

AN IMPROVED APPROACH FOR CONGESTION CONTROL IN WIRELESS SENSOR NETWORK

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ABSTRACT

The Wireless Sensor Network (WSN) is used in an environment where wires or cables are not possible to reach or installation cost is comparatively much higher. WSN is easy to install and maintenance is less as compared to cable network. WSN is a combination of small sensor nodes where resources are running on these nodes to consume the energy. Increase the life of WSN, there is a need of clustering which divides the load between the nodes. In the literature we have seen various congestion control clustering algorithms to increase the lifetime of the WSN. The aim of this research work is to provide effective congestion control clustering mechanism to increase the network stability. In this work, we have studied and analyze existing priority based application specific congestion control clustering protocol. We have analyzed and compare existing protocol with the proposed protocol on the basis of parameters lifetime, no of rounds, throughput. We have implemented a congestion control using grid-based clustering technique. With the help of this technique congestion is less as compared with an existing technique. The experimental results are showing that our grid based network performance is much better than the PASCOC.

1. INTRODUCTION

1. WIRELESS SENSOR NETWORK: The **Wireless Sensor Network (WSN)** is used in environments where wires or cables are not feasible to install or where installation cost is comparatively much higher. WSN is easy to install and requires less maintenance compared to a cable network [1]. Nowadays, wireless systems and Mobile Ad-Hoc Networks (MANET) are widely used for the purpose of data transfer. With the latest WSN technologies, small sensor nodes are being used for transferring data packets. A few sensor nodes are utilized to handle these data packets. Traffic jams typically occur while transferring data from the source node to the sink node. In WSN, every sensor node requires detailed hardware such as receiving mechanisms, memory, processing units, etc. [2].

Energy is an essential parameter while transmitting data in the network.

WSN is used in many areas:

- Home CCTV camera networking
- Military regions
- Pollution monitoring
- Aircraft management
- Traffic management systems
- University intranet

1.1 CLUSTERING (GROUPING)

The main goal of clustering in wireless sensor networks is to collect data packets between sets of nodes within a group. After collecting the data packets, the cluster head is responsible for transferring those packets to the Base Station (BS) [3]. Clustering provides a good lifetime to a wireless sensor network. Clustering usually uses two techniques. First, it elects a cluster head with a higher energy level. Second, it rotates the cluster head in every round to distribute the energy load among the nodes in each cluster group. Energy consumption notification in clustering is a function that provides information about the remaining energy. Each sensor node has its own energy level. Apart from this, a lot of work has been done in WSNs with the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol. Nowadays, there are other clustering methods that are commonly used in place of the LEACH protocol. These methods include HEEP (Hybrid Energy Efficiency Protocol) and PEACH (Power Efficient and Adaptive Clustering Hierarchy) [3]. The objective of these methods is to minimize energy usage by the sensor nodes.

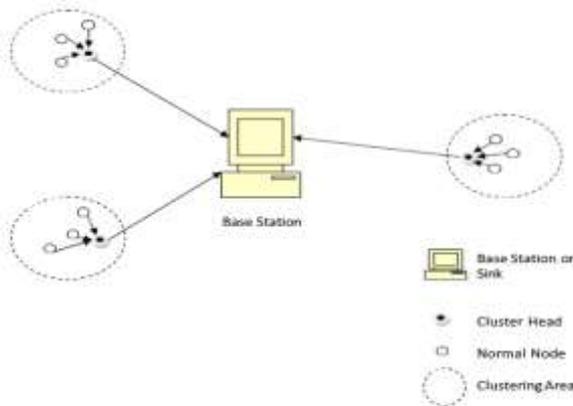


Figure 1.1: Overview of wireless sensor network [2]

Clustering Objectives

Clustering is a way of grouping the nodes. It is mostly used in wireless networks. Various aspects are involved in clustering. The main objectives of clustering are listed below.

1.1.1 Fault-tolerance

WSN networks are connected with small sensor nodes. Each node has its own battery life and hardware. In the complete system process, functional failure of each node is to be inspected, including when a node acts as a CH (Cluster Head). This issue arises when some sensor nodes suddenly stop working in harsh situations or under different circumstances. Some nodes may get physically damaged or crash. To deal with such issues, several clustering methods are recommended. It is the responsibility of the clustering mechanism to remove the failed node from the connected network or to switch the network to another working node to transfer the data packets [4].

1.1.2 Maximizing Network Life-time: There are different kinds of wireless networks such as mobile networks. Resources run on these networks and consume the energy of nodes. Battery life of these nodes is quite limited in mobile networks. While transferring data packets from one node to another, the energy level decreases every time. To manage energy consumption in WSN, clustering plays an important role in extending the lifetime of nodes and reducing their burden during data transfer. A few methodologies are used for transmitting data packets to the base station through the cluster head. The main aim of clustering is to offer an energetic node, called the CH node, in every cluster group. In each round, the CH node is changed based on its energy value. Through this rotation of the CH node, the network lifetime is improved [8].

1.1.3 Load Balancing

In the clustering mechanism, load balancing is another useful technique. In every round, while transmitting data packets from one node to another, the available energy of each cluster member node is checked [12]. Therefore, in every round, the energy of the cluster head node is also checked, and the node with the maximum energy level gets elected as the cluster head. So, in each round, the sensor node may be rotated, ensuring the load is balanced. This load balancing technique helps in the efficient transmission of data packets. Figure 1.2 below shows the concept of load balancing.

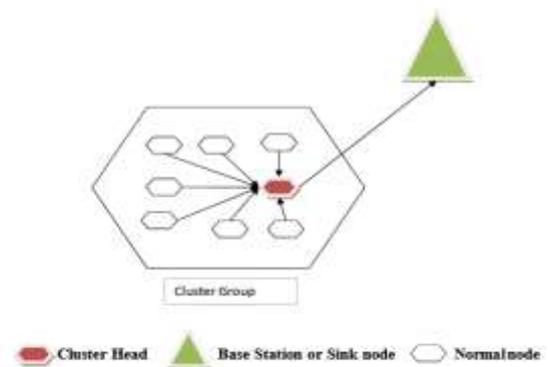


Figure 1.2: Clustering mechanism in WSN [5]

Types of Clustering

There are basically two types of clustering mechanisms used. The first one is inter-clustering and the second one is intra-clustering. The whole network is divided into several regions, and each region is called a cluster group. Inside a group, there are non-cluster-head nodes and a cluster-head node. Intra-clustering is a mechanism where communication happens between the nodes within the same group. Inter-clustering is a mechanism where the node of one group sends data to the node of another group; this is called inter-clustering. Most of the time, inter-clustering happens with the help of cluster-head nodes in various groups.

1.2 PASCCC – PRIORITY-BASED APPLICATION SPECIFIC CONGESTION CONTROL CLUSTERING PROTOCOL

PASCCC was the protocol used to enhance the network lifetime using energy management. In this network, the energy is divided among the nodes. The data was transferred through the nodes. A problem arises when all sensor nodes need to send

data packets to the sink node, which creates congestion and results in overloading. PASCCC introduced a cluster hierarchy using congestion detection and mitigation based on the priority of packets. The priority was based on two types of packets: humidity packets and temperature packets. In this network, the priority of humidity packets was lower compared to temperature packets. In this protocol, temperature packets needed to report immediately to the base station when the hard threshold was reached for a particular value [12]. With the help of the cluster head, packets reached the sink node as shown in Figure 1.2. When a node transfers data packets from one node to another, the available energy of nodes decreases. To resolve this problem, the sensor nodes were classified into small groups called cluster groups, where each group had a coordinator called the Cluster-Head (CH). In each cluster, the node having the maximum energy was elected as the CH node. Cluster-heads rotated randomly in each group due to energy consumption and communication overheads [13]. The threshold value [14] was used for CH selection. If the energy level of a CH was less than the threshold value, then that node would not be selected as a cluster-head in the current round. Apart from this, while using clustering, all normal sensor nodes did not require direct communication with the base station. Cluster heads are responsible for arranging the cluster members (CMs), collecting their data packets, and sending them to the base station. In WSN, every node has its timestamp. A timestamp is a time period during which a node must respond to another node. If a node does not respond due to any circumstance, all other sensor nodes must be re-clustered to identify the dead nodes. Finally, it should be noted that PASCCC was mainly designed to work in a temperature range of 50–100°C. As the author mentioned, the priority of temperature packets was high; therefore, during congestion, humidity packets were dropped from the queue to give priority to temperature packets. Every sensor node had temperature sensors that awoke only when a data packet with temperature above 50°C arrived. This value was saved in a local variable of each sensor node. Thus, this protocol only works where the key parameter is temperature.

1.2.1 Clustering Stages: PASCCC

- **Setup Stage**
- **Steady State Stage**

In the Setup stage, each sensing node had a random number. If that random number was less than the threshold value [12], then that node was selected as a cluster head (CH) for that specific round. The cluster head sent an acknowledgement message to

all neighboring nodes with its identity. After receiving the message, nodes transmitted a joining message to the CH. The probability of a node becoming a CH is $1/p$. If there were 100 nodes in a network, then each node could be a CH for a maximum of 10 times. After creating a cluster group, each CH assigned a TDMA slot to each of its group members. In PASCCC, 10% of the nodes were advanced nodes having greater energy compared to others. Therefore, a heterogeneous number of nodes were created in the network. In the Steady State stage, nodes transmitted data packets to their Cluster-Head. The CH then transmitted the data packets to the base station. After the steady state stage completed, a new round began for clustering where a new CH was selected based on energy levels.

1.2.2 Energy Dissipation: PASCCC

Energy consumption occurs in WSN due to transmission of data packets and data aggregation. Energy consumption of a cluster head is different compared to non-cluster-head nodes. Thus, in PASCCC, first the energy used by non-CH nodes is calculated and then the energy for the CH node using certain equations [12]. These equations help check the temperature, humidity, and energy level of nodes.

1.2.3 Mitigation and Congestion Identification: PASCCC

A balanced clustering mechanism was used in PASCCC to ensure the selection of different cluster-heads in each round. In cluster groups, some regions remained vacant. To handle this, PASCCC inherited a mobility feature which was used to cover vacant regions within cluster groups. The mobility mechanism ensured connectivity between nodes and covered empty areas. During connectivity, high-priority temperature packets were sent to the base station within the TDMA schedule. To reduce congestion, humidity packets were dropped. In PASCCC, sensor nodes were capable of covering vacant regions randomly and preventing packet loss. In the setup stage of PASCCC, the cluster-head assigned a TDMA schedule to its associated members. If the requested messages exceeded the threshold limit, the CH opened a **1-bit piggyback time slot** for non-CH nodes. When the piggyback slot was opened, the humidity sensor of the CH turned off automatically. The piggyback was used to prevent congestion in the network.

1.2.4 Queue Model: PASCCC

The queuing model [12] was based on First Come First Serve (FCFS). In this model, there were two load-balancing mechanisms:

1. Normal network mode (used when the packet load was normal)
2. Congested network mode (used when the network was overloaded)

In this model, the **PL** and **PH** parameters represented low and high priorities of packets, while **QTH** and **QTL** represented high and low threshold limits. Some rules of the queue-based model were:

- If congestion occurred, drop low-priority packets in the queue and keep high-priority packets.
- Incoming packets were buffered.
- If the queue reached the threshold limit, drop low-priority packets based on node type.

1.3 CCGBC – CONGESTION CONTROL USING GRID BASED CLUSTERING

Grid-Based clustering was a mechanism where the lifetime of the network was enhanced using energy management among the nodes. Nodes were rotated in each round, and the node with the highest energy in that group was elected as the cluster head. Figure 1.3 shows a grid-based network in which nodes are positioned randomly with different energy values. CCGBC was a cluster-based technique using congestion detection and mitigation based on packet priority. The priority of packets was based on the energy of the nodes. There was a queue in this model based on FIFO. The packet that arrived first in the queue with higher priority (based on node energy) was processed first. The inter-clustering mechanism was implemented in the CCGBC network. With the help of the cluster head, packets reached the sink node as shown in Figure 1.3

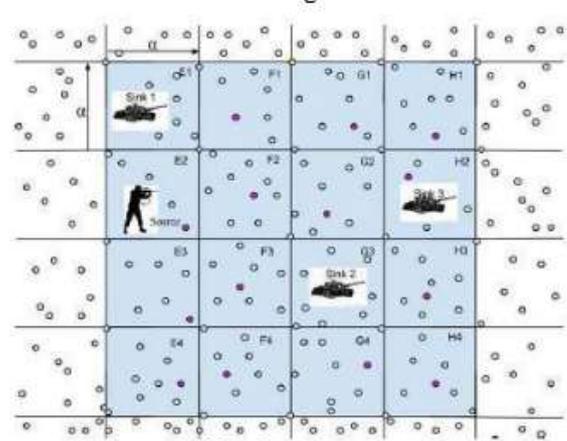


Figure 1.3 Grid based Network [55]

In the above figure, there were N-Sink nodes that collected data from their native nodes. In this setup, there were N cluster heads in the network. They collected the data from their native nodes and passed it to the cluster head of that group. The cluster head then forwarded the data to another cluster head until the packet reached the base station, which was known as the sink node. With the help of this network, we implemented our developed model, which is shown in Figure 1.4.

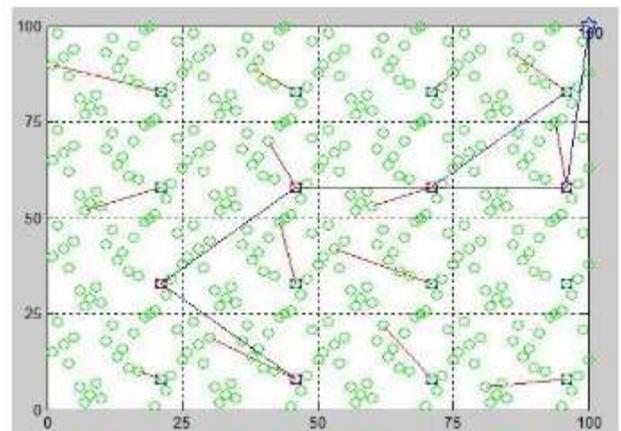


Figure 1.4 Cluster head based Grid

In the inter-clustering mechanism, when a cluster-head node transfers data packets from one cluster-head of a different group, the available energy of the nodes decreases. To resolve this problem, a load-balancing mechanism was implemented in the developed network, wherein the sensor nodes having high energy in every round were selected as the cluster-head node of that group, and so on. Cluster-heads rotate randomly in each group due to their energy consumption as well as communication overheads [13]. The threshold value [14] was used for CH

selection. If the energy level of a CH was less than the threshold value, then that node was not selected as a cluster-head in the current round. In Figure 1.4, there were various groups in the network and the nodes were placed randomly. Green rounded nodes were non-cluster-head nodes, and the rectangular-shaped node in each group was the CH node, which was elected based on its energy value. On the top right, there was a base station, which was referred to as the sink node. The responsibility of the cluster-head nodes was to collect the data from their native nodes and pass it to the base station with the help of the inter-clustering mechanism, where a CH node of one group transferred the data to another CH node of another group. This process continued until the data packet reached the base station. If a node was not responding due to any circumstance, its color was changed to red, marking it as a dead node. No data was transferred to dead nodes in this mechanism.

1.3.1 Clustering Stages: CCGBC

- Data Broadcast
- Data Forward

Data Broadcast:

In a grid-based network shown earlier in Figure 1.4, each grid was created with a 25×25 distance. In each group, there were normal nodes and a cluster-head node. Each node had its unique ID when packets were transferred from the normal node to the cluster-head (CH) node. A few parameters were considered, such as energy consumed while transferring the data packet, time consumed, and other relevant factors. Each node was randomly generated, and with the help of a mobility mechanism, nodes were rotated simultaneously. The cluster-head was more advanced, as it could transfer its data in all four directions—up, down, left, and right. Figure 1.5 shows how a CH can transfer its data in both directions. In our developed work, this criterion was followed.

Data Forward:

In this work, data packets were transferred from one CH to another based on two conditions: network traffic and the shortest path of CHs. A single cluster-head was compared with a maximum of 5 nearest cluster-heads, and after sorting, data was forwarded. The data was transferred through the shortest CH path, but if traffic occurred along that path, it was rerouted to the next optimal path. Through this mechanism, data was broadcast.

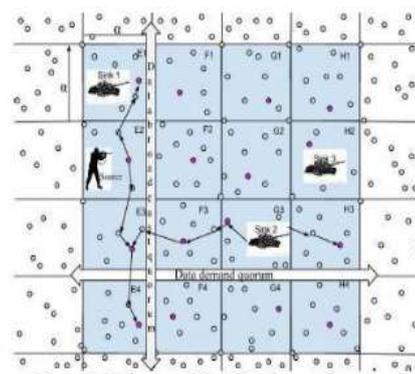


Figure 1.5 Data Broadcasting [55]

1.3.2 Energy Dissipation:

Energy consumption occurs in WSN due to packet transmission and data aggregation. The energy consumed by a CH is different from that of non-cluster-head nodes. In CCGBC, the energy consumed by non-CH nodes was calculated first, followed by CH nodes using certain equations [12]. These equations consider Euclidean distance, packet size, and node energy level.

1.3.3 Mitigation and Congestion Identification:

A balanced clustering mechanism was used in CCGBC to ensure different cluster-heads were selected in each round. In cluster groups, some regions remained vacant. To address this, CCGBC used a mobility feature to cover the vacant regions in cluster groups. The mobility mechanism ensured node connectivity and covered empty areas. In the base paper, the congestion rate was high compared to our proposed work because the network area was larger in the base paper, whereas the grid-based network in our work had smaller regions for CH selection. The area was divided into grids where each grid had a cluster-head that collected data from its native non-cluster-head nodes. During connectivity, high-priority packets were placed into the queue using data compression with the RLE technique within TDMA. To reduce congestion, low-priority packets were dropped from the queue.

1.3.4 Model of Queue: CCGBC

The priority-based queuing model [12] was used, based on first-come, first-serve. For overloaded and congested networks, a limit of 10 packets was set in a single group. A queue was not considered congested if packets were fewer than ten. When packet size increased beyond 10, congestion occurred, and packets at the front were dropped because the queue followed the FIFO model.

WSN. In this paper, it is explained that in clustering mechanisms, there is always a need for a cluster head. If the CH fails in any circumstances, it will stop receiving the data packets, and the data would be lost in this scenario. To resolve this issue, the authors present an alternative clustering wherein a BCH (Backup Cluster Head) will always be present in the absence of the CH. In this paper, authors discussed a self-configurable clustering (SCCH) mechanism to detect CH failure and replace it with a BCH in place of the failed CH. **A. V. D. Byl et al. [3]** state an evaluation of Compression Techniques for WSN. In this paper, the author discussed that in a wireless sensor network there is limited bandwidth between nodes, which makes it important to reduce the data bits to meet the application performance. If fewer data bits are transferred between nodes, then energy would be saved. So, for this, the authors show the various techniques for data compression in WSN. These compression techniques are lossless compression, lossy compression, and hybrid compression. The focus of this paper was to identify and evaluate compression techniques for data transmission and for saving energy. This paper compares lossless. **E. D. Raj et al. [4]** worked on a technique called **EDRLEACH** (Energy Distance Relation Low Energy Adaptive Cluster Hierarchy), which is based on distance-based cluster head selection. In this paper, the authors used an energy-efficient algorithm for selecting the cluster head. They showed the consumed energy by the cluster head and the relationship between cluster heads and non-cluster-head nodes. The authors also discussed a few limitations of LEACH, the comparison of node density and the distance between nodes. An energy-efficient formula is used to identify the node with the highest energy in the clustering groups, and that energetic node becomes the cluster head for the current round. This cluster head transfers the data packets to the Base Station.

Apart from this, the authors also discussed the energy consumed by the cluster head node itself so that in the next round, the node with the highest energy will again become the cluster head to transfer the data packets.

P. Papadimitriou et al. [5]

presented a new end-to-end node protocol called **Scalable Streaming Video Protocol (SSVP)**. In this protocol, various kinds of functions are used for unicast video streaming over UDP layers. SSVP employs **Multiplicative Decrease Additive Increase (MDAI)** techniques which manage and forward data packets efficiently and correct inter-packet gaps (GIP). This enables smooth video broadcasting. MDAI results show that SSVP is

supported by the protocols in networks where video streaming occurs. However, rough network conditions may spoil video quality. The paper explores a layered adaptation technique that considers the user's buffer capacity and video quality, along with the variations in available bandwidth at the user's endpoint. The proposed technique checks the receiver's buffering level and the pending bandwidth and prevents unnecessary layer switching that degrades the end-user video quality.

S. Jancy et al. [6] discussed Packet Level Data Compression methods in WSN. Wireless device networks consist of a set of wireless nodes. Every node has its different Processing capacity and different storage sizes are major constraints in wireless sensor networks. The main challenge in this networking field today is to implement effective energy management in these devices. Various researchers have introduced different methods to address this issue. This paper introduces a sequential compression technique, which is a packet-level data compression method aimed at improving the energy level of sensor nodes. **S. Kaur et al. [7]** investigated the LZW data compression algorithm, which is lossless in nature. This method uses a dictionary-based text compression approach that generates a 5-bit code for every character instead of the standard 7-bit ASCII code. Using this technique, the storage and transmission space utilization is reduced compared to other compression methods. Text data can easily be compressed, and the compressed data is transmitted across the network through node-to-node communication. Finally, the data reaches the base station, where decompression is performed. In this study, an LZW compression rate of 30.3% and a physical space reduction of up to 60.25% were achieved.

T. Jinjing et al. [8] presented an efficient cluster-based routing protocol (ECBRP) for real-time multimedia streaming in mobile networks. First, a new algorithm was introduced to improve the stability of cluster heads during cluster creation. Second, a device was designed to identify the cause of data packet loss, helping reduce routing overhead and improving the decodable quality of video at the application layer. Third, with the help of an adaptive packet-saving plan, the routing protocol was enhanced to address network traffic issues. Simulation results show that ECBRP performs significantly better than the standard Cluster-Based Routing Protocol (CBRP), reducing cluster-head changes by 80%. As a result, the quality of real-time multimedia streaming is significantly improved. **A. Tripathi et al. [9]** conducted a survey on data combination in wireless device networks. Wireless sensor networks consist

of small sensor nodes with limited processing capacity and low battery power. These networks are used in various fields such as home monitoring, disaster management, security, and defense. Due to their constraints, these networks are prone to failure. Data collection plays a vital role in such networks. Data aggregation helps reduce energy consumption by eliminating redundant data. This paper focuses on methods such as address-centric and data-centric approaches for data aggregation and energy conservation. S. Sheikh et al. [10] discussed data compression using Huffman-based algorithms. With the growth of digital libraries and the increasing popularity of the World Wide Web, the need for efficient text storage and data transfer has increased. Huffman compression is widely used for data transmission across multiple locations. Huffman encoding is a two-pass procedure that enables searching within compressed data without decompressing it. Therefore, lookup speeds are usually faster than with plain text. S. Tyagi et al. [11] proposed a method for wireless sensor networks based on automata-based heterogeneous energy-efficient selective clustering. Each sensor node is assumed to have a robot along with two categories of sensor nodes: Normal and Advanced. These nodes are designed based on probability-weighted election (PWE), through which the system selects cluster heads. The robot at each sensor node receives feedback from the environment based on the PWE of various nodes. This automata-based method ensures efficient clustering. Key parameters such as the death of the first node (DFN) and the last alive node (ALN) are used to evaluate network lifetime. Using these parameters, comparisons with earlier protocols like SEP, LEACH, and LEACH-SC are discussed for different network setups.

M. Ahmad et al. [12] worked on the Priority-Based Application-Specific Congestion Control

Clustering (PASCCC) protocol. This study presents heterogeneous nodes where 10% of the nodes are advanced nodes with higher energy levels. PASCCC manages congestion by selecting a cluster head in each round and balancing the load among nodes. The paper describes two types of nodes: temperature-based nodes and humidity-based nodes. Temperature-based node packets have higher priority than humidity-based ones. During congestion, low-priority packets are dropped. This approach is suitable for time-critical applications. The comparison results prove that the PASCCC technique provides a much better congestion control mechanism compared to approaches such as LEACH and SIP. R. Periyasamy et al. [13] discussed Game Theory-based congestion control. Network congestion occurs when the traffic load exceeds the available network

capacity. During congestion, channel quality declines and node energy consumption increases, resulting in packet drops. Therefore, congestion control is essential for establishing an efficient network. This literature proposes reducing the power consumption of nodes involved in game-based operations by using the Hybrid Medium Access Control (GH-MAC) protocol. GH-MAC is integrated with a game-based energy-efficient TDMA protocol for intra-cluster communication between Cluster Members (CMs) and the Cluster Head (CH). The performance of GH-MAC is evaluated by comparing it with simple MAC schemes and testing parameters such as energy consumption and delay. Results show that GH-MAC greatly reduces power utilization and improves overall network performance. G. Nivetha [14] highlighted Energy Optimization Techniques in Wireless Sensor Networks (WSN). The author surveyed various clustering protocols used for energy optimization in WSNs. Some well-known routing protocols discussed include LEACH (Low Energy Adaptive Clustering Hierarchy), PEGASIS (Power-Efficient Gathering in Sensor Information Systems), HEEP (Hybrid Energy Efficiency Protocol), and PEACH (Power-Efficient and Adaptive Clustering Hierarchy). The study concludes that PEACH introduces no overhead during cluster head selection, while LEACH significantly improves network lifetime and energy efficiency compared to other clustering protocols. J. N. Al-Karaki et al. [15] reviewed Routing Techniques in Wireless Sensor Networks. The paper surveys various routing methods such as grid-based, flat-based, and hierarchical routing techniques. These routing strategies are used across different types of computer networks. S. Chand et al. [16] presented a heterogeneous clustering scheme for packet transfer between source and destination nodes.

In heterogeneous communication, the participating nodes belong to different categories. The cluster head is selected from nodes with the highest energy. Performance analysis shows that this approach performs better than existing techniques like LEECH and DEEC. P. Bansal et al. [17] proposed a hierarchical clustering algorithm that is both efficient and stable. Stability is measured based on the number of dead nodes, which is significantly reduced in this method. The energy-efficient approach of PEGASIS is also discussed. The main aim of this paper is to provide a comparative analysis of LEECH and PEGASIS techniques. K. Zhang [18] introduced an energy-efficient offloading approach in cloud computing. In cloud systems, each data center is assigned a specific workload. When the load exceeds its limit, performance degrades. Offloading ensures that data centers do not become overloaded. When

utilization goes beyond the threshold, offloading is triggered. Mobile applications commonly support this feature, particularly through mobile edge computing. This approach is implemented using 5G heterogeneous networks. A combination of radio resource allocation and offloading improves overall system performance. K. Bousselmi et al. [19] stated that energy-aware scheduling enhances system performance by executing jobs in an optimal order for cloud environments. Jobs are scheduled in a resource-efficient manner and allocated to data centers with the best performance availability. Numerous scheduling techniques exist. In this study, workflow partitioning is used for scheduling. The proposed technique uses a swarm-based partitioning algorithm. In the first phase, the Workflow Partitioning for Energy Minimization (WPEM) method helps reduce network energy consumption and data transmission workload with high accuracy. In the second phase, a hybrid cat-swarm heuristic is used to schedule the generated partitions, thereby reducing the workflow's global energy consumption and overall execution time. K. Gai et al. [20] performed energy-aware scheduling in a heterogeneous environment. The rapid expansion of mobile and embedded systems has led to hardware upgrades that support multi-core processors. As computation capacity increases, energy usage also grows. Cloud computing is considered a promising solution to reduce energy cost. However, simply offloading tasks to remote servers does not always reduce energy consumption, especially when wireless transmission costs exceed the energy spent on local devices. This work focuses on minimizing energy waste when tasks are allocated either to cloud servers or to different processor cores. The proposed solution aims to reduce total energy consumption of mobile and embedded systems using an optimal task assignment strategy for multi-core processors and mobile cloud environments. The presented model, Energy-Aware Heterogeneous Resource Management Model (EA-HRM2), uses an Optimal Heterogeneous Task Assignment (OHTA) algorithm. Experimental results show that EA-HRM2 effectively saves energy when deploying embedded systems through mobile cloud systems. Z. Zhau et al. [21] proposed an energy-efficient data transfer technique for wireless sensor networks. The approach uses data dissemination schemes to maintain energy efficiency. A buffer is used to temporarily store transmitted data. When a new packet is received, it is compared with the buffered packet. If the packet has already been transmitted earlier, it is discarded. This reduces the number of transmitted packets and thereby saves energy. M. Singh et al. [22] presented energy-efficient and fault-tolerant techniques for wireless sensor networks. Data in WSNs is primarily transferred using sensor nodes, which

have limited energy. Energy conservation is the main focus of this work. A node recovery procedure is proposed to handle node failures without significantly increasing energy consumption. X. Cui et al. [23] proposed an energy-efficient scheduling technique to achieve fault tolerance and energy optimization. Their strategy reduces excessive energy usage and decreases CO₂ emissions from sensor nodes. Although based on cloud concepts, the technique can also be applied to wireless sensor networks. S. Gupta et al. [24] provided a comparative analysis of various energy-efficient scheduling schemes used in WSNs. Algorithms discussed include MSE and HGOP, among others. MSE is observed to perform optimally, especially when mobile sink nodes are used to reduce node energy consumption. WSNs do not forward data to nodes that lack neighboring nodes, which are termed sink nodes. By eliminating such sink nodes, the proposed system increases network lifetime and improves stability compared to LEECH. X. Zhu et al. [25] proposed an energy-aware mechanism for virtualized cloud systems, focusing on real-time tasks that interact with real environments. The EARH protocol is used in this case. Experimental results demonstrate significant improvements in energy conservation. P. Chatterjee et al. [26] considered multi-hop sink-node elimination to enhance the lifetime of wireless sensor networks. A WSN does not forward data toward nodes with no neighboring nodes, identified as sink nodes. By eliminating sink nodes, the system reduces energy consumption and improves the efficiency of data transmission. J. Zheng et al. [27] discussed localization mechanisms used to group nodes based on different properties. Distance may or may not be considered. When distance is used, the mechanism is called a range-based method; when distance is not used, it is a range-free algorithm. The authors proposed a range-free algorithm combined with a neural network approach for improved energy efficiency. R. Singh et al. [28] discussed vulnerabilities in WSNs due to interactions from a wide variety of users. Localization is used to manage communication based on node distances. Both range-free and range-based localization algorithms are proposed. The paper also addresses Sybil attack mitigation along with energy conservation techniques. C. F. Wang et al. [29] focused on sink-node handling in wireless sensor networks. A WSN does not forward data toward nodes lacking neighbors, which are treated as sink nodes. The study discusses strategies to manage such nodes effectively. Such nodes are known as sink nodes. The system increases network lifetime by eliminating sink nodes and reducing energy consumption, which results in better data transmission. Nodes with limited energy are prevented from transferring data. The proposed technique significantly enhances the network

lifetime by removing sink nodes to conserve energy. I. Jawhar et al. [30] used a graph-based approach to handle redundancy and minimize energy consumption. Reducing energy consumption is the primary goal of this work. The alignment (lining) of sensors is used to achieve energy conservation and improve the speed of network operations. M. Ayaz et al. [31] explained fundamental challenges in underwater wireless sensor networks (UWSNs), where acoustic links require high transmission power and suffer from severe channel deterioration. These underwater channels exhibit high error rates and temporary path losses due to the unstable aquatic environment, which reduces network performance. Limited resources and continuous node movement further affect accurate data delivery. To address this, the authors proposed a Two-Hop Acknowledgment (2H-ACK) mechanism that ensures data delivery from sensor nodes to the surface sink. In this model, two nodes maintain identical copies of each data packet, thus increasing data transfer reliability. R. Devi et al. [32] discussed Wireless Sensor Networks (WSNs), which play a major role in modern applications. Sensor networks consist of energy-constrained nodes, making energy efficiency a crucial factor. Some energy is always lost during communication between nodes, so it is necessary to reduce overall communication to save energy. Most sensor networks follow a specific architecture—one common structure is clustering, where the network is divided into clusters, each controlled by a cluster head. A base station manages communication across the network, and its placement is usually static and centralized. V. James et al. [33] described the clustering process in WSNs. They proposed a hybrid energy-efficient distributed clustering methodology. The Capacity-based Clustering Low Energy Adaptive Clustering Hierarchy (CC-LEACH) was used and evaluated against the standard LEACH protocol. Results show significant improvements in throughput, packet delivery ratio, and reduced packet reception at the base station. The clustering approach reduces energy consumption and decreases data transfer delays, especially in dense WSNs. N. Goyal et al. [34] discussed data aggregation techniques for UWSNs, which have been developed over recent years for monitoring and surveillance applications. Data aggregation improves network lifetime and reduces energy consumption during transmission. According to their study, data aggregation techniques fall into two main categories: cluster-based and non-cluster-based. The authors also compared simulation results of a technique with and without data aggregation to demonstrate its impact. They evaluated three cluster-based techniques—K-Means, Round-Based Clustering (RBC), and Distributed Underwater Clustering

Scheme (DUCS)—and represented the results graphically in terms of delay, packet drop, and energy consumption using the NS-2 simulation tool. A comparison table of existing aggregation techniques and future research challenges for data aggregation in UWSNs is provided, highlighting the importance of integrating aggregation with routing protocols. M. Akbar et al. [35] discussed two data-gathering schemes in Wireless Sensor Networks (WSNs). The first scheme uses a Mobile Sink (MS) that moves along random paths (RMS), while the second uses a predefined MS trajectory (DMS). The network field is divided into small logical squares in both schemes. The center of each square is known as the sojourn location of the mobile sink. The authors proposed three linear-programming-based models to improve network lifetime, reduce path loss, and minimize end-to-end delay. The geometric model is designed to avoid redundancy while collecting information from the network nodes. Simulation results show that the designed schemes perform better than the selected existing schemes in terms of the chosen performance metrics. Authors also compare their proposed schemes with UC-MS and DYN-NBC, and the results prove that RMS performs better than DMS when data collection from dense regions is performed first and then the remaining areas. However, the DMS trajectory shows better performance in terms of stability. K. Hirpara et al. [36] elaborated a novel approach for Target Tracking by combining clustering and prediction-based techniques to improve the lifetime of a Wireless Sensor Network. Target tracking is one of the most widely used applications of WSNs. Target tracking is another important criterion related to tracking accuracy, which can be achieved by using an appropriate tracking mechanism. Special characteristics of WSNs represent a trade-off between tracking accuracy and power consumption. By using the concept of clustering and prediction techniques, it can improve tracking accuracy as well as provide an energy-efficient solution. Furthermore, an Energy-Efficient Constant Gain Kalman Filter-based Tracking (EECGKFT) algorithm is used to optimize energy usage and increase tracking accuracy. It is required to collect data from a network having a mobile Base Station (BS). In addition, the proposed algorithm also provides accurate trajectory tracking by minimizing the RMS error. The proposed technique becomes computationally lightweight and provides more accurate results in WSN. O. Chughtai et al. [37] introduced a Congestion Detection and Alleviation (CDA) mechanism to handle impairment of network performance in terms of PDR, throughput, end-to-end data transmission, and energy consumption per packet. CDA detects both node-level and link-level congestion within a time-division management framework and alleviates it in

a reactive manner. Congestion detection at nodes and buffering is highlighted in this paper. Additionally, a novel procedure is used to detect link-level congestion by determining link utilization using the back-off stage of Collision Avoidance with Multiple Access Carrier Sense (CA/MACS). Apart from this, CDA alleviates congestion reactively by either rerouting the data traffic to a less congested, more energy-efficient route or bypassing the congested area. The results show that CDA performs better than CAF and NOCC in terms of PDR, throughput, end-to-end transmission, and energy consumption per data packet. T. Du et al. [38] explained an analysis of Wireless Sensor Networks and proposed a Dynamic Message List for Efficient and Real-Time (DLER) data aggregation algorithm. DLER is developed using a cluster-based structure, and routing methods are derived from previous research. DLER works at the network layer of WSN, and a dynamic rundown is created in the filtering device to store historical information packets transferred by the device. When messages arrive at the filtering hub, they are compared with all items in the list. If the packet's contents are already in the list, it is discarded; otherwise, it is transmitted without delay. The items in the list are updated, and the list length is adjusted based on item frequency. In DLER, the transmission performance of real-time applications increases, and filtering efficiency is improved. S. Uke et al. [39] discussed a formal approach in Wireless Sensor Network data aggregation using an object-oriented model and UML diagrams. Various applications utilize complex information structures and distinct aggregation algorithms. The authors demonstrated UML techniques for data aggregation in wireless sensor networks, helping to develop applications more effectively. Due to additional sensor nodes being placed in the network system, the request load on resource-limited nodes reduces, which decreases redundant information. To reduce this repetition or to sort information efficiently, data aggregation protocols are used. These modeling tools enable the division of limited WSN applications into convenient components, leading to rapid and efficient application development. A. Sarkar et al. [40] discussed and analyzed various parametric features of routing protocols. These protocols are categorized based on node participation, clustering protocols, mode of functioning, and network structure. Selecting the best route is significant in WSNs, and the selection depends on several parameters. Routing problems lead to reduced network lifetime and increased energy consumption. Various routing protocols are developed to solve this issue. According to the authors, chronological research reports reveal that 42% of the work in 2015 addressed routing problems occurring during data transmission from

sensor nodes to the base station. Energy-efficient problems, which constitute about 44%, still require further research. Moreover, the meta-heuristic study depicts that 16% of routing problems were analyzed using non-heuristic procedures, while 10% used bio-inspired algorithms. R. Ramya et al. [41] explained that energy utilization plays a vital role in wireless sensor networking. Clustering is one technique used to optimize energy consumption and increase network lifetime. A wireless sensor network (WSN) consists of low-cost, low-power, small-sized, and multi-functional sensor nodes. Routing protocols in WSNs are typically application-specific, leading to the development of various protocols. The authors classify routing protocols in WSNs as data-centric, hierarchical, and location-based depending on network structure. Data-centric protocols use metadata to transmit sensed information to the base station. Hierarchical routing protocols use clustering to group sensor nodes, making the method highly scalable and suitable for many applications. In location-based protocols, nodes are addressed by their location, and distance to neighboring nodes can be estimated using signal strength or GPS receivers. E. D. Raj [42] provides a brief overview of cluster head selection. The cluster-head selection process is done using algorithms for cluster-head selection. Energy is the primary constraint in practically designing any wireless network. In this paper, authors optimize power consumption in WSN using Low-Energy Adaptive Clustering Hierarchy (LEACH) and LEACH variants. Cluster-head selection is based on cluster-head algorithms that help optimize power consumption. The authors analyzed three algorithms—Density and Distance-based Cluster Head, Energy-Efficient Algorithm for Cluster-Head Selection in WSNs, and Consumed Energy as a Factor for Cluster Head—and developed a new algorithm called EDRLEACH, which is based on clustering for maximum network lifetime. This protocol improves LEACH by distributing clusters equally and reducing unequal topology issues. K. Maraiya et al. [43] analyzed various cluster head selection algorithms for data aggregation in Wireless Sensor Networks, but all of them consumed a high level of energy to complete the task. Therefore, the authors introduced a new scheme related to clustering for data aggregation called “**Efficient Cluster Head Selection Scheme for Data Aggregation in Wireless Sensor Network (ECHSSDA)**”. Comparison has been made with the LEACH clustering algorithm in terms of energy consumption, cluster head selection, and cluster formation. Results show that the proposed algorithm performs better than LEACH in terms of energy consumed by the cluster node and cluster head. O. Banimelhem et al. [44] proposed a **Grid-based Multipath with**

Congestion Avoidance Routing protocol (GMCAR) as an efficient QoS routing protocol suited for grid sensor networks. The sensor network is divided into grids. One of the sensor nodes in each grid is selected as a master node. This master node is responsible for delivering the data generated by any node in that grid and for routing the data received from other master nodes. Each master node builds multiple diagonal paths connected to the sink. Apart from this, it also creates horizontal or vertical paths in boundary grids. In this way, the protocol utilizes densely deployed grids and prolongs the overall network lifetime. Relay requirements cannot be fulfilled by routing based only on grid densities. Therefore, the authors used hop count as a second factor for routing decisions. The proposed protocol shows superiority in achieving better utilization. R. Grodi et al. [45] discussed a new prototype design of a **parking occupancy monitoring and visualization system** that provides commuters with real-time updates on parking space availability. This system uses wireless sensor networks and wireless communication to check parking space status and report to a database in real time. By using mobile applications or websites, commuters can easily access parking status information. According to the authors, successful implementation of smart parking significantly reduces economic and time costs associated with traffic jams, fuel wastage, and the time spent searching for empty parking spaces. G. Xie et al. [46] focused on the use of a **mobile sink** in wireless sensor networks to enhance network lifetime. In real environments, several obstacles make it difficult for the mobile sink to find an obstacle-avoiding shortest route. Therefore, the authors introduced an **energy-efficient routing mechanism based on clustering**. The mobile sink periodically starts its data-gathering route from a starting point, collects data directly from cluster heads within a single-hop range, and returns to the starting point. Furthermore, to avoid the complexity of scheduling in WSNs, the authors proposed a scheduling mechanism based on spanning graphs and presented a heuristic tour-planning algorithm for the mobile sink to find an obstacle-avoiding shortest route. M. A. Alsheikh et al. [47] introduced **data compression algorithms with error-bound guarantees** for wireless sensor networks by compressing neural networks. This algorithm is used to manage data congestion and reduce energy consumption. Compression addresses the adaptive distortion rate problem and is applied to real-time information. Signal enhancement is used to maintain network effectiveness and energy efficiency. Compression saves the energy of nodes across the network. An energy comparison provided in the paper shows that compression reduces the energy level of nodes and prolongs the lifetime of the network. J. Qin et al. [48] discussed

distributed consensus theory in multi-agent systems. The authors deployed a **distributed K-means clustering algorithm** and a **distributed Fuzzy C-means algorithm** for cluster-based network data in WSNs. The distributed K-means algorithm partitions data observed by nodes into groups with small in-group and large out-group gaps. The distributed fuzzy C-means algorithm groups nodes based on membership values ranging from 0 to 1. The results compare distributed algorithms with centralized clustering algorithms and show differences in performance. J. S. Lee et al. [49] discussed energy conservation issues in WSNs. Many clustering algorithms have been designed for this purpose. Most existing approaches focus on LEACH and its variants, which are based on a two-layer hierarchy. However, very limited research studies three-layer hierarchical schemes. The authors proposed **HHCA**, a three-layer hierarchical clustering algorithm. In this algorithm, grids are determined centrally, and cluster heads are selected in a distributed manner. A semi-distributed clustering approach is applied by combining distributed clustering for lower-level cluster head selection and centralized gridding for base station selection. Simulation results show that the proposed approach is more efficient than other distributed algorithms, making it suitable for large-scale WSNs. Y. Huang et al. [50] discussed a **Communication Cost Reduction Scheme** for Wireless Sensor Networks. Energy efficiency is a primary concern in WSNs, and radio communication is one of the most energy-intensive operations. The authors introduced **PKF**, a scheme suitable for typical WSN applications with adjustable data quality and computation cost. Through mathematical analysis, they formulated the trade-off between energy efficiency and reconstruction quality. Validity and accuracy were verified using both artificial and real signals. Simulation results using real temperature values show that PKF reduces communication cost by more than **88%** compared to previous KF-based work. PKF also reduces transmission rate by at least **29%**, while requiring less computation and maintaining reconstruction quality. PKF can be integrated with network-level techniques to further extend network lifetime. L. Cheng et al. [51] proposed the **Seamless Streaming Data Delivery (SSDD)** protocol for multi-hop clustering-based WSNs with mobile elements (MEs). They designed a scalable, energy-efficient inter-cluster route construction algorithm to improve energy and scalability during inter-cluster communication. To support mobility, the authors introduced a **cross-cluster handover mechanism** and a **lane reduction scheme**. SSDD retains end-to-end connectivity of mobile elements while avoiding constant flooding of sink location information as MEs traverse multiple clusters. Simulation results

using ns-2 demonstrate that SSDD is lightweight and efficient, making it suitable for delivering streaming data in WSNs with mobile elements. H. Chen et al. [52] proposed a new paradigm of audio information collection based on the concept of audio-on-demand. The authors considered a sink-free environment targeting disaster management, where audio chunks are stored inside the network for retrieval. The challenge is to ensure a high search success rate without infrastructure support. To address this issue, a novel replication algorithm was designed that deploys an optimal number of replicas across the sensor network. It proves the optimality of the algorithm in terms of energy consumption. They implemented a sink-free audio-on-demand (SAoD) WSN system and conducted extensive simulations to evaluate its performance and efficiency. Experimental results show that it provides satisfactory audio-on-demand service with short startup latency and minimal playback jitter. The system achieves a search success rate of 98% while reducing search energy consumption by an order of magnitude compared to existing schemes. X. Ding et al. [53] tested a large amount of data to identify WSN signal transmission characteristics in factory environments and residential areas. Two types of tests were used in the experiments. Indoor signal transmission characteristics of WSNs are summarized from the analysis of massive test data. An energy-balanced big-data gathering algorithm called RTBDG is proposed to collect real-time data and perform risk analysis for industrial operations. Although two sensor nodes can communicate depending on distance, the RTBDG algorithm uses a round strategy and a method of rebuilding the cluster structure. The algorithm's performance is compared with three well-known algorithms, and the results show that RTBDG performs very well in terms of energy consumption and enhances the system lifetime for gathering real-time big data.

Y. Hu et al. [54] discussed clustering methods for energy-efficient overlapping adaptive clusters. Improving energy efficiency in WSN clustering plays an important role. The authors proposed energy-efficient overlapping adaptive clustering methods. They discussed both single-hop and multi-hop clustering schemes, along with time-driven and event-driven clustering methods. S. J. Shobana et al. [55] discussed grid-based congestion clustering control. The authors focused on N-Sink node networks mostly used in military areas where tanks are positioned across the region. GPS systems send signals about suspected areas to the tanks, which then position themselves and fire at the moving target. Two types of data packets are transferred in the network: Broadcasted Data Packets (BDP) and Demand Data Packets (DDP). When a sink needs data, DDP packets are used, and

on the occurrence of an event, BDP packets are transmitted. J. K. D. Keynes et al. [56] discussed dense wireless networks using a distributed clustering technique for hybrid energy. The authors highlighted the enhancement of network energy levels using HEED (Hybrid Energy-Efficient Distributed Clustering). Most techniques in clustering are based on the LEACH protocol. Energy efficiency and communication cost are significant advantages in HEED. This protocol avoids random selection; the selection of the cluster head is based on communication cost and the energy level of nodes. HEED improves LEACH through this hybrid approach. V. Krishnani et al. [57] discussed a compression technique called K-RLE. This in-network compression technique is used to save network energy. The benefit of this technique is reduced data broadcasting time because compression saves energy during data transmission. The authors compared their K-RLE method with another compression technique called LZW. Simple RLE is a lossless technique, whereas K-RLE is a lossy technique. The authors reported that K-RLE performs 40% better than simple RLE. K. C. Lan et al. [58] discussed clustering in WSNs for compressibility-based data gathering. Collecting data from node to node is the primary operation in WSNs. With the rapid growth of internet usage, people frequently download and gather information, making compression important in data collection. The authors stated that Hierarchical Compressive Data Gathering (HCDG) is one of the best methods currently used. Traditionally, HCDG uses Random Clustering (RC), but in this paper, Compression-Based Clustering Algorithm (CBCA) is used. CBCA results in smaller data transmission sizes compared to RC. CBCA was tested on water-level data collection during flood conditions. A hierarchical tree structure is used in this network. Nodes transfer data to neighboring nodes. Cluster head selection in this technique is based on a threshold value, and energetic nodes are chosen as cluster heads to transfer data to the base station.

3.SCOPE OF THE STUDY

The proposed system helps in controlling network traffic while sending data from one relay node to another. Before transmitting the data, it is compressed, which reduces the overall transmission time. Data is passed from one cluster head to another in compressed form and eventually reaches the base station. With this work, the reader can understand the benefits of using RLE compression in a clustering-based approach, how the inter-clustering mechanism is utilized in the proposed Congestion Control using Grid-Based Inter-Clustering (CCGBC), how congestion is reduced through cluster-head load balancing, and how

vacant areas are efficiently utilized using random area selection in each round while forming cluster groups. A combination of RLE compression and the inter-clustering mechanism with a grid-based architecture provides advantages such as improved load balancing and reduced packet drop in the system.

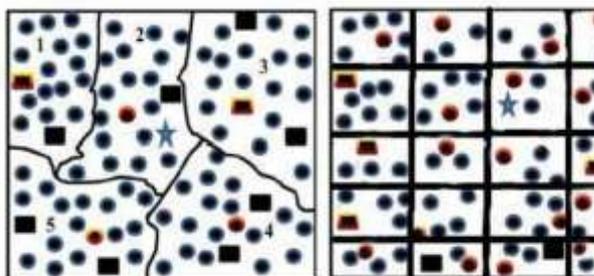


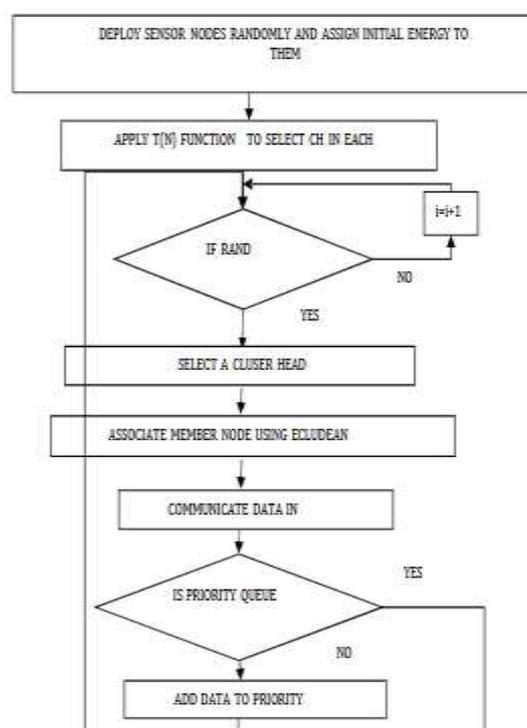
Figure 3.1 (a) Existing PASCCC Routing and (b) Proposed CCGBC Routing Technique

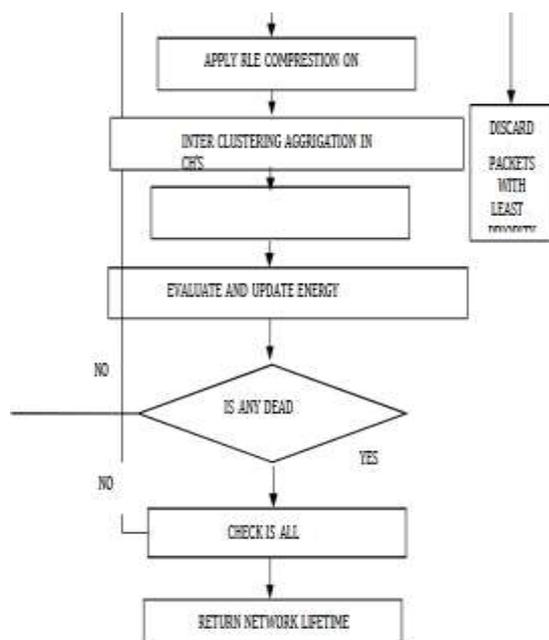
Black nodes represent non-cluster-head nodes, whereas yellow nodes represent cluster-head nodes. The star symbol indicates the base station, also called the sink node. The comparison of these techniques is presented in Chapter 4.

3.1 PROBLEM FORMULATION: PASCCC is the first protocol that introduces a cluster hierarchy with congestion detection and mitigation. It operates based on packet priority. Two types of packets are used: **humidity packets** (LOW priority) and **temperature packets** (HIGH priority). Temperature packets must be reported immediately to the base station when the hard threshold reaches a specific value [12]. With the help of the cluster-head, these packets **reach the base station (sink node)**. When a node transmits data packets from one node to another, its available energy decreases. To overcome this issue, sensor nodes are divided into small groups called **cluster groups**, where each group has a coordinator called the **cluster-head (CH)**. In clustering, the node with the maximum energy is elected as the CH for each group. A threshold value [14] is used for CH selection. If the energy level of a node is lower than the threshold, that node cannot be selected as the CH for the current round. Cluster-heads arrange cluster members (CMs), collect data packets from them, and transmit these packets to the base station. Although PASCCC is an effective protocol, it has several drawbacks. The CH selection process is performed over a large area, and CH selection is random. While selecting a CH based on energy, the process itself consumes a significant amount of energy. Based on the analysis of the PASCCC paper, the results show that the clustering mechanism, compression technique, and energy

management are not highly efficient during transmission of data packets to the base station. In addition, the inter-clustering mechanism is ignored while forwarding data toward the base station. A **grid-based architecture** addresses these drawbacks. In a grid-based approach, the packet drop ratio is reduced and node load is balanced. In addition, the RLE compression technique, which is lossless, is applied, and the inter-clustering mechanism is implemented to enhance node energy levels and control congestion. Therefore, PASCCC performance is improved through the proposed CCGBC mechanism.

3.2 RESEARCH METHODOLOGY OF CCGBC





3.3 ALGORITHM

The aim of this algorithm is to work with a network application in which random nodes are arranged, and the network is used to examine the surrounding nodes. The steps written below are used to solve the problem. Step #1: Initialize the number of nodes, energy, and the location of the base station for the network. Step #2: Establish a grid-based network. Step #3: Since it is assumed that initially all nodes have the same energy (E_{max}), 10% of the nodes are advanced nodes. Hence, using a threshold function, a cluster-head (CH) is selected. In this paper, the total number of neighbors and the average number of neighbors are used to obtain the threshold value. Step #4: Choose a random value and compare it with each node of a group. If the value of a node is greater than the random value, that node will be elected as a CH for that round. In the first round, each node has a probability of becoming the CH. A node selected as a CH for a round will become CH again after $1/p$ rounds. For example, if there are 100 nodes, then $1/p = 1/100$. Thus, a single node could be a CH around 10 times. Step #5: Once CHs are created, each CH transmits its identity to all other nodes in its group using Euclidean distance. Step #6: After sending their identity, the CH waits for acknowledgements from the nodes. Once the CH receives acknowledgements from all nodes, it becomes ready to receive data packets from these nodes. Step #7: In a group, the CH checks the **Priority Queue**. If it is full, it discards the lowest-priority packets. Otherwise, it adds the received packets to the queue. Step #8:

When data packets are received by the CH, it combines these packets into one packet and compresses it using the **RLE compression technique**. Step #9: These compressed data packets are then transmitted to another group using the inter-clustering technique. This process continues until the packets reach the sink node (base station). Step #10: At the sink node, the data is evaluated and energy dissipation is calculated. Step #11: At this point, the system checks whether any node is dead. If **no**, go back to **Step 3**. If **yes**, it checks all nodes to determine which ones are dead. Step #12: If all nodes are dead, the system automatically returns the network lifetime. If not, then go to Step 3.

3.4 OBJECTIVES

The proposed research work reduces the workload on nodes using a grid-based clustering mechanism. In the clustering mechanism, nodes are balanced with the help of cluster heads. During compression, the cluster head compresses the packets and converts them into a single packet. Then, using the inter-clustering technique, it forwards the compressed packet to another group where the next cluster head receives it. This process continues until the packets finally reach the base station. To speed up the operation, the shortest path algorithm was utilized. The main purpose of clustering is to generate an energetic node for each group for a particular round. In every round, the node with the highest energy becomes the cluster head, ensuring energy balancing. Additionally, compression was effectively used to utilize the available bandwidth efficiently.

The research work includes the following:

- Enhance energy consumption in the proposed system
- Use of RLE compression and data aggregation through inter-clustering in the proposed CCGBC
- Simulation results display several parameters, such as:
 - When the first node dies
 - When the last node dies
 - Total number of rounds
 - Lifetime of the network
 - Energy consumption

3.5 TOOL USE

Both the existing and proposed systems were simulated using the **MATLAB** application. MATLAB is a mathematical tool used for all types of mathematical calculations. It is widely used in image processing and various literature-based research works. The practical implementation of the code in the simulation domain worked perfectly.

MATLAB

MATLAB provides a mathematical environment to create simulations for a given problem and definition. It is developed by **Matrix Laboratory**. To design a system, MATLAB offers a strong mathematical environment along with a good GUI. The graphical user interface (GUI) allows users to operate through clicks and double-clicks, while the command user interface (CUI) allows operations through typed commands. When the user begins installing MATLAB, the following screen appears:



Figure 3.2: Simulation Tool Matlab

4.RESULTS AND DISCUSSION

4.1 EXPERIMENTAL RESULTS

The simulation was conducted in MATLAB. Energy consumption was evaluated on average while maintaining a fixed area of 100×100 . Packets were transmitted from sensor nodes to their respective cluster heads, and then the cluster head forwarded the aggregated data to the base station.

We compared CCGBC with PASCCC, which was the base reference protocol. The experimental results were obtained using the following parameters:

- **Eelec = 50 nJ/bit**
- **r = 100**
- **EDA = 5 nJ/message/bit**
- **Packet size = 4000 bits**
- **Energy = 0.015 nJ/bit**
- **Efs = 10 pJ/bit**
- **ETwo_Ray = 0.0013 pJ/bit**
- **Queue size = 10 packets/group**

4.1.1 Lifetime of Network :The network lifetime was evaluated based on the **stability** and **instability** periods.

- The **stability period** is the duration until the **first node dies**.
- The **instability period** begins after the first node dies and continues until the **last node dies**.

The experimental results (Fig. 4.1) show the following: Stability Period

- In PASCCC, the first node died at **round 850**.
- In CCGBC, the first node died at **round 1080**.

Instability Period

- In PASCCC, all nodes died at **round 4950**.
- In CCGBC, all nodes died at **round 5500**.

Thus, the **lifetime of the CCGBC protocol is significantly better** than PASCCC. The stability region indicates packet transmission under **low-congestion conditions**, where packets are successfully delivered without blockage. The instability region reflects packet transmission under **high-congestion scenarios**, where packet drops are more likely to occur.

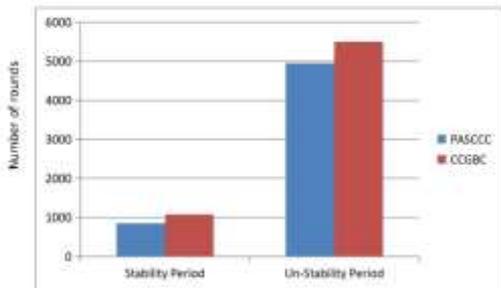


Figure 4.1: Life Time of Network

4.1.2 Residual Energy

The residual energy of CCGBC was evaluated in Figure 4.2 and compared with the existing PASCCC protocol. The figure shows that the total initial energy was 50 J for each protocol, and the simulation was run for 5000 rounds. The experimental results indicate that:

- At round 500, the residual energy in PASCCC was 47.3 J,
- While in CCGBC, the residual energy was 48.3 J.

As the simulation begins, the residual energy gradually decreases because the cluster heads start receiving packets and forwarding them toward the base station. Residual energy was calculated using threshold cluster-head and threshold base-station values. A threshold cluster-head value of 0.17 was considered. As the number of rounds increases, energy consumption also increases by a factor of 0.17. In the existing PASCCC protocol, approximately 0.17 or more energy is consumed in each round, causing faster energy depletion and leading to packet drops when the energy fully vanishes. To solve this problem, our proposed method used a priority-based queue. With the help of this priority queue, packets were properly managed within the queue and then forwarded efficiently, reducing the chances of packet drop.

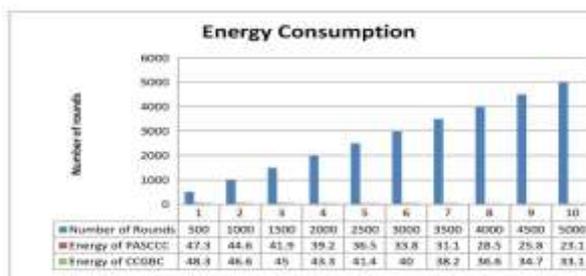


Figure 4.2: Energy consumption in a Network

4.1.3 Data Transmission

The total number of rounds and the packet transmission ratio—from normal nodes to cluster head nodes and from cluster heads to the base station—were evaluated. The duty cycle of CCGBC was lower compared to the existing PASCCC protocol. After 5000 rounds:

- The total number of packets delivered to the cluster head was 79,690 in PASCCC 103,520 in CCGBC

During each grouping, data aggregation was applied to transfer data from one cluster head to another cluster head in the next group. This method helps increase the overall lifetime of the network. Packets transmitted toward the base station must be delivered efficiently. Higher congestion levels increase the chances of packet drop. To address this issue, a priority queue was maintained in the proposed work. As a result, packet delivery performance was significantly improved, as shown in Figure 4.3.

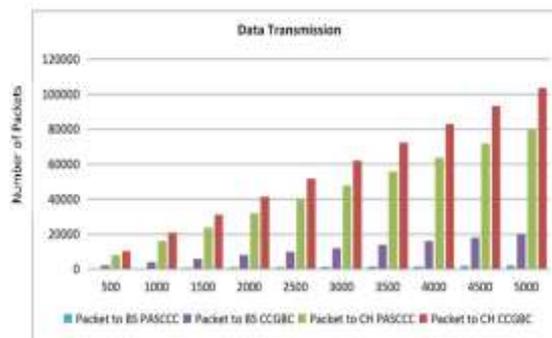


Figure 4.3: Packets received to Cluster head and Base station

Packets were transferred based on the lifetime of the network. The PASCCC protocol had a shorter lifetime; therefore, the network stopped functioning before reaching 120,000 packets. In PASCCC, finding the cluster head (CH) required more energy because the entire network area (100 × 100) was used for CH selection. In comparison, CCGBC consumed less energy because the area was divided into smaller 25 × 25 regions, and CHs were selected within these smaller regions. As a result, the energy consumption in PASCCC was higher, while CCGBC significantly reduced the energy required for CH selection. The congestion rate was also higher in PASCCC. In contrast, congestion was reduced in the proposed CCGBC approach.

5. SUMMARY AND CONCLUSION

In the study of PASCCC, authors worked on a clustering protocol based on a priority-based queue model for identifying congestion in a network. This protocol was used in time-critical applications such as plant fire detection, home automation, etc., where sensor nodes had to send data packets to the base station within the given timestamp. A minor delay would result in loss of information, which was very important for the base station. There were two kinds of packets arriving in a queue: one was temperature-based and the second one was humidity-based. The priority of temperature packets was high. If congestion occurred in a network, the humidity packets started dropping because the priority of these packets was low compared with temperature packets. In addition to that, in this protocol, clustering was performed with two kinds of nodes: Advanced and Normal. The energy level of advanced nodes was high compared to normal nodes. After the analysis of PASCCC and CCGBC, we reached the conclusion that the grid-based inter-clustering routing technique was better than the existing PASCCC technique because it provided better results. The benefit of grid-based architecture was to prevent packet loss and balance the nodes while using clustering. We simulated the CCGBC to check the packets transmitted to the base station. In addition to this, the data compression with the RLE compression algorithm and data aggregation using the inter-clustering mechanism enhanced the performance of CCGBC. The benefit of RLE compression was that it compresses the data before passing it to another node, which is very beneficial for energy saving of the nodes. The benefit of the inter-clustering mechanism in CCGBC was that it saved the energy of the CH node while passing the data to the base station. In addition to that, in grid-based architecture, packet dropping ratio was less and the energy consumption was high as compared with PASCCC.

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