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Fault-Tolerant Routing for Wireless Sensor Networks using a Gaussian Network

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***Abstract:** Wireless Sensor Networks (WSNs) are utilised for sensing various physical and environmental variables like temperature, pressure, motion, and pollution. A component of a network to continue operating even when some sensor nodes fail is regarded as fault tolerance in wireless sensor networks. Due to battery life deadlines and the challenges associated with charging or replacing failing nodes, the deployment of sensor nodes in the target area is done in a dense manner to maximise coverage and connection. This paper implements a hybrid fault-tolerant routing methodology to address the problem of fault tolerance in hierarchical topology for wireless sensor networks (WSNs). The network location is partitioned into small square grids, with a Gaussian integer serving as each grid's cluster head. A Gaussian network is created through communicating these cluster heads together. Discovering the Gaussian network's shortest path and multi-path routing, the project implements a hybrid Fault-tolerant Clustering routing protocol based on Gaussian network for Wireless Sensor Network (FCGW). The purpose of FCGW is to improve fault tolerance and reduce energy consumption for Wireless Sensor Networks. Experimental results using MATLAB shows that FCGW protocol has high data reliability. In addition, the FCGW protocol consumes lesser energy in the network compared to other protocols namely FT-LEACH, HEED and PSO-UFC.*
***Keywords:** wireless sensor networks, cluster selection, fault tolerance, fault recovery.*

I. INTRODUCTION

Wireless Sensor Networks (WSNs) development and use have accelerated in recent years. The fundamental purpose of a wireless sensor network is to monitor an environment devoid of infrastructure like a power supply or wired internet connection as well as without human contact. Sensor nodes are small, inexpensive sensing devices with wireless radio transceivers. Data dependability, ideal energy consumption, memory limit and data latency present significant difficulties in wireless sensor networks (WSN) deployment. The scarcity of sensor nodes combined with challenging communication settings like rain, wind, snow, and water constantly results in incorrect connections. As a result, increasing network fault tolerance will increase WSN availability and service quality.

A. Clustering

One important component for prolonging the network lifetime in Wireless Sensor Networks is Clustering. The Cluster Heads (CHs) for every cluster are chosen after the sensor nodes have been organised into groups called clusters.

B. Fault-tolerance

Fault tolerance is the ability of a network to continue operating even when certain sensor nodes in Wireless Sensor Networks. The deployment of sensor nodes in the target region is done in a dense way to maximise coverage and connection due to battery life limitations and the difficulties of charging or replacing failing nodes.

C. Gaussian Network

Combining clustering and labelling sensor nodes as Gaussian integers creates a hierarchical topology. As a result, the network area is divided into tiny square grids, with a Gaussian integer serving as the cluster head for each grid. A Gaussian network is built by connecting these cluster heads together.

D. Multi-path Routing

Over the past ten years, research on routing in wireless sensor networks has been seen as being of significant importance. In order to increase network performance by effectively utilizing the resources provided by the network, wireless sensor networks frequently use multi-path routing strategy.

This paper's major contributions are:
1) Formation of cluster nodes in the proper location.
2) Effective communication among nodes within a cluster.
3) Identification of fault in sensor nodes.

The rest of the part of the essay is organised as follows the section II presentation of related work. The preliminaries of selection cluster head in the cluster formation models are given in section III Section IV discuss the planned FCHW's details. Section explains the simulation results. V. Finally section VI concludes the paper.

II. RELATED WORK

The author in [1] summarizes various issues and challenges in WSNs.

A. Energy

Power is needed by sensors for its effective functioning. Data processing, data exchange, and data collection need energy. Even when they are inactive after being used up, batteries that provide electricity need to be replaced or recharged. Designing, developing, and implementing energy-efficient hardware and software protocols for WSNs is the most important area of research for WSN researchers.

B. Level of Service

The level of service given by sensor networks to its users is known as quality of service. Many real-time essential applications use wireless sensor networks, therefore, the network must deliver high-quality service.

C. Fault Tolerance

Sensor network should remain functional even if any node fails while the network is operational. Network should be able to adapt by changing its connectivity in case of any fault. In that case, well- efficient routing algorithm is applied to change the overall configuration of network.

Redundancy guarantees accurate facts for making decisions [2]. The analysis, monitoring, and forecasting of system behaviour depend heavily on reliable data, whereas poor quality data may lead to incorrect results in the decision-making process. Endpoints in Wireless Sensor Networks (WSNs) are widely dispersed around an area to gather data. Sensors gather comparable data and send it to the sink.

Often, redundant data at the sink results from these comparable data. Eliminating duplicated data improves accuracy, dependability, and security while using less energy because dealing with redundant data consumes most of the sink network node energy. Even if network costs and/or time increase, data accuracy in fig 1 show the must still be guaranteed.

In order to give a more consistent, accurate and trustworthy data collection in an energy-efficient manner, a technique must be created to extract information from redundant data. The strategies for data fusion assist in preserving the same.

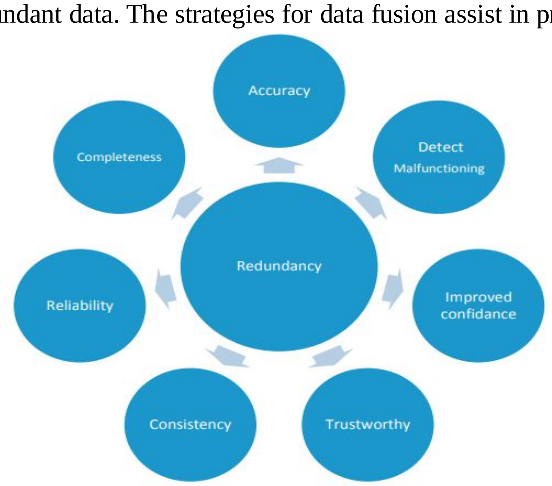

Figure.1 Redundancy improves various Quality factors.

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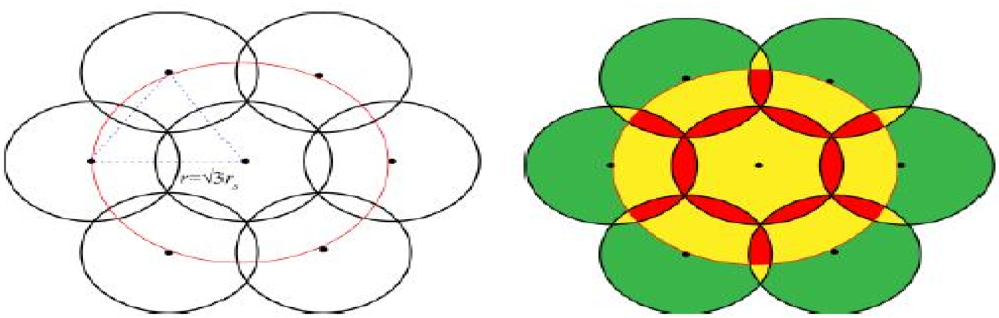
Energy depletion, node software or hardware issues [3], environmental occurrences, hostile attacks, and other factors are frequently to blame for failures in Wireless Sensor Networks (WSNs).

It is crucial to guarantee that a WSN application system is functional in the event of a failure or interruption. An acceptable topology can increase the robustness of WSN, according to recent topology control research. However, due to the restricted supply of sensor nodes, topology control finds it difficult to balance energy conservation with fault tolerance.

In order to solve this issue, this study offers a Regular Hexagonal-Based Clustering Scheme (RHCS) and a Scale-Free Topology Evolution Mechanism (SFTEM) for WSNs. These techniques improve network survivability and maintain energy balance. For clustering sensor nodes, RHCS employs a regular hexagonal topology that provides at least 1-coverage fault-tolerance.

SFTEM takes advantage of the synergy between a reliable clustering scheme and topology evolution to connect clusters and create a resilient WSN that can withstand a wide range of defects, including random failure and energy failure. Additionally, simulated experiments were conducted to compare three factors, including fault-tolerance, intrusion-tolerance, and energy balance, with other approaches described in the literature in order to assess the performance of SFTEM. The simulation results ef [3] demonstrate that SFTEM performs well and is depicted in figure 2.2 & figure 2.3



(a) (b)

Figure.2 Regular hexagonal-based clustering scheme
(a) Regular hexagonal structure of node clustering.
(b) k-coverage fault-tolerance.

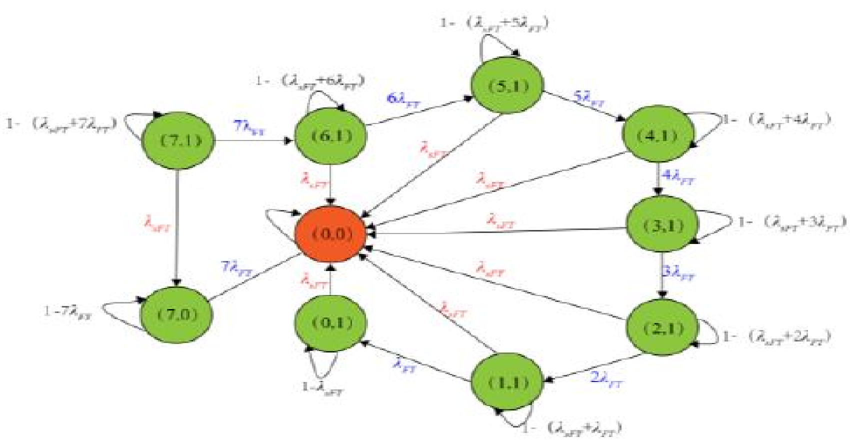


Figure.3 Markov models of RHCS with no faulty nodes**.**

Topology control improves network scalability and longevity while balancing the load on sensor nodes[4]. Sensor node clustering is a successful topology control strategy. For long-lived ad hoc sensor networks, we provide an unique distributed clustering approach is proposed. Other than the presence of several power levels in sensor nodes, neither the existence of infrastructure nor the capabilities of nodes are assumed in our proposed solution.

This paper presents HEED (Hybrid Energy-Efficient Distributed clustering) protocol, which regularly chooses cluster heads based on a hybrid of the node residual energy and a secondary parameter, such as the node degree or node proximity to its neighbours.

HEED may asymptotically virtually certainly ensure connection of clustered networks with the right restrictions on node density, intra-cluster, and inter-cluster transmission ranges.

The four main goals of HEED are
1) Spreading out energy use to extend network lifespan.
2) Ending the clustering procedure after a predetermined number of repetitions.
3) Reducing control overhead.
4) Generating evenly spaced cluster heads.

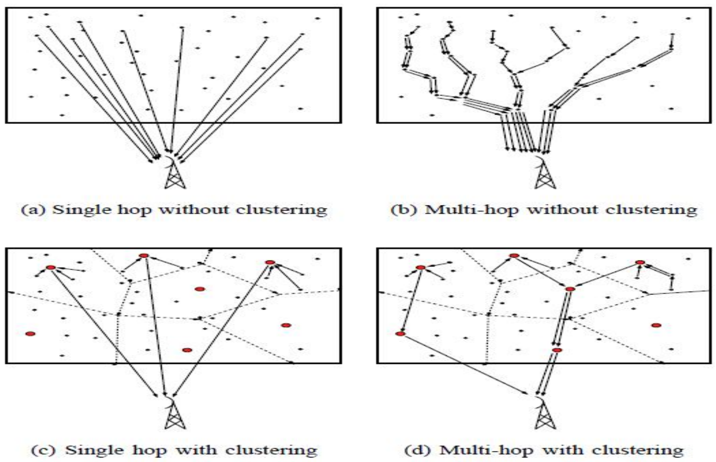


Figure.4 Sensor information forwarding with and without clustering and aggregation

Network nodes can rarely be visited or even recharged after being planted in the environment, energy constraints are a significant barrier for wireless sensor networks. The nodes quickly grow flaws since they are positioned in hostile and challenging environments. As a result, it is crucial to manage these networks to increase their fault-tolerance capacity in the face of scarce resources.

Wherein each node, in its acting as a cluster member, must report its most recent energy level to the head cluster upstream. Additionally, the node will make sure that it only communicates sensed data to the cluster head when it differs from the sensed data from the prior period in order to avoid rework and energy loss (CH)[5].

The first hierarchical routing protocol for wireless sensor networks, LEACH, served as the prototype for numerous subsequent hierarchical protocols.

Cluster formation and stable phase are its two primary phases. A Round is the name of the two phases cycle of execution.

Following the selection of the CHs, NCH nodes join the CH nodes. In the CH selection process, each sensor node should produce a number between 0 and 1, and if that number is less than a threshold (Tn), that particular node will be designated as a CH node and will broadcast its status to the other nodes.

$$T(n) = \left\{ \begin{array}{ll} \dfrac{P}{1 - P(R \bmod (1/P))} & \text{if } n \in G \\ 0 & \text{others} \end{array} \right\} \longrightarrow \quad \text{equation (1)}$$

Using TDMA timing, the member nodes deliver ambient data to the appropriate CH. In order to prevent sending unnecessary data, CH nodes evaluate incoming data before delivering it to the sink. Then they send the aggregated data to the sink.

Leach protocol is a well-known hierarchical clustering algorithm for wireless sensor networks. It served as the inspiration for numerous other protocols that branched off from it and enhanced specific fields, but none of them took the aforementioned fault-tolerance techniques into account.

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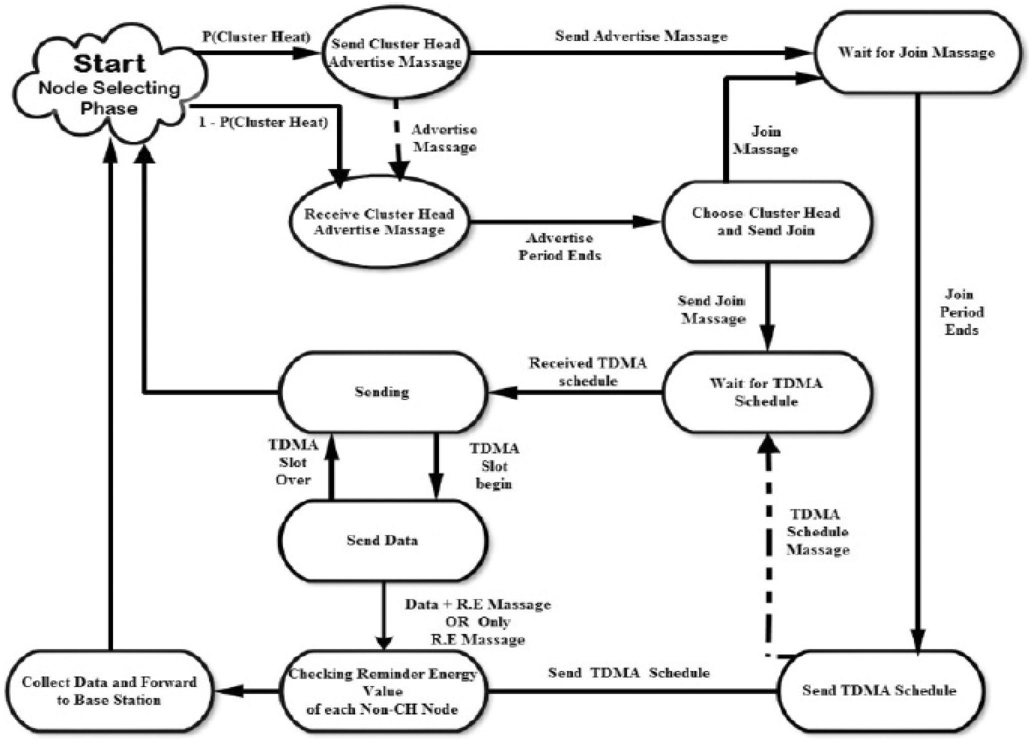

Figure.5 State diagram of nodes configuration in the proposed FT-Leach protocol

Wireless sensor networks, clustering are one of the most effective energy-saving approaches for maximising network lifetime. Due to the high inter-cluster relay traffic load in the multi-hop strategy, cluster heads (CHs) near to the base station soon run out of energy, creating the hot spot issue. A clustering protocol must be fault-tolerant and energy-efficient. a particle swarm optimization (PSO)-based unequal and fault tolerant clustering protocol referred as PSO-UFC[6].

Protocol addresses imbalanced clustering and fault tolerance issues in the existing energy-balanced unequal clustering (EBUC) protocol for the long-run operation of the network.

The PSO-UFC protocol uses an unequal clustering technique to balance the Master CHs intra-cluster and inter-cluster energy consumption in order to address the imbalanced clustering issue (MCHs).

a) PSO based clustering mechanism to solve hot spot problem in WSN.
b) Derivation of the cost functions for unequal clustering mechanism to balance the intra-cluster and inter-cluster energy consumption.
c) Construction of a multi-hop routing tree to ensure the network connectivity among the MCHs.
d) Election of Surrogate Cluster Head in each cluster to address the fault tolerance issue.

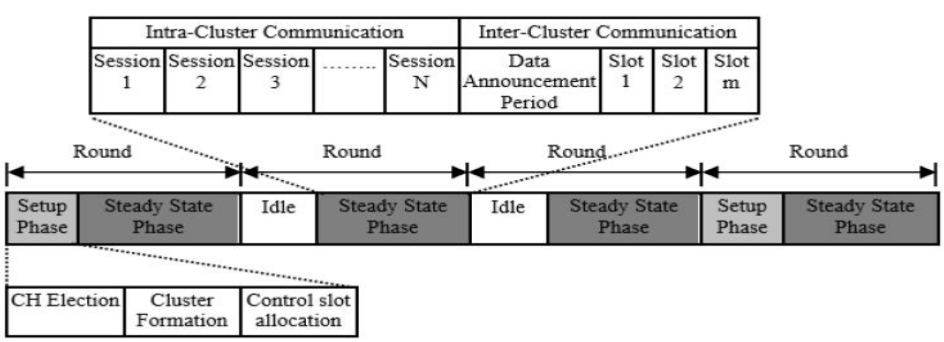

Figure.6 Operation of PSO-UFC protocol

III. PROPOSED SYSTEM

A. *Objective*

Combining clustering and labelling sensor nodes as Gaussian integers creates the hierarchical topology. The network region is partitioned into tiny square grids, with a Gaussian integer serving as the cluster head for each grid. A Gaussian network is built by connecting these cluster heads together. Through node symmetry, the Gaussian network's shortest path, and the benefits of multi-path routing.

B. *System Model*

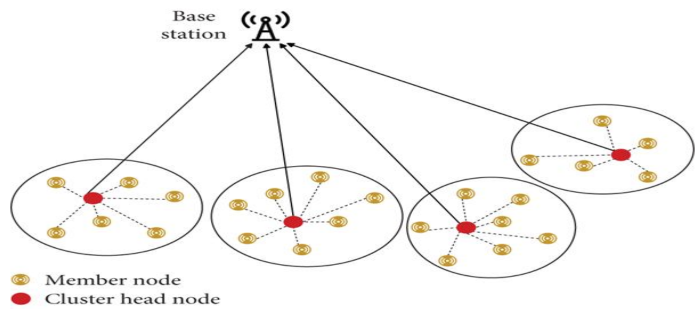

Figure.7 Cluster Formation Methods in Wireless Sensor Networks

1) *Wireless Sensor Network Model*

This considers project a WSN model that consists of N identical sensor nodes that are randomly distributed around the rectangle, together with a base station node (BS) or sink nodes = X * Y . Based on the geographical position of the nodes.

Each grid's nodes will be assigned to one of three states: discovery, sleep, or active at once. All nodes first begin in the discovery state and set a predetermined time.

If a node's energy level exceeds a certain threshold and it doesn't receive any additional discovery messages, it will transition to active mode and set a time for operation (Ta), otherwise it will switch to sleep mode and set a time for sleep.

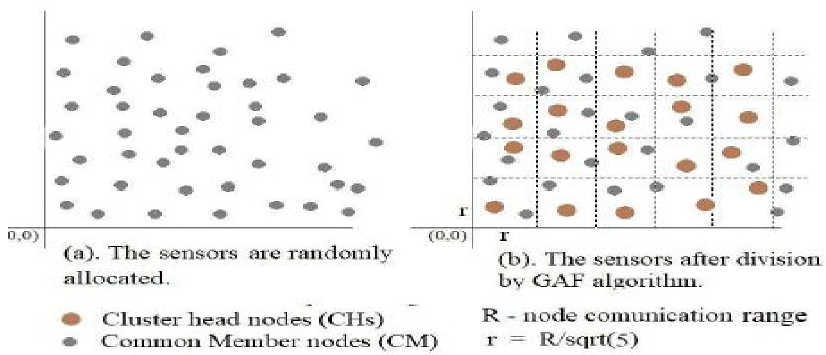

Figure.8 The GAF algorithm divides the network into many virtual square grids.

2) *The CH-Gaussian Network*

In order to increase the effectiveness of WSN architecture, a hierarchical topology based on Gaussian network connection is used.

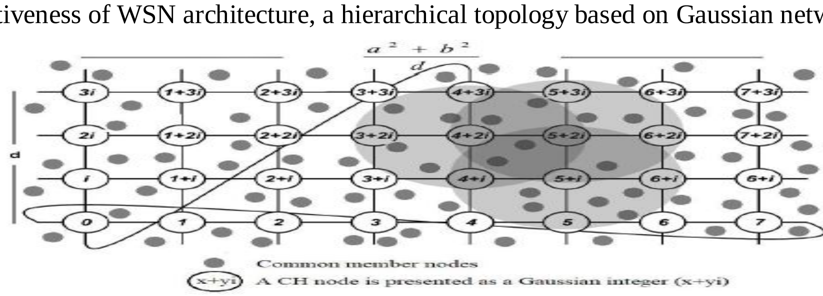

Figure.9 The Gaussian network connection approach, the CHs are connected as a mesh network.

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3) *Shortest Path Routing Protocol*

Connecting the CH nodes in each cluster results in the creation of a Gaussian network of CH nodes in the network region. S = X*Y as in formula. S = { X * Y | X = d * r;Y = f*r }.

The clustering of the network will increase the wireless sensor network's energy efficiency. To further improve routing efficiency, we proposed the shortest path routing protocol, which is based on the Gaussian network's shortest distance.

The data transmission path P() from CH node to BS node consists passing through X min steps in the real axis (x-axis) and Y min steps in the imaginary axis (y-axis). A simple presentation of a routing path as shown in equation 1 , in which the packets pass through nodes on the x-axis, then the nodes on the y-axis. In addition, the

$$P_{(\beta,\gamma)} = \{ \sum_{m=0}^{|X_{\min}|} ((x_s \pm m) + y_s i) \cap \sum_{n=0}^{|Y_{\min}|} (x_s + (y_s \pm n)i) \} \longrightarrow \text{equation (2)}$$

C. *Fault Tolerance Mechanism*

Clustering and multi-path routing combined into a hybrid fault-tolerant routing protocol, which is based on the hierarchical topology of a WSN based on a Gaussian network is implemented.

The CH node, the fault tolerance mechanism is primarily concerned with fault detection and fault recovery. Similarly, based on the shortest path routing and the symmetric links of the Gaussian network The fault recovery procedure will be optimized as multiple path routing, as in the formula. The fault recovery procedure will be optimized as multiple path routing, as in the formula.

1) *Fault Detection Phase*

In Wireless Sensor Networks network connection failures can be caused by a variety of issues, including software bugs, hardware malfunctions, environmental conditions, and severe device deployment environments.

Throughout the course of an information exchange period, each CH node will update a CH neighbour table (NeigTableCH), which contains the nearby grid-ID, CH-ID, and CH statuses of adjacent clusters. ($T_{heathCH}$ ($T_{heathCH}$ < Ta), A CH will update the state of the related CH in the CH neighbour database as false if it does not receive information from the neighboring CHs.According Our suggestion will determine whether a CH node fault exists based on the CH status in the CH neighbor database.

2) *Fault Recovery Phase*

The Cluster Head nodes or Common Member nodes defects could result in the loss of the link between them (extra-connections) or between them and CMs (intra connections). Automatic removal of CM nodes from the cluster in the event of a CM fault, and a CH fault causes the fault recovery mechanism to be activated until another CH is re-selected in the cluster. In the fault recovery procedure, it will obtain the subsequent CH state from NeigTable CH one CH before transmitting the packet. The packets will automatically be sent to other next CH nodes if this next CH fails.

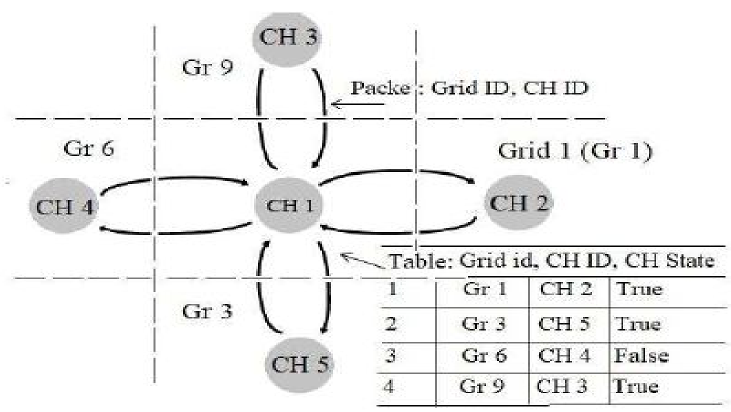

Figure.10 the CH neighbor table is defined. (NeigTableCH)

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IV. IMPLEMENTATION

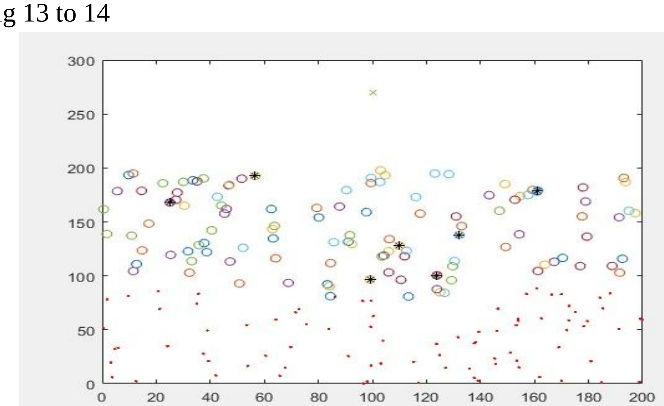
The choice of CH to create an effective data transmission method is very important in the Wireless Sensor Networks environment. To reduce the communication delay and to enhance the routing performance, it is required to choose CH among the number of sensor nodes. The cluster members are unable to communicate with BS directly instead, the nodes can communicate with CH directly, who then transfers the data packets to BS[19]. The objective elements are taken consider when choosing CH, including intra-cluster and inter-cluster distance, ode energy consumption, delay, displayed energy, and LLT, with the idea being that the solution having the shortest goal value is the best.

A. Network Area Parameter In Simulation

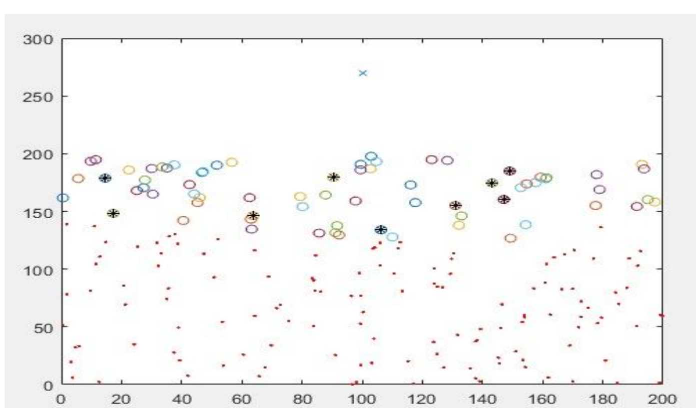
Parameter	value
Network area	1000 (m) x 500 (m)
Initial energy	0.3J
Simulation rounds	600 (rounds)
Communication range	200 (m)
E_{ele}	$50 * 10^{-9}$(J/bit)
E_{mp}	$0.0013*10^{-12}$ (j/bit/m^4)
E_{fs}	$10*10^{-12}$(j/bit/m^2)
CH packet size	4000 Kb
CM packet size	1000 Kb

B. Experimental Results

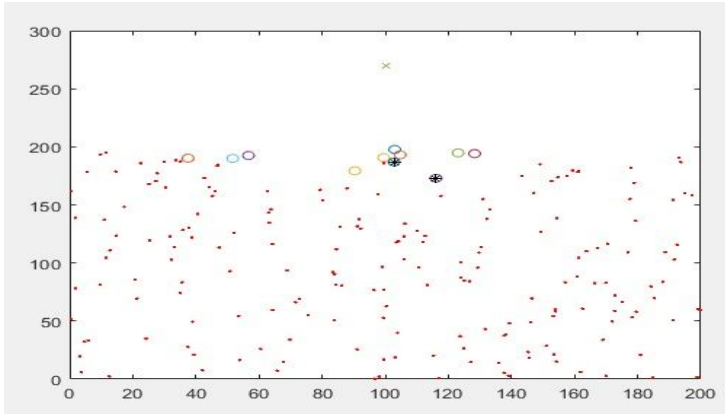
For experimental purpose, MATLAB is used. The following network area parameters are used for simulation purpose figure 11intial setup and figure 12 fifure4 shows 200 nodes based on the energy consumption few nodes become based the final stage of active to inactive on energy are ducted in fig 13 to 14



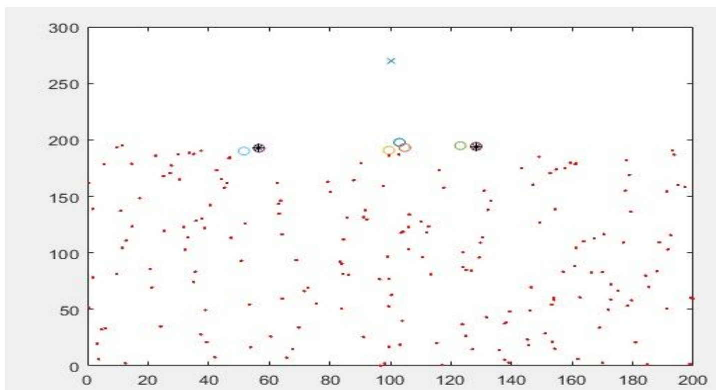
11 Initial stage for nodes and cluster heads



12 Second stage for nodes and cluster heads



13 Third stage for nodes and cluster heads



14 final stage for nodes and cluster heads

V. PERFORMANCE AND RESULT ANALYSIS

A. Energy Efficiency and Dead Nodes

Energy efficiency can be evaluated through parameters such as energy consumption, average residual energy use, network lifespan, the quantity of dead nodes, etc. The amount of bits l and the distance d determine how much energy is used at a node to send and receive data[17]. The model for transmitting and receiving energy usage as in equation (3)

E_{elec} is the energy is consumed per bit, E_{fs} represents amplification energy

$$E_{TX}(l,d) = \begin{cases} l \times E_{elec} + l \times E_{fs} \times d^2, & (d < d_0) \\ l \times E_{elec} + l \times E_{mp} \times d^4, & (d \geq d_0) \end{cases} \longrightarrow \text{Equation (3)}$$

$$E_{RX}(l,d) = l \times E_{elec},$$

for free space. E_{mp} is the multi-path model's amplification energy,and $d_0 = E_{fs}/E_{mp}$ is the threshold transmission distance.

FT-LEACH and PSO-UFC have lower energy than HEED's average residual energy. (energy consumption>more energy), while the average residual energy of FCGW is about 46% (energy consumption <50%).

B. Data Reliability

The hostile environment, limited transmission power, and fault factors are some constant influences on the connection quality of the sensors. assumes that the probability of successful packet transmission P for each connection in order to evaluate the data dependability from the CH to BS without sacrificing generality The FCGW protocol claims that multi-path increases the likelihood of successful packet transmission. Because FCGW has the fewest dead nodes, the volume of packets delivered and received is always higher. When compared to FT-LEACH, FCGW consistently receives more packets. the network with 200 nodes, BS position outside.

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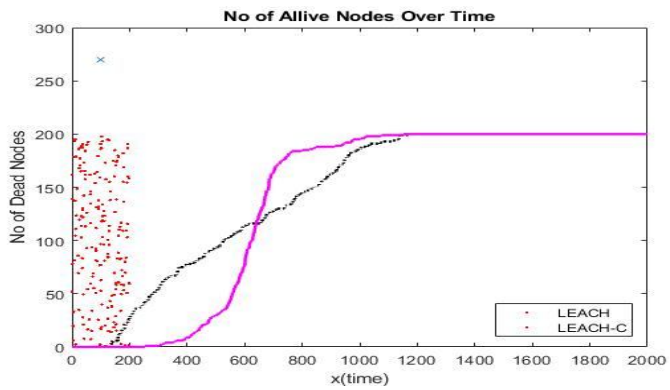

Figure.15 no node alive

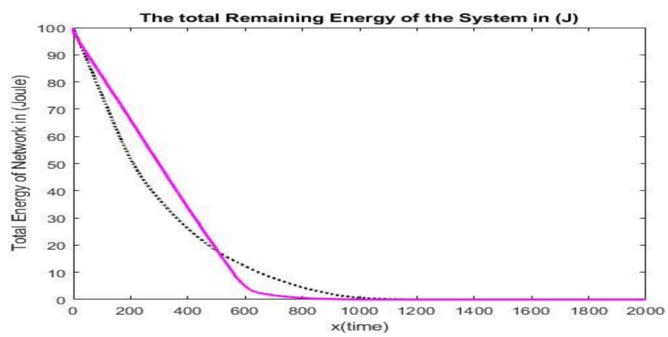

Figure.16 the total remaining energy of the system

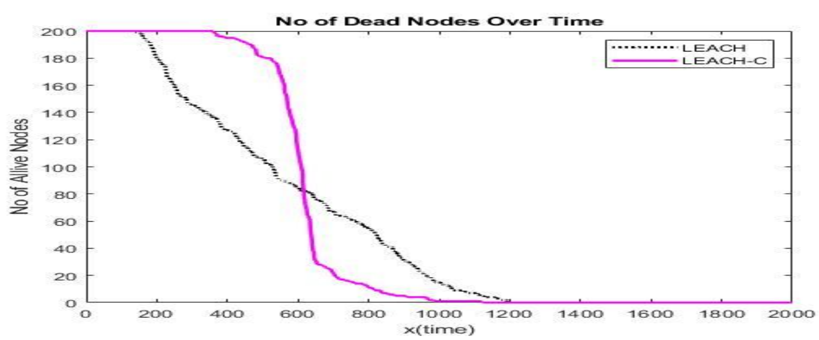

Figure.17 no of dead nodes over time

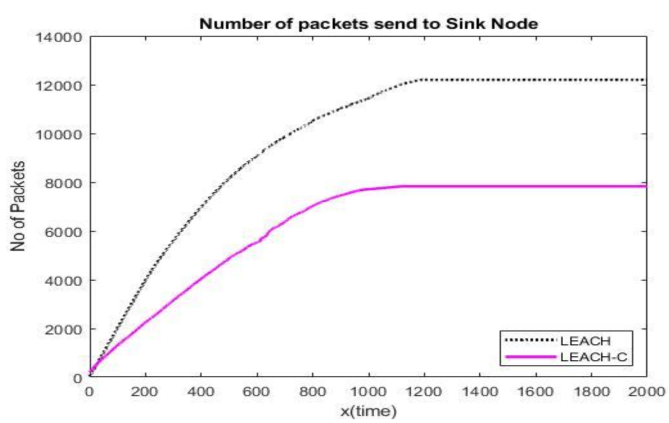

Figure.18 number of packets sends to sink node

VI. CONCLUSION

A hierarchical topology for a Wireless Sensor Network utilizing clustering routing and the Gaussian network connection features is presented. This method places the sensors in a rectangle region at random and groups them into various square grids. Through symmetric links and multi-path routing, this technique has increased fault tolerance because the CH nodes are joined to form a Gaussian network. The routing protocol uses the representation of the CH nodes as Gaussian integers to simplify the routing algorithms. Experimental results show significant reduction in the cost of multi-path routing maintenance and routing. It is a significant difficulty that increases packet delay to connect long-distance sensor nodes as a Gaussian network in a wireless environment. The characteristics of the Gaussian network and its Hamiltonian cycles will be used to address broadcast problems in Wireless Sensor Networks in the future.

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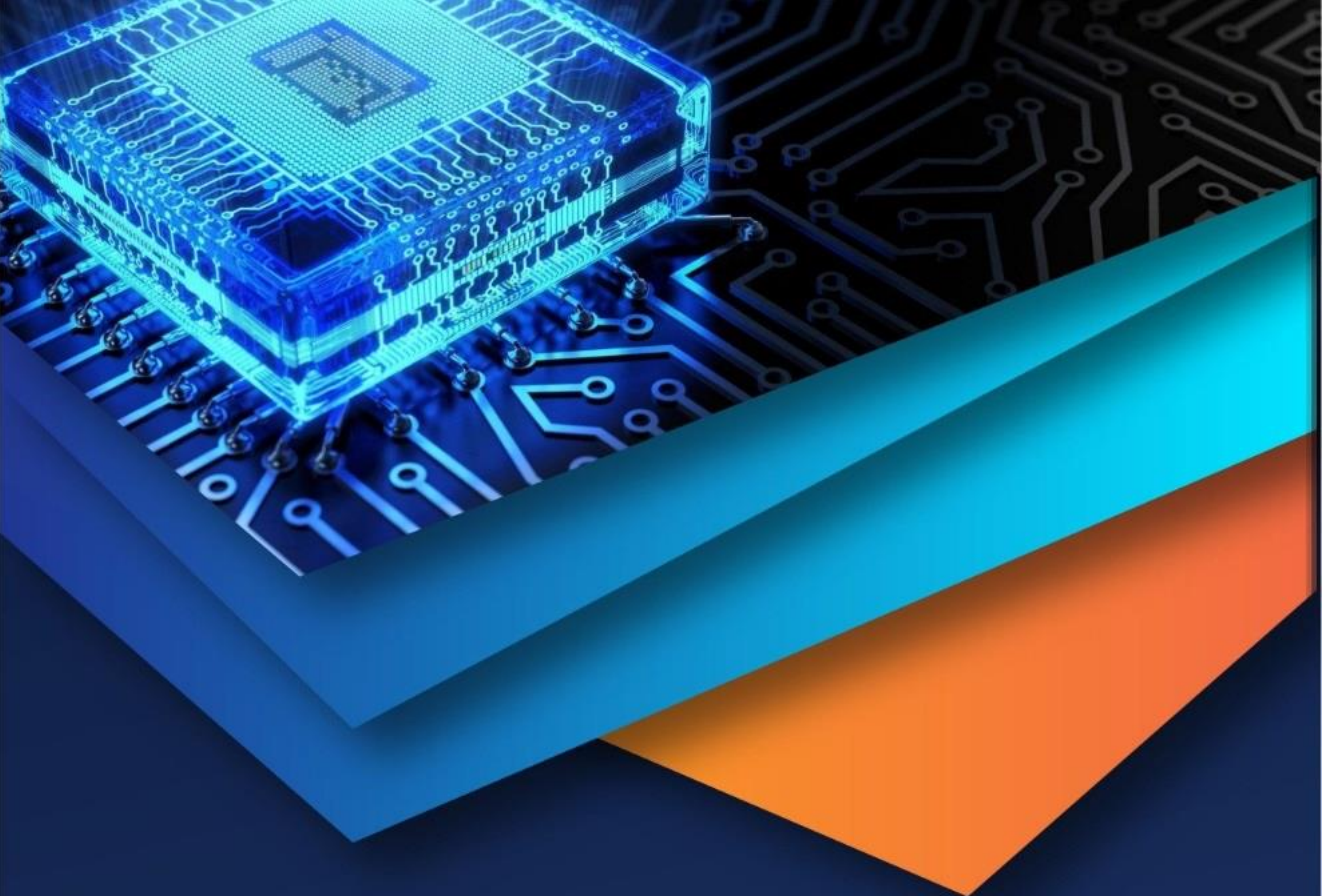

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