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A Comprehensive Analysis of Soft Computing Techniques for Effective Routing in WSNs

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Abstract: Wireless Sensor Networks (WSNs) are self-deploying, dynamic network architecture with extremely confined and organized nodes. Nodes in this environment have limited transmission range, processing capacity, and energy resources. Extending the network's lifetime is dependent on managing energy constraints and improving the usage of sensor node processing capabilities. Effective power management approaches are critical for attaining the objective of decreasing the consumption of energy at the individual sensor node level. Furthermore, adaptive and efficient routing systems have received significant academic interest due to their potential for improving network operation. The inclusion of Soft Computing concepts is an effective strategy for addressing the numerous issues in WSNs. Soft computing methods are well-known for their adaptability and compatibility with WSNs, which are suitable for solving essential complications. This study provides an overview of several Soft Computing-based routing models optimized for WSNs, with a focus on increasing network lifetime. Soft Computing routing models use approaches including fuzzy logic, neural networks, evolutionary algorithms, and swarm intelligence to create routing choices that maximize energy efficiency and network operating duration. These models provide potential solutions to the energy and processing limits in WSNs by intelligently adapting to changing environmental circumstances and network dynamics, thereby enhancing network lifetime and dependability.
Keywords: Network's Lifetime, Neural Networks, Routing, Soft Computing, Wireless Sensor Networks.

I. INTRODUCTION

WSNs are made up of distributed autonomous devices known as sensors or nodes that work together to sense, compute, and communicate wirelessly [1]. These nodes are severely limited in terms of power, memory, and computing capabilities, depending mostly on battery power, so the susceptibility of these sensors directly impacts the entire lifespan of WSNs [2]. Furthermore, the network's size may be changed dynamically by node additions or deletions, resulting in unexpected changes in its topological structure. WSNs have significant problems [3] in terms of battery capacity, bandwidth, and computational power. It is carping to conserve energy and total network energy to increase the network's lifetime. As a result, routing algorithms are critical in enabling long-distance and large-scale communications in WSNs [4]. Routing in WSNs varies greatly from routing in traditional fixed networks since just choosing the shortest route between the source and sink does not necessarily equal efficient routing. Sensors' limited power resources represent a fundamental problem for WSN routing methods [5]. As a result, power-aware routing algorithms are required to save WSN power and longer lifetime of the network. Considering the essential limitations of WSNs, execute routing protocols for these networks remains a complicated issue. Based on the network structure, traditional WSN routing techniques [6] are segregated into triple categories: flat-based routing [7], hierarchical-based routing [8], and location-based routing [9].

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To solve the issues posed by WSNs, researchers have gradually utilized the intelligence and flexibility of soft computing models. These paradigms excel at managing data ambiguity and uncertainty in complicated situations, making them an appealing alternative for WSN post-deployment usage. SC techniques are ideally suited to wireless sensor network needs, notably in areas such as power management, autonomous decision-making, knowledge-based routing, and node processing. The intent of this work is to examine the suggested routing protocols in WSNs that use Soft Computing paradigms. This research paper is given as follows: Section 2 presents prior works done on WSN routing. A thorough review or taxonomy of several kinds of WSN routing protocols and several Soft Computing approaches for WSN routing is presented in subdivision 3. Section 4 presents a comparative analysis whereas the problems identified are presented in Section 5. Eventually, the conclusion is in Section 6.

II. RELATED WORKS

Deep Kumar Bangotra et al. [10] developed a smart opportunistic routing protocol (IOP) using machine learning methods in their study. The fundamental goal of this protocol was to enhance both energy efficiency and network dependability by choosing relay nodes from a collection of prospective forwarder nodes. In contrast to traditional approaches, this protocol uses machine learning to intelligently choose relay candidates from the forwarder list, resulting in greater energy efficiency. Notably, when contrasted with EEOR and MDOR, the proposed approach has lower packet loss. This benefit is due to the forwarder node selection method, which works on both relay and source nodes. Importantly, the protocol guarantees that nodes located distant from the Base Station (BS) are identified as relay nodes only if they have the energy resources to perform this function properly. Dung Nguyen Quoc [11] suggested a unique hybrid fault-tolerant clustering routing protocol intended particularly for WSNs. FCGW's major goal was to enhance fault tolerance, data dependability, and energy usage in WSNs. This revolutionary protocol takes a novel method in which each Cluster Head (CH) node was described as a Gaussian integer, and these nodes are linked together to create a Gaussian network. FCGW has a significant benefit in that it uses Gaussian integers to describe CH. This method enhances node operations in a variety of ways, including node discovery, data transfer, and cluster administration expenses. However, a significant problem related to FCGW must be acknowledged: the establishment of a Gaussian network by linking distant sensor nodes inside the wireless environment. This component of the protocol involves additional packet latency, which requires careful planning in its implementation. Vipul Narayan [12] suggested a new clustering strategy by employing Particle Swarm Optimization (PSO) in combination with fuzzy logic-based routing algorithms to enhance data transmission efficiency towards the BS. The major goal of this strategy was to diminish the frequency of Route Establishment (RE) events in Sensor Nodes (SNs), hence decreasing energy consumption and increasing the network's operational lifespan. PSO was a multi-criteria optimization approach in which several particles within a swarm collaborate to enhance a fitness function, leading to quicker protocol convergence. The suggested routing approach incorporates fuzzy logic, which takes into consideration many characteristics, resulting in enhanced network performance. This novel strategy purposefully minimizes several of the RE nodes in the network. Furthermore, removing remaining nodes, considerably diminishes total energy dissipation, eventually leading to a longer network lifetime...

Regonda Nagaraju et al. [13] developed an energy-efficient and secure routing method for Internet of Things (IoT) applications in heterogeneous WSNs. With the Multipath Link Routing Protocol (MLRP), this unique system ensures the secrecy of IoT data transported across sensor nodes with changing energy levels. After establishing safe routing, the method takes a step further to enhance energy efficiency and network longevity by including the Hybrid-based Threshold Sensitive Energy Efficient Sensor Network (H-TEEN) protocol, which also has load balancing capabilities. This approach also increases data storage capacity by using the Ubiquitous Data Storage Protocol (U-DSP). In terms of network performance, the findings show that the developed MLRP-HTEEN-UDSP procedure outperforms previous protocols. Due to the hierarchical design of the CHs, the system displays low latency, continually picking routes with fewer hops and high-quality connections, guaranteeing efficient data transmission throughout the network. Mohammed Zaid Ghawy et al. [14] developed a MPSORP using an optimization strategy based on the PSO algorithm. This novel protocol aimed to choose the most energy-efficient option among the shortest routes available, prolonging the operational lifetime of wireless networks. MPSORP was created particularly for WSNs in IoT applications with large traffic volumes and network flow imbalances. One significant feature of MPSORP was its capacity to successfully tolerate link failures by using other pathways, resulting in low data loss, particularly in small-scale networks. Furthermore, MPSORP has a relatively small latency. This is due to its multipath nature, which depends on route tables to speed route finding, lowering the time necessary for connection establishment.

III. TAXONOMY OF SOFT COMPUTING TECHNIQUES FOR EFFECTIVE ROUTING IN WSNS

A. Network Structured Based Routing

The optimization of network lifetime provides a major problem because of the privacy neighbouring the energy distributions in WSNs. Some additional variables come into performance if the limited energy efficiency of battery-powered devices has a major influence on network lifetime. These considerations include the length of the data transmission line, the even distribution of the data load along the route, and the dependability of the selected path, all of which exhibit a major effect on the total WSN lifetime. In WSNs, data follows a predetermined path, beginning from the source node and moving via chosen successor nodes, repeatedly following precise selection criteria until it reaches the sink node. Routing protocols in WSNs may be classed based on either network topology or the functioning of the protocol. WSNs routing algorithms are broadly classified into three types:

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1) Flat-based routing: This routing method gives all network nodes the same responsibilities and functions. The network's nodes have no organized distribution and create both direct and indirect communication linkages with the central BS. BS is critical in handling communication with the large node population. Every node finds its neighbours and sends data using a data-centric routing strategy. Flat routing is useful due to its simplicity and lack of unneeded overhead. It enhances scalability by guaranteeing that all nodes have the same responsibilities and functions. Furthermore, it extends network lifespan by using effective multi-hop routing, which balances data load by limiting power levels at which sensor nodes communicate. Gossiping, Flooding, Directed Diffusion (DD), and Sensor Protocols for Information through Negotiation (SPIN) are flat routing protocols.

2) Hierarchical-based routing: The hierarchical-based routing protocol provides a structured method in which different nodes within the network are assigned specific roles, capabilities, and responsibilities. The network is separated into clusters, each of which is made up of a group of nodes that is led by a single node. Communication inside the network takes place largely between nodes and their cluster leaders, which subsequently transmit messages to the central sink. CH is accountable for controlling, gathering, gathering, and retransmitting data from cluster nodes to the BS. The capacity of the CH to recognize and recover from faults intelligently defines the cluster's sustainability, which ultimately decides its lifespan. The selection and assignment of CH occur regularly to optimize energy usage and extend the network's lifetime. The significant power consumption encountered by CH is one of the key difficulties addressed by this protocol. As a result, it is highly advised to rotate the cluster leader job among the nodes regularly. This rotation approach seeks to maintain uniform energy distribution throughout the network, reducing the likelihood of energy hotspots and improving overall energy efficiency. Energy saving by clustering adds greatly to the system's scalability, longevity, and overall energy efficiency. Another key advantage of hierarchical-based routing is its ability to aggregate data. This method enables the consolidation of data from cluster nodes, substantially reducing data redundancy by combining it with CH. Some instances of hierarchical-based routing are Minimum energy consumption network (MECN), Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN), Threshold sensitive Energy Efficient sensor Network protocol (TEEN), and Low-Energy Adaptive Clustering Hierarchy (LEACH).

3) Location-based routing: Location-based routing is a routing technology that controls data transfer by using the exact placements of sensor nodes inside the network. Every single node in the network is uniquely recognized by its geographical coordinates, and this location data is utilized to assess, choose, and maintain the most efficient data packet routing routes. The protocol is based on continuous distance computations between nodes and ongoing prediction of energy consumption levels, requiring recurrent information of node location information. Power management solutions are utilized to diminish energy usage and extend the network's lifetime. During times of inactivity or deactivation, some solutions entail putting certain nodes into a low-power sleep state. The efficiency of location-based routing systems is intimately related to area partitioning techniques and location information accuracy. The simplicity and enhancement of network management operations is a significant benefit of using location-based routing algorithms. Furthermore, such protocols help to diminish network control overhead, which enhances network efficiency and overall performance. Examples of Location-based routing are Greedy Perimeter Stateless Routing (GPSR) and Geographical and Energy Aware Routing (GEAR).

B. Soft Computing Techniques for Routing in WSN

The effective management of energy resources within WSNs is a crucial problem that affects network performance and overall life time. To successfully address this problem, recent research initiatives have stressed energy usage awareness and power control solutions. WSN performance and network longevity are heavily influenced by optimal routing algorithms and energy optimization. Given the limits inherent with WSNs, notably the limited energy resources of individual sensors, advanced routing solutions are required. Smart routing is required to balance energy usage across nodes, extending network life and guaranteeing proper coverage. As demonstrated in prior research, using advanced and intelligent strategies enhances the overall efficacy of wireless sensor networks Researchers investigated alternative soft computing paradigms which are shown in Figure 1, to maximize WSN routing while considering network problems, power consumption, and design and deployment. The next section of this survey article highlights current implementations of soft computing paradigms in WSN routing while taking into consideration the network's dynamic and diverse personality. The purpose of this work is to provide a practical guide for exploiting soft computing principles to enhance WSN performance and endurance.

Reinforcement learning (RL): Reinforcement learning (RL) is the SC technique that performs at enhancing system performance via simple incentive inputs for agent learning. RL is the most appropriate and feasible technique for routing in WSNs. The physical location of sensor nodes within the network, as well as their closeness to the sink node, have a substantial impact on each node's energy consumption levels. To enhance overall network performance and encourage energy conservation, every single node requires an adaptive energy consumption and optimization procedure. The Q-learning algorithm is the fundamental reason behind RL's efficacy. Q-learning excels at developing enhanced solutions for dynamic difficulties such as clustering and routing in WSNs while decreasing communication overhead and computing demands. The comprehensive contextual aspect of RL complements the properties of WSNs. Nodes may effectively optimize their power reserves and decrease system latency in a distributed way by adopting a reinforcement learning method. This method enables WSNs to function more efficiently and effectively, improving overall performance and increasing operational longevity.

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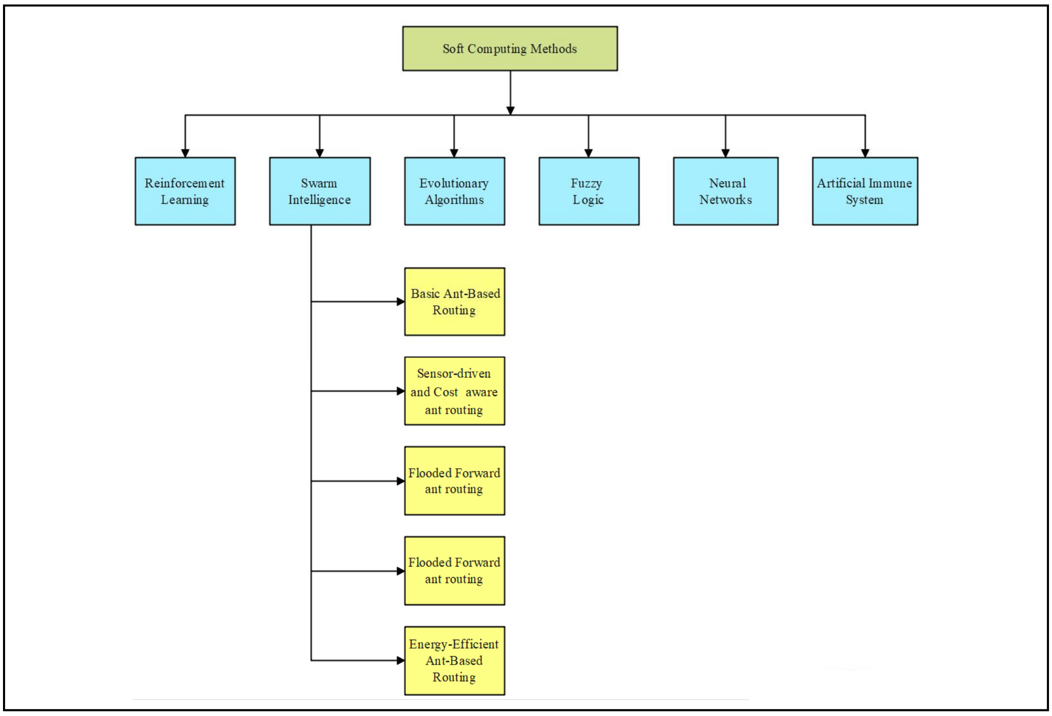

Fig. 1 Taxonomy of various soft computing techniques

4) Swarm Intelligence (SI): The concept of SC is an advanced framework including collective intelligence shown by simple entities interacting with one another and their surroundings. This paradigm is distinguished by its decentralization, in which individual agents follow simple rules and the cumulative impact of their activities determines the global system's behavior. When applied to Wireless Sensor Networks (WSNs) routing, Swarm Intelligence (SI) stands out as a particularly strong soft computing model. Because of their common environmental context, WSNs and SI have an intrinsic harmony that allows for the creation of extremely efficient routing strategies. SI provides an effective technique for regulating the collective behaviors of components in decentralized and self-deployed systems that are in sync with WSN goals. Recent advancements show that maximizing the distribution of uncontrolled systems is a unique notion within SI. Innovative routing strategies may be designed using such cutting-edge ideas to discover the shortest route inside a "ants' colony" model. For reducing energy consumption and balancing WSN's nodes power, researchers have discovered several techniques such as Sensor-driven and Cost aware ant routing (SC), Flooded Forward ant routing (FF), Basic Ant-Based Routing (BABR) algorithms, and Flooded Piggybacked ant routing (FP). The primary impression overdue these approaches is to identify the most efficient route between transmitter and receiver nodes while promoting energy-saving solutions to prolong the network's lifetime. A propagation of pheromone trails between nodes along the transmission channel is based on assessing the energy state of surrounding nodes and the concentration of pheromone trails along the connections between these nodes. Following successful data transfer, a reverse travel along the same established route is performed to record the number of nodes visited and the amount of energy spent. This procedure iterates through many trials, eventually resulting in the building of a routing hierarchy with energy-optimized branches.

5) Evolutionary Algorithm (EA): SC is an AI approach to computational optimization methods that focuses on population-based heuristics. Among these algorithms, the Genetic Algorithm (GA) is one of the greatest well-known EA, deriving influence from natural evolution principles. Despite their popularity, EAs such as GAs [15] have not consistently exhibited optimum performance in WSN routing situations. Energy consumption at individual nodes becomes a crucial aspect of WSNs because the main goal is to optimize network longevity.

6) The main problem is to choose an optimum routing between the source and sink nodes. To do this, a cost function must be computed for each alternative route between the source and sink. This cost function is a significant statistic for determining the shortest and most efficient approach. The capacity of EA, especially GAs, to solve unconstrained issues and discover optimum pathways between nodes based on restricted functions is their strength. However, depending on the exact features and limits of the network, their efficacy in WSN routing may vary, making it critical to investigate alternate ways and fine-tune these algorithms to better meet the unique problems given by WSNs.

7) Fuzzy Logic (FL): The soft computing concept is a flexible mathematical and computational framework meant to deal with data's inherent fuzziness and uncertainty. Specialized decision-making procedures are required in the configuration of WSNs, which often operate in unpredictable conditions with limited data availability. WSNs need adaptive and fine-tuned routing strategies to enhance overall network lifetime. By relieving WSNs of the complexity of rigorous mathematical modeling and giving them extraordinary flexibility to manage uncertainties and imprecisions throughout their operational lifetime, fuzzy logic provides a beneficial solution.

8) Fuzzy logic is especially well-suited for addressing critical tradeoffs in WSNs, such as the delicate balance between minimizing energy consumption and selecting the optimal transmission route, deciding between multi-hop and direct communication strategies, and managing the computation-communication trade off. WSNs acquire the capacity to make nuanced judgments that account for the ambiguity and unpredictability of real-world data by using fuzzy logic, hence boosting their overall efficiency and efficacy.

9) Neural Network (NN): The SC is a trainable arithmetic system capable of mapping complicated interactions between inputs and outputs across several contexts utilizing supervised learning approaches. When applied to WSNs, using the neural network model gives a comprehensive understanding of WSN operations. The structural similarities between ANNs and sensor nodes in WSNs, as well as their connection patterns, provide a striking parallel between the two. As a result, substituting standard signal processing methods in WSNs with ANNs may result in more efficient implementations and diminished resource use. ANN has shown amazing compatibility with WSNs, thus contributing to their survival. It excels in predicting and reducing energy consumption at sensor nodes, hence minimizing the energy needed for each route. While clustering plays a significant part in increasing network lifespan, it is also critical to minimize energy usage while increasing the scalability of sensor networks. To effectively minimize energy consumption, achieving scalable sensor networks by pre-assignment and selection of CHs may be supplemented by cluster-based routing. ANN-powered sensing nodes can be developed with a series of power measurements for diminishing energy consumption, but ANNs are simple and their compatibility with WSN routing contains numerous difficulties. ANNs need an offline learning phase and multiple computations, which may not be in sync with the dynamic and constantly changing nature of WSN characteristics and topologies.

10) Artificial Immune System (AIS): The SC is based on the computational replication of human biological capabilities, mimicking intelligent human behaviours to accomplish computerized tasks and difficult issues. While AIS have not previously shown substantial compatibility in the field of WSN routing, new advancements have started to highlight its potential, notably in the context of clustering and CH selection. Historically, WSN routing and clustering depended heavily on a set number of clusters inside the network design. However, AIS has emerged as a promising but neglected study field. Even though just a few articles have looked into its implementation, these results have begun to indicate its efficacy, especially in the context of clustering in WSNs. As a result, AIS might constitute a novel path for future research and development in the area of WSN clustering and routing, with untapped potential for enhanced network performance and efficiency.

IV. COMPARATIVE ANALYSIS

TABLE I Comparative Analysis

Author	Methods	Advantages	Limitations
Biswa Mohan Sahoo et al [16]	A GAPSO-H is proposed for CH selection and optimizing sink mobility to complete optimum network performance.	The inclusion of Energy Consumption Rate (ECR) components inside the fitness function utilized in GAPSO-H is credited with the increase in network longevity. Furthermore, increasing the number of surrounding nodes results in a considerable decrease in the average distance mid CH and nodes.	GAPSO-H protocol assumes network energy reduction during data transmission; therefore, it is critical to monitor how the network's residual energy reacts as the No. of rounds boosts.
WAN-KYU YUN AND SANG-JO YOO [17]	A Q-learning-based data aggregation-aware energy-efficient routing (Q-DAEER) algorithm	The Q-DAEER algorithm suggests rewards from surrounding nodes that consider both energy levels and data aggregation degree, allowing nodes to choose the most efficient route dynamically. The results show that the suggested algorithm outperforms traditional approaches consistently, delivering more optimum pathways that enhance both energy consumption and data aggregation efficiency.	-
Liangrui Tang et al [18]	An Energy Efficient and Reliable Routing Algorithm based on DS evidence	The DS-EERA consumes the least amount of energy while properly managing energy use, resulting in the longest network	As the network size grows, it is clear that the ANH curve follows an increasing trend. DS-EERA, on the other hand,

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	theory(DS-EERA)	lifespan.	constantly maintains the lowest place on the curve. This is due to the algorithm's focus on increasing the "energy transmission ratio," which prioritizes using the shortest route to diminish the number of hops.
Lalit Kumar Tyagi et al [19]	Energy Efficient Routing Protocol using Next CH Selection Process in Two-Level Hierarchy For WSN	The use of multi hop schemes and advanced NCH selection techniques has enhanced not only packet delivery within the network but also the stability of CHs in the protocol, resulting in a significantly enhanced network lifetime when compared to the SEP protocol.	However, this study failed to place a high value on node density as well as communication quality.
SARA NASIRIAN [20]	A Joint Sector Shape and Minimum Spanning Tree-Based Clustering Scheme for Energy Efficient Routing in WSNs	Reducing communication distances between nodes, eliminating reverse data flow from the BS, evenly distributing energy consumption among network nodes, and preventing hotspots are all critical components of Pizzza's energy-saving mechanism, which ultimately extends network lifetime by reducing energy consumption	However, its usefulness in small-scale networks has been proven, and the necessity for large-scale WSNs is evident in the current environment.

V. PROBLEM STATEMENT

The GAPSO-H protocol assumes network energy reduction during data transmission; therefore, it is critical to monitor how the network's residual energy reacts as the number of rounds increases. However, a significant problem related to FCGW must be acknowledged: the establishment of a Gaussian network by linking distant sensor nodes inside the wireless environment. This component of the protocol involves additional packet latency, which requires careful planning in its implementation. The protocol guarantees that nodes located distant from the BS are identified as relay nodes only if they have the energy resources to perform this function properly.

VI. CONCLUSION

The field of wireless sensor networks (WSNs) faces multiple challenging problems, with routing at the core of ongoing developments and evaluation. This study attempts to give a complete assessment highlighting the most recent achievements in WSN routing, with a special focus on the integration of SC techniques. The incorporation of SC techniques into WSNs brings in a time labelled by energy-efficient solutions that exhibit extraordinary compatibility with the dynamic and sometimes unforeseen variations that WSNs face in their operating environments. Soft computing, known for its flexibility and proficiency in processing uncertain and imprecise data, has great potential for resolving the long-standing energy conservation challenge that has plagued WSNs. The many researchers in the WSN field are likely to use the SC techniques capabilities not only to augment and durability of entire performance in SNs. But it also opens the door for novel applications in various domains such as healthcare, industrial automation, monitoring, smart cities, and so on. In the Future, the hybrid Bio-inspired computing paradigms are required to be utilized in further research for solving WSNs optimization.

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