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Energy-Efficient Cluster Head Selection Protocol in WSNS using Meta-Heuristic Approach

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ABSTRACT: A significant amount of focus has been placed by the research community over the course of the last ten years on the topic of energy-effective data routing inside wireless sensor networks (WSNs). Also, WSNs have left their mark in a variety of domains; nevertheless, sensor nodes (SNs) are powered utilising batteries and have a limited lifespan. Therefore, the primary aim during the process of building the routing protocols (RPs) is to drop the total energy utilised while also boosting the network's longevity. The chief purpose of the investigation is to carry out a study on the energy-effective cluster head (CH) selection protocol in WSNs utilising the meta-heuristic approach. The purpose of this review research was to conduct an exhaustive assessment of RPs with the primary objective of extending the network's lifespan. Studies conducted between the years 2016 and 2024 were the primary focus of this research. Given the findings of this research, because of the constrained resources of sensor nodes in wireless sensor networks and scenarios wherein recharging or supplanting the battery cannot happen easily, it is vital to create and execute energy-effective strategies in order to optimize the chief functional characteristics. This is because charging or swapping the battery is not feasible. In spite of the fact that clustering is widely regarded as the most prominent method for extending the lifespan expectancy inside WSNs, the procedure of selecting CHs to improve the lifespan of the network yet remains a hurdle. Continuous research has been conducted on the development of effective CH determination procedures, data procurement algorithms, and routing optimization algorithms to conjure a solution to this problem.

Keywords: Wireless sensor networks, IoT, network organization, clustering protocols, Cluster Head Selection Protocol, energy efficiency, Meta-Heuristic Approach

INTRODUCTION

A WSN is a collaborative system including small, wireless, battery-powered nodes referred to as SNs and central nodes known as Base Stations (BS) [1]. A WSN consists of hundreds or even thousands of minuscule sensors with wireless communication modules for transmitting data to a system [2]. SNs are limited in memory storage, processing capability, bandwidth, and battery due to resource constraints. SNs are commonly utilized in distant, inaccessible, and occasionally dangerous environments as battlefields or even borders for military purposes, or implanted within the human body for medicinal purposes. Recharging or replacing SNs' batteries can be exceedingly challenging, expensive, and sometimes not feasible. Optimizing energy utilisation and prolonging WSN lifespan has been a primary focus of the research community for many years. Moreover, many WSN applications necessitate deploying a large count of nodes (i.e., hundreds or even thousands of SNs) to accomplish their main objective [3].

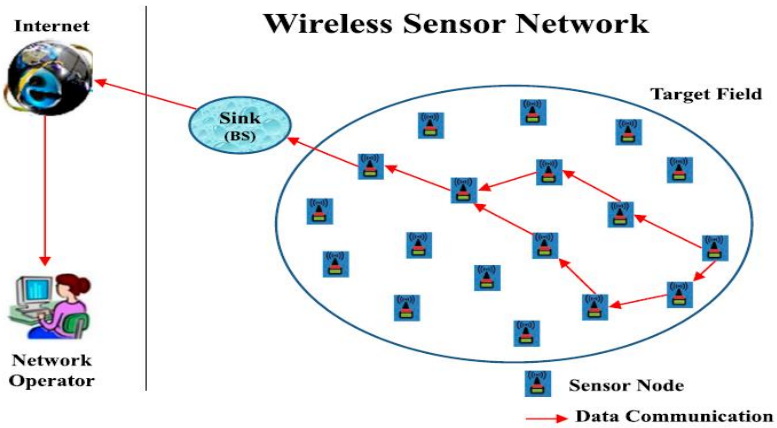

Figure 1: Basic WSN Architecture [4]

Scalability, which may be described as the network's capability to cope and perform under a large or increased node count while preserving the network's performance, is related to the management of such a big and dense deployment.Scalability helps ensure that the network continues to function effectively. Because the transmission power is positively relative to the transmission range, which is probable to be large in a flat topology, wherein SNs directly broadcast to the BS(s), trusting a flat physical topology is not a viable option for ensuring scalability. The transceiver, also known as the transmitter/receiver circuit, happens to be the constituent of a mobile network that consumes the most energy [5]. As a result, this is an ineffective method of operation.

Researchers utilized topology management approaches to create an optimum virtual topology within the WSN. The primary technique is clustering, as described by [6],[7]. This method involves partitioning the network into distinct groups, wherein every group has a specified Cluster Head (CH) node. Community hosts acquire data from their members and transmit it right to the base station. CHs may engage in additional responsibilities including consolidating the gathered data or coordinating media access directly for their members. The main premise in clustering is confining message transmission inside clusters along with across CHs along with BS, resulting in benefits counting bandwidth preservation, along with redundancy prevention, along with communication overhead reduction. The CH-nodes' election mechanism is essential as it determines where the processing and transmission burden will be focused. Several clustering protocols have been suggested, addressing every fundamental necessities like coverage and connectivity, while also tackling specific challenges in WSNs such as maintaining stability in the face of node movement or failure, ensuring quality of service, and enhancing security. While criteria and problems vary amongst protocols, energy-efficiency is a universal and collective goal.

Most of the clustering techniques discussed later rely on heuristics along with meta-heuristics. Heuristics are algorithms that are problem-specific and prioritize immediate gains. They use predefined rules to select CHs and create clusters based on the inherent features of the SNs. Meta-heuristics are broad framework algorithms; Genetic Algorithm (GA), along with Simulated

Annealing (SA), along with Particle Swarm Optimisation (PSO), that are problem-independent and may be adjusted to address the clustering problem.According on their clustering mechanism,clustering protocols are categorized into three groups: distributed, centralized, and hybrid [4]. The next section delivers brief descriptions of representative protocols from every of these three areas.

LEACH (LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY) PROTOCOL:

LEACH is among the initial clustering protocols introduced in academic literature. The approach operates in rounds and employs a dispersed probabilistic method to select CHs in every round [8]. Every SN generates a random no. from 0 to 1. If the number is below a threshold T (n) where n is the count of rounds, the SN declares itself as a CH for that round. Also, the threshold is set by a specific proportion of CHs inside the network along with the frequency of the SN serving as a CH up to now. Every non-CH SN selects its CH per the signal strength it gets, opting for the CH that can be accessed with the least amount of energy transmission. To balance the load along with energy dissipation inside the network, the CH's job is cycled across the SNs periodically by reiterating the process at every round's start.

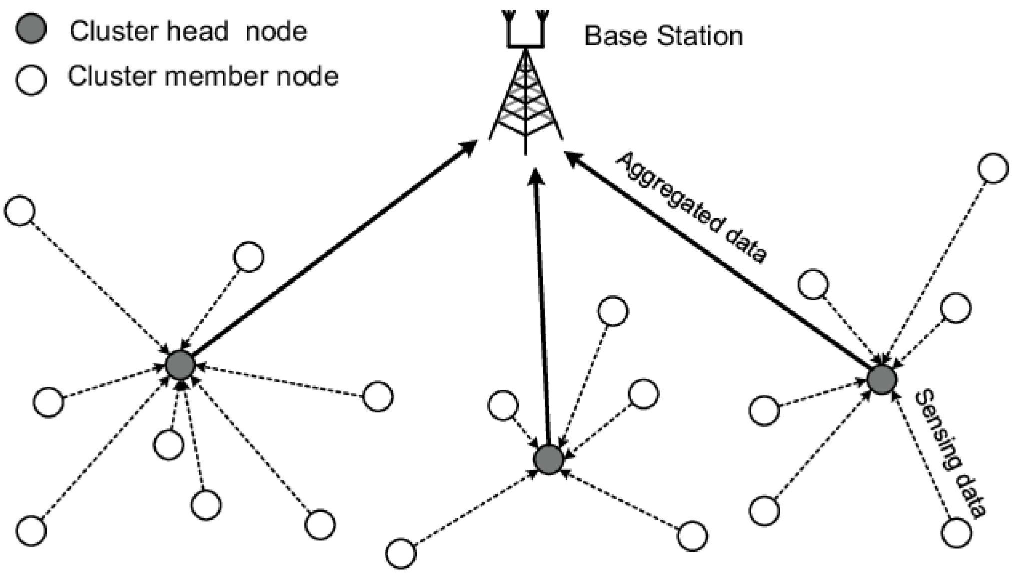

Figure 2: Overview of LEACH [9]

Several recent methods have been suggested using LEACH. Several solutions are outlined below.

LEACH – DT (LEACH with Distance Based Threshold):
The main goal of LEACH-DT is to equilibrate energy consumption inside the network by factoring in the seperation across the SN along with the BS while determining the chance of every SN becoming a CH. Clusters in LEACH-DT are created by considering the seperation across the SNs along with CHs, similar to LEACH. So, the authors suggested a multi-hop extension to LEACH-DT to prevent distant CHs from depleting energy through direct comm. with the Base Station [10].

LEACH-MF (LEACH – Modified Parameter):
The purpose of LEACH - MF is to minimize packet loss and stretch the mobile WSNs' network longevity. This protocol alters the CHs determination method of LEACH by incorporating a fuzzy inference system having three inputs: SN remaining energy, along with moving speed, along with pause duration. Nodes with greater residual energy, reduced velocity, and extended pause duration are more probable to be chosen as CHs in the next round. Stable connections utilised for data dissemination can be improved by taking into account the moving speed along with pause duration of every SN, leading to an enhanced packet delivery ratio. So, after selecting the CHs, every SN connects to its closest CH, similar to the LEACH protocol [11].

LEACH-ERE (LEACH - Expected Residual Energy):
This protocol utilizes an energy approximation model to determine the anticipated remaining energy of every SN after a round of operation as a CH. The fuzzy inference systems utilize the SN's anticipated residual and remaining energy to compute the likelihood of the SN becoming a CH. Nodes having greater probability across their neighbours are chosen as CHs for the next round. The remaining stages of LEACH-ERE closely resemble those of LEACH [12].

FUZZY LOGIC APPROACH:
Lotfi-Zadeh initially introduced fuzzy logic (FL) as a method for representing human behaviour in decision-making [13]. FL mimics the flexible nature of human cognition, contrasting with the typically stiff computations performed by computers. A fuzzy system offers numerous distinctive qualities that make it a favourable method, particularly for various control challenges [37]. It can handle ambiguity and uncertainty, enabling the combination of several factors, even when they clash, into a single measure. Fuzzy logic offers robustness, ease of implementation, and the capability to manage nonlinear systems [14], [2].

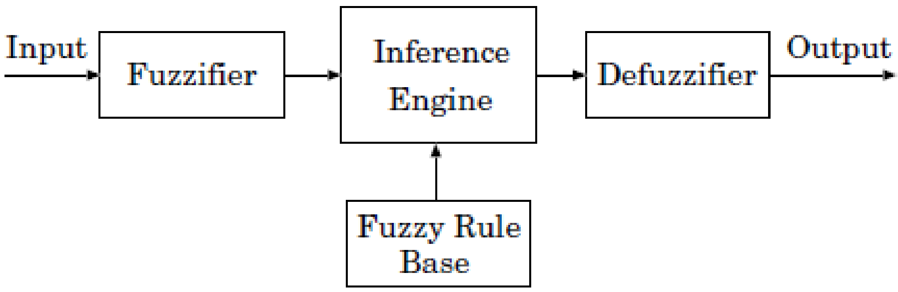

Figure 3: Fuzzy Logic System's basic structure [15]

Developing a routing strategy in WSN that conserves nodes' energy is fundamental for prolonging the network's lifespan. The approach utilizes a Fuzzy Inference System inside WSN for routing. Clustering selects CHs utilising a fuzzy logic (FL) approach that considers the following variables: node seperation right to the base station, along with seperation right to the cluster head, and the node's residual energy [2]' [37]. The suggested protocol is modeled and contrasted with the LEACH protocol. Performance conclusions are drawn from the offered method's simulation outcomes.

- The technique chooses the CH close to the cluster members having great remaining energy levels utilising FL. This process assigns a probability value to the SN to identify the most suitable node to be the CH for overall energy efficiency.
- By utilizing three factors to choose CH by FIS and implementing an Energy Level limit, wherein the energy is evenly distributed in the simulated network. The suggested approach avoids the issue of premature node failure caused by uneven energy consumption among nodes.
- Various elements are significant in selecting the CH, as no single factor alone can determine the choice of the node as the CH. Additionally, the probabilistic approach does not deliver a reliable selection of the CH.

Table below delivers a comparative overview of the various RPs that are currently in use.

Table 1: Comparative Exploration of different protocols

PROTOCOLS	OBJECTIVES OF THIS PROTOCOL	MERITS	FUTURE WORKS
CHRA (Colouring Based hierarchical Routing Algorithm) [16]	Energy optimization in diverse WSNs. CHs are selected using	Improved stability period along with	Integrating many mobile sinks to extend

	the same method as in LEACH-C, which involves Mixed Integer Programming.	optimized energy usage	the lifespan.
NR-LEACH (Node Ranked – LEACH) [17]	reducing the energy amount that is consumed. CHs selection by the use of a weighted evaluation.	Increased network longevity while also decreasing delay.	Enhanced network lifespan obtained by the utilization of sink mobility and fault tolerance
CREEP (Cluster Head Restricted Energy Efficient Protocol) [18]	lowering the amount of computing complexity involved in the CH selection process." Similar to how CHs are selected in DEEC, along with threshold, along with dual-hop based comm., CHs are selected in this manner.	Because of the limitation placed on the count of CHs, complexity was decreased.	An enhancement for scalability, latency, along with reliability
HEEMP (Hybrid Energy Efficient Multi Path RP) [19]	Reducing the amount of energy that the network uses as much as possible. An assortment of CHs that is centralized and considers both the residual energy and the degree of the node	Improved lifespan, along with lowered energy depletion and delivers great scalability	Work can be expanded to demonstrate the trade-off across heightened latency and minimizing energy consumption
WECRR (Weighted Energy – Efficient Clustering with Robust Routing) [20], [4]	Prevent uneven energy usage. Deterministic clustering utilizing a Weighted Cost Function andMulti-faceted characteristics.	Effective and dependable data transmission	Improving network lifespan through the utilization of heterogeneous WSNs and mobile sink.
CL-LEACH (Cross Layer – LEACH) [21]	Extending network lifespan by minimizing energy consumption. CHs are chosen as per residual energy along with seperation and also Route maintenance	Extended network lifespan similar to LEACH.	Optimizing energy consumption with the use of a wake-up sleep scheduling algorithm
MFABC (Multi – Objective Fractional Artificial Bee Colony Algorithm) [22]	reducing the amount of energy used, both in terms of time and seperation. The selection of CHs using ABC algebra and fractional calculus	Nodes should have their lifespans maximized.	Increasing the network's lifespan through the incorporation of fault tolerance along with mobility enhancements
CAMP (Cluster Aided Multi Path RP) [23]	Energy depletion that is uniform. Sink is accountable for CH selection, while the Intelligent Routing Process is managed by Virtual Zones.	Improved coverage ratio, increased network lifespan, and decreased energy use are all benefits of this technology.	Improvements to the protocol in order to manage sink mobility, heterogeneity, security, and reliability
BEE-SWARM [24]	WSNs that incorporate energy-effective routing. CH selection by the use of the Swarm Intelligence approach, often known as the Artificial Bee Colony	Efficiency for energy consumption and scalability	Actual testing of the system on a test bed that contains multiple types of networks
PSOBS (Particle Swarm Optimization Based Selection) [25]	with the goal of lengthening the lifespan of the network. Mobile Sink Optimization and Particle Swarm Optimization utilised as the methodology	Administration of network resources in an effective manner	For a more accurate selection of rendezvous locations (RPs), Firefly is recommended.
DEFL (Distributed Efficient Fuzzy Logic) [26]	Within the context of maintaining a balance between energy efficiency and energy balance. In this particular instance, the	Boosted network lifespan	End to end delay minimization inside multi-hop network and capitalize on

	methodology utilized includes Sequential Quadratic Programming, along with Fuzzy Logic, and the Bellman Ford Algo.		network lifespan
DBRkM (Delay Bound Reduced K-Means) [27]	To drop the energy amount that is consumed. The methodology used is k-Means, TSP, Mobile Sink	Increased network longevity while also reducing energy consumption	Changing the amount of data that is generated and the amount of time that accounting takes on as in real-time scenarios
HEBM (Hierarchical Energy-Balancing Multipath RP) [28]	This protocol used to drop the network's total energy consumption while maintaining a balanced energy dissipation. Load balancing, Hierarchical Clustering, and Sleep/Awake Mechanism are the respective methodologies that are utilized.	Prolonged network lifespan, Boosted FND along with LND, along with mean data transmission delay	Mobile BS notion to attain further energy saving, along with BS and CHs can be prepared to be more fault tolerant
COARP (Caching-Optimized Adaptive RP) [29]	In order to establish energy balance and maximize the lifespan of the machine. The selection of CHs by the utilization of Cuckoo Search Optimization in a variety of circumstances	Death of the first node as optimized	The incorporation of mobility in order to guarantee coverage, standard of service factors like fault tolerance and reliability
EEACBR (Enhanced Energy Aware Clustering Based Routing Algorithm) [30]	The incorporation of mobility in order to guarantee coverage, standard of service factors like fault tolerance and reliability. Initial along with final CHs selection utilising Genetic Algo. Along with K-means Clustering, correspondingly	Utilizing K-means clustering allows for a more rapid clustering procedure.	Decrease in the total amount of transmissions by the incorporation of mobility into BS

METAHEURISTIC APPROACH:

The field of metaheuristic optimization focuses on the application of metaheuristic algorithms to solve optimization problems. Optimization is a pervasive concept that finds application in various domains, encompassing technical design, economics, holiday planning, and Internet routing. Given the inherent limitations of money, resources, and time, it is imperative to prioritize the optimal utilization of these finite resources. Real-world optimizations often exhibit a high degree of nonlinearity and multimodality, as they operate within a range of intricate constraints. Diverse objectives frequently exhibit conflicting tendencies. In certain cases, it is possible for optimal solutions to be non-existent, even while considering a singular purpose [39]. Finding an optimal solution, or even sub-optimal solutions, is typically a challenging endeavor. This research's objective is to conduct a study on the fundamental principles of metaheuristic optimization, along with an overview of several widely used metaheuristic algorithms.

Metaheuristic algorithms typically consist of two primary components, namely intensification along with diversification, or even exploitation along with exploration. Diversification refers to the process of generating a wide range of solutions to probe the search space on a global level. On the other hand, intensification involves narrowing down the search to a specific local region, recognizing that a satisfactory solution already exists in that location. In order to enhance the rate of algorithm convergence, it is imperative to strike a suitable equilibrium between intensification and diversification while selecting optimal solutions. The process of selecting the optimal solution guarantees that the solutions will thus converge to the optimal solution. Additionally, diversification through randomization enables the search to move away from local optima and simultaneously enhances the variety of options. An ideal combination of these two primary components typically guarantees the attainment of global optimality. Numerous metaheuristic algorithms are documented in literature, and a selection of these algorithms will be further examined below.

GREY WOLF OPTIMIZATION (GWO) ALGORITHM:

GWO happens to be a meta-heuristic algorithms that mimics the food probing behavior, hunting strategy, along with leadership structure of grey wolves (GWs) in the wild. GWs attack in groups along with the optimal posture for every wolf can be determined. They adhere to a rigid social dominance hierarchy with alphas (α), along with beta (β), delta (δ), along with omega (ω) roles, as depicted in the figure below, which involves hunting, along with searching, along with encircling, along with attacking victims. The dominance diminishes as you move down the ladder. This approach is used in WSNs where the wolves' positions symbolize the CHs' positions in every cluster, and the GWs' positions update the CH positions in the LEACH protocol.

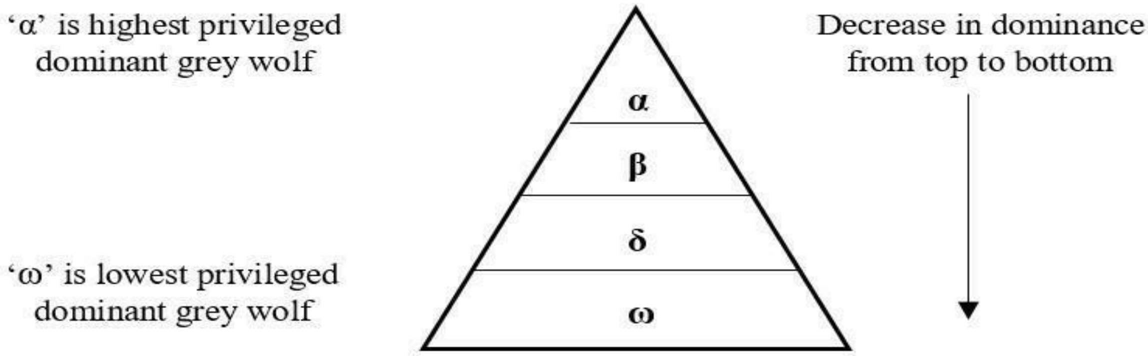

Figure 4: Grey Wolf Hierarchy [31]

Alpha wolves, both male and female, are vital in decision-making, organization, and discipline within a wolf pack, with other wolves in the group following their lead. At the second level, beta wolves, regardless of gender, assist the alpha wolf by providing guidance, feedback, and transmitting orders to wolves lower in the hierarchy. The wolf in δ class is subservient to α and β wolves, but is dominating over ω wolves. Wolves serve as scouts, sentinels ensuring safety, protection, and experienced elders assisting alpha and beta wolves. They also act as hunters, aiding in providing food, and caretakers for weak, along with ill, along with wounded GWs. The GW, known as the omega, is the lowest-ranking animal in a pack and obeys the dominant wolves [38]. If the omega wolf is missing from a pack, there is a risk of internal conflict arising from other GWs' frustration. The primary stages of group hunting by GWs include: 1) Tracing, chasing, and approaching the prey along with 2) Pursuing, encircling, and harassing the prey until it ceases movement; 3) Attacking the prey. So, the GWO algorithm is thus designed based on the social hierarchy along with hunting skills of GWs to improve its performance. The GWO method is utilized for addressing real-time engineering issues in many sectors [32].

CH selection in standard LEACH schemes is suboptimal, however using GWO enhances the optimal CH selection in the LEACH process [33]. The GWO happens to be a metaheuristic algo. that imitates the social behaviour of GWs, focusing on their leadership hierarchy and attacking technique. The GWO technique can tackle localization challenges in WSNs by searching for unknown nodes' geographical locus utilising anchor nodes. The selection process in CHs employing GWO takes into account the seperation across clusters along with the sink, remaining energy of every node, along with anticipated energy usage [34], [35]. This method involves maintaining the same clustering in successive rounds to improve energy efficiency. The conserved energy can then be used for cluster reformation. CHs located far from the BS can utilize dual-hop routing to achieve optimal energy efficiency [31]. GWO is utilized to establish objective purposes and deliver weights for effective cluster creation along with selection of CH [36]. An appropriate fitness function is utilized to assure WSN coverage and is inputted into the GWO algo. to identify the optimal solution. This approach surpasses the LEACH clustering along with routing algorithm inside network throughput, longevity, and residual energy [31].

CONCLUSION:

Based on the findings of this review study, it is imperative to develop and execute energy-efficient strategies in order to enhance the main performance parameters of SNs inside WSNs and in scenarios where recharging or even replacing the battery is not a viable option. While clustering is widely recognized as a major strategy for extending the lifespan of WSNs, the task of selecting CHs to improve network longevity remains a significant difficulty. The traditional routing methods that rely on clustering provide fault tolerance, along with load balancing, and dependable communications, but they come at the expense of reducing the lifespan of the CH. In order to address this challenge, extensive research has been conducted on the development of effective approaches for selecting CHs, acquiring data, and optimizing routing algorithms. So, the forthcoming research will focus on the assortment of energy-efficient cluster heads inside WSNs through the utilization of metaheuristic algorithms.

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