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Energy Optimization in Wireless Body Sensor Networks: A Review

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Abstract— ***This paper provides a comprehensive review of en-ergy optimization techniques for Wireless Body Sensor Networks (WBSNs), a crucial technology for revolutionizing healthcare monitoring. The critical issue of energy efficiency in WBSNs is addressed, as it directly impacts the sustainability and practicality of these networks. A systematic literature review is conducted, examining the interplay of low-power hardware, energy-aware routing protocols, data management techniques, and duty cycling strategies. The potential of metaheuristic algorithms in optimiz-ing WBSN energy consumption is also explored. The review highlights the importance of a multifaceted approach to energy optimization. Advancements in low-power hardware design, cou-pled with intelligent routing protocols, demonstrate significant improvements in energy efficiency. Data compression techniques and in-network processing help reduce data traffic, further enhancing network longevity. Effective duty cycling strategies are essential for balancing energy savings with responsiveness, with adaptive techniques showing particular promise. Energy optimization is an ongoing challenge for the widespread adoption of WBSNs in healthcare. This review emphasizes the intercon-nectedness of diverse strategies and identifies promising areas for future research, including the integration of novel low-power technologies, development of hybrid optimization approaches, refinement of metaheuristic algorithms for WBSN constraints, and an increased focus on energy optimization solutions with embedded security mechanisms.***

Index Terms— ***Wireless Body Sensor Networks, WBSN, Energy Efficiency, Healthcare Monitoring, Metaheuristic algorithms, Energy-aware routing protocols***

I. INTRODUCTION

Wireless Body Sensor Networks (WBSNs) are gaining traction in healthcare monitoring and sports performance analysis. These networks, comprised of miniature sensors transmitting data wirelessly, have revolutionized healthcare by integrating patient data processing and communication into traditional settings. Their architecture, topology, communication protocols, and low-power Medium Access Control (MAC) mechanisms are crucial for optimizing energy efficiency, a critical challenge for WBSNs due to their limited battery life [1].

WBSNs hold immense potential for applications beyond healthcare, including entertainment, gaming, and military fields. Energy efficiency remains paramount as WBSN device energy consumption primarily stems from sensing and wire-less communication. Optimizing communication protocols and exploring alternative energy harvesting methods are crucial to extending battery life and achieving sustainable network operations. Therefore, minimizing communication-related energy consumption, utilizing environmentally friendly energy sources, and optimizing network topologies are essential to maximizing WBSN sustainability.

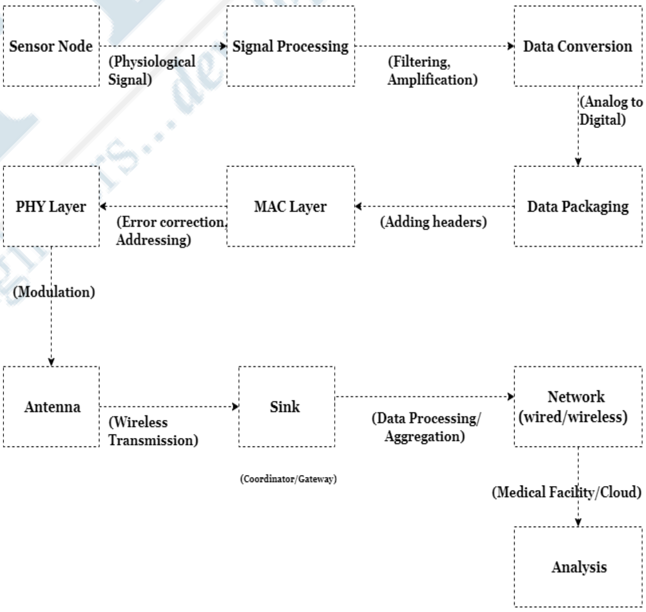

Fig. 1: A WBSN Architecture

II. LITERATURE REVIEW

Wireless Body Sensor Networks (WBSNs) are a technology that allows for remote physiological monitoring of patients without the use of wired connections. WBSNs use lightweight sensors to collect data from the human body, which is then transmitted via the network for analysis and decision-making[2]. These networks have the potential to enhance patient monitoring systems in terms of data accuracy, reliability, routing, and channel access. The design and performance analysis of WBSNs, specifically the channel modeling between wearable wireless sensors, is an important aspect of this technology. WBSNs have applications in the healthcare do-main, improving the intelligence and capabilities of healthcare systems [3]. However, concerns about the security of patient data in WBSNs remain, and research has proposed strategies for protecting patient-provider communications using hybrid cryptographic architectures [4]. Overall, WBSNs have the potential to revolutionize healthcare by enabling continuous health monitoring and facilitating timely decision-making for patient care.

Existing challenges in wireless body sensor network (WBSN) energy efficiency include limited hardware resources and en-ergy on tiny body sensors, which cannot ensure practical life-time of the sensing system. Power supply lifetime of WBSN should match that of sensor node lifetime, and researchers have explored various energy harvesting methods, with elec-tromagnetic sources being the most promising [5]. Distributed energy measurements in WSNs are challenging due to the large number of nodes and complex communication paths [6]. Energy efficiency mechanisms are crucial for extending the network lifetime, while fault tolerance ensures normal operation in the event of failure [7]. Energy management is a significant challenge in WBSNs, and cluster-based architec-tures with energy-aware rotation of cluster head roles can help distribute energy consumption evenly and prolong network lifetime [8].

Previous research on energy optimization in wireless body sensor networks (WBSNs) has focused on various approaches and techniques to address the energy challenges in WBSNs. These research efforts aim to improve energy efficiency and extend the lifespan of resource-constrained sensor nodes in WBSNs [9]. Optimization strategies such as particle swarm optimization, ant colony optimization and Whale Optimization Algorithm have been explored to minimize energy consump-tion and maximize network lifespan [10][11]. Additionally, studies have categorized and reviewed existing energy opti-mization schemes in WBSNs, highlighting their strengths and weaknesses. The research community has also emphasized the need for optimal energy optimization strategies, includ-ing radio optimization schemes, data reduction schemes, and sleep/wake-up policies, among others[12].

The paper “Power minimization of WBSN using adaptive rout-ing protocol” addresses the critical issue of energy efficiency in Wireless Body Sensor Networks (WBSN) [13]. By propos-ing an adaptive routing algorithm based on ant optimization techniques, the authors aim to distribute energy consumption effectively among nodes, thereby extending the network’s lifespan and minimizing energy usage. A comparative analysis with the conventional LEACH routing protocol demonstrates the efficiency of the proposed algorithm in enhancing node longevity and reducing energy consumption. Overall, previous research in this area has aimed to develop optimized solutions for energy challenges in WBSNs, with the goal of improving energy efficiency and prolonging network lifespan.

III. DIFFERENT APPROACHES

A. Low-Power Hardware Technologies

When selecting low-power components for Wireless Body Sensor Networks, factors such as power consumption, relia-bility of data transmission, and network security are crucial [14]. Error correction codes like Reed Solomon can enhance reliability and reduce energy consumption in WBSNs [15]. To address challenges including energy consumption, power supply, performance, and installation cost various solutions have been proposed. These include the use of renewable en-ergy sources like solar cells to power nodes improving lifetime and reducing costs, development of low-power VLSI designs to minimize overheating issues, efficient routing algorithms based on ant optimization techniques to distribute energy efficiently on nodes extending their life cycle, and proper soft-ware architectures like ZigBee contributing to cost-effective systems [16]. Low Power Listening solutions significantly impact overall energy reduction in WBSNs by focusing on lowering energy usage during the listening phase through a channel check mechanism but with highlighted limitations that require further improvements such as multi-parameter dynamic duty cycles.

B. Energy-Aware Routing

Different approaches to energy-aware routing in wireless body sensor networks include the use of graph-based energy optimized dynamic routing (GEODR) mechanism [17], a hybrid fuzzy with a modified Rider Optimization Algorithm (MROA) [18], and evaluation of average energy consumption for various protocols such as Energy Efficient Clustering Scheme and Stable Election Protocol [19]. These approaches aim to balance energy consumption minimization and throughput enhancement, address dynamic changes in network topology, and optimize CH selection and routing. The GEODR mechanism employs a clustering scheme based on graph theory and selects cluster heads based on residual energy, distance between CHs, and sink node mobility. The hybrid fuzzy with MROA approach uses optimization factors like distance, latency, and power consumption to achieve CH selection and routing.

Energy-aware routing protocols offer significant advantages in WBSNs compared to conventional protocols by extending network lifetime and improving overall energy efficiency. Conventional protocols often prioritize factors like latency, throughput, or path reliability, leading to higher energy expenditure. While the former ones may be more complex, the benefits outweigh the costs for applications where battery life is crucial. Choosing the best protocol depends on factors like network size, topology, data type, and energy requirements.

C. Advanced Energy Conservation Strategies

1) Data Aggregation Techniques: Data aggregation techniques for Wireless Body Sensor Network (WBSN) healthcare include the use of Fire Bug Swarm Optimal Cluster-Based Data Aggregation (FSOCDA) [20], One Time Pad-Quasi (OTP-Q) and Diffie-Hellman key exchange algorithms for en-cryption and mutual authentication [21]. FSOCDA is a method that enhances bandwidth utilization, network lifetime, and minimizes data transmission in WBSNs. OTP-Q and Diffie-Hellman algorithms are used in a secure WBSN architecture to reduce CPU cycles and computational cost, ensuring mutual authentication and privacy preservation. These techniques aim to address the challenges of data transmission in WBSN healthcare, such as limited resources, privacy concerns, and security attacks.

2) Data Compression Techniques: Data compression techniques for Wireless Body Sensor Networks (WBSN) in health-care have been explored in several papers. Hanoune and Lysmos present various data compression mechanisms, includ-ing forecast compression, sampling compression, scheduling compression, and distributed compression, using lossless data compression algorithms such as LZ4, LZO, and Bzip2 [22]. Sankar, Abinaya, Jeez, and Sunju propose the L-LEACH routing algorithm for energy-efficient and faster data transmission in wireless networks [23]. Kim, Jung, Lee, and Kim propose an ECG compression algorithm based on Discrete Wavelet lifting Transform (DWLT) and Multistage Vector Quantization (MSVQ) for ECG monitoring systems over Zigbee networks. Das and Rahman propose a novel compression technique through encoding to reduce the size of medical data before transmission in slow-speed networks [24]. These papers pro-vide insights into different approaches for data compression in WBSN for healthcare applications.

Data compression is crucial for the performance of Wireless Body Sensor Network healthcare. It reduces data size before transmission, thereby reducing memory and storage space requirements on sensor nodes and extending network lifetime. Data compression also directly reduces power consumption of a sensor node, contributing to overall energy efficiency and enhancing network performance. Specifically designed data compression algorithms can outperform existing ones when dealing with large entropy datasets, resulting in better compression performance. Overall, data compression improves network efficiency, reduces power consumption, and enhances system performance.

D. Duty Cycling Techniques

Duty cycling is a fundamental mechanism in the design of Wireless Sensor Networks (WSNs) to conserve energy. Various approaches exist, differing in hardware needs, com-plexity, and impact on aspects like synchronization, topology dependence, and delay. Some achieve ultra-low cycles (0.1%), while others integrate with energy harvesting for extended network life. [25] WBSNs utilize two primary duty cycling approaches:

- Topology control: Selects active nodes to maintain net-work connectivity while others sleep.
- Power management: Cycles individual active nodes be-tween active and sleep states to save energy during inactivity.

Duty cycling often serves as the underlying MAC protocol for routing solutions in WSNs, balancing energy efficiency and communication reliability. Dynamic adjustments based on network conditions can further optimize delay and energy consumption. A receiver-initiated MAC protocol called C-MAC has been proposed for concurrent traffic in WBSNs, which utilizes asynchronous duty cycling to avoid collisions and reduce energy consumption.[26]

1) Adaptive Duty Cycling Algorithms: Adaptive duty cycling algorithms (ADCAs) are crucial for improved WBSN healthcare performance. ADCAs address power constraints by optimizing sleep schedules and network coding, enhancing energy efficiency, reliability, and data accuracy. One approach is the Gait Adaptive Duty Cycle-Human Activity Recognition (GADC-HAR) algorithm, which incorporates energy-efficient and reliable network coding and optimizes sleep/wake timers for synchronization between controller and relay nodes[27]. Another approach is the joint MAC and routing mechanism, which includes adaptive sleep-wake scheduling based on nodes' utilization and energy level, as well as prioritizing channels based on competing nodes and channel utilization. This mechanism improves power consumption, end-to-end delay, and packet delivery ratio[28]. Adaptive scheduling and the use of an ADB protocol can help regulate and control duty cycles, manage traffic, and improve network efficiency and performance.

WBSNs face challenges such as limited resources, noise and interference, and sensitive and voluminous data. Therefore, adaptive duty cycling algorithms need to ensure a trade-off between energy efficiency and meeting the accuracy, delay, and quality of service requirements of healthcare applications. Future research will focus on optimizing ADCAs for WBSN healthcare, considering these trade-offs and addressing challenges like limited resources, noise, and data security.

IV. DIFFERENT META-HEURISTIC ALGORITHM

Metaheuristics are frameworks for creating problem-solving algorithms [29]. They provide general guidelines rather than strict, step-by-step procedures for a specific problem.

Metaheuristic algorithms iteratively refine solutions through exploration and exploitation. Exploration expands the search space, seeking out new and potentially better solutions. Exploitation then takes these promising solutions and attempts to improve them through local search. This

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balanced process, along with randomization within exploration, increases the chances of finding an optimal solution and avoids stagnation in local optima[30].

Types of Metaheuristic Algorithms Nature-inspired:

1) Evolutionary algorithms (like Genetic Algorithms): Mimic biological evolution, with processes of selection, crossover, and mutation.

2) Swarm Intelligence (like Particle Swarm Optimization, Ant Colony Optimization): Model the collective behavior of social insects or other animal groups.

Non-nature inspired:

1) Simulated Annealing: Inspired by the physical process of annealing in metallurgy.

2) Tabu Search: Employs memory structures to avoid re-visiting bad solutions and guide the search process.

TABLE I: Comparison of Metaheuristic Algorithms for WBSN Optimization

Metaheuristic Algorithm	**Working Principle**	**Strengths**	**Weaknesses**
Ant Colony Optimization (ACO)[31]	Simulates ant foraging behavior, using pheromone trails	Works well for complex optimization problems; excels at finding efficient paths	Sensitive to initial parameter settings; struggles with complex network topologies
Whale Optimization Algorithm (WOA)[32]	Inspired by the bubble-net hunting strategy of humpback whales	Good at balancing energy consumption and network lifetime	May converge slowly in large networks
Particle Swarm Optimization (PSO)[33]	Simulates the movement of a flock of birds or a school of fish searching for food	Efficient for finding optimal paths for data trans-mission	Might get stuck in local minima for complex problems
Firefly Algorithm (FA)[34]	Inspired by the flashing patterns of fireflies	Adaptable to dynamic net-works	Can be computationally expensive for large-scale problems
Bat Algorithm (BA)[35]	Models the echolocation behavior of bats searching for prey	Effective for power optimization	Might require fine-tuning parameters for specific scenarios
Simulated Annealing (SA)[36]	Inspired by the physical annealing process in metallurgy	Robust and avoids local minima	Can be slow and require careful cooling schedule design
Genetic Algorithm (GA)[37]	Inspired by natural evolution, using selection, crossover, mutation	Versatile for various optimization tasks	Often needs careful con-figuration and can be computationally intensive
Artificial Bee Colony (ABC)[38]	Simulates the foraging behavior of honey bees	Efficient for clustering and routing	Might require adjustments for specific node behaviors

V. DISCUSSION

This review highlights the inextricable link between energy optimization strategies in WBSNs and the potential for long-term, sustainable healthcare monitoring. Developments in low-power hardware components and energy-harvesting technologies lay the foundation for minimizing energy expenditure at the node level. Intelligent routing protocols, particularly those demonstrating hybrid and adaptive characteristics, are essential for establishing energy-efficient communication path-ways. Strategic data compression and in-network processing techniques reduce the volume of transmitted data, con-tributing to extended network lifespan. The value of well-constructed duty cycling mechanisms, especially those adapting to network conditions, lies in their ability to achieve an optimal balance between energy conservation and timely responsiveness. Furthermore, the exploration of metaheuristic algorithms demonstrates considerable promise in optimizing diverse WBSN parameters. By carefully tailoring algorithm selection and parameter tuning to the unique constraints of WBSNs, researchers can unlock even greater gains in energy efficiency.

VI. CONCLUSION

Energy optimization within WBSNs demands a multi-pronged strategy encompassing hardware design, routing pro-tocols, intelligent data management, and well-crafted duty cycling techniques. Progress in these areas has significantly enhanced energy efficiency, but further exploration is crucial for realizing the full potential of WBSNs in revolutionizing healthcare.

Key areas for future research include the integration of novel low-power technologies and renewable energy sources,

the development of hybrid optimization strategies tailored to WBSN constraints, the refinement of metaheuristic algorithms for dynamic WBSN environments, and most importantly, the integration of security-focused energy optimization solutions. Addressing these challenges will propel WBSNs towards re-liable, sustainable, and secure long-term health monitoring, transforming healthcare practices and patient outcomes.

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We declare that there is no conflict of interest with anybody.

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There is no subject which uses human or animal data so consent is not applicable. I promise to abide rules and regulations of my society, community and country. We give our consent in favour of publisher to publish this manuscript which can include figures, tables and details within the manuscript.

Data and Materials availability:

Research is in algorithmic in nature and no data has been used.

Author contribution:

I, Aleena Ariz, wrote this article for thesis work and Dr. T.P. Sharma reviewed and analysed the results of this article.

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