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An Optimal Routing for Chain-based Heterogeneous Wireless Sensor Networks

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Abstract: The longevity of the network depends on making the correct route decisions. The term "optimal routing" in wireless sensor networks refers to selecting the best path among the available routes in order to reduce energy consumption and increase network lifetime. Numerous optimization algorithms considering parameters like energy remaining in a node, node distance, network topology, and link quality when choosing the best routes. In order to enable data aggregation and energy-efficient routing through the CH, optimal routing techniques are typically implemented in cluster-based WSNs. In Heterogeneous WSNs (HetWSNs), reliability studies pertain to the network's capacity to deliver information to the base station. Extreme weather conditions, sensor node battery depletion, hardware and software malfunctions, and other factors all have an impact on a heterogeneous WSN's reliability. This article examines the application of optimal routing to both chain-based HetWSNs and also focuses on reliability studies in HetWSNs with chain-based connections that use optimal routing. For five levels of energy-based HetWSNs, an algorithm known as ORB-PEGASIS (Optimal Routing Based Power Efficient Gathering in Sensor Information System) is created. Our suggested ORB-PEGASIS algorithm increases the network lifetime of the HetWSNs by, according to a comparison of the obtained results with various algorithms, including PEGASIS-E by 68.42%, PEGASIS by 112.8%, PEG-ACO by 60.43%, and IEEPB-KMO by 58.47%.

Index Terms: Heterogeneous WSNs, Sensor nodes, Residual energy, Network lifetime, Reliability

1. Introduction

A Wireless Sensor Network (WSN) is a self-organizing system of tiny, independent devices known as sensor nodes, or motes, that cooperate to keep an eye on environmental or physical parameters like pressure, sound, and temperature. In contrast to conventional wired networks, WSNs are usually infrastructure-less, which means they are deployed on an as-needed basis and communicate wirelessly to transfer data to a central location called a Base Station [1]. To complete the task, sensor nodes and the base station collaborate. A data processing unit, a communication unit, and a sensing unit make up a sensor node [2]. WSNs are used in versatile nature of applications such as environmental monitoring [3,4], precision agriculture [5], military operations [6,7], continuous health monitoring [8], industrial automation [9], and traffic surveillance and control [10]. Due to the use of WSN in the versatility of applications, The reliance on WSN is growing daily. The primary determinant of the sensor node types utilized in a WSN is the application. Both homogeneous and heterogeneous sensor nodes are possible. Sensor nodes in a heterogeneous wireless sensor network have different energy levels, sensing capacities, and storage capacities than those in a homogeneous wireless sensor network [11]. The features of the network's nodes enable complex data processing and a longer network lifetime. The "hot spot" issues in homogeneous WSNs are lessened by heterogeneous nodes in a network. Sensor nodes have two possible modes of operation: distributed and cluster-based [12]. In the proposed ORB-PEGASIS algorithm, we have considered the chain-based connection with reliability-based routing. The nodes near the source, sense the information and work collectively alongside additional nodes to relay the information to the destination. PEGASIS is another nearly perfect chain-based protocol. Each node in PEGASIS only communicates with its immediate neighbors and alternates transmitting to the base station [13]. Every node in the HetWSN using ORB-PEGASIS communicates with a neighboring connected node, alike PEGASIS algorithm. However, ORB-PEGASIS considers heterogeneous nodes placed in the predetermined slots. To what degree the WSN is capable of providing the services is mainly dependent on network reliability. Reliability is typically used to describe a system's capacity to carry out its intended function [14]. A node's reliability is crucial for both sensing information and sending packets to base station. The capacity of a node to sense information and transfer it to another node or destination increases with its reliability. An essential component of designing engineering system is it's reliability assessment [15]. The approaches related to determining the network reliability of wired networks are presented in [16,17,18,19,20,21,22,23,24,25,26,27,28,29,30]. Because WSNs are dynamic, these methods are not applicable to them. Nodes in WSN fail frequently due to their exposure to harsh environments and limited battery power.

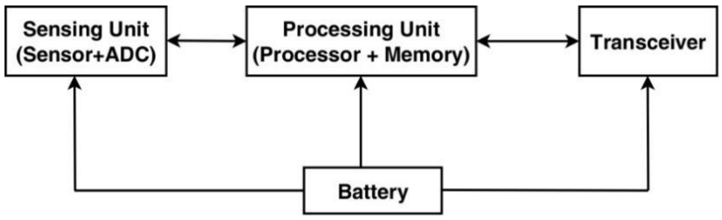

Fig. 1. Internal design of a sensor node [44].

Connectivity and the nodes' ability to handle traffic are two important factors that affect a network's reliability [31]. The likelihood that there is a working path between the base station and the multiple sensor nodes is known as WSN reliability based on connectivity. WSN reliability is the probability, based on capacity, that a minimum total amount of data is transmitted from the multiple-sensor node(s) to the Base-station [31]. Connection-oriented WSN approaches are presented in [32,33,34,35,36,37,38,39] and flow-oriented WSN reliability are presented in [40,41,42]. WSN reliability, according to the event-driven approach, is the likelihood that the sink node will successfully receive the event-specific data sensed by the sensors [31]. Using the network's minimal paths or minimal cut-sets, one can determine the system's network reliability. The group of nodes whose operation guarantees the WSN's operation is known as the minimal path. In a WSN, a minimal path indicates the network's operation, that in turn depends on each node in the set operating correctly. The only thing that each minimal tie-set consists of is the chain-based link that connects the nodes from source to destination. A node may appear in any number of minimal tie-sets based on its connectivity with the neighboring nodes. When some of a WSN's nodes fail, it can split into several interconnected parts, a phenomenon known as a “cut" [43,44,45]. The system fails when any one of its parts malfunctions. We refer to this as the minimal cut-set. However, the system won't malfunction if none of the components have failed. Minimal cut-sets of the network can also be used to evaluate the network reliability of any system [15].

Figure 1 depicts the internal design of a sensor node. The limited battery power present in the sensor node is used by the transceiver, processing, and sensing components. Sensing, producing and transmitting data to BS are capabilities of the sensor node. Authors in [46] suggests that, the hybrid protocols that combines the topologies such as chain, cluster, grid and tree enhances the lifetime of the network. Authors in [47] proposes the novel a vertical network partitioning technique called EEPEG-PA-V to send data from the working nodes to the base station (BS). This method states that the vertical partitioning occurs when the node's remaining energy is about to expire. When compared to current routing techniques, the proposed method has the potential to significantly increase the average network longevity. For example, when compared to PEGASIS, EEPEG-PA improves it by 21.7092 percent. Authors in [48] proposes EEPEG-PA-H horizontal network partitioning technique to send data from working nodes to the base station (BS). When a node has little energy left, the transition takes place. When compared to current routing techniques, this approach has the potential to greatly extend the average network lifespan. Compared to PEGASIS, EEPEG-PA-H increases longevity by 22.7763 percent. Authors in [49] compares LEACH and PEGASIS protocols considering mobility in a Python-based simulation tool. This study demonstrates that both regimens have characteristics that complement one another. This gives rise to the concept of a hybrid routing system that blends the chain-based energy efficiency of PEGASIS with the cluster-based adaptability of LEACH. In subsequent WSN deployments, this integrated approach may more effectively address the two issues of mobility and energy conservation. Authors in [50] proposes a robust routing framework for heterogeneous wireless sensor networks, addressing critical challenges in energy efficiency and network longevity through adaptive optimization and role-aware resource allocation. The integration of dynamic CH selection, hybrid transmission strategies, and heterogeneity-aware modeling enables balanced energy distribution across nodes with diverse capabilities. Experimental validation confirms the framework’s superiority over conventional protocols, particularly in mitigating energy hot-spots and extending operational lifespan under realistic deployment scenarios.

In the proposed ORB-PEGASIS algorithm, the nodes near the source in the WSN senses the information and transmit it to the neighboring connected nodes. Only in the RELAY state are the other nodes in the WSN utilized to transfer data between nodes. In a WSN, there are multiple ways for data to travel from the source to the sink. There must always be at least one path connecting the source and the destination for data to travel there. We find minimal paths and minimal cut-sets of WSNs. We evaluate WSN reliability using minimal tie-sets. This article presents an ORB-PEGASIS algorithm, which places the heterogeneous sensor nodes in the predetermined locations/slots in the network according to how many appearances there are overall of the slots in the minimal paths and minimal cut-sets together. Further, the reliability of each minimal path is calculated using Fuzzy AHP. The minimal path, which is more reliable than other minimal paths, gets the first opportunity to send the information from the sensor nodes to the destination. Depending on their reliability, the remaining minimal tie-sets will transmit the data from the sensor nodes to the destination. As far as we are aware, there isn't a single approach like that in the literature. The strengths and limitations of the existing protocols are listed in Table 1. According to the Simulation results, the suggested ORB-PEGASIS algorithm performs better than LEACH *[51], PEGASIS [13], PEGASIS-E [52], PEG-ACO [53],* IEEPB-KMO *[54],* according to the network's lifespan, residual energy, and average energy consumption. For the majority of networks, our suggested algorithm's stability is also enhanced. The five categories of heterogeneous nodes used by ORB-PEGASIS — Extra-ordinary nodes/ultra-super nodes, super nodes, advanced nodes, semi-advanced nodes, and normal nodes —vary in terms of their energy levels and capacities. ORB-PEGASIS considers randomly connected heterogeneous nodes in a chain-based fashion placed at predetermined locations/slots. Firstly, in ORB-PEGASIS, minimal tie-sets (minimal paths) and minimal cut-sets of a WSN are determined. Fuzzy AHP calculates the reliability of each minimal path by considering variables such as the initial energies present in nodes in the minimal path, the individual reliability of every node in the minimal paths, and the separation between the destination and the sensor nodes. Depending on how reliable each minimal path is, the nodes are allowed to deliver information from the source sensor nodes to the destination. The nodes that make up the incredibly reliable minimal tie-set/path is first allowed to send the information to the base station from sensor nodes. Depending on how reliable their minimal path is, the nodes that belong to the other minimal paths are permitted to send the data. The findings indicate that, ORB-PEGASIS performs better than LEACH, PEGASIS, PEGASIS-E, PEG-ACO, and IEEPB-KMO algorithms in relation to the WSN lifetime, energy remaining in the network, and the utilized energy by the WSN.

Table 1. Strengths and Weaknesses of Existing Protocols.

Protocol	Strengths	Weakness
LEACH	Distributed execution and simple	Low-power nodes may be killed early
PEGASIS	Transmission distances are reduced	Significant data latency
PEGASIS-E	Path length is evenly distributed	Single-point-of-failure
PEG-ACO	Shorter chains and stable network	Requires more processing head
IEEPB-KMO	Excellent load balancing and scalability	Architectural complexity

1.1. Assumptions made in the ORB-PEGASIS algorithm

- There is no consideration of data loss during the journey from the various sources to the sink node.
- Reliable links are present between the nodes.
- Data is not divisible when it comes to transmission between nodes.
- The information transferred between sensor nodes is dependent on the capacity of the nodes.
- No limitations are imposed on the links for the data transfer.
- In terms of statistics, nodes are independent of one another.
- A sensor node's reliability declines as its energy level drops.
- Heterogeneous nodes in a WSN are placed in the predetermined locations over the network.

1.2. Limitations of our ORB-PEGASIS algorithm

The baseline assumption of perfect communication links, zero data loss, and strict node independence is a major limitation of this study. Although these presumptions make mathematical modeling easier and isolate the system's basic dynamics, node dependencies and environmental interference are unavoidable in real-world deployments. As a result, theoretical upper bounds are represented by the performance metrics presented in this study. In order to assess the model's resilience in more realistic, lossy situations, we hope to expand this framework in subsequent work by adding correlated node behaviors and stochastic link failures. The system model of our ORB-PEGASIS protocol is simplified. Isolating factors such as interference, collisions, and dynamic topology gives us the standard baseline approach for establishing fundamental theoretical upper bound to evaluate the performance before adding complex stochastic variables.

1.3. Benefits and Motivations of our ORB-PEGASIS algorithm

According to the review of literature, cluster heads (CHs) are chosen at random in many protocols designed for heterogeneous WSNs [55]. Existing routing protocols consider low-reliability nodes for cluster head selection in heterogeneous networks. The low-reliability nodes die too soon, cutting off communication with the rest of the network. So, there is a need to develop a heterogeneous routing protocol that extends the network lifetime considering reliability of each node. So, we are motivated to develop an optimal routing protocol for chain based heterogeneous WSNs that extends network lifetime. It is also observed from the literature review that, not one of the methods concentrates on the reliability-based optimal routing protocol with chain-based connection for power-efficient gathering in sensor information systems (ORB-PEGASIS) for five levels of chain-based HetWSNs based on energy levels using Fuzzy AHP. We were inspired to create a chain-based routing protocol utilizing five-level heterogeneous nodes to extend network lifetime in the WSN following the literature review. The network lifetime, energy left in WSN, and mean energy used by the network are all improved by the suggested ORB-PEGASIS routing protocol.

1.4. Novelty of the proposed ORB-PEGASIS algorithm

- None of the algorithms proposed for HetWSNs considers five tiers of sensor nodes for a chain based WSNs. We design and develop an ORB-PEGASIS algorithm considering five levels of wireless sensor nodes for chain based WSNs.
- ORB-PEGASIS selects the cluster heads by considering the reliability parameter along with energy and distance between the nodes and the base-station. None of the algorithms proposed for chain-based HetWSNs consider the reliability parameter to enhance network lifetime.

1.5. The ORB-PEGASIS's innovations and contributions

- We create an energy-efficient chain-based routing protocol for energy-based heterogeneous wireless sensor networks with five tiers.
- Depending on how many times a node appears overall in both the minimal paths and the minimal cut-sets, it is assigned to the designated spot.
- The Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) is used to determine the reliability of each minimal path by considering the node's initial energy, the separation between the sensor nodes and the destination, and the reliability of each node in the minimal path.
- The chance to deliver the information from source sensor nodes to the base station is granted to heterogeneous nodes based on the reliability of each minimal path.

The article's remaining sections are arranged as follows. The system model is covered in section 2. We go over our suggested ORB-PEGASIS for HetWSNs in section 3. We go over the outcomes of our algorithm's simulation and conclusions in section 4 and 5 respectively.

2. Model of the System

Here we present the utilization of energy model of WSN and the assumptions made by us during the implementation of our proposed ORB-PEGASIS algorithm. Five energy-based HetWSN levels— ultra-super nodes, super nodes, advanced nodes, semi-advanced nodes, normal nodes —are used in the proposed ORB-PEGASIS protocol. Compared to normal nodes, which we define as having an energy of 0.5 J, other types of nodes have greater energy. The initial energies of ultra-super, super, advanced, and semi-advanced nodes are 3.2,3,2.5 and 2 times higher than normal nodes respectively. Compared to regular nodes, higher energy nodes are more potent in terms of storage and processing power.

2.1. Assumptions

In the area of 100*100 m^2 is where we place the diverse sensor nodes.

The nodes, whose batteries cannot be replaced or recharged, are placed in specific slots within the sensing region and in a hostile environment.

The kinds of heterogeneous sensor nodes that should be positioned in the predetermined slots are determined by the number of times the predetermined slots appear in the minimal paths and minimal cut-sets.

It is assumed that sensor nodes remain motionless.

3. ORB-PEGASIS Algorithm

Each node is made up of a transceiver, processing, battery unit, and sensing units, as shown in figure 1. Wireless sensor nodes are prone to malfunction since they are placed in a hostile environment. In this work, we assume that the processing, transceiver and sensing units work fine until the battery dies. The states in which each sensor node can function are as follows:

- ACTIVE: A sensor node can communicate as well as sense. This shows the probability that the sensor node is in the ACTIVE state of operation

$$\text{Pactive(x)} = \text{Pcomm(x)} * \text{Psense(x)} \tag{1}$$

where '$P_{active}(x)$' represents the likelihood that a node x's transceiver unit is operational. `$P_{sense}(x)$' indicates the likelihood that a node x's sensing unit is operational. `$P_{comm}(x)$' indicates the node x's communication unit's probability of working.

- RELAY: A network node's sensing unit is turned off, so while it can communicate, it cannot sense. The probability that, the node in the network works in RELAY state is

$$\text{Prelay(x)} = \text{Pcomm(x)} * (1 - \text{Psense(x)}) \tag{2}$$

- FAIL: A node fails when the transceiver unit is failed or the battery is exhausted. Sensor node is not able to communicate or sense in this state. The likelihood that the sensor node will be in the FAIL state is

$$\text{Pfail(x)} = 1 - \text{Pactive(x)} - \text{Prelay(x)} \tag{3}$$

$$\text{Pfail(x)} = 1 - \text{Pcomm(x)} \tag{4}$$

The designated spot in the sensing area is where the sensor nodes are placed. The sensor node can be in one of three states at any time: ACTIVE, RELAY, or FAIL. The proposed ORB-PEGASIS protocol is designed to send the information to the destination from source point. As a result, nodes that are connected to the source point operate in an ACTIVE state in order to senses the information and transmit it to nearby nodes. The remaining nodes work in RELAY state to receive and transmit the information from the neighboring nodes. We take into account five levels of energy-based HetWSNs in our ORB-PEGASIS method. The network uses a variety of node types, including super, semi-advanced, advanced, ultra-super, and normal nodes. The additional energies found in advanced, super, ultra-super, and semi-advanced nodes are indicated by *b, c, d*, and a respectively. We define

$$\begin{cases} \sigma = w \\ \upsilon = (1-w)(w0) \\ \psi = (1-w0)(1-w)(w1) \\ \mu = (1-w1)(1-w)(1-w0)(w2) \\ ♭ = (1-w2)(1-w1)(1-w0)(1-w) \end{cases} \tag{5}$$

Where w is the fraction of normal nodes present in the sensing area and w2, w1, and w0 are the fraction of other nodes such as, super, advanced, and semi-advanced nodes respectively out of the remaining nodes. The complete energy present in the homogeneous WSN is found using

$$EWSN = n.E0 \tag{6}$$

In a homogeneous WSN, every node's energy present in it initially is represented by E0. The complete energy in HetWSN with five heterogeneous node levels is

$$E_{HetWSN} = E_{WSN}\{\sigma + \upsilon(1+a) + w(1+b) + \mu(1+c) + ♭(1+d)\} \tag{7}$$

When compared to homogeneous WSNs, the total additional energy discovered in the HetWSNs with five energy levels is as follows

$$\sigma + \upsilon(1+a) + w(1+b) + \mu(1+c) + ♭(1+d) \tag{8}$$

'dn' is the separation between each sensor node and 'd_{BS}' is how far away the sensor node is from the base station.

$$dn = \sqrt{Square(S(k)(f).xpos - S(k+1).xpos) + Square(S(k)(f).ypos - S(k+1)(f).ypos)} \tag{9}$$

$$d_{BS} = \sqrt{Square(S(k)(f).xpos - S(BS).xpos) + Square(S(k)(f).ypos - S(BS)(f).ypos)} \tag{10}$$

In which S(k)(f).xpos represents the location of f^{th} node in x-axis. S{k+1}(f).x{pos} represents the location of the adjacent node in x-axis. In which S(k)(f).y{pos} represents the f^{th} node's location in y-axis. S{k+1}(f).y{pos} represents the location of the adjacent node in y-axis. S{BS}(f).y{pos} represents the base station's location in y-axis. 'D_{ave}' represents the mean distance from base station to all other nodes.

$$d_{ave}=\sum_{i=1}^{n} dBS/n \tag{11}$$

The network's sensor locations are determined by equation 9. Once the position for placing the heterogeneous nodes is decided, the minimal cut-sets and minimal paths for the WSN are found. The individual reliability of each minimal tie-set $R_{mintieset}$ are determined by using Fuzzy Analytic Hierarchy (Fuzzy-AHP) technique considering the criteria such as energy present in the sensor nodes initially, distance among base station and the sensor nodes, and each node's reliability.

$$R_{mintieset}(j)=\alpha(E_{initial}(j)/E_{ave}).\beta(d_{ave}/d_{BS}).\zeta(R_{nodeavgintieset}(j)/R_{ave}) \tag{12}$$

Where j={1,2,.....m}, m represents the number of minimal paths in the network, the energy initially available in the minimal paths is $E_{initial}$. The mean energy considering all the nodes is E_{ave}, The mean reliability of a minimal path considering the reliability of every sensor nodes present in the minimal path is $R_{nodeavgintieset}$, and the mean reliability of all the sensor nodes in the network is R_{ave}.

E_{ave} is the average energy of all the nodes in the sensing area, $R_{nodeavgintieset}$ is the average reliability of all the nodes in the minimal tie-set, and R_{ave} is the mean reliability of every node in the sensing area. Where , α, β and ζ are the weights that is found using Fuzzy AHP technique.

$$R_{ave}=\sum_{i=1}^{n} Rnode(i)/n \tag{13}$$

$$R_{nodeavgintieset}(j)= \sum_{i=1}^{n} Rtiesetnodes(v)/z(v) \tag{14}$$

In which i={1,2,.....n}, The network's total node count is represented by n. Each minimal path's node count is stored in z(v) i.e z(v) = h1,h2,..........hj, Rtiesetnodes(v) denotes the reliability of every node present in the minimal path. Rnode(i) is the each node's reliability, $R_{normalnode}$ is the normal node's reliability, $R_{semiadvancednode}$ is the semi-advanced node's reliability, $R_{advancednode}$ is the advanced node's reliability, $R_{supernode}$ is the reliability of a super node, and $R_{ultrasupernode}$ is the ultra-super node's reliability.

$$Rnode = \{Rnormalnode, Rsemiadvancednode , Radvancednode, Rsupernode, \ Rultrasupernode\} \tag{15}$$

The average amount of energy remaining is supplied by the five levels of energy-based heterogeneous wireless sensor networks

$$Eave(r) = (1/n)EHetWSN(1 - r/R) \tag{16}$$

With the available remaining energy, the number of rounds possible is

$$R = EHetWSN/Eround \tag{17}$$

Although the baseline equations are standard, the primary methodological novelty of our work lies in designing the five levels of heterogeneous nodes as in equation 5 and The Rmintieset is found using parameters such as energy, distance, and average reliability as given in equation 12. The weights such as, α, β and ζ are found using fuzzy AHP.

3.1. Fuzzy Analytical Hierarchy Process

The technique used for determining cluster head weights for energy α, distance β and reliability ζ are found using fuzzy AHP. These parameters are multiple decision makers for the selection of cluster heads in the network. We create a pairwise comparison matrix using triangular fuzzy numbers between the parameters such as energy, distance and reliability. Fuzzy weights for each of these parameters are obtained. Fuzzy weights obtained are converted to numerical values and ranked to obtain the priority for energy α, distance β and reliability ζ. By using Fuzzy AHP, the stability of the network, energy consumption and throughput have all improved when compared to conventional methods used in the algorithms proposed in the literature review.

3.2. Finding the minimal paths of a chain-based WSN

The ability of a WSN to carry out the intended tasks, like sensing information and sending information from the sensing area to the destination, is known as reliability in WSN. Either the minimal paths or the minimal cut-sets of a

WSN can be used to determine a WSN's reliability. In a WSN, a minimal path also known as minimal tie-set, is one in which every node in the set must carry out the desired tasks for the network to operate. A chain-based connection between the source and the destination is all that constitutes a minimal path. If one of the nodes in a minimal path fails, the path will fail. The principle of series systems is used to determine the reliability of each minimal tie-set if $P(T_1)$ is the probability of occurrence of a node in the minimal path. The minimal path is regarded as the highly reliable path since it has the highest reliability when compared to the other minimal tie-sets. The reliability of all the minimal tie-sets provided by is used to determine the reliability of a WSN.

$$RWSN = P(T1 \cup T2 \cup T3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Ty) \quad (18)$$

3.3. Minimal cut-sets of a chain-based WSN

Sensor nodes are positioned in challenging environments where failure is a possibility. Transmission of data from the sensor nodes to the destination may occasionally be stopped by the failure of a few WSN nodes. A cut can be formed by dividing a WSN into several connected nodes. A WSN's minimal cut-set is one in which data cannot be transmitted from the sensor node to the destination if every node in the cut-set fails. The unreliability of a WSN is given by if the j^{th} minimal cut-set is termed as C_j and its occurrence probability of a node in a minimal cut-set is designated as C_j.

$$QWSN = P(C1 \cup C2 \cup C3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Cy) \quad (19)$$

Then the reliability of a WSN is found using

$$RWSN = 1 - QWSN \quad (20)$$

3.4. Deployment of heterogeneous nodes in the WSN

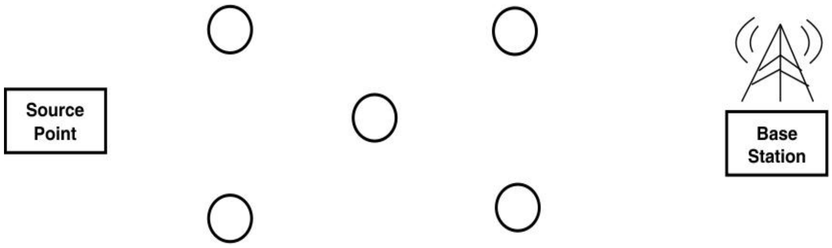

Fig. 2. Predetermined slots from the source point to the destination

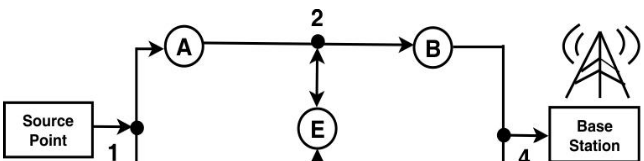

Fig. 3. The theoretical (expected) connections between the slots and their naming

Within a 100 * 100 m^2 area, heterogeneous sensor nodes are placed in the designated locations (slots). Five different kinds of heterogeneous nodes — ultra-super, super, advanced, semi-advanced, and normal nodes—are being used. Figure 2 displays the predefined network slots to the destination point from the source point. We think about allocating an equal number of heterogeneous types of nodes in the designated slots. Initially, predetermined slots are found, using the Euclidian distance formula. Knowing the range of communication of the normal nodes, the theoretical (expected) connections between the slots are drawn. The expected connections between the predetermined locations are established prior to placing the nodes in these locations. The connected predetermined slots are equidistant to each other and are named in alphabetical order from the source point to the destination as designated in the Figure 3.

Based on the theoretical connections established between the slots, the minimal paths and minimal cut-sets of the WSN are found. The slots in the sensing area are named `A', `B', `C', `D', and `E'. Based on the overall number of appearances of these slots in the minimal paths and in the minimal cut-sets, the placements of heterogeneous nodes in these slots are decided. We consider that there are five heterogeneous nodes are available to us.The five heterogeneous nodes are ultra-super/Extra-ordinary, super, advanced, semi-advanced, and normal nodes. Depending on how many times in total, the slots appear in the minimal tie-sets and minimal cut-sets of the network depicted in the figure 3, these nodes are positioned in the assigned predetermined slots. The types of nodes to be placed in the slots, which are connected from the source point (i.e. in Figure 3's point 1) to the other points (i.e. Figure 3 's point 2, 3, 4), are decided at first. Later, the types of nodes to be connected between the points other than the source point (from the 2nd and 3rd points in the network up to the destination point 4 as shown in Figure 3 are decided later.

Table 2. Total number of appearances of each slot in the minimal paths and in the minimal cut-sets

Slots	Appearances in minimal tie-sets	Appearances in minimal cut-sets	Appearances in both
A	2	2	4
B	2	2	4
C	2	2	4
D	2	2	4
E	2	2	4

3.5. Deployment of heterogeneous nodes in the slots, that connects from the source point to other points in the WSN

At first, the overall number of appearances of each slot from the source point to the other points, in the minimal paths and in the minimal cut-sets are considered. In Figure 3, we observe that slots `A' and `B' are the only two slots available from source point `1' to other points 2, and 3. No direct connection exists between source point `1' and destination point 4. The minimal paths of the WSN shown in the Figure 3 are CD, AB, AED, and CEB. WSN's minimal cut-sets are AC, BD, AED, and CEB. The total number of appearances of slots E, D, C, B, and A for the network shown in Figure 3 are given in Table 2. Slots `A' and `C' are the ones that connect from the source point 1 to other points 2, and 3 respectively. The slots, that connects from the source point to the other points and their total number of appearances in the minimal paths and in the minimal cut-sets, are given in Table 3. If the sum of a slot's appearances (count) (i.e. A or C) from the source point `1' to other points 2, and 3 is lesser than other, then the sensor node with a lesser energy level is placed in that slot (i.e. the normal node). The slot with the second lesser count is placed with the node, that has the second lesser energy level node available to us. This goes until all the slots that connect from the source point to other points are completed. The total number of appearances of the slots `A' and `C' in the network, shown in Figure 3 are the same (i.e. 4) as given in Table 3. Therefore, a pseudo-random number generator (PRNG) is utilized to eliminate selection bias. Based on the pseudo random number generator we have placed the lesser energy node (i.e. the normal node) at slot `A' and the next lesser energy node (i.e. the semi-advanced node) at slot `C'. The nodes placed at `A' and `C' configure themselves and establish the connection from the source point as shown in the Figure 4.

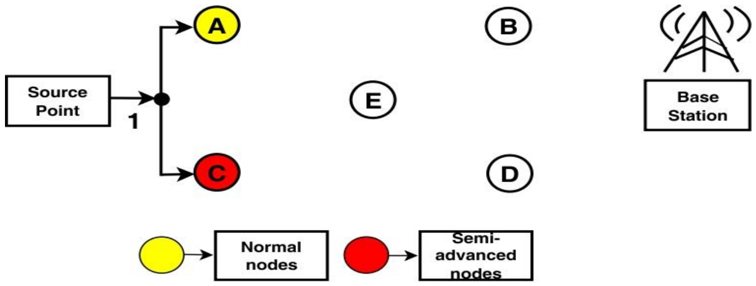

Fig. 4. Deployment of nodes in the predetermined slots from source point to other points

Table 3. Slots that connect from source point to other points and their appearances in the minimal paths and in the minimal cut-sets

Slots	Appearances in minimal tie-sets	Appearances in minimal cut-sets	Appearances in both
A	2	2	4
C	2	2	4

3.6. Deployment of heterogeneous nodes in the slots, that connects from the points other than the source point to the Destination

The type of nodes to be placed in the slots, which connect from the points other than the source point to the base station, is considered next. The overall number of appearances of each slot in the minimal paths and in the minimal cut-sets are noted. If the count of a slot is lesser than the remaining slots, then the sensor node with a lesser energy level remaining with us is placed in that slot. The slot with the second lesser count is placed with the sensor node, which has the second lesser energy level node remaining with us. If the total appearance of any slot in the minimal paths and in the minimal cut-sets, is higher than the other slots, then the sensor node with the highest energy level available with us is placed in that slot. This goes until all the slots, that connect, from the points other than the source point to the destination are completed. The slots `B', `D', and `E' are the available slots, that connect from points other than the source point 1. The remaining nodes with us are ultra-super, advanced, and super nodes. The overall number of appearances of the slots `B', `D', and `E' in the minimal paths and in the minimal cut-sets are given in Table 4. The total number of appearances of these slots is equal (i.e., 4). Therefore, a pseudo-random number generator (PRNG) is utilized to eliminate selection bias. Based on the pseudo random number generator we have placed the lesser energy sensor node available with us (i.e. the advanced node) at the slot `B' and the next lesser energy level available with us (i.e. the super node) at slot `D'. The slot `E' is placed with the ultra-super node. The nodes placed at `B', `D', and `E' configure themselves and establish the connection as shown in the Figure \ref{fig: deploymentsourcepoint3}. If there exists only a single slot, that connects the source node points to other points in the WSN, then the assignment is similar to the one given in the Table 2 (i.e. the total number of appearances of each slot in the minimal paths and in the minimal cut-sets) is used to assign the heterogeneous nodes to the slots. Therefore, we will not segregate and assign the deployment of nodes as in Table 3 and Table 4.

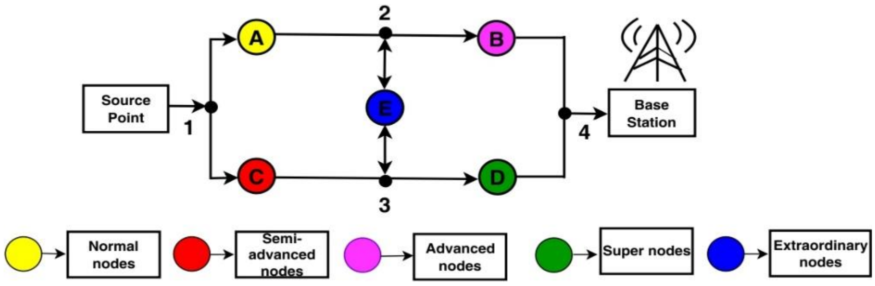

Fig. 5. Deployment of nodes in the predetermined slots from the points other than sensor point to the base station

Table 4. Slots, that connect to base station from other than the source point

Slots	Appearances in minimal tie-sets	Appearances in minimal cut-sets	Appearances in both
B	2	2	4
D	2	2	4
E	2	2	4

3.7. Transmitting the information to the Base station from the source

After placing the sensors in the predetermined slots, the nodes organize themselves as given in Figure 5 and the nodes that are the part of each minimal paths are noted. The reliability of each minimal path is calculated based on the separation between the source and the base station, the mean initial energies of the nodes in the minimal path, and the mean reliability of all the nodes that are part of the minimal path. We compare the individual reliability of each minimal path. The first chance to send information from the source to the base station is given to the minimal path, which has the highest reliability. If any node in the minimal tie-set dies after transmitting the information, then the next minimal tie-set with the highest reliability gets the opportunity to transmit the information from the sensor nodes to the base station (BS). This goes on until all the minimal path gets the opportunity to transmit the information. The nodes connected to the source point operate in ``ACTIVE state'' by gathering information from the source point, while other nodes in the network operate in ``RELAY state'' to transmit the sensed information from the source to the destination.

3.8. Methodology of the proposed algorithm

The suggested ORB-PEGASIS algorithm consists of the following steps:

a. Determine the slots (i.e. A, B, etc.) to place the heterogeneous nodes in place.
b. After positioning the nodes, the theoretical connections are first established between the slots by keeping the same distance between the nodes.
c. Considering the predefined slots and their connections from the beginning to the end, determine the network's minimal paths and minimal cut-sets.
d. The kind of heterogeneous nodes to be positioned in the predefined slots is decided and deployed based on how frequently the slots appear overall in the minimal paths and minimal cut-sets.
e. Initial energies and reliability of the heterogeneous nodes are noted down.
f. Utilizing the individual reliability of each node in the minimal paths, determine the reliability of each minimal path.
g. Assess the reliability of each minimal tie-set. The minimal tie-set with the highest reliability can transmit

information from the source to the destination first, followed by other minimal paths, depending on how reliable it is.

h. After information is transmitted from the sensing area to the destination, the reliability of each minimal tie-set is found to decrease as the node's energy level decreases.
i. If a sensor node in the minimal path dies, then the minimal path that contains that node also fails due to series arrangement of nodes in the minimal path.
j. If a minimal path fails, the information cannot be transmitted from the source to the BS.
k. The information will be transmitted from the sensing area to the destination by the minimal tie-set that has the topmost reliability among the remaining active minimal tie-sets in the event that any node in the minimal tie-set has died. Until all of the minimal tie-set has a chance to send the information, this continues.

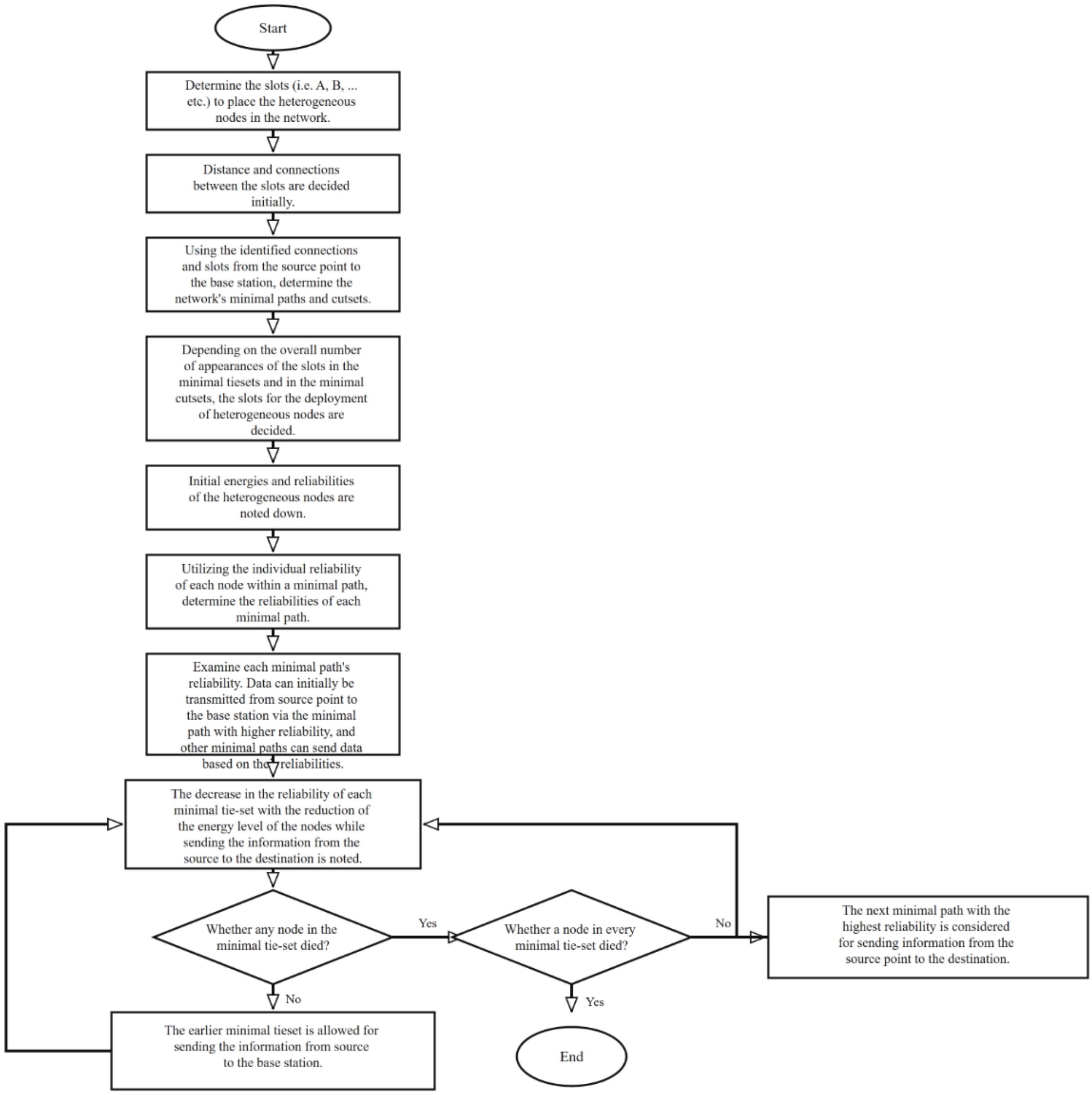

Fig. 6. Approach of the suggested ORB-PEGASIS algorithm

Figure 6 illustrates the proposed ORB-PEGASIS algorithm's methodology. After placing the nodes on to predetermined slots. Using the Fuzzy Analytic Hierarchy (Fuzzy-AHP) technique, each minimal path's individual reliability is determined by taking into account factors like the nodes' initial energy, the separation between the starting point and the base station, and each node's reliability. To transmit the information from the source to the destination, the sensor nodes that make up the minimal path with the highest reliability are activated (Wake-up). The other nodes that are not the part of the minimal path with highest reliability are made to sleep to conserve the energy. After transmitting the information from the sensor nodes to the destination in many rounds, a node in the minimal path may die. The minimal path with next highest reliability is allowed to transmit the information from the source to the base station by turning on (Wake-up) the nodes in it. This goes on until a single node in every minimal path dies. The minimal path selection using Fuzzy-AHP is given in Figure 7.

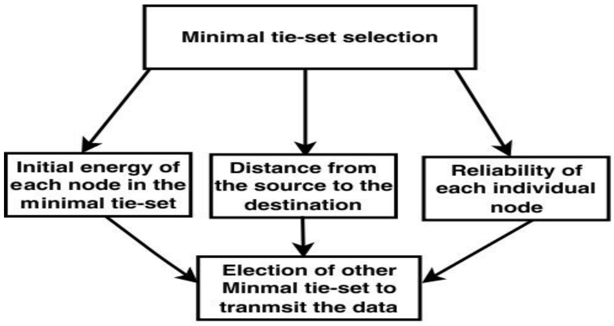

Fig. 7. Minimal tie-set selection to transmit the data from the source to the destination

4. Simulations

We use five different types of nodes— ultra-super, super, advanced, semi-advanced and normal nodes in the 100 m x 100 m. Sensing area to determine the performance of our proposed ORB-PEGASIS. The amount of energy contained in each of these five types of sensor varies. Ultra-super, super, advanced, and semi-advanced nodes have 3.2, 3, 2.5, and 2 times greater energy than normal nodes. Higher energy nodes have more sophisticated hardware and powerful processors. The corresponding reliability values are 0.99,0.98,0.97,0.96, and 0.95 for ultra-super, super, advanced, semi-advanced, and normal nodes respectively. Table 5 displays the simulation parameters for our suggested algorithm. Our suggested algorithm is compared with the LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms using the same parameters and their values. We compare the network lifetime, stability, average leftover energy and energy consumed by the network with the existing algorithms stated above. Our proposed ORB-PEGASIS algorithm outperforms LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms in terms of lifetime of the network, average leftover energy, and energy consumed by the network.

Table 5. The simulation's parameters and their corresponding values [12]

Parameter	Value
Sensing Area (N)	100m x 100m
Position of BS (m)	(50,50m)
Initial Energy E_0	0.5 J
E_{elec}	50 nJ/bit
E_{Rx}	50 nJ/bit
P_i	0.1
η_{fs}	10 nJ/bit/m^2
η_{mp}	0.0013 pJ/bit/m^2
E_{DA}	10 nJ/bit/signal
Number of packets	4000 bit

To evaluate and contrast our suggested ORB-PEGASIS algorithm's outcomes, we take into consideration the initial sample network depicted in Figure 8. The minimal path of the sample network-1 are AB, CD, AED, and CEB. The minimal cut-sets of the sample network-1 are AC, BD, AED, and CEB. After following the steps stated in our proposed algorithm, we place heterogeneous nodes in the predetermined slots. The placement of heterogeneous nodes and their configurations are shown in Figure 9. Using the minimal path method, the minimal paths' reliability is calculated. The minimal paths AB, CD, AED, and CEB have calculated reliability values of 0.912, 0.9506, 0.9216, and 0.9218, respectively.

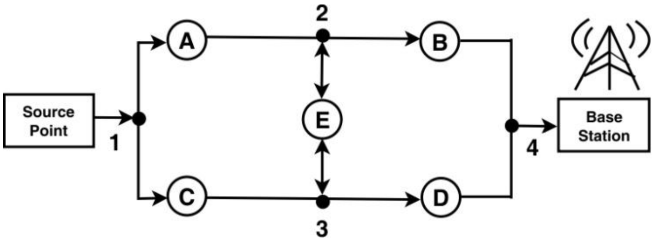

Fig. 8. Sample network-1 and its excepted connections

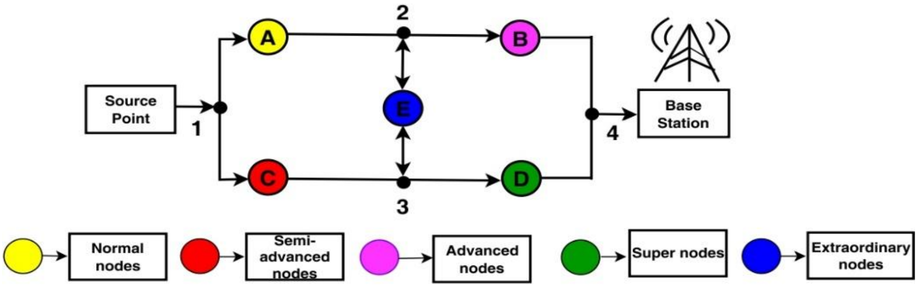

Fig. 9. Placement of heterogeneous nodes in the predetermined slots and their self-configured connections in the sample network-1

The number of nodes in sample network-1 that are alive as well as dead and its comparison with other existing algorithms is shown in the Figure 10 and Figure 11 respectively. In sample nework-1, the first node dies in round number 3410. Whereas, for the same number of nodes (i.e. 5) in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms, the first node dies at 774, 1409, 2174, 2282, and 2435 respectively. As a result, for the sample network-1, our suggested algorithm's stability is significantly superior to that of the existing algorithms. The minimal paths of the sample network are AB, CD, AED, and CEB. Every minimal path's reliability is calculated. CD is the very reliable minimal path. Consequently, CD' has the first chance to move the data from the source to the destination. The super node placed at `D' will receive the information from the semi-advanced node placed at `C' and then forward it to the base station. Therefore, the super node at `D' consumes more energy than the semi-advanced node at `C'. The super node placed at `D' dies in the 3410th round and therefore the minimal tie-set `CD' cannot transfer the information from source to the destination. The next highly reliable minimal tie-set is `CEB'. Therefore, `CEB' gets the next opportunity to transfer the data next. It transfers the information from the 3411th round until the 4546th round. By that time, the semi-advanced node placed at `C' dies. The next highly reliable minimal tie-set 'AED' cannot transfer the information from source to the destination due to the death of super node 'D'. The next highly reliable minimal tie-set is `AB'. It transfers the information from the 4547th round until the 6251th round. By that time, node `A' dies, therefore, minimal tie-set `AB' cannot transfer the information further. Therefore, we can conclude that the sample network-1 can transfer the information from the source to the destination until round 6251. Whereas, for the same number of nodes (i.e. 5) in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms, the last node dies in the rounds 1082, 2937, 3712, 3897, and 3965 respectively for the same parameters and their values defined in Table 4. Consequently, we can draw the conclusion that our suggested algorithm has a longer network lifetime than current algorithms like LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO.

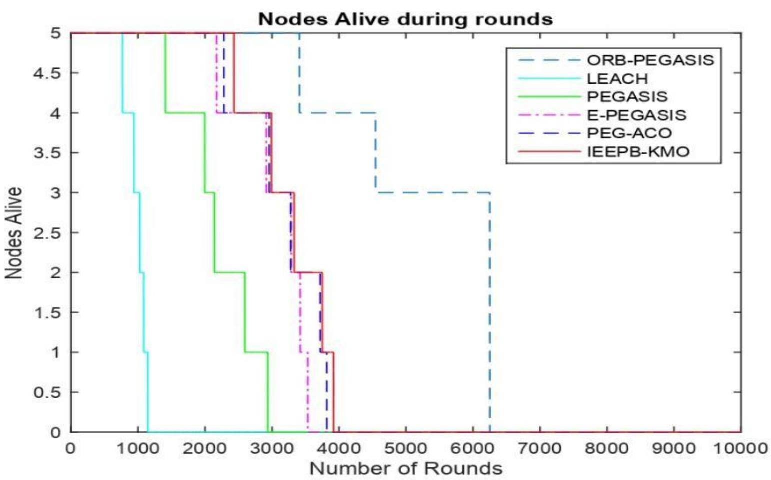

Fig. 10. The sample network-1’s number of alive nodes and a comparison with other algorithms currently in use

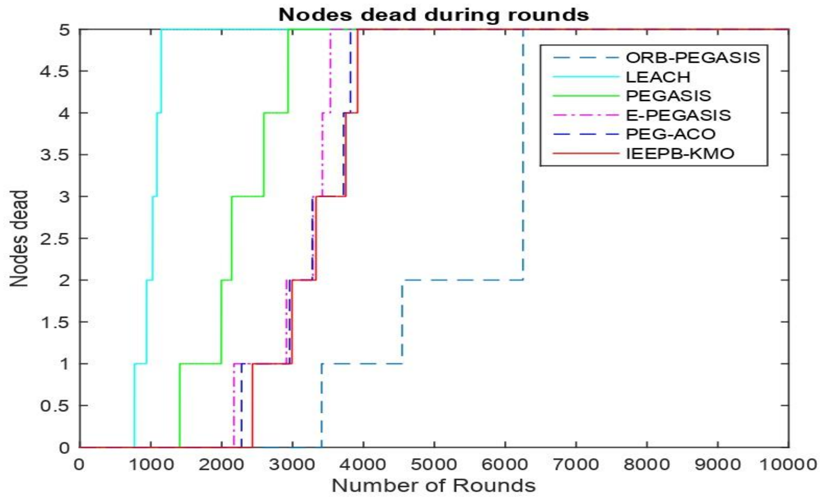

Fig. 11. The sample network-1's dead node count and a comparison with other algorithms currently in use

Five sensor nodes make up sample network-1, and the LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms all use the same number of nodes for comparison. The total energy in the sample network-1 is 5.85J (i.e. considering 0.5J of energy from the normal node, 1J from the semi-advanced node, 1.25J from the advanced node, and the 1.5J from super node, and the 1.6J from ultra-super node). The same total energy of 5.85 J is used in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms and this energy is equally distributed among five nodes, i.e. each node gets 1.17 J of energy. The comparison of residual energy and energy consumed by the sample network-1 with other existing algorithms are shown in Figure 12 and Figure 13 respectively. The residual energy remaining in the sample network-1 after each round by applying our proposed ORB-PEGASIS algorithm, is more than LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms. Energy consumed by the sample network-1 after each round by applying our proposed ORB-PEGASIS algorithm is less than LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms. We used the standard first-order radio model and initialized each normal node with a fixed energy of 0.5 J to guarantee an entirely fair and standard comparison. Until every node naturally runs out of energy, the simulation operates dynamically. Plotting is done for parameters like total remaining energy per round and network lifetime (FND, HND, and LND). This eliminates experimental bias and clearly separates each protocol's actual energy-efficiency benefits. Table \ref{tab:12} and Table 7 gives the performance of each protocol in terms of stability and Network lifetime when each protocol has utilized 5.85J and 4.5J of energy respectively.

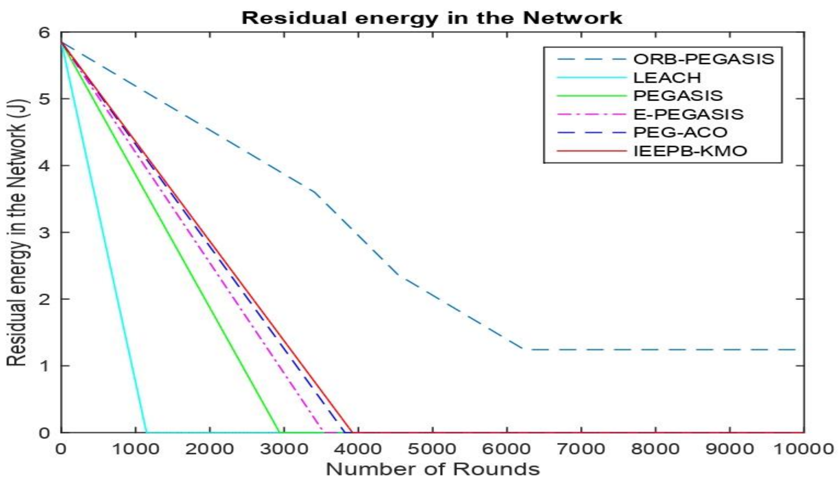

Fig. 12. Residual energy in the sample network-1 and its comparison with other existing algorithms

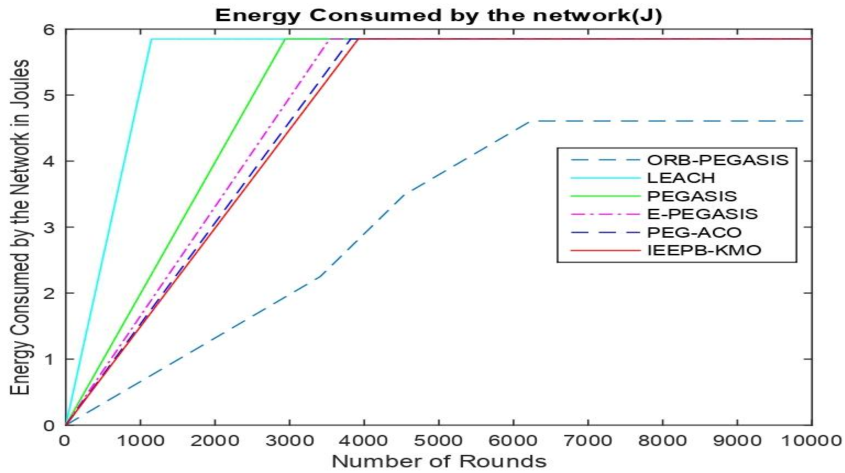

Fig. 13. Energy consumed by the sample network-1 and its comparison with other existing algorithms

Table 6. Quantitative Metrics-1

Protocol	Stability	Network Lifetime	Energy Consumed
LEACH	774	1082	5.85 J
PEGASIS	1409	2937	5.85 J
E-PEGASIS	2174	3712	5.85 J
PEG-ACO	2282	3897	5.85 J
IEEPB-KMO	2435	3965	5.85 J
ORB-PEGASIS	3410	6252	5.85 J

Table 7. Quantitative Metrics-2

Protocol	Stability	Network Lifetime	Energy Consumed
LEACH	624	894	4.5 J
PEGASIS	1161	2614	4.5 J
E-PEGASIS	1695	3154	4.5 J
PEG-ACO	1721	3364	4.5 J
IEEPB-KMO	1919	3424	4.5 J
ORB-PEGASIS	2796	5432	4.5 J

Sample network-2 and its excepted connections are shown in Figure 14. The points of origin and destination are 1 and 11, respectively. We assume that we have two super nodes, one ultra-super node, two semi-advanced nodes, two advanced nodes, and two normal nodes. EJ, ABI, GCD, EHI, GHI, ABCJ, ABCD, ABCJ, GCJ are the minimal paths of the Sample network-2. ACJH, AJGH, ACHE, AJDH, AJGI, BCJH, AGE, BJGI, BCHE, JDI, BGE, CJI, CIE, BJDH, and BJGH are the minimal cutsets of the sample network-2. Following the steps of our algorithm and based on the number of appearances of each slot, in the minimal paths and in minimal cut-sets, the slots are placed with heterogeneous nodes as shown in the Figure 15.

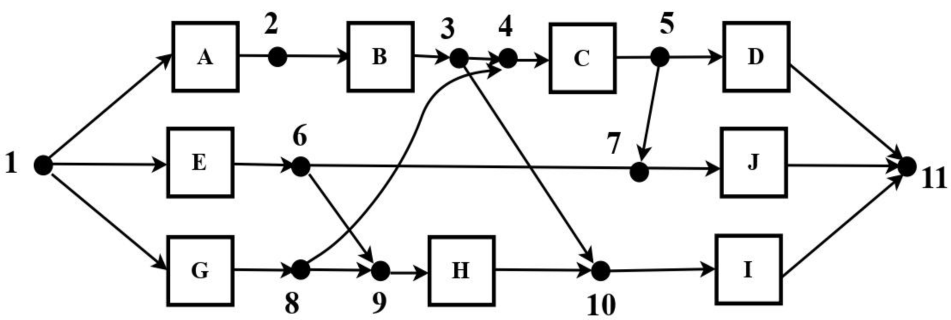

Fig. 14. Sample network-2 and its excepted connections

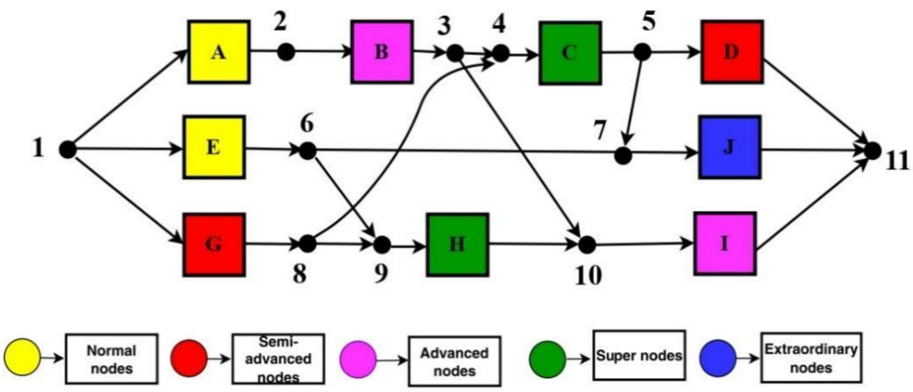

Fig. 15. Placement of heterogeneous nodes in the predetermined slots and their self-configured connections in the sample network-2

The sample network-2's node count, both alive and dead and its comparison with other existing algorithms is shown in the Figure 16 and Figure 17 respectively. In sample nework-2, the first node dies in the round number 2271. Whereas, for the same number of nodes (i.e. 9) in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms, the first node dies at 774, 1409, 2174, 2282, and 2435 respectively. Therefore, the stability of our proposed algorithm ORB-PEGASSIS is better than LEACH, PEGASIS, and E-PEGASIS, for the sample network-2. From Figure 17, we can observe that, our proposed algorithm sends information up to the round number 8529. Whereas, algorithms such as LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO are able to send this information up to rounds 3872, 4163, 4210, and 4390 respectively. Therefore, the network lifetime of our proposed ORB-PEGASIS algorithm is far better than the existing algorithms stated above. Sample network-2 considers nine nodes, and compared with LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms having nine nodes. This network uses two normal nodes of 0.5 J each, two semi-advanced nodes of 1 J each, two advanced nodes of 1.25 J, two super nodes of 1.5 J, and one ultra-super node of 1.6 J. Consequently, the sample network-2's total energy is 10.1 J. The same total energy of 10.1 J is used in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms and this energy is equally distributed among nine nodes, and i.e. each node gets 1.12 J of energy. The comparison of residual energy and energy consumed by the sample network-2 with other existing algorithms are shown in Figure 18 and Figure 19 respectively. The residual energy remaining in the sample network-2 after each round in our proposed ORB-PEGASIS algorithm is more than LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms. Compared to LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms, the sample network-2 uses less energy following each round in the ORB-PEGASIS algorithm.

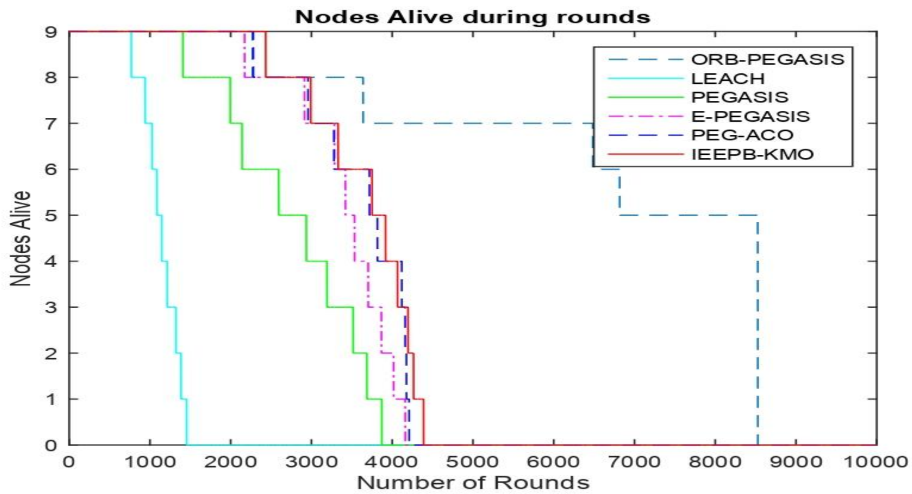

Fig. 16. The sample network-2's number of alive nodes and a comparison with other algorithms currently in use

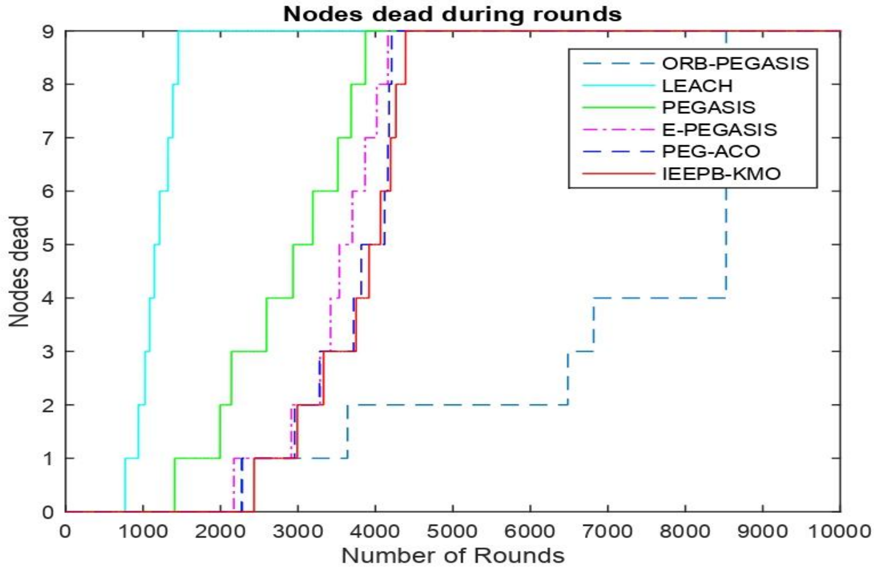

Fig. 17. The sample network-2's number of dead nodes and a comparison with other algorithms currently in use

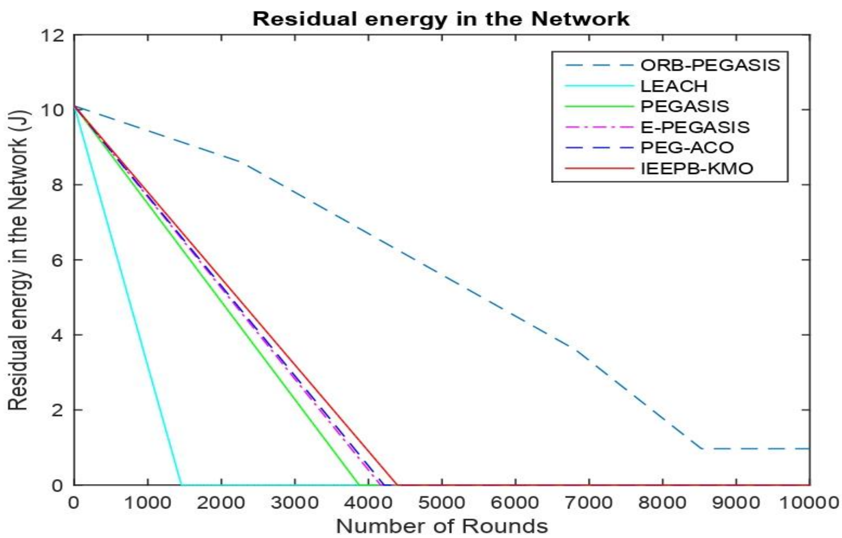

Fig. 18. Residual energy in the sample network-2 and its comparison with other existing algorithms

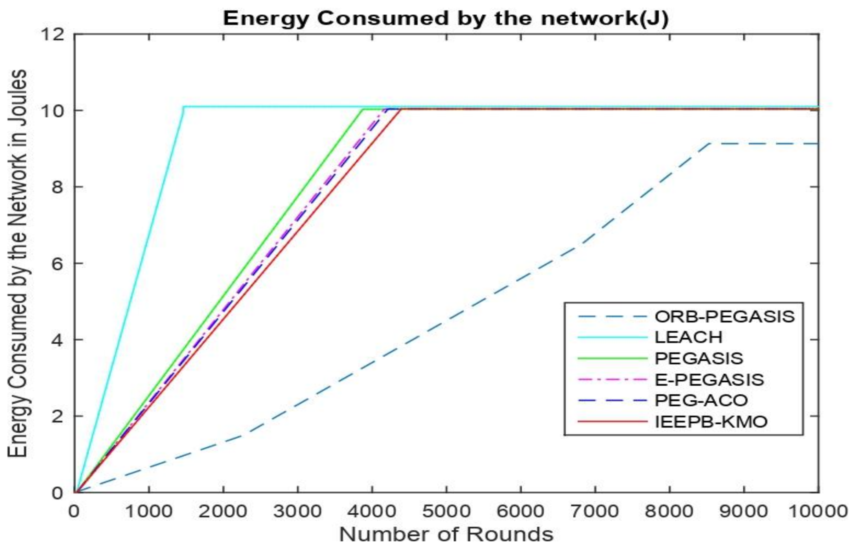

Fig. 19. Energy consumed by the sample network-2 and its comparison with other existing algorithms

Sample network-3 and its excepted connections are shown in the Figure 20. The minimal paths of the sample network-3 are ABEF, ACEF, ACF, ABDF, and ABF and the minimal cut-sets of this network are `A', `F', and `BC'. The total number of appearances of each slot in the minimal paths and in the minimal cut-sets of the sample network-3 is as per Table 8. The node, placed at `A', is the only node, which connects from the source point to other points in the WSN. So, the placement of heterogeneous nodes in the sample network-3 solely depends on table 8 as per our algorithm. We consider that we have two normal nodes, one semi-advanced node, one ultra-super node, one advanced node, and one super node are available with us to place the nodes in the slots of sample network-3. The placement of heterogeneous nodes in the predetermined slots for the sample network-3 is seen in Figure 21. The number of active and dead nodes in sample network-3 and its comparison with other existing algorithms is shown in the Figure 22 and Figure 23 respectively. The first node in the sample nework-3 dies in round number 2845. Whereas, for the same number of nodes (i.e. 6) in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms, the first node dies at 774, 1409, 2174, 2282, and 2435 respectively. Therefore, the stability of our proposed algorithm ORB-PEGASSIS is better than LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms for the sample network-3. We can see from Figure 23 that our suggested algorithm can transmit data up to the round number 5123. Whereas, algorithms such as LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO are able to send this information up to rounds 3872, 4163, 4210, and 4390 respectively. As a result, our suggested ORB-PEGASIS algorithm has a much longer network lifetime than the previously mentioned algorithms.

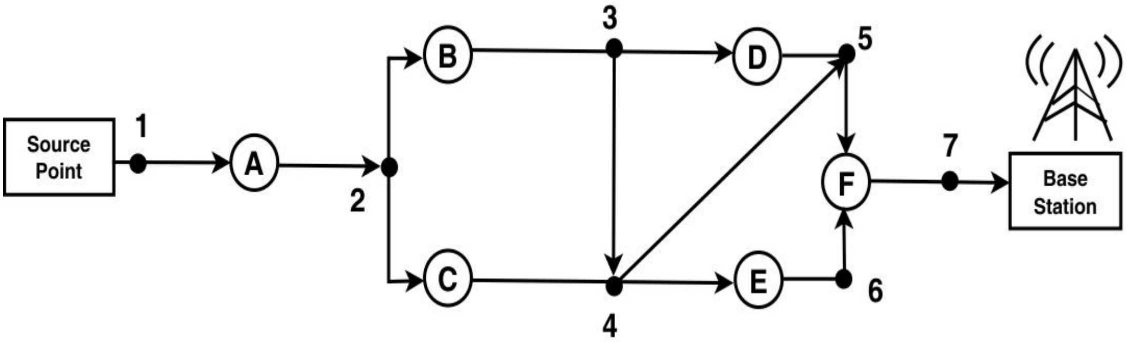

Fig. 20. Sample network-3 and its excepted connections

Table 8: Quantitative Metrics-2

Slots	Appearances in minimal paths	Appearances in minimal cut-sets	Appearances in both
A	5	1	6
B	3	1	4
C	2	1	3
D	1	0	1
E	2	0	2
F	5	1	6

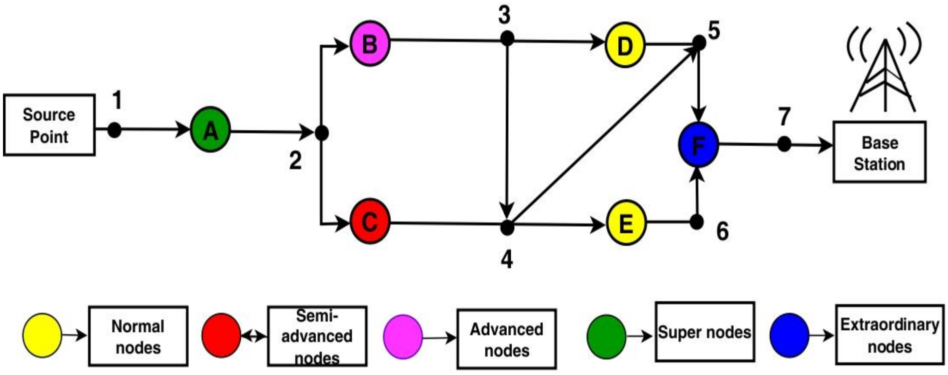

Fig. 21. Placement of heterogeneous nodes in the predetermined slots and their configurations in the sample network-3

Six nodes make up sample network-3, and the LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms all use the same number of nodes for comparison. The sample network-3 has a total energy of 6.35 J. The same total energy of 6.35 J is used in LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms and this energy is equally distributed among five nodes, and i.e. each node gets 1.058 J of energy. The comparison of residual energy and energy consumed by the sample network-3 with other existing algorithms are shown in Figure 24 and Figure 25 respectively. The residual energy remaining in the sample network-3 after each round in our proposed ORB-PEGASIS algorithm is more than LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms. Compared to the LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms, the sample network-3 uses less energy following each round in the ORB-PEGASIS algorithm.

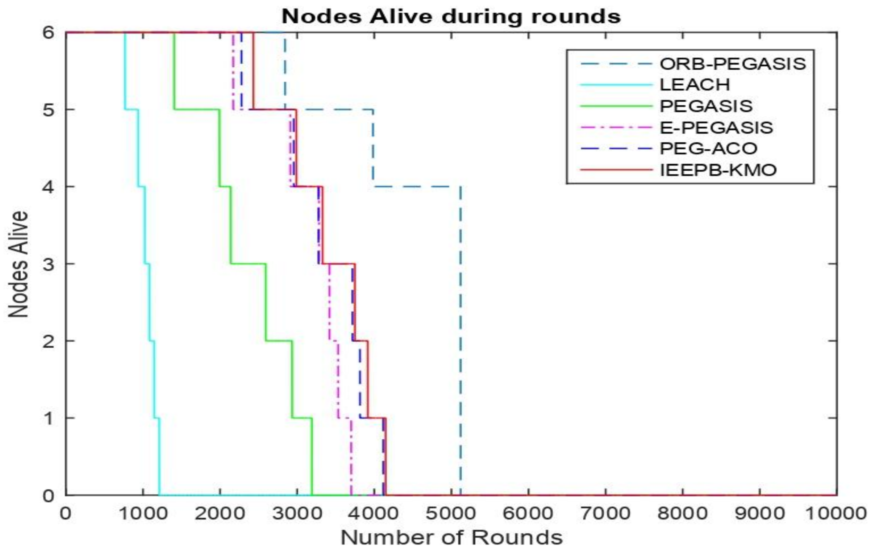

Fig. 22. The sample network-3's alive node count and a comparison with other algorithms currently in use

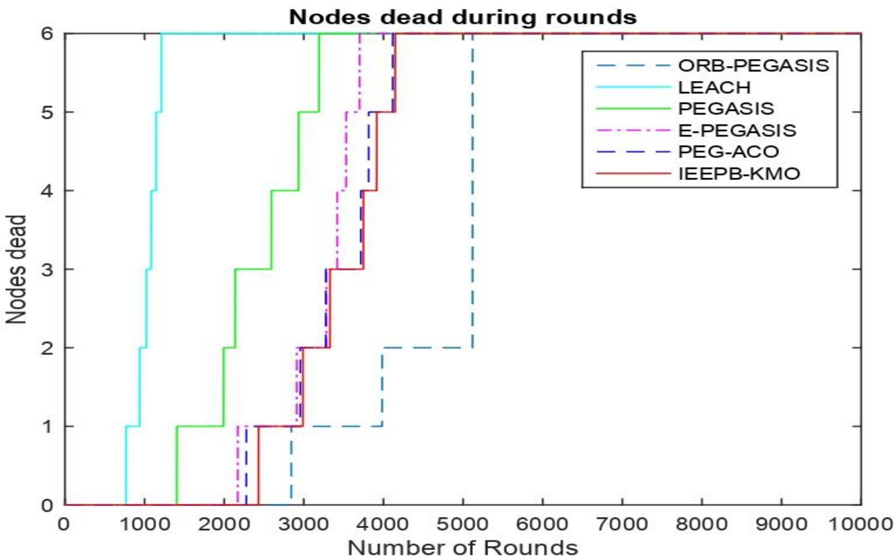

Fig. 23. The sample network-3's dead node count and a comparison with other algorithms currently in use

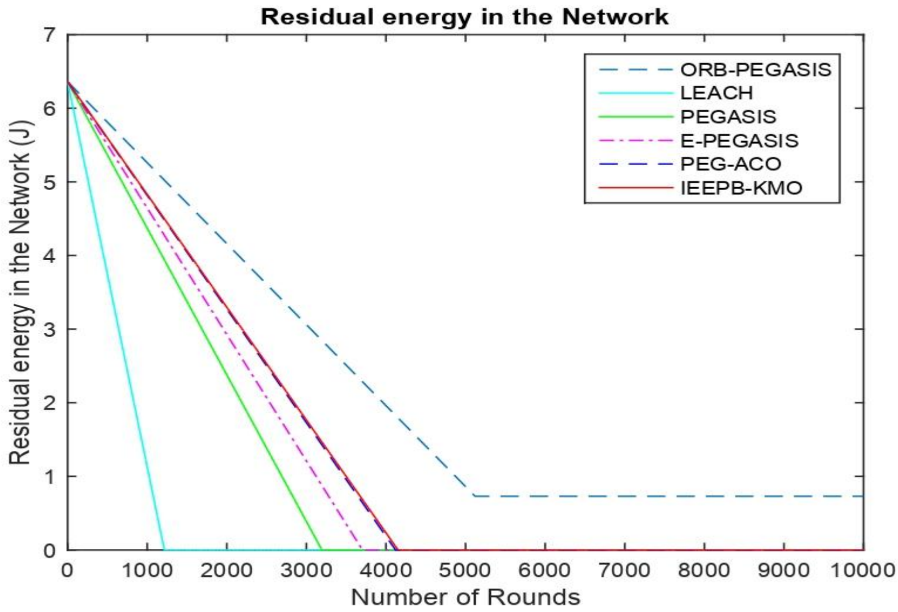

Fig. 24. Residual energy in the sample network-3 and its comparison with other existing algorithms

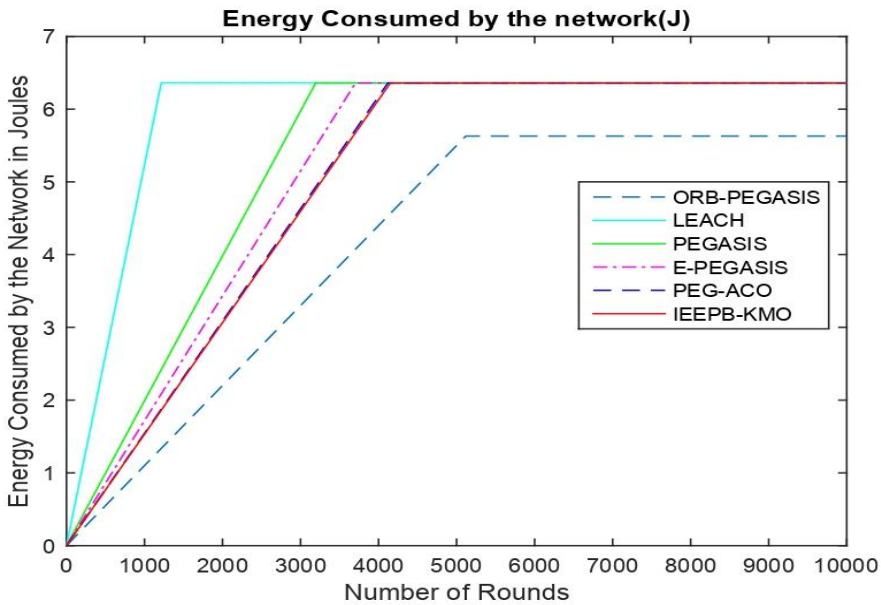

Fig. 25. Energy consumed by the sample network-3 and its comparison with other existing algorithms

The sample network-4 with 11 nodes is as shown in the figure 26. Heterogeneous nodes are placed in the sample network-4. The first node death for the sample network-4 is in the round 2674 and last node death is in the round 6897 after utilizing 5.85 J of energy.

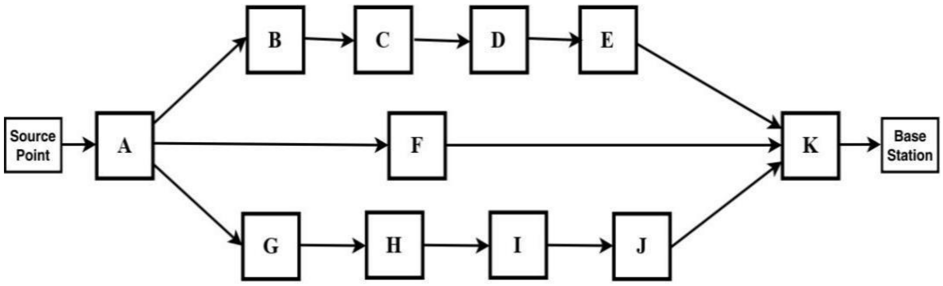

Fig. 26. Sample network-4 and its expected connections

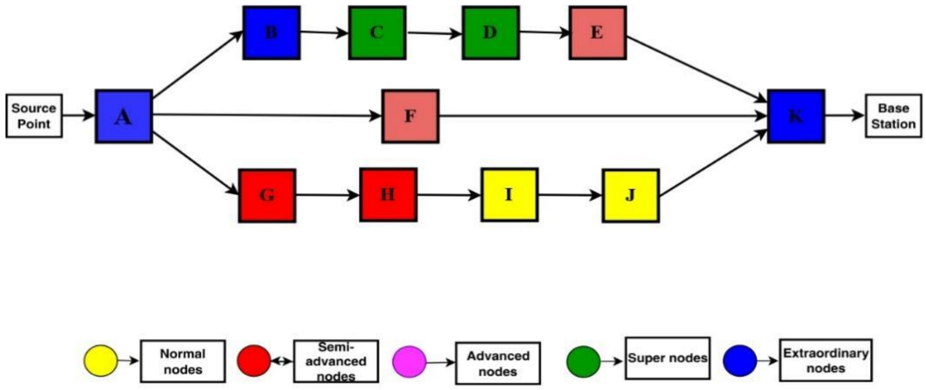

Fig. 27. Placement of heterogeneous nodes in the predetermined slots and their configurations in the sample network-4

We compare our suggested ORB-PEGASIS routing protocol with the optimization algorithms such as LEACH-GA [56], I-HEEL(Ex-GWO) [57], I-HEEL (I-GWO) [57], and I-HEEL (GWO) [57]. Table 9 shows how well our suggested ORB-PEGASIS algorithm performs with optimization algorithms in terms of the rounds at which first node death (FND), half node death (HND), and last node death (LND) occur. LND, HND, and FND of sample network-2 are 8529, 2845, and 2271 respectively and for sample network-3, LND, HND, and FND are 5123, 4379, and 2845 respectively. So, our proposed ORB-PEGASIS algorithm outperforms optimization algorithms by distributing the energy uniformly among the nodes.

Table 9. Last node death (LND), Half node death (HND), and First node death (FND), performance analysis for sample network-1

Performance	**LEACH-GA [56]**	**I-HEEL(Ex-GWO) [57]**	**I-HEEL(I-GWO) [57]**	**I-HEEL(GWO)[57]**	**ORB-PEGASIS**
LND	5	2525	2110	2270	6252
HND	3	1650	1635	1650	4546
FND	2	630	1245	660	3410

5. Conclusions

This article discusses ORB-PEGASIS, a novel reliability-based algorithm that takes into account a chain-based topology. ultra-super nodes, super nodes, advanced nodes, semi-advanced nodes, and normal nodes are the five categories of heterogeneous nodes that are taken into consideration for research. These five different kinds of heterogeneous nodes will be positioned in the network's designated slots and vary in their energy levels and computational capacities. The nodes to be placed in the slots are equidistant to each other. Initially, the theoretical connection between these slots is determined. Based on the theoretical connection between these slots, minimal paths and minimal cut-sets of a given WSN are found. Heterogeneous nodes are inserted into the designated slots once the total number of times these slots occur in the minimal tie-sets and minimal cut-sets has been determined. Depending on how reliable each minimal path is, the nodes in those minimal paths are given the chance to send the data from the source to the BS. The first chance to transmit the data is given to the extremely reliable minimal tie-set. Depending on their reliability, the other minimal tie-set is given the chance to transmit later. The network lifetime, stability, average residual energy, and energy consumed by the HetWSNs is found. The proposed ORB-PEGASIS algorithm outperforms the existing algorithms such as LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms in regards to network lifetime, stability, mean remaining energy, and the network's energy consumption for sample network-1 and sample network-3. ORB-PEGASIS performs better than LEACH, PEGASIS, E-PEGASIS, PEG-ACO, and IEEPB-KMO algorithms for sample network-2 with respect to mean remaining energy, network energy consumption and network lifetime. The stability of our ORB-PEGASIS algorithm for sample network-2 is better than LEACH, PEGASIS, and E-PEGASIS algorithms. The assumptions made is that, the slots in the suggested algorithm are the same distance apart. It is also assumed that nodes positioned in these slots are motionless. The computation needed to use ORB-PEGASIS grows with the number of nodes in the WSN. Therefore, future research can build on this work by considering mobile nodes and different slot distances with reduced complexity.

All the Declarations and Statements

Author Contributions Statement
Prashanth G. S. – Conceptualization, Proposed ideas, Methodology, and Supervision.
Suprith P. G. – Formal analysis, visualization, writing, review and editing.
Yashavanthakumar T. R. –Project Management: Reviewed and edited the manuscript

All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement
The authors declare no conflicts of interest.

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Data Availability Statement
The data used in the work are available in this paper.

Ethical Declarations
None

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Declaration of Generative AI in Scholarly Writing
None

Abbreviations
The following abbreviations are used in this manuscript:

ORB-PEGASIS- Optimal Routing Based Power Efficient Gathering in Sensor Information System.
WSNs: Wireless sensor networks
HetWSNs: Heterogeneous wireless sensor networks

Appendix A/B/C…, with appendix title
None

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