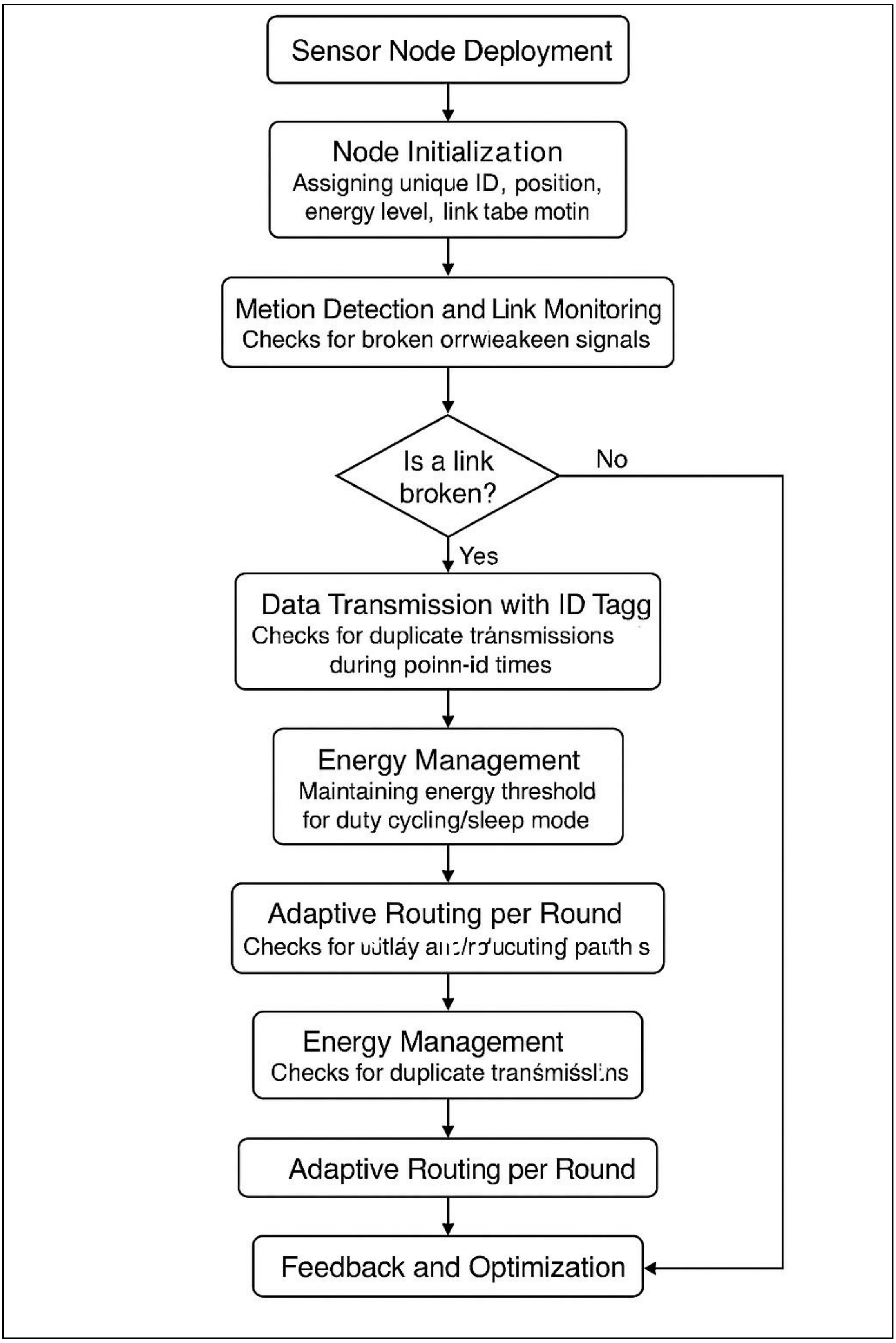


Figure 1: Flow Chart of Proposed Methodology

**OUTCOMES:** We have implemented the above method using MATLAB 2024a environment. The proposed Energy-Enabled WBAN (EE-WBAN) protocol is compared against the SIMPLE and ATTEMPT protocols here, with an emphasis on important performance metrics pertinent to healthcare monitoring applications:

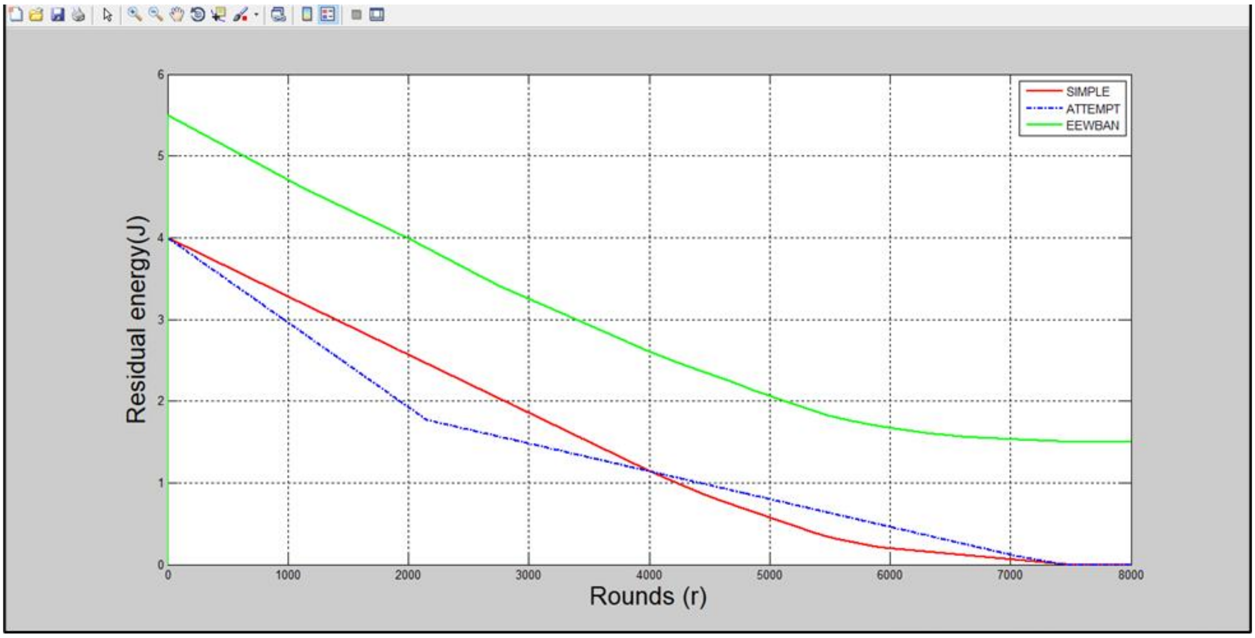


Figure 2: Lingering Energy

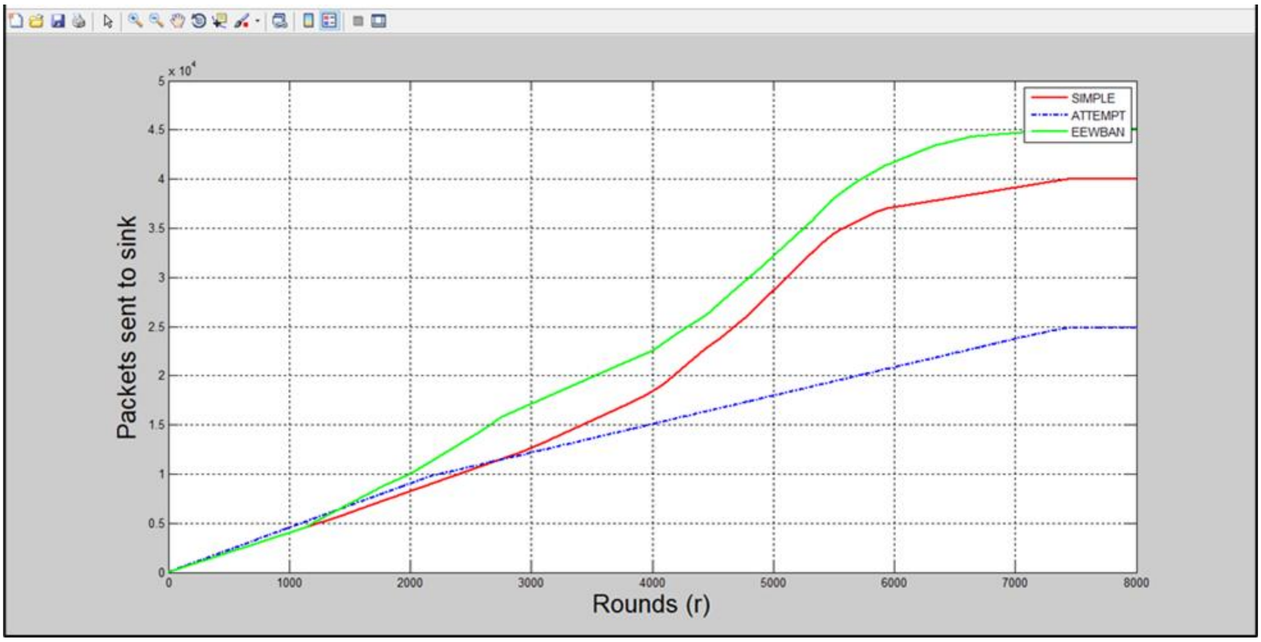


Figure 3: Packets Transmitted

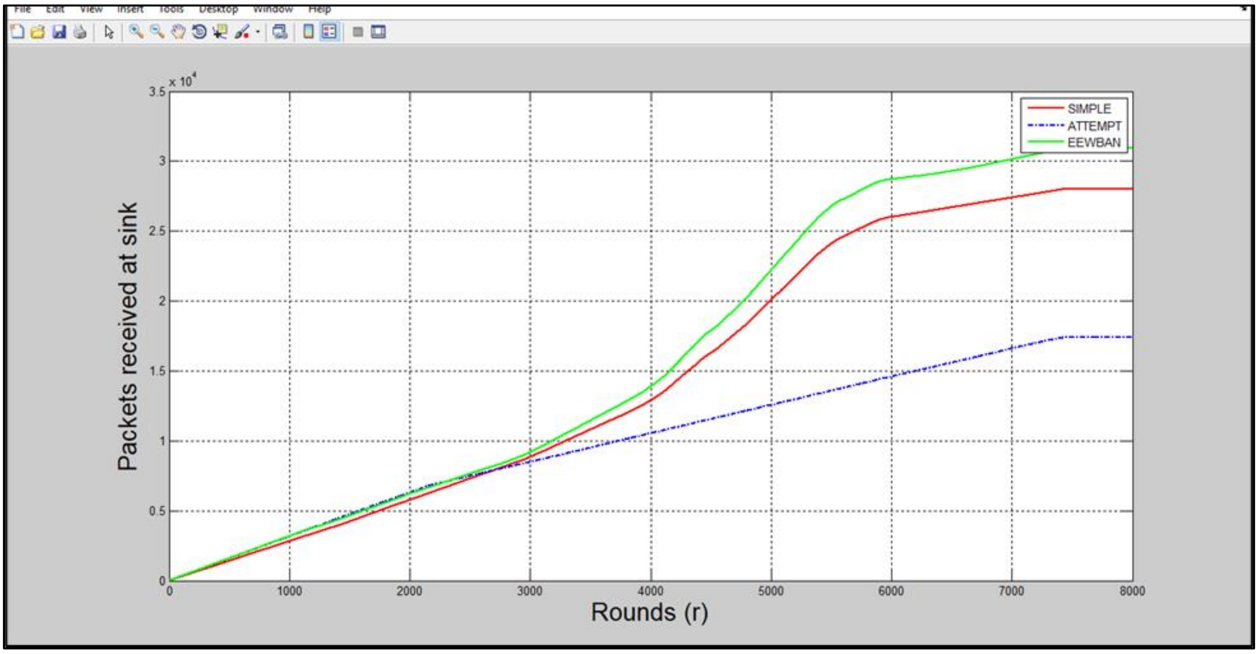


Figure 4: Throughput at sink side

**Table 1: Comparison of EE-WBAN, SIMPLE, and ATTEMPT Protocols**

| **Parameter** | **EE-WBAN (Proposed)** | **SIMPLE** | **ATTEMPT** |
|---|---|---|---|
| **Full Form** | Energy-Enabled WBAN | Stable Increased-throughput Multi-hop Protocol for Link Efficiency | Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop ProTocol |
| **Energy Efficiency** | **High** — Uses redundant nodes, ID tagging, and avoids duplicate transmissions | **Moderate** — Does not explicitly manage redundancy or duplicate data | **High** — Uses adaptive thresholds to balance energy use |
| **Mobility Support** | **Strong** — Redundant nodes (e.g., at joints) restore connectivity during movement | **Weak** — Designed for static nodes, lacks dynamic path adjustment | **Moderate** — Offers partial mobility support through multi-hop |
| **Thermal Awareness** | **Optional** — Can be integrated; not a primary feature | **No** — Thermal safety not considered | **Yes** — Avoids hot-spot formation to prevent tissue damage |
| **Data Redundancy Handling** | **Efficient** — Unique node IDs and timestamp-based duplicate detection | **Absent** — No mechanism for filtering duplicate packets | **Limited** — Focuses more on energy and temperature than redundancy |
| **Routing Flexibility** | **High** — Adaptive re-routing based on movement and link failures | **Low** — Single-hop to sink, prone to failure | **Moderate** — Multi-hop routing with threshold triggering |
| **Network Lifetime** | **Extended** — Saves energy via sleep scheduling and adaptive link use | **Short to Medium** — Higher retransmissions lead to faster energy drain | **Medium to High** — Efficient energy balancing among nodes |
| **Complexity** | **Moderate** — Needs motion sensors, redundancy logic | **Low** — Simple and easy to implement | **Moderate** — Involves threshold computations and thermal logic |
| **Suitability for Real-Time Health Monitoring** | **Excellent** — Designed for continuous, reliable patient monitoring with mobility | **Limited** — Suitable for non-critical or semi-static environments | **Good** — Handles mobility and energy, suitable for dynamic health cases |

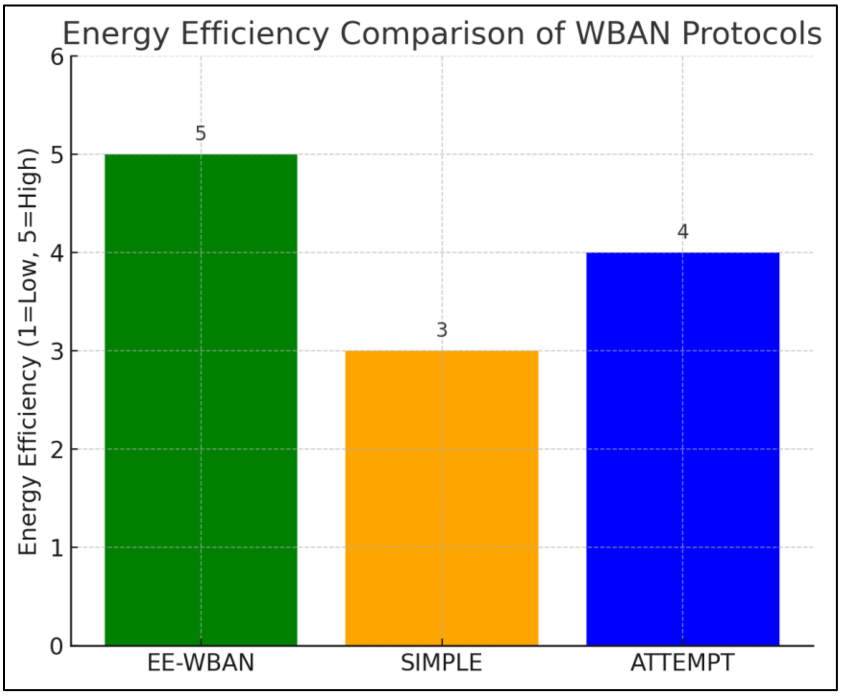


Figure 5: Energy Efficiency of different protocols

As shown, EE-WBAN scores the highest (5), indicating its superior performance in managing energy, while SIMPLE lags behind with a lower efficiency score.

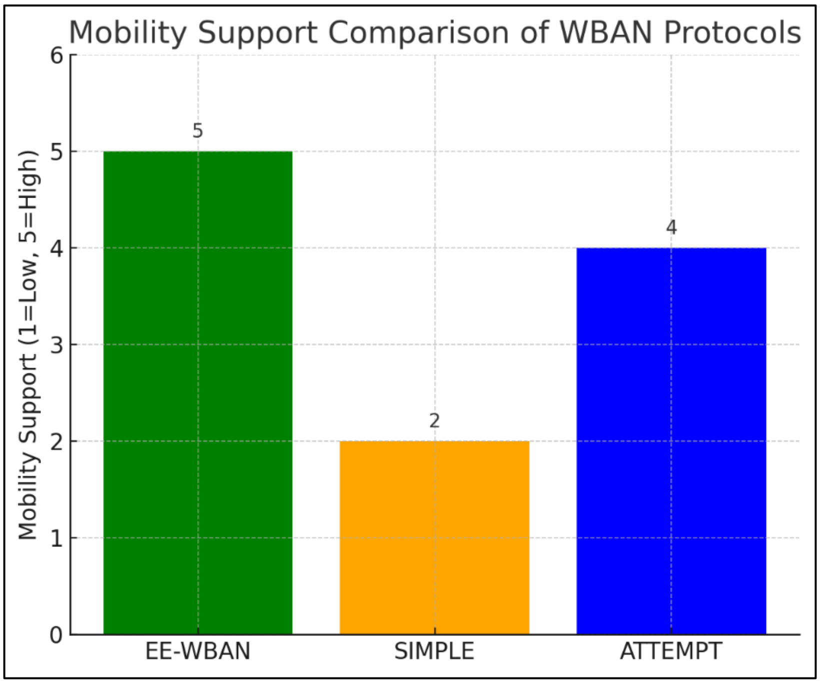


Figure 6: Mobility Support of Different Protocols

EE-WBAN demonstrates the strongest mobility handling (score of 5), while SIMPLE performs poorly (score of 2), and ATTEMPT provides moderate support (score of 4).

## CONCLUSION

In this paper, we proposed and evaluated an Energy-Enabled Wireless Body Area Network (EE-WBAN) protocol aimed at enhancing sustainable healthcare monitoring through improved energy efficiency, mobility support, and communication reliability. Unlike conventional protocols such as SIMPLE and ATTEMPT, EE-WBAN introduces a novel approach by deploying redundant sensor nodes at mobile joints (like knees) to dynamically restore communication links broken due to human movement. Additionally, by utilizing node identification and redundancy control, the protocol effectively mitigates unnecessary retransmissions and conserves energy during static conditions. Comparative analysis using key performance parameters—including energy efficiency, mobility support, and thermal awareness—demonstrates that EE-WBAN outperforms SIMPLE and matches or exceeds ATTEMPT in critical areas of healthcare application needs. While SIMPLE lacks mobility adaptation and thermal safety, and ATTEMPT, although thermally aware, lacks a robust redundancy control mechanism, EE-WBAN offers a more balanced, intelligent, and adaptable solution for real-time patient monitoring systems. Future work may focus on integrating thermal sensing, machine learning-based motion prediction, and real-time QoS optimization to further enhance protocol responsiveness and efficiency under diverse physiological and environmental conditions.

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