A Comprehensive Review - Energy Efficient Wireless Sensor Network

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Abstract - **In recent years, both the research community and end users have initiated to give more attention to wireless sensor networks (WSNs). WSNs are spatially dispersed networks with a large number of nodes that can monitor and record a variety of ecological conditions including humidity, temperature, pressure and lightning conditions. As a result of recent developments in advanced data transmission, the deployment of WSNs has substantially improved. A number of real-world issues can be solved at low cost using wireless sensor networks. Energy efficiency is the main criteria for routing protocol design for the wireless sensor networks since the life-time of the systems depends on the durability of each sensor node. The small sensor node in a WSN runs on a very small battery that has a limited amount of energy. It is not possible to change the battery or recharge the battery. So, the crucial factor is how energy-efficiently WSN operates. This article provides a brief overview of various secure and energy-efficient routing protocols including LEACH, PEGASIS, SEP, DDEEC, EESAA, IAATPC, and EESCA for wireless sensor networks**.

Keywords: Wireless Sensor Network, Routing Protocols, wireGoL, E3AF, Dijkstra-Huffman Method (DHM), MBER

I. INTRODUCTION

In the modern world, wirelessly connected devices are everywhere. We can gather data about our immediate surroundings using wireless sensors with minimal manpower. A wireless sensor node is integrated with power supplies, radio transceivers, and sensing and processing equipment. Computer networks that don't need any form of cables are known as wireless networks. With the use of a wireless network, firms can avoid the expensive process of installing wires inside of buildings or as a means of connecting various pieces of equipment. The term "Wireless Sensor Network" (WSN) refers to a wireless network, without any physical infrastructure that is deployed ad hoc using a large number of wireless sensors to monitor system, physical, or environmental factors. The United States Military's Sound Surveillance System (SOSUS), developed in the 1950s to find and track Soviet submarines was the first wireless network that resembled a modern WSN in any significant manner. In the Atlantic and Pacific oceans, this network made use of hydrophones, submerged sound sensors. Even while it now performs more benign tasks like keeping an eye on underwater fauna and volcanic activity and this sensing equipment is still in use.

WSN is quickly becoming a vital resource for cutting-edge technologies such as the Internet of Things and smart monitoring systems. WSN has become a valuable resource for many current applications such as smart cities, smart health, and smart buildings due to better sensor capabilities and advanced data exchange. Inaccessible places can now be easily monitored because of wireless sensor networks. It is a powerful tool for data collection in a variety of applications such as military surveillance, battlefields, forestry, oceanography, temperature, pressure, humidity, and so on [16]. WSNs are made up of a number of sensor nodes that are linked together and to a base station. The deployed sensors in the WSN work with limited battery a level, which limits data transfer. Since the sensors are dispersed across a large region, battery replacement is not possible. Understanding how WSNs operate at very low power is critical for extending network life. Understanding the distinct elements of WSN is critical for improving its performance in terms of network life. Researchers are investigating enhanced clustering-based hierarchical protocols with appropriate routing techniques to improve the energy-efficiency of WSN operation. Routing protocols are used in cluster WSNs to guide the selection of cluster heads (CHs) and to find the optimum route to save node energy.

The IEEE 802.15.4 standard is followed by WSN. WSN sensors are placed in a consistent or arbitrary manner based on the application needs. The sensor node's communication range is between 75 and 100 meters. Sensors in WSN will function in the 868 MHz, 915 MHz, and 2.4 GHz frequency bands, depending on the technological needs of the application. The battery of the smart sensor diminishes owing to numerous operations such as data transmission and receiving, data processing, and, most significantly, data retransmission due to collisions. The WSN uses direct sequence spread spectrum for secure data delivery. The physical quantity is sensed by the network's source node (sensors) and transmitted to the network's end node (destination). Advanced research strategies, such as energy conservation, must be proposed to handle this data dissemination [18]. According to the literature, each sensor uses 1nJ (1*10-9 joules) of energy for each command. In

WSN, a cluster of sensors forms and elects a CH (cluster head). Cluster nodes communicate with CH and are in charge of data aggregation. Data that has been aggregated and processed is transferred to the base station. Hence energy drained in CH high. Hence, to overcome this problem, researchers have proposed selecting CH dynamically within the cluster to assure improved node and network life.

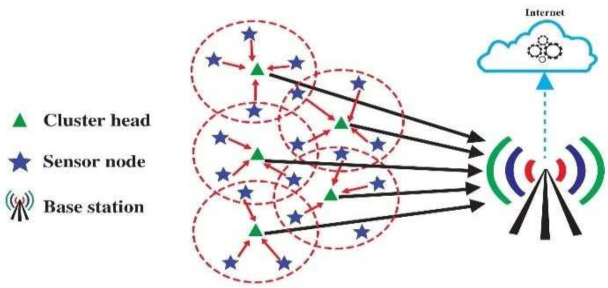


Fig.1 Typical Clustering Environment of WSN

Figure 1 shows the cluster-based WSN. The main function of CH is to collect the data from the sensor node, aggregate the raw data, and transfer it to BS. Hence, it is very important to conduct research to improve the energy of nodes and, indeed, the network life.

II. WIRELESS SENSOR NETWORK ROUTING PROTOCOLS

A. LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH - 2000)

LEACH is based on the Medium Access Control (MAC) protocol, which uses time division multiplexing. The LEACH protocol's purpose is to reduce the energy consumption of nodes and WSN [1]. LEACH also offers enhanced cluster building and routing approaches. According to the LEACH protocol, energy minimization in WSN can be achieved through uniform load distribution among WSN nodes. Based on the foregoing, LEACH outperforms alternative static clustering algorithms that select high-energy nodes as Cluster Heads (CHs). When compared to similar traditional transmission and energy routing techniques, LEACH reduces communication energy by eight times.

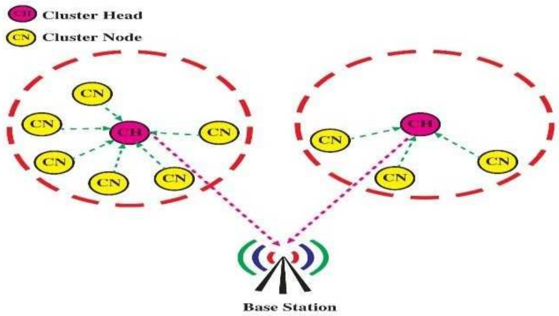


Fig.2 Data Transmission in LEACH Protocol

Figure 2 shows the radio model of communication between sensor nodes used to transmit their gathered data in LEACH protocol.

Node Overhaul Scheme for Energy Efficient Clustering in WSNs:

LEACH-USC [10]. The proposed system employs uniform-size clusters (USCs), giving rise to the name LEACH-USC, as well as a shortened intra-cluster communication distance. LEACH-USC's clustering strategy focuses on balancing network load by forming clusters of uniform size. In terms of cluster size and total intra-cluster communication distance, the proposed LEACH-USC has established high-quality clusters. The simulation findings demonstrate that LEACH-USC has higher FND (Round First Node Dies), HND (Round Half Node Dies), and LND (Round Last Node Dies) values than LEACH by 33, 43, and 27%, respectively, but the ESCC scheme has values that are 11, 29, and 16% higher for FND, HND, and LND, respectively.

B. PEGASIS

Power-Efficient Gathering In Sensor Information Systems-(PEGASIS -2002)

PEGASIS is a greedy chain protocol for better data collecting from WSN nodes that is considered an improvement over LEACH [2]. In the PEGASIS method, each node transfers data to only the nearest neighbour node and secures a turn to transmit data to the BS, lowering the amount of energy per round. For varying network sizes and topologies, the PEGASIS outperforms the LEACH by 150-300%.

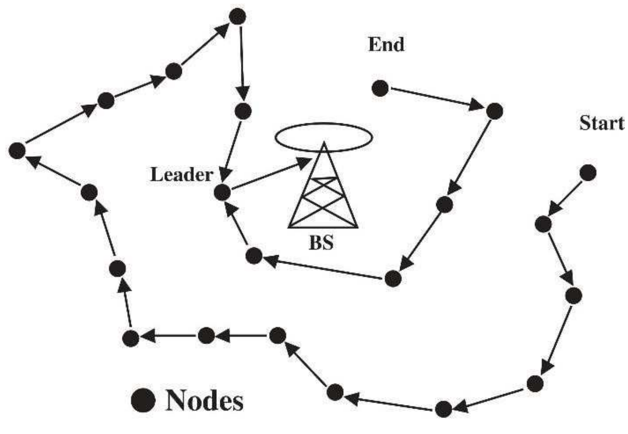


Fig.3 Schematic Diagram of PEGASIS Protocol

Figure 3 illustrates how the data delivered from each node reaches the base station in order to complete the data transmission using the PEGASIS protocol.

C. SEP

Stable Election Protocol (SEP - 2004)

SEP is built on a heterogeneous two-level hierarchical WSN. The LEACH and PEGASIS protocols did not take node heterogeneity into account. while compared to the aforementioned procedures, the SEP analyses optimal energy consumption even while considering various WSN.

The SEP improves the stable region of the clustering hierarchy technique by using heterogeneity restrictions, which are the fractions of the additional energy factor (α) and advance node (m) between the advance and normal nodes. Assume that E_O was the initial energy of each normal sensor. The energy of each progressed node is then $E_O(1 + \alpha)$.

D. IAATPC

Interference Aware Adaptive Transmission Power Control (IAATPC -2017)

The IAATPC approach was proposed, planned, and implemented for multi-channel ZigBee wireless networks. To improve WSN performance, QoS parameters, as well as channel fluctuation, must be considered. During transmission power control (TPC) co-channel interference and communication failure may happen [3]. The suggested algorithm is broken down into two stages: startup and operation. The factors that impact the information transmission efficiency, such as the received signal strength indicator (RSSI), signal to interference noise ratio (SINR), and primary transmit power, are analysed during the initialization step to design the communicate power matrix [11]. The transmitter node then begins broadcasting its data stream to the receiver node in the second stage of the proposed approach, known as the active phase.

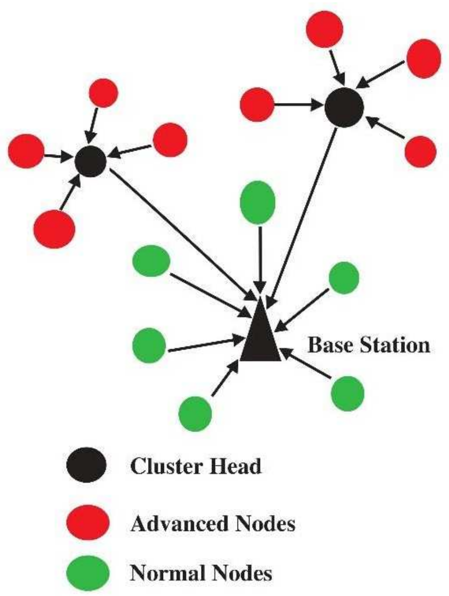


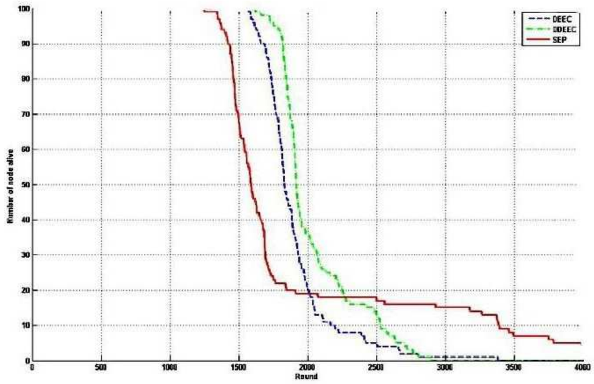
Fig.4 Illustration of SEP Protocol

There are two sorts of nodes, as shown in **Figure 4**, advanced and normal. The advanced node sends data to the base station via the cluster head. Even though it is a normal node, all nodes are designated as CH nodes before transferring data.

E. DDEEC

Developed Distributed Energy-Efficient Clustering (DDEEC -2010)

The DDEEC protocol is designed for heterogeneous WSNs. In this approach, CHs were chosen based on primary and residual energy. DDEEC is superior to DEEC(Distributed Energy-Efficient Clustering) and SEP in a multi-level, heterogeneous WSN situation [2]. DDEEC is an energy-aware adaptive clustering technique that uses the network's average energy to obtain adjustable methods. The DDEEC implemented an equalized and dynamic system because it distributes expended energy very equally among nodes.

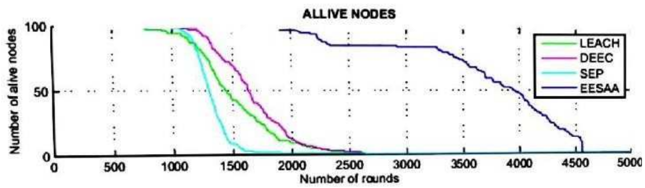


Graph.1 Number of SEP, DEEC, and DDEEC nodes that have remained active over time after 20 simulations of two-level heterogenous networks

F. EESAA

Energy Efficient Sleep Awake Aware (EESAA -2012)

EESAA proposed a new, optimized energy-efficient WSN method. Protocol selects CHs on a regular basis, and energy is dissipated uniformly by altering the position of the node. Energy load is dispersed in protocol by either forming a chain or being maintained by BS [3]. The worldwide understanding of the network required for the construction of a chain, and finally the findings demonstrating resource waste. Sensor nodes are individually selected as CHs in the DEEC protocol depending on initial and residual energy. To deal with the heterogeneous network, SEP was designed, which introduced the acceptance of advance and normal nodes for CH election. We sought to improve all of these variables in EESAA while keeping homogeneity in mind. EESAA selects CHs based on residual energy. To reduce energy consumption, EESAA nodes will alternate between sleep and active mode. In the first round, when all nodes have an equivalent beginning energy, i.e., E_O, nodes in active mode will elect themselves as CHs, aided by a distributed algorithm's likelihood of selecting a CH.



Graph.2 Number of LEACH, DEEC, SEP, and EESAA nodes that have remained active over time after 20 simulations of two-level heterogenous networks

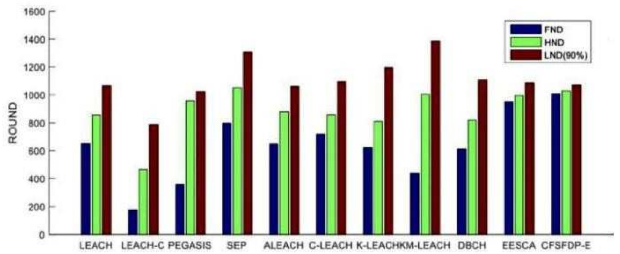
G. EESCA

Energy-Efficient Structured Clustering Algorithm (EESCA -2018)

EESCA was proposed for environmental monitoring fields. Many energy-efficient algorithms such as LEACH, PEGASIS, and SEP have been suggested to optimize the network. The optimized algorithms are primarily concerned with energy efficiency, network lifetime, and the CH selection process [4]. EESCA is fairly simple, and it uses a hybrid CH selection technique. CHs are chosen in this protocol based on the average communication distance between CH and BS as well as the node's remaining energy. A new parameter termed CH to a traditional ratio (CTNR) was also introduced. It introduced the rotation of the CH location among the nodes. To compute performance in terms of network stability, i.e., First Node Die (FND), execution time, scalability, load balancing, and complete useful data percentage (CUDP), where CUDP is a new metric evaluated in this research effort. In this study paper, the authors can assign responsibilities to nodes as CH or standard nodes based on the requirements in each cycle.

H. Game of Life (GoL) Cellular Automaton.

GoL is a bio-inspired model that cannot transmit packets; the A-star algorithm is modified to the suggested model with the goal of lowering the number of hops required to relay data to the sink node in a dynamic way [5]. As a result, a dynamic routing system is built, which avoids obstacles and allows access to the destination node in a many-to-one network. The Game of Sensors (GoS) is a fusion of the GoL CA's new set of rules and a new form of the A-star algorithm.



Graph.3 LEACH, LEACH-C, SEP, ALEACH, C-LEACH, K-LEACH, KM-LEACH, DBCH, EESCA, and CFSFDP-E network lifespan comparison

When compared to the most recent proposals, simulation testing show that the GoS technique improves energy balance while increasing network longevity and the number of packages transmitted via the network. Furthermore, the model retains the simplicity of cellular automaton models, making it suitable for large-scale networks.
Despite the fact that the Game of Life cellular automaton evolved as a biological model, it can be employed in WSNs. In WSNs, for example, neighbouring sensors typically collect identical data values [14]. As a result of turning off the majority of nearby sensors at each stage, the above transition rules avoid having too many sensors provide redundant information to the sink node. Furthermore, because only two or three sensors can be active at the same time in the vicinity of a focal cell (hence, the terms cell and sensor will be used interchangeably), these rules save energy.

Attribute	Description
$\omega_{i,j}(t)$	Current state of the cell at time t
$\omega_{i,j}(t+1)$	State to which the cell will transit to at time-step $t+1$
$e_{i,j}$	Battery charge of the cell *(i,j)*

Table.1 Attributes for a sensor *(i,j)* at *t*

To use GoL as a WSN model, the notions of CA must be mapped to WSN components, where C represents the total network made of sensors. is the set of possible sensor states (active and inactive). V denotes all sensors within the communication range of the focused sensor, and f denotes the algorithms and protocols (rules) that each sensor must follow. The node properties are summarized in **Table 1.**

One of the primary concerns with WSNs is increasing network longevity, because sensors are typically supplied with small batteries that cannot be easily recharged or replaced. As a result, implementing energy-saving practices has become a primary priority. A "symmetric die-hard cellular automaton," for example, which lasts 1638 ticks in a 32×32 bounding box, was recently presented. **Figure 5** depicts this CA at various time intervals. Even though this model can increase lifetime in a two-dimensional lattice, it produces the patterns depicted in **Figures. 5b-5f**, which do not fit well in WSNs since a high number of sensors remain switched off for numerous time-steps, resulting in information loss. Furthermore, because there are no nearby relay sensors, routing protocols may not function effectively with these rules. Variations to these principles are thus required to allow sensors to turn on after being dormant for numerous time steps.

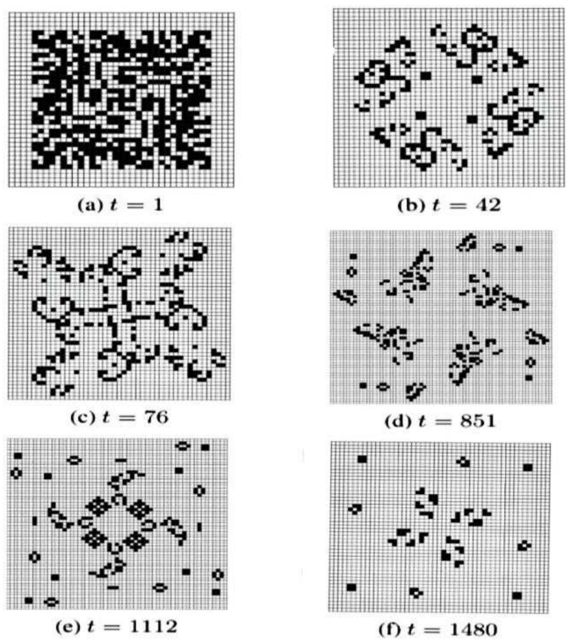


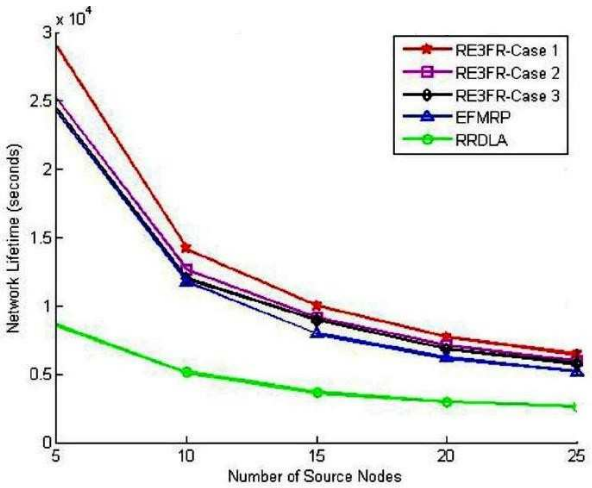
Fig.5 Symmetric die-hard pattern

I. E3AF: Energy Efficient Environment-Aware Fusion Based Reliable Routing

The suggested E3AF solution is divided into two phases. If the source node has a data packet to convey, it sends a forward ant across surrounding relay nodes until the data is absorbed by the sink node [6]. At each node, the forward ant chooses a neighbour node to relay data with a probability determined by the environmental effect metric, residual energy load function, hop count function, and link quality. These factors, coupled with the pheromone value, are used to calculate the likelihood of selecting a neighbour node to act as the next-hop node. When a forward ant arrives at the sink node, it transforms into a backward ant, and the second phase begins. The backward ant returns to the source node via the same path that was taken to reach the sink node in the opposite direction, with the aim of leaving the pheromone trail at each node it encounters.

J. DH Method

Dijkstra's algorithm and Huffman coding are combined in the Dijkstra-Huffman Method (DHM) [7]. Dijkstra's algorithm is used to locate nodes with the highest energy and shortest distance links. To generate an end-to-end security code, Huffman coding is utilized. A different security called Binary Hop Count (BHC) is offered to provide security at each hop.



Graph.4 Impact of increasing number of source nodes on network lifetime in E3AF

ENERGY OF THE NODE AND EVALUATION OF OPTIMAL DISTANCE PATH (ODP)

Only considering distance does not provide an appropriate evaluation because the shortest path may not incorporate the efficient energy of the node, causing the route to collapse. The energy of a node is critical in WSN communication. A node with less energy dies within a short period of time and is no longer capable of delivering data packets. As a result, when creating an effective path to the end nodes, such aspects must be taken into account.

BINARY HOP COUNT SECURITY AND END-TO-END AUTHENTICATION

The BHC security approach is used to secure communication between intermediary nodes. The node is tested for BHC security after the two parameters (energy and distance) are evaluated. If it matches the desired security [15], then that node can access the prior node's data. The entire operation should be completed within the stipulated time-to-live (TTL). Following the establishment of the path from source to destination, the authentication from source to destination is provided by the code formed by the energy values of the final path nodes using the Huffman coding technique. A trial packet is transmitted from the source to compare surrounding nodes in terms of energy, distance, and BCH security in order to determine which neighbouring node should receive the data. Once the best path from source to destination has been determined, an authentication code is sent from the destination to the source. If this code is found, the data is transferred from the source to the destination [17]. This technology is capable of transmitting data to nodes with higher energies while also offering secure communication. The most essential characteristic in WSNs is node energy, and the provided technique is effective for distributing packet loads with respect to node energies and avoiding network failure. The simulation results show that the suggested strategy minimizes packet loss and latency while also improving network longevity, which is crucial in WSN communication.

K. Energy efficient cooperative caching for Information-centric networking (ICN)

Information-centric networking (ICN) is an outstanding candidate for future network architecture because it shifts the networking attention away from host locations and onto transmitted data. Packets are provided directly through the information names and can be briefly stored in the network to serve subsequent requests [8]. As a series, ICN can relieve WSN bandwidth pressure and shorten sensor data fetching delays. Because of these distinguishing characteristics, ICN has lately been examined as a possible WSN network design, also known as information-centric wireless sensor networking (ICWSN). Recently, cooperative caching has been researched to reduce energy consumption while also improving networking speed.

L. Energy-Efficient Cooperative Routing Scheme for Heterogeneous Wireless Sensor Networks (EERH)

WSNs deployed in the same geographical area form a heterogeneous sensor network, with sensors relaying packets generated by their own WSN as well as other WSNs [9]. The packet delivery routes are dynamically determined based on the communicated directions of events as well as the residual energy of the underlying sensors and their neighbours. In addition, packets routed in the same direction by the same sensor are aggregated as one to save energy while notifying the associated sinks. The EERH efficiently increases the lifetime of a heterogeneous WSN, according to simulation data. As a result, the monitoring system can survive longer and the sinks can receive many more event packets.

The simulation findings show that aggregating event packets in a heterogeneous sensor network can reduce packet delivery energy consumption [13]. Without exchanging sensor statuses or electing a cluster head, properly utilizing aggregation can help to extend the lifetime of sensors, allowing them to monitor the underlying environment for much longer. Furthermore, while employing the EERH, we may select the suitable size of event packets and sensor transmission range, as well as alter the aggregation parameters, such as the ratio of event occurrence and delay constraints of distinct event notifications, in an attempt to extend the life of WSNs.

The EERH extends sensor lifetime and increases the flexibility of relaying opportunities in a heterogeneous WSN. As a result, it efficiently elaborates the sensors in the environment for detecting and transmitting events, thereby extending network monitoring lifetime. Furthermore, when employing the EERH, we can alter its parameters to meet the needs of the monitoring environment, such as the ratio of event occurrence and event delay limitations.

M. Maximum Bottleneck Energy Routing (MBER)

There are efforts being implemented to reduce energy usage in data aggregation and network security. These systems do not include a procedure for determining cluster heads or a routing strategy at the cluster level, whereas MBER does. They presume that clusters have already formed, that nodes are connected to one another, and that cluster heads have already been determined. This approach of energy savings can be included into energy-efficient routing algorithms. **Figure 6** shows basic structure of MBER.

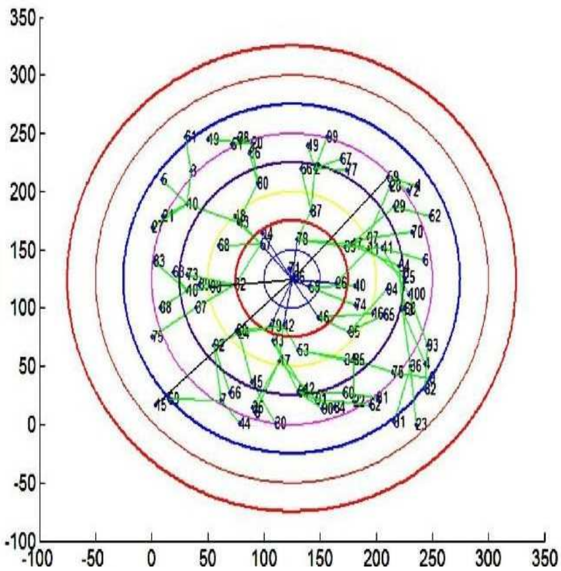
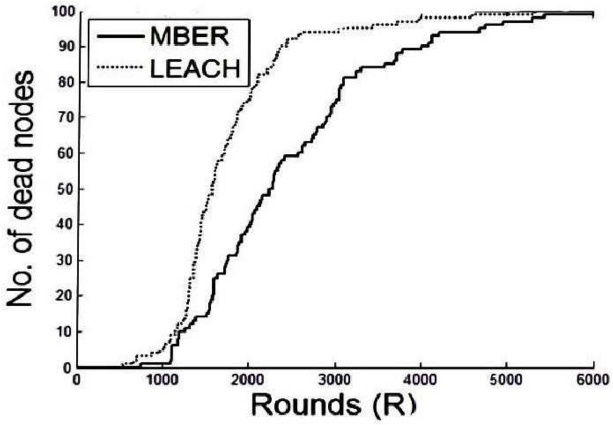


Fig.6 MBER – structure image

Using MBER, network nodes will be able to specify the optimum energy-efficient route for delivering acquired data to the base station. MBER eliminates nodes with lower energy as cluster head candidates at each level based on the maximum bottleneck energy they exhibit [12]. This contributes to a more even distribution of cluster head responsibilities among nodes at the same level. In terms of energy efficiency and the number of packets transmitted to the data sink node, simulation findings show that MBER surpasses other studied protocols such as MTE, LEACH, PEGASIS, DEEC, and DDEEC. The number of packets transmitted to the sink can imply that more accurate data will reach the sink for better data collection by the system.



Graph.5 The network lifetime, measured in terms of how quickly nodes die.

After analysing 6000 rounds of MBER and LEACH while keeping the limits of 2000 packet length, 100 nodes, an initial energy of 0.5 J per node, and an area of 250m*250m in consideration, it was evident that MBER outperformed LEACH as portrayed in Graph 5.

III. CONCLUSION

This work examines an overview of various significant procedures based on energy efficiency and WSN lifetime. Researchers are still interested in the WSN protocol LEACH in order to better understand low-energy performance. In terms of network life and network excellence, PEGASIS was recommended for outperforming other protocols such as LEACH and direct transmission. The SEP protocol was one of the first in heterogeneous networks to deal with two additional levels of hierarchy and two types of nodes. In the DDEEC protocols, every sensor node elects itself as a CH based on primary and lingering energy without a shared understanding of energy at every election node. The DDEEC protocol is built in an equitable and dynamic manner to more evenly distribute expended energy among nodes. The residual energy of the node is used to select CHs in EESAA. In EESAA, the node switches between sleep and active modes to conserve energy. However, research has shown improved techniques that outweigh existing ones. LEACH-USC's clustering strategy focuses on balancing network load by forming clusters of uniform size. In terms of cluster size and total intra-cluster communication distance, the LEACH-USC has established high-quality clusters. The simulation findings reveal that LEACH-USC has significantly higher FND, HND, and LND than LEACH as well. The MBER allows nodes to pick the optimal energy-efficient route for delivering their collected data to the base station. MBER exceeds other studied protocols in terms of energy efficiency and the number of packets transmitted to the data sink node because it negates nodes with lower energy. According to simulations, the EERH extends sensor lifetime and increases the flexibility of relaying opportunities in a heterogeneous WSN. As a result, it efficiently further explains the sensors in the environment to sense and transmitting events, thereby extending network monitoring lifetime. The simulation results for GoL show that the model accurately balances energy consumption, thereby prolonging the network's lifetime. For improved information fusion, the E3AF considered environmental variables as well as other essential aspects such as link load balancing, node energy, reliability, and an effective routing system. The DH technique is capable of delivering information to nodes with higher energies while also offering secure connection. The simulation results show that the DH approach minimises packet loss and delay while increasing the network's lifespan.

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