A Comprehensive Investigation On Clustering Strategies for Enhancing the Design of Cluster Head Selection in WSN.

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Abstract

In Wireless Sensor Networks (WSNs), nodes have finite and unique power resources. Clustering techniques are used to reduce energy consumption, collect data, and extend the network's operating life in order to overcome this difficulty. Despite the advantages associated with Clustering algorithms, determining the cluster head (CH), a crucial factor influencing energy efficiency, remains a significant challenge. To ensure to overcome this difficulty, clustering techniques are used to collect data, use less energy, and increase the network's lifespan. These CHs collect data obtained from WSN nodes and send it to a Base Station, which then distributes the compiled data even farther. The benefits of WSN node clustering encompass scalability, enhanced energy efficiency, and reduced routing delays. This research scrutinizes various clustering algorithms to assess their respective merits and drawbacks. A comprehensive analysis of diverse clustering strategies in WSNs is conducted, focusing on energy efficiency and power management. Finally, several concerns related to clustering are deliberated upon.

Key words: *Clustering, Nodes, Data Transmission, Energy Efficiency, Routing Delay.*

1. INTRODUCTION

New developments in wireless communications and electronics have made it possible to create Low-power sensors, small size, affordable price, and an extensive variety of applications. This development has made it possible to create wireless sensor networks, introducing a novel approach to building networks using small sensors capable of detecting environmental data, processing it, and transmitting it. The fundamental components of a Sensor networks that are wireless (WSN) are the diminutive sensor nodes. These nodes typically include a battery, a central processing unit (CPU), memory, and a radio, and the development of networked sensors has become conceivable by this advancement to fulfil a precise function [2].

1.1 Wireless Sensor Network (Wsn) Taxonomy

(i) Sensor Nodes: They are the nodes situated within the wireless network. Sensor nodes undertake various tasks, including data sensing, routing, and processing

(ii) Clusters: They are the node groups formed within the network structure. The cluster head, elected within each cluster, holds ultimate authority and is crucial for reliable data transmission

(iii) Cluster Heads: They are responsible and tasked with efficiently managing cluster operations. The key function includes data transmission, initiating and overseeing data transmission. Also they disseminate and manage the distribution of data within the cluster.

(iv) Base Station: They are regarded as a critical element in the hierarchical wireless network. It serves as a communication hub connecting the sensor network with end-users.

1.2 Challenges and Issues of WSN

In real-world applications, sensors demonstrate the capacity to grow and Work alongside with each other, which makes it easier for deployed sensors to gather a significant amount of data [3]. Sensors can be deployed in challenging environments where data collection and transmission are inherently difficult. To maximize the effectiveness of sensor networks, it is imperative to comprehend the issues and problems they confront. The protocol employed in networks addresses various challenges, and the following difficulties are notable:

(i)Data Collection in Remote Areas: Sensors placed in remote or inaccessible regions pose challenges in collecting and transmitting data

(ii)Scale of Data Accumulation: The abundance of data collected by sensors introduces challenges in efficient management and processing.

(iii)Protocols and Network Concerns: The protocols used in sensor networks must contend with various concerns to ensure optimal performance.

B A multitude of concerns and challenges are anticipated in the continued development and utilization of Wireless Sensor Networks (WSN).

Numerous concerns and other critical challenges lie ahead for Wireless Sensor Networks:

• **Energy:** In the realm of Wireless Networks, the predominant and widely encountered design challenge is power efficiency. The escalation in power consumption mandates a meticulous optimization of the three fundamental functional domains of the system: sensors, communications, and data processing. In real-world applications, sensors demonstrate mutual expansion and cooperation, which makes it easier to gather a significant amount of data from distributed sensors. The architecture of sensor networks is inherently constrained by the finite energy resources of the sensor nodes. Furthermore, the duration of an operation is contingent on the outdoors of the software employed in the system.

• **Limited Bandwidth:** Efficient information transmission with minimal energy consumption is achievable within the range of 10 to 100 kb/s. However, the transmission of data between sensor nodes is impeded due to bandwidth limitations, as acknowledged by previous studies [4].

• **Node Cost:** Wireless communication in sensor networks employs optical, radio, or infrared communication technologies. The financial metrics of the entire system are primarily determined by the sensor nodes themselves. Achieving comprehensive metrics necessitates a substantial investment in sensors, making it a crucial factor in system planning. Sensors are selected centred on the application, considering factors such as high cost of sensors necessitates strict tolerance level management.

• **Deployment:** Reducing the complexity of a deployment can be achieved through the adoption of an efficient method. Utilizing sensor nodes at a relatively long range requires the implementation of specialized techniques. There are basically two techniques of node deployment, known as "dynamic deployment" and "static deployment."

• **Security:** Ensuring the high-level security of sensors poses one of the most significant challenges, particularly considering the sensitive data they collect. To become part of a cluster, a node must undergo authentication by the cluster head. Any unauthorized nodes are promptly isolated and segregated from the network.

1.3 Unique and Valuable Additions:

The primary objective is to offer a swift introduction to Wireless Sensor Network clustering methodologies for researchers at various levels of experience. Additionally, the paper aims to assist readers in choosing a clustering strategy that aligns with the specific requirements of their applications. To achieve this goal, an in-depth examination of the most recent clustering solutions was conducted. The subsequent sections of the paper are organized as follows:

(i) Fundamentals of Clustering Approaches in Sensor Nodes: This section introduces the foundational aspects of Clustering algorithms employed in networks of wireless sensors.

(ii) Objectives and Characteristics of Clustering: Provides a comprehensive overview, this section presents the goals and distinctive features associated with clustering methodologies in WSNs.

(iii) Challenges of Clustering Based on CH Selection and Formation: Focused on challenges, Section 4 delves into the difficulties encountered in clustering, specifically addressing the selection and formation of Cluster Heads (CH).

(iv) Description of Existing Techniques: This section elaborates on the current techniques employed in WSN clustering, offering insights into the methods currently in practice.

In essence, the paper serves as a resource for researchers, guiding them through the essentials of WSN clustering and aiding in finding an appropriate strategy tailored to their specific applications.

2. CLUSTERING METHOD

Clustering involves classifying data into unsupervised learning subsets and organizing them into clusters based on shared properties. A cluster, in this context, is a collection of entities that exhibit both similarities and differences. Distance criterion, where objects closer together form a cluster, is often employed in clustering, known as distance-based clustering.

Clustering serves as a method to identify groups of entities sharing a common characteristic. The absence of a universal standard for sample clustering highlights the user's discretion in determining the appropriateness of grouping samples. Despite this, the several requirements for optimum clustering have been proposed to guide users in achieving suitable clustering. A significant challenge in clustering is The decision-making process of the cluster number's, which are either specified by the user or specified by the algorithm itself [7].

Cluster topology necessitates dividing the network into smaller groupings termed "clusters," each serving a specific purpose. The cluster's head (CH) supervises connections among cluster members and distributes data from the cluster to the central station (BS). Nodes within a cluster architecture collaborate to send the active data to the BS collectively, enhancing efficiency and also the reducing energy consumption, thereby extending device life. Nodes may assume distinct roles in cluster protocols, functioning as either cluster members or CHs. It is typical for member nodes to provide noticed data to the CH. or to use the CH's aggregated data [8]. Fortunately, it is essential to remember that CHs often use more energy because of their higher processing loads and longer message transmission distances. Clustering algorithms play a crucial role in reducing energy usage and prolonging network lifespan.

3. DISTINCTIVE GOALS AND FEATURES

When nodes are clustered, they are more effectively organized into groups, resulting in the overall improvement of the network's performance.

3.1 Clustering algorithms pursue various objectives:
(i)Scalability: The ability of the network to grow and expand.
(ii)Node Energy Consumption: The total power consumption and energy expended by each node to fulfil its assigned task
(iii)Fault-Tolerant-Data Collection Issue: Challenges related to the data collection of nodes characterized by intermittent fault tolerance, Error-resistant and Robustness.
(iv)Lifetime: The period until all nodes exhaust their energy, marking the conclusion of the network's operation.
(v)Throughput: The volume of packets transmitted to the central station and their data transfer rate.
(vi)Data Aggregation and Analysis: The method by which data from member nodes is transmitted to the BS for further analysis, synthesis, aggregation, and compilation.
(vii)Uneven Load Distribution: If the load is distributed unevenly among cluster members, network performance may be adversely affected.
(viii)Residual Energy Reduction: Each individual node energy decreases with each round, the network's residual energy is gradually reduced.
(ix)Network Stability: The endurance of the network, Robustness and Reliability are often determined by the lifespan of the initial node.
These goals encompass various aspects of network performance and efficiency, addressing concerns such as scalability, energy consumption, data collection, and overall stability.

3.2 The Clustering Characteristics outlined include:
(i)Total Number of Clusters: The overall number of clusters can either be fixed or variable partitioning and cluster group formation, depending on the clustering procedure employed.
(ii)Hop Count in Communication: They include Jump Count and Step Count. The hop count, this displays an amount of communication steps between nodes, determines whether a communication is single-hop or multi-hop.
(iii)Clustering Strategies: Various grouping approaches and clustering strategies are available, including homogeneous/heterogeneous and single-hop/multi-hop clustering, providing different ways to organize nodes within clusters.
(iv)Upper Bound on Cluster Size: Certain algorithms may define Maximum Limit (upper bound) for the greatest total amount of nodes that can coexist in a cluster.

4. CHALLENGES OF CLUSTERING

The selection of the heads of clusters (CH) has a significant impact on the network's lifetime and the effectiveness of the clustering approach. Energy usage can be significantly decreased with the right choice of CH. The following are the most important problems with the CH assortment process:

4.1 Tasks of the CH selection

The decision about the number of Cluster Heads (CH) has a considerable impact on the clustering algorithm's efficiency and network durability. Optimized CH choosing can lead to a substantial reduced usage of energy. The primary difficulties in the CH assortment process are:

• It is feasible to centralize the process of selecting cluster head stations (CHs), with a central station performing this function. An alternative strategy is a distributed procedure in which nodes independently take on the function of CHs [9].

• The heads of the cluster (CH) may have been chosen at random or using a predefined formula. Nodes with greater amounts of energy may be more likely than nodes with a lesser amount of energy to be designated as the CH during this strategy. The amount of peers, clustering dimension, and distance characteristics are possible additional factors impacting the choice of CH.

• Extended and complex Cluster Head (CH) selection procedures could put further strain on the network's energy consumption. To reduce this expense, it is imperative to choose a CH selection procedure that is effective and ecologically friendly.

• To reduce CH congestion, a homogeneous distribution of the heads of clusters (CH) is optimum. Internal communications inside the cluster become energy-intensive in dense CH settings, where apparently is a significant distance between cluster participants and their respective CH. Consequently, the problems brought on by high internal energy consumption are lessened when CHs are distributed uniformly.

• The term "delay time" can refer to the duration it takes to select a channel. Alternatively, it might denote the time required for the formation of a cluster. This parameter is essential for clustering to be successful [10].

4.2 Cluster Formation and its Task

Now that the cluster construction step is complete, every node is updating the network with its current state. While some nodes serve as the cluster's Cluster Heads (CH), others are just normal nodes. During this stage, clustering algorithms must consider a variety of issues in their execution.

• Many contemporary probabilistic and randomized algorithms inherently result in the generation of varying numbers of clusters. However, in several works, the set of heads of clusters (CH) may already be established, thereby predetermining the volume of clusters.

• Earlier clustering systems envisioned direct (one-hop) communications between sensors and their designated Cluster Heads (CH). However, as the number of CH and sensors is constrained, particularly in scenarios with a significant number of sensors, there is a growing need for multi-hop intra-cluster communications.

• Direct or indirect communication is possible Between the Main Station (BS) and the set of heads of cluster. When using direct mode, the CH transmits input to the central station in a single hop. In indirect mode, data is routed through a CH and transmitted via multi-hop transmission, with the data passing through a CH connected to the central station before reaching its destination.

• Clusters are distinct in regard with the quantity of nodes they contain the distance that exists between themselves and the ground station, the total number of clusters in the environment. Some clustering algorithms aim to balance elements like The amount of connected nodes, the spatial placement of each group in sequence to produce an even distribution of clusters throughout the environment. On the contrary, other techniques introduce imbalance by generating clusters randomly and without prior knowledge, leading to modifications in the total amount of neighbors distances between clusters and the BS, and other parameters [11].

4.3 Parameters of Clustering

Numerous parameters can be used in the clustering process to compare and categorize clustering approaches.

(i) Location Awareness: The calculation of distances in sensor networks requires sensors to be cognizant of their surroundings, encompassing the entire network and even the neighbors of other sensors. Achieving this awareness often involves the installation of GPS systems or the measurement of the intensity of a returning signal, both of which require energy. However, in certain algorithms, nodes may not need to know their physical geography or possibly where they were of their neighbors.

(ii) Energy Efficiency: The most significant constraint in sensor networks is the battery. Sensors are equipped with a built-in battery that has a finite lifespan and is typically non-rechargeable. Consequently, the primary principle that clustering algorithms should consider is optimizing energy consumption to prolong the network's operational life.

(iii) Clustering Objective: Several benefits come with clustering, such as improved network scalability and lower energy usage via aggregation of data and transmission reduction. Additionally, clustering provides features including load balancing [12], fault tolerance [13], connectivity improvement [14], latency reduction, minimum cluster count [15], and maximum efficiency in resource utilization.

(iv) CH Mobility and Nodes: Clusters tend to be well-balanced and stable when nodes and Cluster Heads (CH) are immobile. This immobility facilitates easier network administration both across clusters and within them. Conversely, if all nodes and CH are movable, the cluster membership of every single node changes dynamically. Additionally, at any specific time, clusters must select a member [16].

(v) Sophistication of Algorithm: Earlier algorithm designs primarily aimed to ensure the swift termination of computations. As a result, it was expected that the temporal complexity or convergence rate would either remain constant or would vary depending upon the amount of Cluster Heads (CH) or hops in the system. Amount of nodes for sensing. may have an impact on some protocols' complexity, with older protocols placing greater emphasis on the quantity of network sensors.

(vi) Categorization: It is possible to classify broadly the clustering technique utilized to cluster information and determine Cluster Heads. Numerous clustering techniques share the randomization of the CH and cluster creation. Certain algorithms create clusters based on information from nearby nodes. Moreover, a variety of environment-segmenting techniques can be used to accomplish clustering.

5. INVESTIGATION OF CURRENT CLUSTERING APPROACHES

(i) A Wireless Sensor Network (WSN) could have a longer lifespan if a clustering protocol was implemented. This study categorizes WSNs based on algorithms, with a specific focus on convergence time, emphasizing energy efficiency, power management, and network categorization, among other factors. An energy-based protocol within the LEACH system, known as LEACH-EP [17], determines Cluster Head (CH) decisions based on data from the preceding round. The algorithm involves comparing Cluster Head Energy with Average Cluster Head Energy (Avg. CH Energy) and shares similarities in execution phases with the LEACH protocol. Additionally, the hierarchical architecture of WSN facilitates power conservation by segregating the network into clusters, each represented by a CH responsible for communication with the central station.

(ii) In [19], the author introduced a cluster-based protocol characterized by two levels of uneven inequality. This protocol proves advantageous for large-scale and dense networks, showcasing its capability to extend the overall network lifespan. This protocol differs in that it uses two different kinds of cluster heads (CHs). The burden of each cluster is evenly distributed amongst both the primary and secondary CHs. Both the primary CH and the central station are considered to be within an acceptable distance of one another. Each cluster node is associated with two primary and two secondary CHs. The incorporation of these dual options allows for finding shorter paths and minimizing energy consumption. The protocol facilitates data transmission through multi-hop routing.

(iii) The Integrated Chaotic Logic Clustering Method (ICLCM [20]) for unbalanced clusters\ing. involves a three-step algorithmic execution. Firstly, for the proper functioning of the network, immediate information sharing is initiated. Subsequently, the network proceeds to establish clusters. Finally, The establishment of a virtual backbone for data transmission. Throughout the node-to-node communication process, nodes gain awareness of each other's locations. The heads of clusters are determined by assessing each node's radius. Each node possesses varying degrees of expertise, with competency levels determined by a set of input parameters. Distance and energy serve as the two variables for these inputs. Subsequently, each node calculates its expertise, and re-clustering takes place based on these computations.

(iv) In the work described by the author of EEFUC [22], an energy-efficient methodology is laid out to enhance communication efficiency through a distributed architecture utilizing multi-hop dispersion via Fuzzy Logic (FL). The procedure involves four main areas, employing fuzzy input parameters in conjunction with fuzzy logic. Extensive analysis reveals that these fuzzy rules have a substantial impact on performance improvement. The suggested technique is further evaluated against other standard algorithms in scenarios of varying scales, demonstrating its effectiveness for both small and large-scale applications.

(v) The GSACP (developed by Kavitha et al. [20]) is a clustering technique designed to allocate nodes with sensors are connected to a competent cluster's head (CH) with the aim of preserving energy stability within the network. GSACP, which is intended to decrease energy consumption and increase network lifetime, outperforms conventional CH selection techniques, especially when it comes to energy dissipation and the total amount of packets transferred from the central station. Nevertheless, has been noticed that there is a challenge with delayed convergence in both the krill and GSA algorithms, necessitating a shift from exploration to exploitation.

(vi) Panchal and colleagues [26] proposed algorithms focused on stabilizing

cluster formation with outstanding energy efficiency based on the LEACH protocol, known as RCH-LEACH. Cluster Heads (CHs) play a crucial role in fulfilling the primary objective of energy conservation. The CH selection method created by CHS considers a number of variables, including node capacity, Euclidean distance, and randomization. Additionally, the algorithm incorporates considerations like threshold power, residual node energy, and optimal cluster size, among other characteristics, to determine the most suitable CH to utilize. By comparing RCH-LEACH with alternative methods, the network's lifespan is increased, measured by First Node Die (FND), in comparison to the LEACH and E-LEACH algorithms. It shows a notable increase of 15 percent or 10 percent concerning FND. However, when compared to other approaches, it is shown that the network clusters stay static.
(vii) To extend the endurance of sensor networks that are wireless while reducing energy usage, researchers Ramin Yarinezhad and Seyed Naser Hashemi proposed the notion of clustering sensor nodes. The suggested strategy handles the Load-Balanced Gathering Problem. (LBGP), with a maximum known approximation factor of 1.5. Demonstrating that no polynomial-time approximation approach can achieve a better approximation factor, LBCP utilizes a Fixed Parameter Tractable (FPT) with an approximation factor of 1.2. The algorithm emphasizes the need for energy-efficient and balanced routes between Cluster Heads (CHs) and the sink. In large-scale WSNs, the suggested algorithm proves practical and outperforms similar algorithms, as indicated by simulation results [10].
(viii) Umashankar and colleagues [15] propose a self-adaptive control technique utilizing node mutation rate and crossover rate to initialize population vectors. Introducing a hybrid ideal model that incorporates the artificial annealing technique as an alternative to the constraints of traditional Low Energy Adjustable Clustering Hierarchy (LEACH), the authors combine the Equilibrium Searching Program (ESP), modified HSA, and differential evolution. By boosting the network's overall life span, hybrid strategy hopes to benefit sensor nodes as well as cluster heads. The technology also supports replacement of batteries and recharge, which promotes network reliability and effectiveness.

6. FINAL THOUGHTS AND FUTURE DIRECTIONS

The present research addresses an understudied element of wireless sensor networks (WSNs) with extensive application. Given the multitude of connected devices employed in Internet of Things (IoT) systems, an effective WSN clustering protocol becomes crucial. Techniques for clustering are essential for maximizing energy use and prolonging the life of networks. Nodes are sorted into clusters according to predetermined criteria during clustering methods. Every cluster has a node that is in charge of gathering and sending data from all other nodes to the cluster's Centre Station (BS). The process involves considerations such as deterministic and random selection methods, distance from the BS, appropriate distribution of the heads of the cluster, and delay. The paper delves into the detailed examination of clustering methods, including the selection and formation of clusters. Clustering sensor nodes is necessary for reliable network operation and effective data distribution. While many clustering methods concentrate on either node energy or trust, to send out information, increase network lifespan, the paper recommends using an integrated energy and trust assessment-driven forecasting strategy when choosing the cluster head.

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