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An Energy-Efficient Clustering Approach for Wireless Sensor Networks to Reduce Hot-Spot Effect and Idle Listening Energy Consumption

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ABSTRACT

Nowadays, wireless sensor networks (WSNs) prove their potential in our daily day-to-day life. However, due to high congestion, energy management becomes the key challenge for WSNs. To increase the lifespan of WSNs, a unique clustered routing strategy is presented in this study. It offers an effective solution for the hot-spot effect and idle-listening issues. Outcomes help in lessening energy consumption. The developed algorithm is based on the principle of balanced energy consumption. Further, the developed WSN involves a node dormancy mechanism. It requires the energy balance technique using the clustering routing mechanism with distance variance. The design of clustering nodes is based on the master-slave principle, where the formation of clustering relies on node position and residual energy. MATLAB provides the simulation results as energy drop of each node to calculate the battery life. According to the achieved results, the developed algorithm can reduce the decay rate which can further lessen the energy consumption of the network. Moreover, it enhances the throughput and prolongs the network lifetime. The paper provides an energy-efficient clustering approach for Wireless Sensor Networks (WSNs) that can directly relate to manufacturing applications by practical solutions to the challenges faced in manufacturing settings, where effective sensor network deployment can lead to significant improvements in production processes and overall operational efficiency.

1. INTRODUCTION

Wireless sensor networks (WSNs) formed from the sensor nodes (SNs) that are basically small micro electro-mechanical (MEMS) as well as a base station (BS) or sink [1]. The primary goal of the SNs is to collect data from nearby nodes and forward it to the BS. In modern life, WSNs have become the integral part as in disaster management, weather forecast, industrial automation, heath care, surveillance and security, etc. [2-4]. SNs can efficiently implement a WSN via indirect or direct interface between each other where every node acts like a router [4]. A network architecture of WSN is categorized into three groups as location-based, hierarchical and fat routing protocols [5]. In general, SNs used an ad hoc fashion for the deployment [1, 6]. The basic differences between the ad hoc networks and WSN are [7]:

·The sensor nodes in WSN are much greater than the SNs in ad hoc networks.

·SNs are generally implemented in a larger number.

·SNs in WSN are open to failure.

·In WSN topology, frequent variations occur.

·Sensor nodes are constrained in memory, computation, and power.

A network is developed as clusters and offers better improvement in network energy as well as lifetime in hierarchical case. The other sensor nodes are known as member or common nodes, and each cluster is led by a cluster head (CH) [8]. SNs are implemented under crucial environments in most of WSN applications. While limited battery power can make the SNs as energy constrained. The lifetime of sensor nodes can be extended under these circumstances by giving the appropriate time to energy-aware routing protocol [9]. Static or dynamic routing strategies can be used by the routing methods [10]. Static routing allows data to be transmitted from sensor nodes to the destination using set pathways. Conversely, data trafficking to the destination is accomplished by dynamic routes in dynamic routing. WSN often uses dynamic routing since it allows data transfer even in the event of a router failure or death. The standard clustering of WSN is shown in Figure 1.

Hierarchical routing system was mainly anticipated for wireline networks [5, 11] because of its energy efficient and good scalability interface. Because of the aforementioned characteristics, Heinzelman [11, 12] developed the hierarchical routing strategy in WSNs. In hierarchical routing, the high-energy sensor nodes use data aggregation and the inert-cluster interface. Conversely, lower-energy SNs are using their specific clusters to gather sensing data. The idea of giving sensor nodes a unique role as cluster members or member nodes leads to improvements in network longevity, data packet collision avoidance, energy efficiency, and network scalability. The most well-known hierarchical routing techniques, including low-energy adaptive clustering hierarchy and hybrid energy-efficient distributed clustering, have made use of WSN protocols.

Extensive research work has been performed that can cover several LEACH based WSN protocols such as energy-efficient uneven clustering (EEUC) algorithm [13], power-efficient gathering in sensor information systems [14], two-level hierarchy LEACH [15], etc.

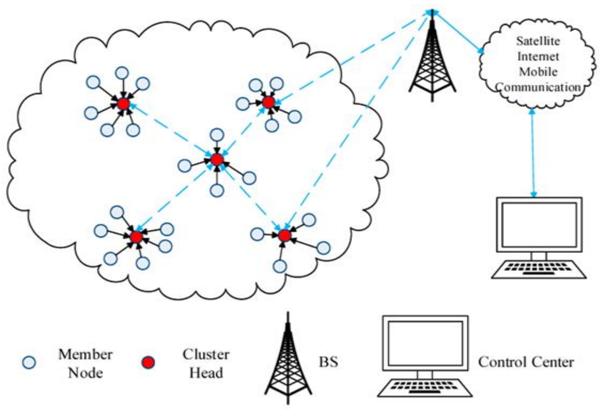

Figure 1. Structure of sensor node deployment and cluster formation in WSN [1]

LEACH [12] becomes the trending hierarchical clustering-based protocol for WSNs. It is an adaptive clustering protocol that utilizes equalized energy distribution and spontaneously organizes itself between the sensor nodes over rounds. The process works in rounds and every round includes the steady-state phase and clustering setup. The sensor nodes place themselves in a group having one node as representative during the clustering phase, known as cluster head (CH). On the other hand, the remaining SNs are named as regular/normal SNs. During the clustering stage, regular sensor nodes decide to either accept or reject a cluster for the existing round. It depends on the achieved signal strength. When utilizing single-hop communication for transmitting data from regular SNs to CH and from CH to BS, the steady-state phase is lengthier than the clustering phase. The member node of the cluster received the TDMA schedule from the cluster head, which further facilitates intra-cluster communication.

LEACH introduced the data compression with randomized rotation of cluster head before transferring it to BS for enhancing the WSN network lifetime. The percentage of CH in a network and the frequency with which the SN has continued to function as a CH in previous rounds are taken into consideration by the SN when making a decision about the CH for the current round during the cluster setup phase. For the current round, the sensor node selects a number between 0 and 1, and is promoted to the CH if its value is smaller than the predefined threshold $T(n)$. The mathematical expression for the threshold $T(n)$ is [16]:

$$T_n = \frac{p}{1-p\left[rmode\frac{1}{p}\right]},\ if\ n \in G \tag{1}$$

$$T_n = 0,\ otherwise \tag{2}$$

Figure 2 displays the radio model of LEACH as well as the intra cluster and direct CHs to BS transmission [12].

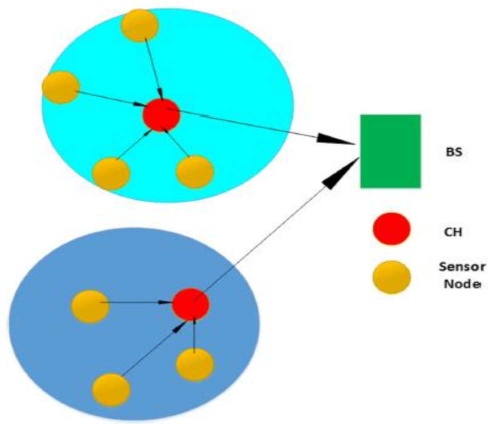

Figure 2. Single hop and intra-cluster communication from Cluster head to the base station

Each CH delivers a message to member nodes during the steady-state phase. It also maintains their receivers on to listen mode as well as responds to respective cluster head accordingly. The subsequent mathematical expressions can define a radio transmission model [16]:

$$E_{TX}(k) = E_{elec}k + \epsilon_{amk}kd^2, \quad if\ d \le d_o \tag{3}$$

$$E_{TX}(k) = E_{elec}k + \epsilon_{amp}kd^4,\ if\ d > d_o \tag{4}$$

$$E_{RX}(k) = E_{elec}k \tag{5}$$

where, d_0 is a threshold distance, ϵ_{amp} is the energy consumed by the radio amplifier as a result, and E_{elec} is the energy needed for k bit transmission over distance d.

This research work has the following contributions:

i. This Paper concerns the energy efficiency of the network which is the most important criterion for applications where battery replacement of sensors is not possible.

ii. Proposed solution minimizes the energy consumption at sensors due to the hot-spot effect. In the proposed solution hot-spot effect is avoided which ultimately results to prolong the network lifetime.

iii. Proposed solution minimizes the energy consumption at sensors during the idle-listening phase in which sensors drain some amount of energy while not transmitting any data. For this sleep and wake-up approach is used to avoid idle-listening energy consumption.

The paper provides an energy-efficient clustering approach for Wireless Sensor Networks (WSNs) that can directly relate to manufacturing applications. To address the hot-spot effect requires careful consideration of node placement (based on distance from the sink) and communication protocols can mitigate the hotspot effect, manufacturing plays a role in producing reliable and energy-efficient nodes for deployment. Efficient sensor deployment and management can lead to improved process optimization, reduced downtime, and cost savings in manufacturing facilities.

The paper can provide insights into how the proposed clustering approach enhances the monitoring and control of manufacturing processes, leading to better product quality, and increased efficiency. The following approaches are used in this work:

i. Energy-efficient Hardware: Designing sensor nodes with energy-efficient components, low-power microcontrollers, and optimized power management systems can extend their battery life.

ii. Advanced Battery Technologies: Integrating improved battery technologies, such as rechargeable or energy-harvesting batteries, can help reduce the frequency of battery replacements.

iii. The clustering approach proposed in the paper involves designing a hybrid hierarchical structure where sensors are organized into clusters. This design aspect is crucial for optimizing network performance and energy consumption. The design of such clustering algorithms requires careful consideration of factors like network topology, communication overhead, and data aggregation strategies. For Coverage Optimization: Utilizing tools like coverage prediction models during the network design phase can help determine the optimal sensor placement to achieve uniform coverage and reduce potential hotspots.

iv. Power Management: Implementing advanced power management techniques such as duty cycling, where nodes alternate between active and sleep modes, can significantly reduce idle-listening energy, using adaptive sleep scheduling algorithms based on traffic patterns or network conditions can further optimize energy usage. Use of predictive models and redundancy strategies during the design phase to optimize sensor placement and ensure consistent coverage.

v. Energy-Efficient Protocols: This paper Employs energy-efficient communication protocols based on Low-Energy Adaptive Clustering Hierarchy (LEACH), which can help in reducing unnecessary data transmissions.

vi. Distance Aware approach: The paper focus on energy efficiency directly involves computing aspects. Clustering algorithms, which group sensors based on distance or other criteria, involve complex computation to determine optimal cluster heads and communication patterns.

The following are the main mechanisms used in this research:

i. Data Aggregation: Implementing data aggregation techniques at intermediate nodes can reduce the number of transmissions, conserving energy.

ii. Wake-up Mechanisms: Utilizing wake-up mechanisms that allow nodes to remain in a low-power state until an actual data transmission is required can reduce idle-listening.

Wireless sensor networks (WSNs) are becoming an essential and dynamic aspect of modern life for humans. The monitoring of the atmosphere is essential to the entire plan, including battle domains, climate monitoring, remises, and more. Nevertheless, the primary issue facing WSNs is energy management. In a wireless sensor network (WSN), non-rechargeable batteries often provide power to sensors because conventional nodes have a limited energy capacity. Energy harvesting techniques are a viable approach to address the battery-related problems with sensors. This study lowers the energy usage from idle listening and provides a workable remedy for the hotspot effect. Energy-efficient plans come in different forms, such as mechanical, thermal, wind, and solar, and they rely on the surroundings.

A novel clustering routing protocol to extend the lifetime of WSN has been proposed through this research. The research paper explains the structure of a new network model and presents an updated version of the original energy consumption scheme. This scheme can find out the optimal number of clusters for the minimization of total energy consumption. The developed algorithm follows the concept of balanced energy consumption involving the node dormancy mechanism, the energy balance strategy using the clustering routing technique, and the introduction of distance variance.

The clustering process involves a cluster head selection considering distinct variants accessible with SNs at run time such as residual energy, hop count and initial energy. Such advanced algorithm increases the energy efficiency of the WSN and thus offers better lifetime, stability, energy and throughput in the network. Moreover, remaining energy and node positioning are important in the clustering formation process. Finally, this protocol is simulated using an initial energy of 0.5 J for heterogeneous networks.

According to the achieved results, the developed algorithm can lessen the decay rate that further reduces the energy consumption of network. Also, it enhances the throughput along with the prolonged network lifetime. It is the updated LEACH version. In LEACH-C, the BS creates clusters, while in LEACH every node self-configures them into cluster.

The BS accepts the entire data about the location/energy of entire nodes implemented in the system. By performing thus, BS finds the CH numbers as well as assembles network into several clusters. Nevertheless, because of insufficient organization between nodes, the CHs number changes from round to round. In LEACH-C the CHs number in every round matches an optimal estimated value. A centralized routing method is one in which for a SNs set, BS measures the average energy of a network consisting energy level greater than average. ACH will be chosen from the nodes set to assure that nodes chosen should have adequate energy to be a CH.

The system has two sub clusters as well as they are additionally separated as the anticipated CHs number. In this manner, the nodes are consistently dispersed to assure that load is ultimately distributed. By employing the minimal spanning tree technique, the BS selects the least energy routing paths and uses CH to distribute the clustering data to every node in the network.

Although, because of centralized system, interface overhead will enhance in the CH reselection, as BS takes the reselection decision. Furthermore, each cluster will transmit the request; therefore, a high energy consumption occurred.

This paper is further organized as follows: Section 2 discusses about the related work. Section 3 explains about the routing problems in a network model. Section 4 describes the LEACH based system model followed by Section 5 demonstrating the results and discussion for both the hardware and software implementations. In last, Section 6 presents the conclusion.

2. RELATED WORK

In WSNs, researchers have performed numerous research studies on the clustering protocol. Presently, the most trending clustering protocol is known as Low Energy Adaptive Clustering Hierarchy [17]. The LEACH process has categorized into two parts, named as the steady phase and the set-up phase. Set-up phase involves the development of cluster as well as the CH assortment by using probability function. The process depends on the residual energy. Stable Election Protocol is an upgradation version of the LEACH and a kind of heterogeneous clustering protocol [18]. SEP protocol involves the separation of sensor node into two parts as normal and advanced nodes. Malathi et al. [19] proposed a hybrid unequal clustering layering protocol (HUCL) that integrated the static with dynamic clustering. Another heterogeneous network named as Centralization Energy Efficient Cluster (CEEC) technique [20]. Such entire system has categorized into three parts as low, medium and higher energy regions.

In another work [21], the researchers suggested an energy-aware routing algorithm (ERA) depending on energy-aware clustering technique. The ERA has two sections named as routing as well as clustering formation. The extensive sensor network system uses sleep awake energy-efficient distributed (SEED) approach [22] i.e. a heterogeneous network model. Researchers also proposed [23] another algorithm named as energy-aware unequal clustering (EAUCF) to decrease several crucial network issues such as hot spot. The efficient unequal clustering protocol utilizes the distributed unequal clustering with the fuzzing method [24]. This technique has selected the cluster head by using a fuzzy approach and depicted balance energy distribution in the sensor network. Furthermore [25], in an algorithm named as distributed energy-efficient heterogeneous clustering (DEEHC) is used to enhance the quality of service of the sensor network. In another work, the energy hole problem and hot-spots problem can be decreased by the multi-objective fuzzy clustering algorithm (MOFCA) [26]. Investigators [27] used the multi-objective immune algorithm (MOIA) and applied an unequal clustering mechanism (UCM). This system improved via inter as well as intra clustering techniques based on the energy consumption.

The balanced flow routing (FBR) technique was proposed by Tao [28] to improve the network's power efficiency and coverage preservation. The FBR approach can use multi-hop routing to extend the lifetime of the network. The discrete particle swarm optimization (DPSO) protocol is applicable to EH-WSNs [29]. It uses the prediction model as EWMA. It works on the energy harvesting concept along with centralized clustering protocol to enhance the SNs network life. Moreover, a hybrid methodology is depending on the distributed centralized approach [30] named as novel energy-efficient clustering (NEEC) protocol. This algorithm has been categorized into three phases as data transformation, set up and handling phases. Also, investigators [31] suggested the advance EH-WSNs system applicable for the dynamic clustering algorithm. Further, this protocol supported cluster head by using relay nodes which is helpful for clustering technique, as the time consumes more energy after aggregation data sent to base station. Researchers further work on distributed clustering by demonstrating the neutral energy clustering (ENC) protocol [32]. This method falls under the category of new cluster head group. The cluster size in this method is comparable. The quantity of cluster reformation can be reduced using the CHG technique. Researchers demonstrated a balanced power and aware clustering routing protocol (BPA-CRP) in a research study [33]. It contributes to improving the energy efficiency amongst SNs.

Table 1 represents the comparative analysis of various LEACH successor on parameters like overhead, scalability, Energy Efficiency, location Requirement, Load balancing, complexity and Delay. Table shows that LEACH variants give good results in terms of above parameters. That's why probabilistic approach of LEACH has been taken in the proposed work.

Table 2 presents a comparative examination of a few LEACH versions on many other parameters, including deployment, CH Rotation, cluster size, transmission method, cluster structure, and cluster mobility. This analysis aids in the creation of the suggested algorithm to provide favorable outcomes.

Wireless sensor networks (WSNs) are becoming an essential and dynamic aspect of modern life for humans. The monitoring of the atmosphere is essential to the entire plan, including battle areas, weather monitoring, remises, and more. Nevertheless, the primary issue with WSNs is energy management. In general, non-rechargeable batteries offer power to sensor in a WSN with conventional nodes having limited energy capacity. Energy harvesting schemes are the substitutive solution that can solve the issues of sensor battery. This research work offers an effective solution for hot-spot effect and reduce the energy consumption. The energy efficient schemes depend on the environment and can be various kinds like mechanical, thermal, wind and solar. Authors have proposed a novel clustering routing protocol to extend the lifetime of WSN. This paper explains the structure of a new network model and presents an updated version of the original energy consumption scheme. This plan is able to determine the ideal number of clusters to minimize overall energy usage. The created method adheres to the notion of balanced energy consumption by including distance variance, the clustered routing approach, and the node dormant mechanism in the energy balancing strategy.

The clustering process involves a cluster head selection considering distinct variants accessible with SNs at run time such as residual energy, hop count and initial energy. Such advanced algorithm increases the energy efficiency of the WSN and thus offers better lifetime, stability, energy and throughput in the network. Furthermore, the construction of clustering relies on the node position and residual energy. In last, authors simulated this protocol for the heterogeneous networks with the initial energy of 0.5 J. According to the achieved results, the developed algorithm can lessen the decay rate that further reduces the energy consumption of network. Also, it enhances the throughput along with the prolonged network lifetime.

It is the updated LEACH type. In LEACH-C, the BS creates clusters, while in LEACH every node self-configures them into cluster. The BS accepts the entire data about the location/energy of entire nodes implemented in the system. By performing thus, BS finds the CH numbers as well as assembles network into several clusters. Nevertheless, because of insufficient organization between nodes, the CHs number changes from round to round. In LEACH-C the CHs number in every round matches an optimal estimated value. A centralized routing method is one in which for a SNs set, BS measures the average energy of a network consisting energy level greater than average. ACH will be chosen from the nodes set to assure that nodes chosen should have adequate energy to be a CH. The system has two sub clusters as well as they are additionally separated as the anticipated CHs number. In this manner, the nodes are consistently dispersed to assure that load is ultimately distributed. The BS uses the minimal spanning tree approach to select the least energy routing paths and distributes the clustering data to all of the network's nodes with the aid of CH.

Although, because of centralized system, interface overhead will enhance in the CH reselection, as BS takes the reselection decision. Furthermore, each cluster will transmit the request; therefore, a high energy consumption occurred.

2.1 Routing problems in a network model

A number of problems affect how routing algorithms and architecture are designed in WSNs. In order to achieve energy-efficient routing methods, all issues must be eliminated. Several noteworthy aspects of the network model are examined as follows:

Deployment of SNs

As per the nature of WSN application, SNs can be implemented either in a random or predefined way. The network maintenance issues can be solved by the implementation of sensor nodes in high numbers with great density. Such problems can be categorized into phases as pre-, re- and post- deployments. Sensor nodes are facing pre-deployment issues during the use of deterministic/random deployment approaches either placing one by one, throwing through artillery or dropping from Planes as per the application. The variation in the characteristics of sensor nodes creates post-deployment issues such as noise, malfunctioning, position and energy depletion issues. Such variations influence the network efficiency and topology. Faulty sensor nodes can be changed with new ones that are compatible with the operation of the network in the deployment phase.

Darabkh et al. validated [33] that the deployment of sensor nodes uses the approaches that substantially influences the inter-cluster communication under specific environment with the eventual influence on QoS. Horvat et al. also suggested [34] the deployment strategy of sensor nodes to optimize error by specifically tracking or searching the location a moving object. The coordinates or position of cluster head and base stations are much significant from the point of view of energy efficiency as well as network lifetime. It occurs generally in case of hierarchical clustering scheme with random deployment. The single-hop cluster head transmission experiences the challenge because of limited transmission power level. It directly depends on the distance among the CHs and BS. Under these conditions, multi-hop communication is preferable during the random deployment of SNs. In case of a heterogeneous WSN, the deployment of sensor nodes may experience additional limitations because of the energy level variations [35].

Load Balancing

WSN clustering experiences a significant problem of load balancing. Based on the WSN protocol, cluster head are selected with the aim to evenly distribute the accessible sensor nodes between network clusters for energy saving and enhance the lifetime of network. Researchers suggested a min-heap based clustering protocol for enhancing the network lifetime named as energy efficient load-balanced clustering (EELBC) system [36]. In other works [37, 38], the developed algorithms are utilized to balance load of the clusters between gateways by locating the sensor nodes in a predefined manner. In WSNs, it has the even density distribution. It further leads transmit, process as well as aggregate data to Base station simultaneously [35, 38].

Fault Tolerance

Usually, the applications of WSN experience the crucial and harsh environments. Thus, the sensor nodes have more chances to get physically damaged. Under such conditions, the sensor nodes or cluster head failure can be resulted in the big data loss. This situation can be recovered by choosing another sensor node to help the cluster head in clustering. It acts as a backup cluster head or coops/cooperative node. In the course of the normal operation of the protocol, the selection of a backup cluster head can inform the sudden failure of cluster head by numerous respects [3, 33]. Fault tolerance gives any network the ability to continue operating in the event of certain SN failures [37, 38]. Using the Poisson distribution, researchers have created a probabilistic operating time for a sensor node that allows it to function flawlessly within the interval of (0, t).

$$R_k(t) = \exp(-\lambda_k t) \tag{6}$$

where, t and λ_k are time period of kth sensor node and the corresponding failure rate [39].

Connectivity

The inter-cluster head's connectivity becomes a major difficulty that ensures data transmission from SNs to BS. The data transmission path's accessibility guarantees the connection to the base station. Researchers suggested numerous protocols to assure the interface between SNs in WSNs. Investigator suggested swarm optimization protocol in order for increasing the lifetime of network by maintaining network connectivity. It works for heterogeneous networks and estimates [39] the maximum number of energy-constrained relay sensor nodes. In another research work [40], researchers have suggested a novel network connectivity protocol to observe as well as sustain the dynamic mobile WSN. Investigators assessed the limits of influences on WSN to depict an evaluation system of connectivity with great accuracy. The energy hole must be avoided that assures connectivity by utilizing the clustering protocols with effective distribution of cluster heads over the complete WSN [33, 41-44].

Scalability

The ability of routing algorithms to manage varying WSN sizes is another crucial feature of these algorithms. Typically, depending on the need, there can be hundreds or even thousands of SNs. In order to autonomously manage densely populated networks, routing protocol and application behavior are also necessary. Moreover, a routing protocol needs to react to each incident that happens in the vicinity of it in an efficient manner [4, 32]. A domain's density is commonly defined as the total number of sensor nodes (SNs) within it; nevertheless, the region's diameter may be less than 10 m [45]. The density of sensor nodes in area A is [46]:

$$Meu(R) = \frac{N\pi R^2}{A} \tag{7}$$

where, N is the sensor node number and R is their corresponding transmission range.

Technical Specifications of Hardware

Four essential components make up a sensor network (SN), including transceivers, data processors, power supplies, and sensing devices (sensors, ADCs). Additionally, components that vary depending on the application, including GPS and energy sources, are also important components. The sensing unit's responsibility is to gather data from the surrounding environment and transmit it to the processing unit. Following data processing, the processing unit must send the data to a transceiver so that it can be shared with the network and then transferred to the base station (BS). The SN size reduces with the passage of time. In general, sensor nodes are implemented under unattended and harsh environments that requires the power supply with great significance. Any sensor has transceiver as the most expensive unit because of the performed operation such as modulation/demodulation, filtering and data communication [47].

Transmission Media

The transmission media in multi-hop WSN communication provides the connections between several sensor nodes that are either optical, infrared or radio links. Radio connections used industrial, scientific, medical (ISM) bands for these communication type because of no standardization issues and high spectrum allocation. Infrared link is also a license-free mode. In case of hierarchical clustering, multi-hop communication performs the inter-cluster communication. The problems associated to the wireless channel may impact on such interface. For intra-cluster communication, HEED and its extended form can use the TDMA based medium access control (MAC) protocol [3, 44, 48].

Data Aggregation and Processing

Sensor nodes in a wireless sensor network may collect undesired and similar data from several observations. Data compression methods for multiple signal processing can be used to handle redundant data. Among the techniques are beamforming, principal component analysis, independent component analysis, and nonlinear principal component analysis. Optimization of data packets can be performed by the data compression of data aggregation i.e. being transferred to base station through multi-hop transmission. It further increases the lifetime of a network [3, 33, 44]. When compared to data processing, data communication uses a lot more energy. The data communication of 1 kB data, or almost 100 million instructions per second per watt, over a distance of 100 meters has been demonstrated by researchers [47]. This research confirms that processing data using the hierarchical clustering approach at the cluster head level lengthens a network's lifespan.

Quality of Service

A small number of delicate, time-sensitive applications must detect data from sensor nodes instantly, or else the significance of delayed data is lost. The majority of applications are able to make trade-offs between quality of service reduction and network lifespan improvement [2, 45].

The term Quality-of-Service (QoS) describes traffic control systems that aim to guarantee or predictably perform for applications, sessions, or traffic aggregates, or to discriminate performance based on application or network-operator requirements. Fundamental QoS phenomena are defined as packet latency and several types of losses.

Unified communications (UC) networks enable seamless collaboration and communication across multiple devices and platforms. To ensure the quality of the UC network, it needed to measure various metrics and indicators that reflect its performance and health. These include latency, jitter, packet loss, and bandwidth. Latency should be below 150 milliseconds (ms) for voice and video calls, while jitter should be below 30 ms. Packet loss should be kept below 1% for voice and video calls. Bandwidth should also be sufficient to support all UC applications and devices without compromising QoS. Numerous metrics related to Quality of Service (QoS) hold significance in schedulability analyses. One example of a Quality of Service (QoS) parameter is the duration of operations. The QoS parameters at the class level comprise, among other things, the following attributes:

·Minimum arrival time
·Average arrival time
·Execution time
·Blocking time
·Jitter

To carry out schedulable analysis both theoretically and empirically, values for these parameters are required. The determination of an acceptable set of QoS timeliness attributes is a key objective for future real-time expansions to the UML. UML-tagged values would be the logical way to do it.

Improvement in Lifetime of a Network

The network lifespan is the crucial parameter in WSNs. This allows sensor nodes to conserve their limited energy resources, which also limits their capacity for processing and transmitting data. Effective strategies are created to extend the network lifetime for the election of cluster leaders, and efficient data routing methods are adopted to facilitate communication between inter-cluster nodes. The SNs have the most energy and are more central to their neighboring SNs. Cluster heads are the nearest supernovae. The inter-cluster interface that maximizes energy efficiency should select the shortest routing path with the highest relative energy of SNs. Network lifetime can also be increased during intra-cluster transmission by taking multi-hop data transmission into account in clusters that are relatively larger in size.

Avoidance of Hot Spot and Energy Hole Issues

In general, a number of WSN protocols are used for data transmission from SNs to BS in inter-cluster node data communication. In these kinds of WSNs, SNs serve as communicating sensor nodes in addition to transferring the data they have personally collected. In comparison to the distant signal nodes, the sensor nodes close to the base station are able to transport more packets. As a result, in comparison to the sensor nodes that are farthest away, the nearby signal nodes run out of energy sooner. Network partitioning happens and is referred to as the energy hole or hot spot problem [16, 49]. Insufficient grouping is recommended to avoid the energy hole issue and to distribute energy usage evenly throughout the network [15, 24, 42, 43, 50]. Clusters closer to the base station are larger than clusters farther away, according to the uneven clustering approach. This idea can limit how much energy SNs nearer the BS need for issues like data processing and intra-cluster interfaces, and the extra energy can be used for data relay [51].

Reduction of Collision and Latency

The WSNs can be divided into clusters using clustering techniques. Both intra-cluster and inter-cluster (multi-hop) communication are used in clustered networks to transfer data. Cluster heads have the ability to communicate amongst other52While network information can be forwarded to base station via an inter-cluster interface, intra-cluster communication takes place within a cluster.

Table 3 addresses various challenges that are to be faced in previous algorithm and it shows challenges along with its provided solution in proposed algorithm.

Table 1. Comparative analysis of Single-hop LEACH and its successors [52]

LEACH and Its Successor	Year	Clustering	Overhead	Scalability	Energy Efficiency	Location Required	Load Balance	Complexity	Delay
LEACH	May 2000	Distributed	High	Low	Moderate	No	Bad	Low	Small
LEACH-C	Oct 2002	Centralized	Low	Low	High	Yes	Moderate	Moderate	Small
LEACH-DCHS	Sept 2002	Distributed	High	Low	High	Yes	Good	Moderate	Small
Solar-LEACH	June 2004	Hybrid	High	Moderate	Very High	Yes/No	Moderate	High	Small
SLEACH	April 2005	Distributed	High	Moderate	Very High	Yes	Moderate	High	Small
LEACH-Mobile	June 2006	Distributed	Very High	Low	Low	Yes	Bad	High	Small
Sec-LEACH	July 2006	Distributed	Very High	High	Low	No	Moderate	Very High	Small
A-SLEACH	April 2007	Distributed	High	Moderate	High	No	Good	High	High
Q-LEACH	May 2007	Distributed	High	High	High	Yes	Good	High	Small
Energy LEACH	Oct 2007	Distributed	High	Moderate	High	No	Good	High	High
LEACH-L (UWSN)	Dec 2007	Distributed	Moderate	High	Moderate	Yes	Good	Low	Small
ME-LEACH	July 2008	Distributed	Low	Low	Moderate	Yes	Bad	High	Small
Armor-LEACH	Aug 2008	Distributed	Very high	Low	Low	No	Good	Very High	Small
TB-LEACH	Sept 2008	Distributed	High	Moderate	Moderate	No	Good	High	Small
ME-LEACH	Dec 2008	Distributed	Very High	Low	Moderate	No	Bad	High	Small
ALEACH	Dec 2008	Distributed	High	Moderate	High	No	Good	Very High	Small
T-LEACH	June 2009	Distributed	Moderate	High	High	Yes	Good	High	Small
LEACH-H	Nov 2009	Hybrid	High	Moderate	High	Yes	Moderate	High	High
U-LEACH	March 2010	Distributed	Low	Low	High	Yes	Good	High	Small
LEACH-B	Aug 2010	Distributed	High	Low	High	Yes	Good	High	High
LEACH-GA	April 2011	Distributed	High	Low	High	Yes	Low	High	Small
MS-LEACH	June 2011	Distributed	Very High	High	Low	No	Bad	High	Small
FL-LEACH	April 2012	Distributed	Low	High	Low	Yes	Good	High	Small
LEACH-SWDN	May 2012	Distributed	Moderate	High	Low	Yes	Moderate	High	Small
EP-LEACH	April 2013	Distributed	High	Low	Very High	No	Good	High	Small
I-LEACH	May 2013	Distributed	Moderate	High	High	Yes	Good	High	Small
MOD-LEACH	June 2013	Distributed	Low	Moderate	High	Yes	Good	High	Small
Weighted-LEACH	Aug 2013	Distributed	High	High	High	Yes	Good	High	Small
LEACH-G	Oct 2013	Hybrid	Low	High	High	Yes	Good	High	Small
BC-LEACH	Nov 2013	Centralized	Low	High	High	Yes	Good	High	Small
LEACH-CE	Dec 2013	Centralized	Low	Low	Very High	No	Good	Moderate	Small
FT-LEACH	March 2014	Distributed	High	Low	Moderate	Yes	Bad	High	Small
IB-LEACH	Aug 2014	Distributed	High	Low	High	No	Good	High	Small
CogLEACH	Oct 2014	Distributed	High	High	Moderate	No	Bad	Moderate	Small
V-LEACH	June 2015	Distributed	High	Low	Very High	No	Good	Very High	High
CogLEACH-C	Aug 2015	Centralized	High	Low	High	Yes	Good	Moderate	Small
EMOD-LEACH	Sept 2015	Distributed	High	Low	High	Yes	Good	Moderate	Small
EHA-LEACH	Feb 2016	Distributed	High	High	Very High	Yes	Good	High	Small
LEACH-MAC	July 2016	Distributed	High	Moderate	High	Yes	Good	High	Small

Table 2. Comparative analysis of Single-hop LEACH successors on other parameters

LEACH Successor	Method of Transmission	Topology of Clustering	Size of Cluster	Cluster Motion	Deployment Method	CH Rotation
GATERP [53]	One-Hop	Centralized	Equal	Static	Homogenous	Yes
HACH [54]	One-Hop	Centralized	Unequal	Static	Homogenous	Yes

MRP-ACO [55]	One-Hop	Hybrid	N/A	Static	Heterogeneous	N/A
GADA-LEACH [56]	Multi-Hop	Distributed	Equal	Static	Heterogeneous	No
ERP [57]	Multi-Hop	Distributed	Equal	Static	Heterogeneous	No
ABC-SD [58]	Multi-Hop	Centralized	Unequal	Static	Homogenous	No
ICWAQ [59]	One-Hop	Centralized	Equal	Static	Homogenous	No
Bee-Sensor-C [60]	Multi-Hop	Distributed	Unequal	Static	Homogenous	No
TPSO-CR [61]	Multi-Hop	Centralized	Equal	Static	Homogenous	No
PSO-ECHS [62]	One-Hop	Centralized	Unequal	Mobile	Homogenous	Yes

Table 3. An energy-efficient routing protocols challenges and solution in the proposed method

Challenge	Proposed Solution
Sensors Deployment	Dynamic
Load Balancing	Clustered
Fault Tolerance	Distributed by probabilistic selection of cluster heads.
Connectivity	Through cluster heads
Scalability	Nodes can be added into nearby clusters
Hardware Specification	Sensors, Base station, Sink etc.
Transmission Media	TDMA/CSMA
Data Aggregation and Processing	At cluster heads data aggregation and fusion are applied
Quality of Service	Data security and Integrity
Network Lifetime	Prolong network lifetime by reducing energy consumption
Hot-spot effect reduction	Distance aware approach is used
Reduction of collision and latency	Inter-cluster and Intra-cluster reduction of collision is applied

3. METHODS

This paper describes an advanced version of LEACH protocol that depends on clustering routing technique. It considers a threshold value of an optimal distance among sink and node. A node act as a forwarder node if it is placed under the optimal distance and will not contribute in clustering. The entire clusters deliver data to such nodes via cluster heads that is to be further transferred to the BS. In clustering, the remaining nodes participates according to the probabilistic approach named as LEACH protocol. This paper suggested a novel scheduled probabilistic clustering routing approach. Probabilistic approach can perform the clustering. SNs still dissipate some energy during the no transmitting phase. Sleep-wake up method can lessen the energy consumption at SNs. In this approach, SNs remain on sleep mode or inactive mode up to these have no data transmission/reception. Therefore, energy drainage because of idle listening is decreased.

Pseudo code for Hot-spot effect

Step 1: Disperse sensors at random across the sensing field.

Step 2: Assume an ideal distance, Opt_Dist, for i=1 to n (number of nodes). Repetition of steps 3 and 4 is required.

Step 3: Calculate the "d" distance between the sink and node.

Step 4: Flag(i)=1 if (d<=Opt_Dist) otherwise Flag(i)=0.

Step 5: If Flag(i)=0, apply LEACH-based clustering based on the Probabilistic Approach for all nodes.

Step 6: Finish

Pseudo code for Idle listening

Step 1: Place sensors in the sensing field at random.

Step 2: For i=1 to R (number of rounds) Steps 3 through 6 should be repeated.

Step 3: Choose the cluster head using a probabilistic technique and residual energy.

Step 4: Counting the number of nodes (i=1 to n).

Step 5: Communicate data since opt_time if Node[i]!=Node[i].Sleep state; n = n+1;

Step 6: If Node[i].receiveData= true; if (Node[i].State=sleep) Node[i].State=Wakeup;

Step 7. Finish.

The energy harvesting schemes for WSN have some framework for the suggested algorithm, which are as follows:

·Implementation of a set consisting N SNs in a two-dimensional structure as A × A with large area.

·Implemented sensor nodes carry the characteristics in a random manner.

·Homogeneous techniques are used for initial energy distribution, Eo.

·Base stations as well as all the connecting nodes are in stationary states.

·Using CSMA and TDMA techniques, this model takes into account the data interface from a cluster member to CH or CH to sink node.

·Harvesting device module is connected to every sensor node.

·When the deployment is in the initial time, every SN has the equal energy amount E0.

·The energy harvesting rate of each SN varies and ranges from ½ to 0; Umax.

·All SNs have the ability to collect energy from the ambient resource or battery.

·In the majority of the rounds in this constructed model, the energy harvesting rate is lower than the energy consumption rate.

·The entire energy harvesting in WSNs operation has been categorized into the round r.

Because ambient resources are unpredictable, energy prediction is a significant challenge for energy harvesting models. Therefore, the energy harvesting techniques of WSNs mostly depend on energy resource management. Exponential Weighted Moving Average (EWMA) is one trending method for estimating the resource that generates uncontrolled energy. The EMWA method is based on the identical time slots that happen throughout the day, which are indicated by the slot duration.Such system depends chiefly on the intensity of sunlight. Kansal [63] discovered a diurnal scale graph depicting that the energy harvesting rate depends on the collected data from sunlight. Nevertheless, the EWMA prediction model also depends on the different seasonal conditions that require to maintain a historical summary. The mathematical equation for estimated energy (E) and harvesting energy (H) is shown in Eq. (9). Such represent the total by using a weighting factor ranges as 0\a\1. In this, a represents high value, while the last harvesting energy is smaller and vice versa. In this expression, n refers the time slots and d represents as present-day.

$$E(d, n) = \alpha E(d-1, n) + (1-\alpha) H(d-1, n) \tag{8}$$

Deployment Strategy

The "Atmel Sam3x8e ARM Cortex-M3" microprocessor was embedded on an "Arduino Due" microcontroller in our network [23]. For a railway control case, a related system utilizing the Xbee mote and depending on Arduino has been depicted. While numerous commercial nodes are static for the physical as well as MAC layers, working with the Arduino microcontroller offers a simple programming interface for the entire layers. The SN is connected to the system by the RF transceiver. The RF module typically functions in one of three modes: send, receive, as well as rest. More energy is consumed in the transmit mode. The medium access algorithm used may affect how much energy is used in the other modes.

Data Transmission

Every cluster head utilizes a non-persistent carrier sense multiple access (CSMA) MAC approach to broadcast an advertisement message (ADV) inside the range Rc. Such message is very small consisting the header and node id of several messages for a declaration purpose. Each non-CH node chooses the CH that requires the shortest transmission range in order to estimate its cluster for the current round. Each node transmits the signal to the join-REQ message and onward to the CH via the non-persistent CSMA MAC protocol. Following cluster formation, CH establishes a TDMA schedule for data transmission from cluster members to CH. The number of sensor nodes in a given cluster determines the TDMA utilization rate. There may have been a collision if the system had more cluster members. The cluster's TDMA scheduling can be used to prevent this collision. Sleep wake protocol can also be provided using TDMA method. It stipulates that each CH gives cluster members a certain amount of time to schedule. After finishing their work, cluster members go into sleep mode. This method can spare a node's excess energy. Another name for this approach is the duty cycle technique.

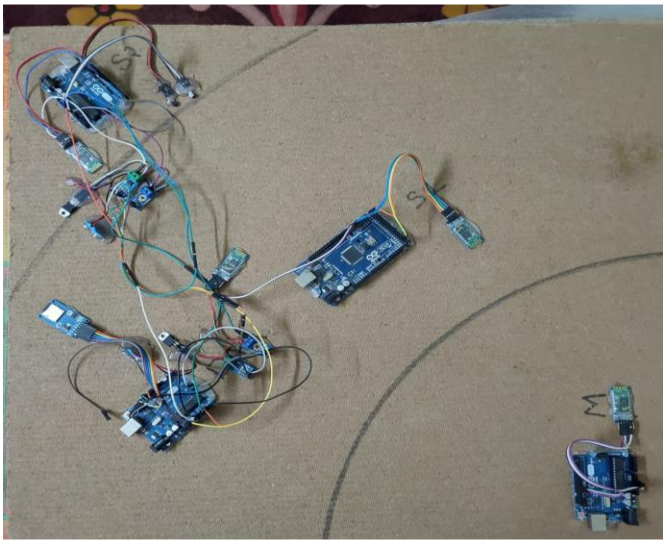

Figure 3. Small embedded scenario for WSN

Following are the hardware details of created embedded scenario (Figure 3):

·REES52 Bluetooth Transceiver

·ROBODO MO41 USB to RS232 PL2303 TTL converter Adaptor for ARDUINO Nano Raspberry Pi

·MicroSD Class 10-8 GB memory card

·9V Rechargeable battery

·REEs52 Arduino Uno R3

·ACS712 30A Hall Current Sensor Module

·Voltage sensor module (25 V)

TDMA schedule can decide the data transmission via CH after setup phase completion. Such phase is categorized as the inter-clustering, intra-clustering and sub phase communication. The CH gathers data from the entire cluster member at the time of intra clustering transmission. Furthermore, least amount of energy is used by the transmission phase. Each member of the cluster has the ability to disable radio energy up to the transmission time allotted by SNs in order to minimize energy consumption in their nodes. The CH gathers and stores data about the received signal from cluster members. Once all the data has been received, the cluster head processes it to create a single signal by compressing it. Data aggregation techniques are procedures that remove redundant and duplicate data.

Afterwards, data aggregating cluster head transfer data to the BS in inter clustering phase by utilizing the single- or multi-hop routing. Another popular protocol is fixed spreading code or CSMA that transforms the data from CH to BS. When CH needs to transfer the information, it should sense the channel first. It requires to wait if it is busy. Else, the cluster head instantaneously transmits information utilizing the base station by spreading code to the BS.

This system utilized an Arduino UNO R1 as well as a PC with Windows 7 as well as E-Prime 2.0.10.182 (Intel Core 2 Quad Q6600, 2.4 Ghz). Sequential port associations were set to 128,000 baud. The outer DAQ was a CED Miniature 1401 mk II (from Cambridge Hardware Gadgets, UK) inspecting at 10000 Hz. For this test, we utilized an Arduino Uno R3. The connection to USB is handled by an Atmega16U2 chip. The board was attached to a Sony laptop running EPrime 2.0.10.242 and equipped with an Intel Core i5 processor. For every preliminary, the preliminary length shipped off the Arduino was 100 ms. The Arduino only waited for the specified 100 milliseconds while examining the conditions of the two connected buttons as well as then transmitted back the time it really waited. For each of the following baud rates, we conducted 500 consecutive trials: 14,000, 38,400, 57,600, 115,200, and 128,000 (all set in E-Prime, the Windows instrument controller, and the Arduino code). We deducted the time the Arduino stated waiting from the response latency calculated by E-prime, which is the time among transmitting as well as obtaining from the serial port, in order to calculate the delay caused by the USB communication.

Figure 4 is for sequential flow of proposed algorithm.

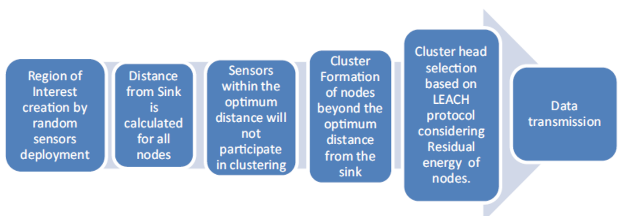

Figure 4. Sequential flow of proposed protocol to overcome hot-spot effect

All through the reenactment, a 100×100 organization setup with 100, 200 as well as 300 hubs is thought about where every sensor hub is relegated an underlying energy of 0.5 J, how much transmission energy is 50 nJ/bit, communicate enhancer energy (Eamp) is 100 pJ/bit. In our reproductions, all sensor hubs are expected to do detecting activity at a proper rate as well as consistently have information to transmit when they get messages from the sink hub. It is likewise expected that entire information transmitted by the past hubs are totaled into an information fragment with a consistent size of 4000 pieces. The channel has the maximum baud rate of 38400.

4. RESULTS AND DISCUSSION

A hardware is developed to validate the authenticity of designed advanced LEACH algorithm. The whole system depends on the Master-Slave concept. It has three clusters and each clusters have many cluster members and single cluster head. When the signal is given, the cluster node gets activated and after passing the signal to next node, the previous node automatically goes in sleep state. It saves a lot of energy consumption as well as the battery life. The technical specifications of the designed algorithm are shown in Table 4. The total rounds were 5000 including two systems. In one the total nodes were 100, while in other the nodes were 200. The EDA of the circuit is 0.5. Initial energy consumption of the circuit is 0.5 J, while the final energy consumption is 10 pJ and Emp is 0.0013 pJ.

Table 4. Technical parameters taken in MATLAB simulation

Simulation Constraints	Value
Total rounds	5000
Total nodes	100, 200
EDA	0.5
Eo	0.5 J
Efs	10 pJ
Emp	0.0013 pJ

Table 5. Simulation results for 100 nodes to show comparison of lifetime of nodes between LEACH protocol and developed approach

	LEACH	Developed Advanced LEACH
Nodes Simultaneously Death and Active States (in Rounds)	2268	3762

Table 6. Simulation results for 200 nodes to show comparison of lifetime of nodes between LEACH protocol and developed approach

	LEACH	Proposed Advanced LEACH
Nodes Simultaneously Death and Active States (in Rounds)	2716	3700

This research work also presents the comparative analysis between LEACH and advanced LEACH protocol for clustering routing protocol. The system operated with 100 nodes first, after that additional 100 nodes were connected (Figure 5). In case of 100 nodes, the first node dead at the round at 997, while for advanced LEACH it is 1236. Whereas the last node dead at round at 3265 and for advanced LEACH it is 4998. Table 5 depicts results of dead and active states nodes by using LEACH protocol and proposed advanced LEACH protocol that are 2268 and 3762 at N=100.

In case of 200 nodes, the first node dead at the round at 992, while for advanced LEACH it is 1299 (Figure 6). Whereas the last node dead at round at 3708 and for advanced LEACH it is 4999. Table 6 depicts the outcomes of dead and active states nodes by using LEACH protocol and proposed advanced LEACH protocol that are 2716 and 3700 at N=200.

As shown in Figures 7 and 8, the voltage drop occurred at battery without sleep and wakeup scheduling at the 27259, while the voltage drops at battery with sleep and wakeup scheduling by using Watchdog algorithm is 58411. It means that the circuit requires more sleep time to consume less battery in order to perform the same task. It can enhance the efficiency of the whole circuit.

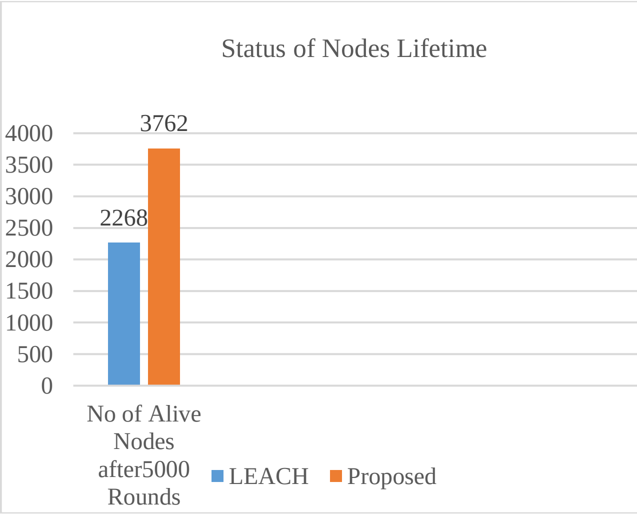

Figure 5. Lifetime status comparison of 100 nodes in a simulation scenario using LEACH and the proposed technique

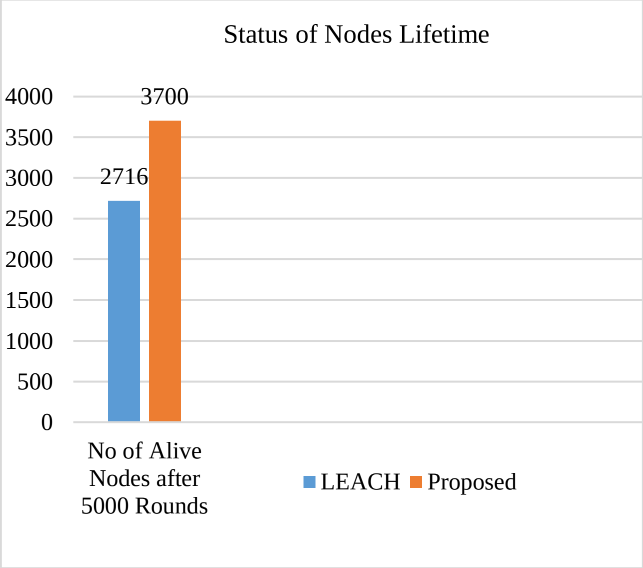

Figure 6. Compares the lifetime status of 200 nodes in a simulation scenario using LEACH versus the proposed technique

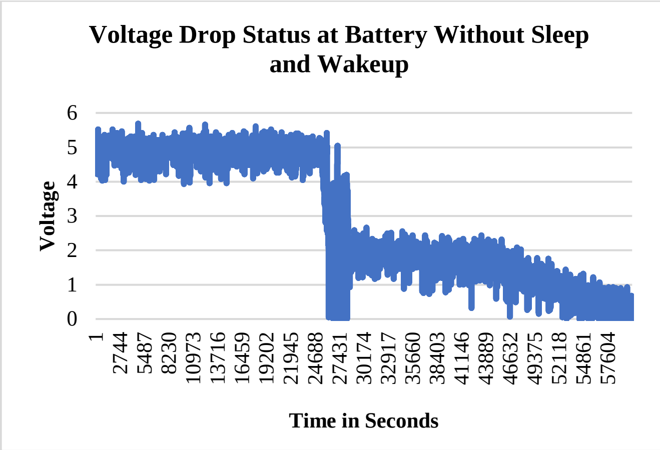

Figure 7. Embedded scenario simulated for 24 hours, calculated Voltage drop at battery without applying sleep and wakeup scheduling

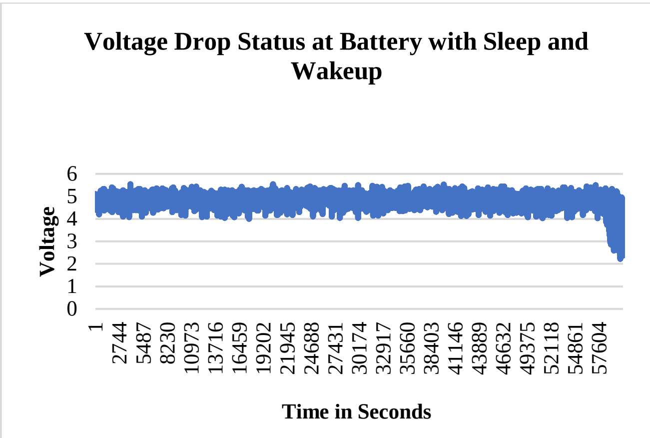

Figure 8. Embedded scenario simulated for 24 hours, calculated Voltage drop at battery with applying sleep and wakeup scheduling (Watch Dog Protocol)

In this exploration, we proposed a planned probabilistic bunching convention. Probabilistic methods are used in clustering. At the point when sensor hubs are not in the communicating stage, actually scatter some measure of energy. This energy utilization can be diminished by relating rest awaken method at sensor hubs. In rest awaken method, sensor hubs stay dormant (rest mode) until they have no information to send/get. As a result, inactivity-induced energy loss is reduced. The hot-spot effect is used in the proposed technique to reduce the energy usage at the sensors. The suggested method prevents the hotspot effect, which eventually lengthens the network's lifespan. The suggested method reduces the energy usage at the sensors during the period of idle listening, when they use some energy but don't send any data.

For this sleep and wake-up approach is used to avoid idle-listening energy consumption.

5. CONCLUSIONS

Wireless sensor networks feature a tremendous scope with enormous number of applications. Several applications between these protocols are energy constraint. WSN has some prevailing techniques that have the potential to attain the energy efficiency. Clustering becomes an appropriate approach that optimize a system. The LEACH procedure is used by the clustering approach, which produces very good energy-efficient results. Although these protocols work extremely well, these systems nonetheless have some serious problems. In idle listening, energy consumption is significantly dependent. In an idle state, SNs dissipate some energy for listening data apart from data transmission. Keeping nodes in sleep mode can reduce this energy consumption during no data transmission mode. Also, when they need to transmit data, it makes them awaken. This work provides an advance form of LEACH-based probabilistic clustering approach. It is a hybrid system to solve the issues of sleep-wake up and hot-spot effect to attain the high energy efficiency. Findings depict that the developed system provides effective results with great performance. Clustering is the process of identifying a natural link between certain things or data, or the grouping of comparable objects. It is used in a variety of fields. Especially in sensor networks, clustering can be used to overcome a number of issues. It reduces the number of nodes involved in long-distance communication by using clusters to send processed data to base stations. This has a direct impact on the total energy dissipation of the system. In addition to sensor networks, data mining and VLSI-CAD have made extensive use of clustering. Clustering is used by a classical analytic VLSI placer to efficiently place standard cells. In this paper, we investigate numerous examples of the clustering problem and find optimal solutions to a few intriguing cases. There are numerous uses for these issue situations in sensor networks, particularly in energy management and master node selection.

The Watch Dog Protocol is used to address the Idle listening problem, it introduces a mechanism where nodes alternate between active and sleep states. During active periods, nodes monitor the channel for incoming data while in sleep period, nodes power gets down. To support this concept, a small embedded scenario has been created. Results show that voltage drop (With Watch Dog) at the battery occurred after a longer time than applied without the Watch Dog concept.

The paper also bridges the gap between manufacturing, design, and computing by addressing practical challenges in deploying WSNs in manufacturing environments. It offers insights into how the design of sensor networks impacts manufacturing processes, contributing to more efficient and optimized manufacturing operations. It may also discuss the hardware design considerations for sensors in manufacturing, considering aspects such as power efficiency, robustness, and communication capabilities. Overall, the paper's focus on an energy-efficient clustering approach for WSNs aligns well with the scope of covering manufacturing, design, and computing. It offers practical solutions to challenges faced in manufacturing settings, where effective sensor network deployment can lead to significant improvements in production processes and overall operational efficiency.

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NOMENCLATURE

WSN	Wireless Sensor Network
MATLAB	Matrix Laboratory
SN	Sensor nodes
MEMS	Micro electro-mechanical system
BS	Base station
CH	Cluster head
HEED	Hybrid energy-efficient distributed clustering
LEACH	Low-energy adaptive clustering hierarchy
EEUC	Energy-efficient uneven clustering
PEGASIS	Power-efficient gathering in sensor information systems
TDMA	Time Division Multiple Access
HUCL	Hybrid unequal clustering layering protocol
ERA	Energy-aware routing algorithm
SEED	Sleep awake energy-efficient distributed
EAUC	Energy-aware unequal clustering
DPSO	Discrete particle swarm optimization
EELBC	Energy efficient load-balanced clustering
ICA	Independent component analysis
PCA	Principal component analysis