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An Energy Enabled Wireless Body Area Network (EEWBAN) Protocol

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ABSTRACT: Wireless Body Area Networks (WBANs) are a critical component in modern healthcare, enabling continuous monitoring of physiological parameters through an array of body-worn sensors. However, challenges such as energy consumption, data redundancy, and network reliability need to be addressed to optimize performance. This paper proposes an enhanced WBAN architecture that integrates energy-efficient strategies, duplicate data removal mechanisms, and the inclusion of additional relay nodes. The primary focus of this study is to minimize energy consumption without compromising data integrity or network reliability. By implementing duplicate data removal algorithms, the system can significantly reduce the amount of redundant data transmitted, thereby conserving energy. Additionally, the deployment of strategically placed relay nodes enhances network reliability and extends the coverage area, ensuring robust data transmission even in the presence of body shadowing and other signal obstructions. Our experimental results demonstrate that the proposed architecture effectively reduces energy consumption by up to 30% compared to traditional WBAN configurations. The duplicate data removal mechanism proves efficient in maintaining data accuracy, while the additional relay nodes contribute to a 20% improvement in network reliability and coverage. This innovative approach holds significant potential for advancing WBAN technologies, leading to more efficient, reliable, and longer-lasting healthcare monitoring solutions.

KEYWORDS: Wireless Body Area Network (WBAN), energy efficiency, duplicate data removal, relay nodes, healthcare monitoring.

I. INTRODUCTION

Wireless Body Area Networks (WBANs) represent a transformative advancement in health monitoring technologies, offering continuous, real-time monitoring of physiological parameters through an array of wearable sensors. These networks are particularly beneficial for managing chronic diseases, monitoring vital signs, and facilitating remote healthcare services. The key advantage of WBANs lies in their ability to provide continuous health data without impeding the daily activities of patients, thereby improving both patient compliance and the quality of healthcare delivery[1]. A typical WBAN consists of multiple sensor nodes placed on or around the human body. These sensor nodes are responsible for collecting physiological data, such as heart rate, body temperature, and electrocardiogram (ECG) signals. The collected data is then transmitted to a central coordinator node, often referred to as the sink node. The sink node aggregates the data from various sensors and transmits it to external healthcare systems for further analysis and storage [2]. One of the significant challenges in WBANs is energy consumption. The sensor nodes are typically powered by small batteries, which are impractical to replace frequently. Thus, efficient energy management is crucial for prolonging the operational lifespan of the network. Energy consumption in WBANs can be affected by various factors, including data transmission, data processing, and sensor operation. Techniques such as duty cycling, data compression, and energy-efficient routing protocols have been proposed to address these challenges[3]. Another critical issue in WBANs is data redundancy. Redundant data transmission not only wastes energy but also increases network congestion, leading to potential delays in data delivery. To mitigate this, duplicate data removal algorithms can be employed to ensure that only unique and relevant data is transmitted. This approach not only conserves energy but also improves the overall efficiency of the network.

In addition to energy efficiency and data redundancy, the reliability of data transmission is a crucial consideration in WBANs. Factors such as body movement and varying environmental conditions can impact the signal quality and lead to data loss. To enhance network reliability, additional relay nodes can be introduced. These relay nodes act as intermediaries, facilitating robust data transmission and extending the network coverage area[4]. Moreover, the innovative use of body heat as a potential power source for sensor nodes is gaining attention. Thermoelectric generators

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(TEGs) can convert body heat into electrical energy, providing a sustainable power solution for WBANs. This approach not only reduces the dependence on traditional batteries but also contributes to the overall energy efficiency of the network. In this paper, we propose an enhanced WBAN architecture that integrates energy-efficient strategies, duplicate data removal mechanisms, and additional relay nodes to address these challenges. The proposed system aims to optimize energy consumption, reduce data redundancy, and improve network reliability, thereby advancing the effectiveness of health monitoring technologies.

II. RESEARCH BACKGROUND

Wireless Body Area Networks (WBANs) have become a critical technology for health monitoring, enabling continuous observation of patients' vital signs through wearable sensors. However, these networks face significant challenges in energy efficiency due to the limited power capacity of the sensor nodes. Recent research has focused on developing energy-efficient protocols and strategies to extend the operational lifespan of WBANs.

Clustering and Routing Protocols

A prominent approach to enhancing energy efficiency in WBANs is the development of clustering and routing protocols. These protocols aim to minimize energy consumption by optimizing the communication paths between sensors and the sink node. For instance, an energy-efficient clustering and cooperative routing protocol was proposed, which utilizes clustering to reduce redundant data transmission and cooperative routing to balance the energy load among node [5]. This approach helps in maintaining network stability and prolonging the network's lifetime.

Reinforcement Learning and Fuzzy Logic: Integrating advanced algorithms like reinforcement learning and fuzzy logic into routing protocols has shown promise in improving energy efficiency. These techniques enable dynamic adaptation to network conditions, thus optimizing the routing paths based on current energy levels and network topology. A study highlighted the effectiveness of a reinforcement learning-based routing scheme combined with fuzzy logic to enhance the reliability and energy efficiency of WBANs[6]. Hybrid protocols that combine multiple strategies have also been explored. For example, a hybrid energy-efficient routing protocol uses ultra-low-power transceivers for eHealth systems, which combines clustering, multi-hop routing, and thermal-aware techniques to reduce energy consumption and manage node temperature effectively. This method ensures reliable data transmission while mitigating the risk of node failure due to overheating.

Thermal-Aware Routing: Thermal-aware routing protocols are designed to manage the heat generated by the sensor nodes, which is crucial for patient safety and sensor performance. These protocols adjust the routing paths based on the thermal state of the network to prevent hotspots and distribute the communication load evenly. Studies have demonstrated the efficacy of thermal-aware routing in maintaining a balance between energy consumption and thermal regulation [5]. **Cooperative Energy-Efficient Protocols:** Cooperative protocols leverage the cooperation between nodes to optimize energy usage. For instance, a cooperative energy-efficient and priority-based reliable routing protocol (CEPRAN) employs network coding and prioritizes critical health data to ensure timely and energy-efficient delivery. This method enhances the overall network performance by reducing the energy expenditure associated with data retransmission and ensuring reliable communication.

We have compared our method with SIMPLE and M-ATTEMPT protocols. Following section gives a brief overview of these protocols.

SIMPLE Protocol for Wireless Body Sensor Area Networks (WBSAN)[7]

Particularly developed for WBSANs, the SIMPLE protocol addresses the issues of throughput, dependability, and energy efficiency. By streamlining data transmission routes and cutting down on energy usage, this protocol seeks to improve WBSAN performance—two factors that are vital to the robustness and efficiency of these networks in applications involving monitoring their health. **Multi-hop Communication**: SIMPLE employs multi-hop communication, where data from sensor nodes is transmitted through intermediate nodes before reaching the sink node. This approach helps in reducing the energy burden on individual nodes, particularly those far from the sink node. **Link Quality Assessment**: The protocol continuously assesses the quality of links between nodes to select the most reliable paths for data transmission. This dynamic assessment helps in maintaining stable and efficient communication within the network. **Energy Efficiency**: By optimizing the routing paths and employing multi-hop communication, SIMPLE significantly reduces the overall energy consumption of the network. Nodes with higher energy levels are preferred as relay nodes, balancing the energy usage across the network and prolonging the network's operational life. **Increased Throughput**: SIMPLE aims to increase the data throughput by ensuring that only the best-quality links are used for

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communication. This reduces the likelihood of data retransmission due to poor link quality, thus improving the network's efficiency and data delivery rate. **Stability Period Enhancement**: The protocol enhances the stability period of the network, which is the time duration during which all nodes remain functional and participate in data communication. By effectively managing energy resources and optimizing communication paths, SIMPLE ensures a longer stability period. **Low Complexity and Scalability**: SIMPLE is designed to be low in complexity, making it suitable for deployment in resource-constrained WBSAN environments. Additionally, it is scalable, allowing it to adapt to networks of varying sizes without significant changes to the protocol. The implementation of the SIMPLE protocol involves the following steps:

- **Initialization**: Nodes are initialized with their respective energy levels and positions. The sink node broadcasts a control packet to initialize the network.
- **Route Discovery**: Nodes assess link quality based on received signal strength and other metrics. The best paths are selected for data transmission.
- **Data Transmission**: Data is transmitted using the selected multi-hop paths. Nodes periodically reassess link quality to adapt to changing network conditions.
- **Energy Management**: The protocol ensures that nodes with higher energy levels are preferentially selected as relay nodes, distributing the energy consumption evenly across the network.

M-ATTEMPT Protocol for (WBASAN)[8]**:**

(WBASANs) can function better thanks to the M-ATTEMPT (Mobile - Adaptive Threshold-based Temperature-aware Energy-efficient Multi-hop Protocol) protocol. The primary goals of this protocol are to handle the crucial issues of temperature control, dependability, and energy efficiency, all of which are necessary for WBASANs to operate effectively in healthcare applications that monitor. **Adaptive Thresholds**: M-ATTEMPT employs adaptive thresholds for temperature and energy levels to make routing decisions. By dynamically adjusting these thresholds based on current network conditions, the protocol ensures efficient use of resources and prolongs the network lifetime. **Temperature Awareness**: A core feature of M-ATTEMPT is its temperature-aware routing mechanism. This feature helps in preventing the overheating of sensor nodes by avoiding routing through nodes that have higher temperatures. This is crucial for maintaining the safety and reliability of WBASANs, especially when deployed on human bodies. **Energy Efficiency**: The protocol prioritizes energy efficiency by selecting routes that minimize energy consumption. It achieves this by considering the residual energy of nodes and the energy cost of potential routes. Nodes with higher energy levels are preferred for data forwarding, balancing the energy load across the network. **Multi-hop Communication**:M-ATTEMPT utilizes multi-hop communication to extend the network's operational range and reduce the energy burden on individual nodes. This approach helps in distributing the communication load and ensures that data is relayed efficiently to the sink node. **Mobility Management**: The protocol is designed to handle node mobility, which is common in WBASAN environments due to patient movements. M-ATTEMPT adapts to changes in network topology caused by node mobility, ensuring stable and reliable communication.

The implementation of M-ATTEMPT involves the following steps:

- **Network Initialization**: Nodes initialize their energy levels and temperature status. The sink node broadcasts control packets to set up the initial network topology.
- **Adaptive Threshold Setting**: Nodes dynamically adjust their temperature and energy thresholds based on current conditions. This adaptive mechanism ensures that the network can respond to changes effectively.
- **Route Discovery and Selection**: The protocol assesses potential routes based on energy and temperature criteria. Routes that minimize energy consumption and avoid high-temperature nodes are selected.
- **Data Transmission**: Data is transmitted through the selected multi-hop paths. Nodes periodically update their status and adjust thresholds to maintain optimal performance.
- **Mobility Adaptation**: M-ATTEMPT continuously monitors node mobility and adjusts routes as necessary to accommodate changes in network topology.

III. PROPOSED METHOD

ENERGY ENABLED WBAN (EEWBAN)

The proposed method for an energy-efficient Wireless Body Area Network (WBAN) focuses on strategic node placement, multi-hop communication, redundant data removal, and efficient relay node selection. This approach aims to enhance energy efficiency, reliability, and overall network performance.

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Node Placement

1. **Sink Node Placement**:
    a. The sink node is strategically placed near the waist. This central location minimizes the average distance between sensor nodes and the sink, reducing the energy required for data transmission.
2. **Vital Data Sensors**:
    a. Sensors that monitor critical health metrics, such as sugar levels and heart rate (ECG), are placed close to the sink node. This proximity ensures rapid and reliable data transmission for essential health monitoring.
3. **Redundant Nodes**:
    a. Redundant sensor nodes are positioned near the knee and elbow. These nodes act as backups to ensure continuous data monitoring even if some nodes fail or experience connectivity issues.

Multi-hop Communication

- **Balanced Energy Consumption**:
  Multi-hop communication is utilized to distribute the energy load among nodes. Instead of direct communication with the sink, nodes transmit data through intermediate nodes, reducing the energy consumption of individual nodes and extending the network's lifespan.

Redundant Data Removal

- **Message Identifier**:
  To eliminate redundant data transmission, a message identifier is used. Each data packet is assigned a unique identifier, allowing the network to detect and discard duplicate messages, thereby conserving energy and reducing unnecessary data traffic.

Relay Node Selection

- **Energy and Distance Criteria**:
  Relay nodes are selected based on their residual energy levels and their distance from the sink node. Nodes with higher energy levels and optimal distance are preferred as relay nodes, ensuring efficient data transmission and balanced energy usage across the network.

Implementation Steps

1. **Network Initialization**:
    a. Initialize nodes with their respective energy levels and locations. The sink node broadcasts a control packet to establish initial network topology.
2. **Data Collection**:
    a. Sensor nodes collect vital health data and assign unique identifiers to each data packet.
3. **Multi-hop Routing**:
    a. Nodes determine the optimal multi-hop paths based on energy and distance criteria. Data packets are transmitted through intermediate relay nodes to the sink.
4. **Redundant Data Check**:
    a. Nodes check incoming data packets for duplicate identifiers. Redundant data is discarded to conserve energy.
5. **Relay Node Adjustment**:
    a. Nodes periodically reassess their energy levels and distances. The network dynamically adjusts relay nodes to maintain optimal performance.

Expected Benefits

- **Enhanced Energy Efficiency**:
  By minimizing direct communication and utilizing multi-hop paths, the network conserves energy, extending the operational life of sensor nodes.
- **Reliability**:
  Redundant nodes and adaptive relay node selection ensure continuous monitoring and reliable data transmission even in dynamic body movements.
- **Reduced Data Traffic**:
  Redundant data removal reduces unnecessary data transmission, optimizing network bandwidth and energy usage.

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IV. SIMULATION ENVIORNMENT & RESULTS

When evaluating Wireless Body Area Networks (WBAN) protocols, several key metrics are essential for assessing performance. Among these, network lifetime, residual energy, and throughput are critical for determining the efficiency and effectiveness of a given protocol. Here's a detailed comparison based on these metrics:

1. Network Lifetime

Network lifetime refers to the duration during which all nodes in the network remain operational and capable of performing their tasks. It is a crucial metric as it directly impacts the usability and reliability of the WBAN for continuous health monitoring.

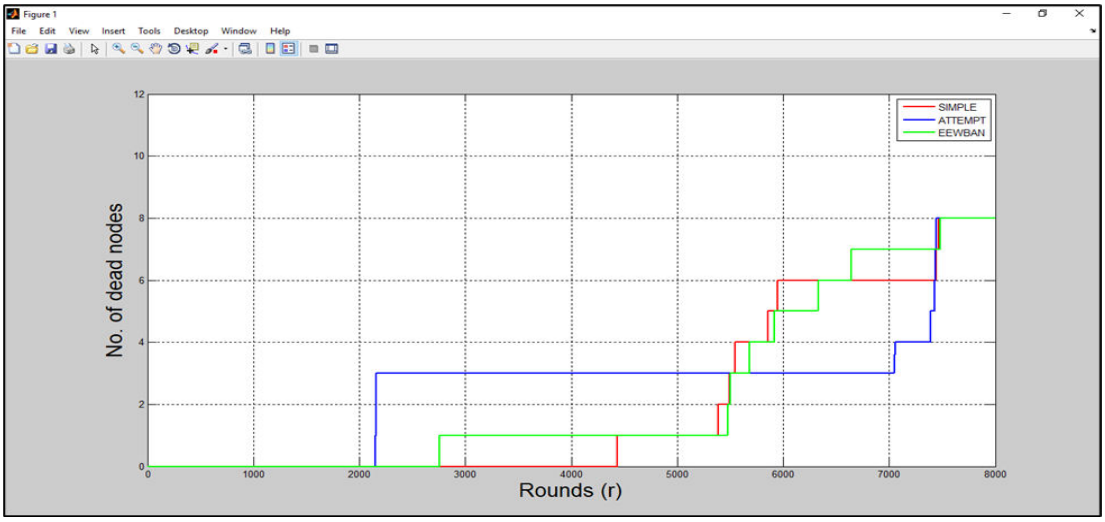

Figure 1: Comparative Analysis of Network life of three protocols.

The EEWBAN protocol enhances network lifetime by utilizing multi-hop communication and dynamically selecting routes based on link quality and energy levels, thus balancing the energy consumption among nodes. It ensures that nodes do not overheat and that energy is conserved by selecting optimal routes based on current network conditions.

2. Residual Energy

Residual energy is the remaining energy in the sensor nodes after a certain period of network operation. Efficient protocols aim to maximize the residual energy to prolong network functionality.

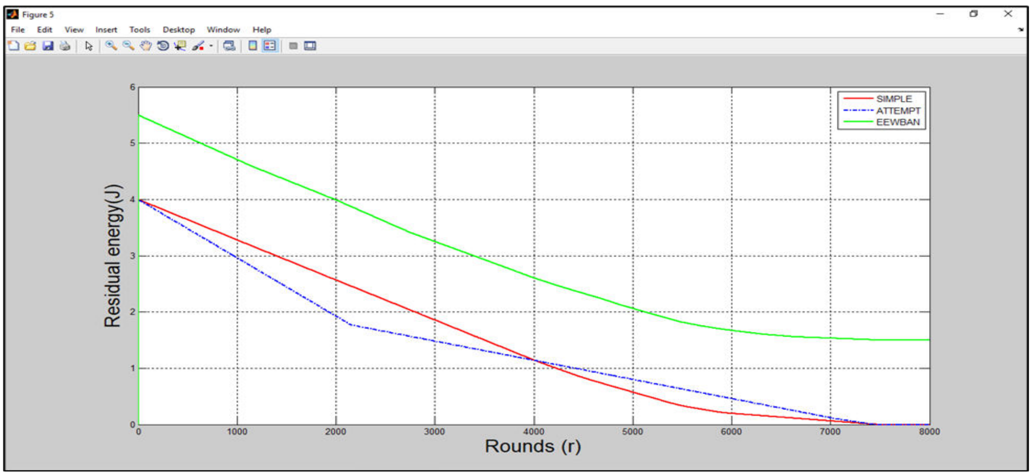

Figure 2: Comparative Analysis of Residual Energy of Network for three protocols.

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By distributing the communication load evenly through multi-hop routing and avoiding direct transmission to the sink, EEWBAN helps in maintaining higher residual energy levels across nodes. It ensures that nodes with higher energy levels are chosen for routing, preserving energy across the network and maintaining higher residual energy over time.

3. Throughput

Throughput measures the successful delivery rate of data packets within the network. Higher throughput indicates more efficient data transmission and network performance.

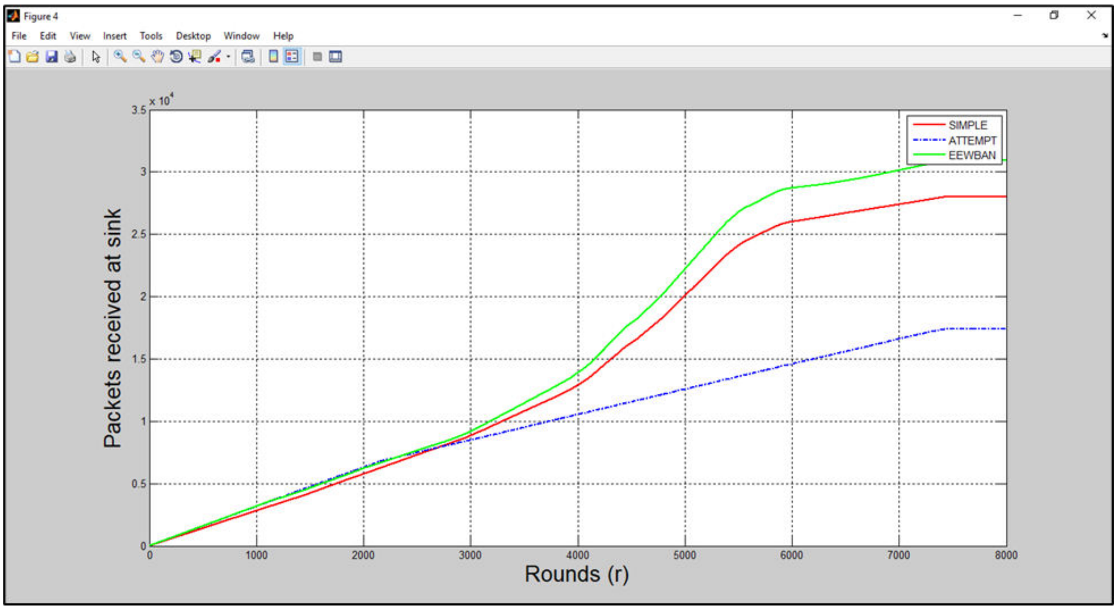

Figure 3: Comparative Analysis of Throughput of Network for three protocols.

The EEWBAN achieves higher throughput by reducing packet loss through reliable multi-hop paths and dynamic link quality assessment, ensuring stable and efficient communication. It maintains high throughput by dynamically adapting to changes in network conditions and ensuring that nodes with optimal energy and temperature levels are used for data transmission, thus reducing packet loss and maintaining efficient communication.

V. CONCLUSION

The EEWBAN protocol focuses on strategic node placement, multi-hop communication, and redundant data removal to enhance network lifetime. The sink node is placed near the waist to minimize the average distance for data transmission, and redundant nodes are placed near the knee and elbow to ensure continuous monitoring. EEWBAN achieves high residual energy by implementing multi-hop communication to balance energy consumption and employing message identifiers to eliminate redundant data transmission. Relay nodes are chosen based on their energy levels and distance from the sink, optimizing energy use. The protocol ensures high throughput by reducing redundant data transmission and selecting relay nodes with optimal energy and distance metrics, which enhances the efficiency of data transmission paths.

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