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ORIGINAL ARTICLE

Optimized Cluster-Based Energy Efficient Routing for WSNs Adopting SA-LEACH

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Abstract

Objectives: To improve the routing protocol in Wireless Sensor Networks considering energy efficiency. The proposed approach is for improving the energy efficiency of the routing protocol. SA–LEACH routing protocol is used for the implementation and enhancing the performance by employing cluster based mechanism. **Methods:** The proposed approach uses two algorithms Simulated Annealing (SA) and LEACH. The purpose of using these two algorithms is that they maximize the energy and also enhance the energy associated with each node in the network. The task of the LEACH protocol is to choose one node as the cluster head. The SA algorithm additionally tries to identify a node that is neighbor node of the cluster head. If there exists, a node that is better than the selected cluster head node, then that node is selected as cluster head. **Findings:** The simulation results show a considerable enhancement in terms a throughput of 5.25% when correlated to the EE–LEACH algorithm and 30% enhancement when correlated to LEACH algorithm. The proposed approach has also shown an increase of 11.15% when correlated to the EE–LEACH algorithm and 23.07% increase when correlated to LEACH algorithm with respect to energy. The proposed algorithm is beneficial in areas where plenty of sensor nodes are installed for tracking the location. One of the specific examples where this approach can be used is in coal mine where all sensors have to be under surveillance for safety reasons. **Novelty:** The approach proposed is straightforward and efficient. The approach is also beneficial for keeping track of the healthcare systems and helps in monitoring them continuously.

Keywords: Wireless Sensor Network; Protocols; Simulated Annealing; Routing; Clustering

1 Introduction

Designing a WSN has become the most prominent areas in research community. WSN is a mechanism that acknowledges and discovers inputs from different sources and the output is transmitted to the locations for processing. WSNs can be referred as infrastructure–less networks or also as self–configured networks. Their main objective is to observe different conditions like motion, pollutants, temperature etc. and to transfer the information along the network to the main location also referred to as sink for further processing of the information. The sink or base station is a link between the user and network. Normally a WSN is composed of thousands of sensors. Every sensor node has two properties namely resource–constrained and energy (battery power). Node–constrained indicates that every node has a limitation on speed, capacity and bandwidth. Also, in WSNs, every node has limited battery power. WSNs are useful for many applications like defense, industry, healthcare and many more. This diversification of applications has changed the inclination of researchers towards WSN. Many researchers have put forward implementations which involved in enhancing the efficiency of the network. Nevertheless, there are some areas that can still be explored to enhance the performance of WSN in terms of throughput and energy efficiency.

Wireless Sensor Networks face difficulties pertaining to the consumption of energy and the lifetime of a sensor node. These have an impact on establishing an effective routing protocol. Clustering technique is considered to be an optimistic approach for this challenge through which the networks lifetime can be extended and also reduces the consumption of energy in a sensor node. For ensuing optimal clustering, the paper proposes SA-LEACH strategy for optimizing the energy in a Wireless Sensor Network. This approach shows a significant improvement in optimizing the consumption of energy by a sensor node and increasing the network scalability. In the proposed approach, the sensor nodes are organized into clusters and nodes associated with less energy are considered for sensing. The gathered information is transmitted to the Cluster Head (CH). This approach aids in minimizing the consumption of energy while information is transferred from the sensor node to the base station. This helps in the prohibition of failures in the network. The networks lifetime is improved by minimizing the consumption of energy of a sensor node. Moreover, this approach minimized the conflicts among the packets thus improving the throughput of the network.

The technique for determining a Cluster Head (CH) and forming clusters for minimizing the energy consumption is considered to be NP-hard problem. The standard approach for forming clusters may not attain an optimal solution. Many researchers used heuristic algorithms Particle Swarm Optimization, Genetic Algorithms, Ant Colony Optimization, and Artificial Bee Colony for finding a cluster head and thereby aim to achieve best cluster solution. These approaches tend to achieve a local optimum solution thereby minimizing the lifespan of the network. Keeping in view of the above issues, the paper proposes a new approach for improving the lifetime of the network and minimizing the consumption of energy by adopting SA-LEACH technique.

The authors Radhika et al [(1)] in their work proposed a design for enhancing the sensor node lifetime. They used the approach called Fuzzy Based Clustering and Machine Learning Based Data Reduction. The advantage of this approach is that it was able to enhance the lifetime of the sensor node, however having a negative impact on the throughput and delay. It has been observed that the proposed approach has pitfalls in terms of increasing the delay time and also minimizing the throughput. In another proposal by Jagan et al [(2)] and Satyanarayana et al [(3)] the work has shown enhancement in the sensor nodes lifetime and energy. However, the model proposed was too complicated. However, this approach might not be an ideal elucidation for most of the real time applications.

Low–Energy Adaptive Clustering Hierarchy (LEACH) algorithm is the basis of our proposal in the paper. LEACH algorithm works on the principle of clustering mechanism. In the LEACH algorithm, a cluster head (CH) selection is done randomly. This algorithm selects the CH regardless of the nodes physical position and the energy associated with the node [(4)]. The disadvantage associated with the approach is that a node chosen as CH might have minimal lifetime or less energy associated with it. Hence, there is a possibility that the node chosen as CH would reduce the efficiency of the network and might increase the transmission time of messages. There have been many proposals by researchers adopting the LEACH protocols [(5)] for identifying an appropriate node as CH. However, few researchers have proposed techniques for creating appropriate clusters in WSNs. BEE–WSN is one approach that designed the honeybee algorithm. The algorithm is used for selecting an appropriate CH. The BEE–WSN algorithm was simulated using varied network parameters for the identifying an appropriate CH. The results of the method have shown better performance than that was achieved using LEACH protocol.

In another work by Yadav et al [(6)], the authors proposed an algorithm Particle Swarm Optimization. The objective of the proposal was to improve the lifetime of CH. The results have shown considerable improvement in the lifetime of CH. In another work by Mehra et al [(7)] the authors proposed a method which evaluated the fitness index for each node. This value was used for identifying the appropriate CH. The authors introduced Fuzzy–based Enhanced Cluster Header Selection based on the energy–conscious fuzzy clustering. The approach Fuzzy–based Enhanced Cluster Header Selection has shown an improvement in data transmission by 42.02% when compared to the basic LEACH protocol. Another achievement over LEACH protocol was

proposed by Sivakumar et al[8]. They designed a protocol Genetic Algorithm based Hierarchical routing (LEACH–GA). The performance was compared with the LEACH protocol. The results of the proposed approach have shown improvement in the lifetime of the network by 54%. This performance improvement was achieved by considering initial energy and CH probabilities. In a work where real time application was considered, the authors Mohammed Moyed et al[9] supervised landslides. The proposed solution was not suitable for an ideal approach since they didn't consider about the improvement of energy.

In this paper, we propose an approach using Simulated Annealing (SA) algorithm. This algorithm is examined on LEACH protocol. Simulated annealing is a global search algorithm. It is a meta–heuristic algorithm used for reducing the loss of energy in the nodes and thus enhancing the lifetime of the nodes in Wireless Sensor Networks. Since the lifetime of a node is associated by its energy, LEACH protocol is the most conventional method for sustaining node connectivity. SA is a technique used for finding a solution for optimization problems[10]. The simulation is performed considering 100 sensor nodes constituting a WSN. The proposed approach has shown enhancement in the efficiency of WSN. The simulation was performed on several parameters like amount of energy consumed while transmitting the data, the total nodes that are dead or active and the amount of energy consumed per node in a WSN. This proposed method is implemented in MATLAB.

MATLAB simulations are better than NS-3 or Contiki. The reason why MATLAB simulation is good can be stated as follows

- If the aim is for testing the optimization algorithms, example Simulated Annealing for routing or clustering, MATLAB is the best choice.
- If the aim is to validate the network protocols like packet loss, end-to-end delay then NS-3 simulator is the best choice.
- If the aim is to develop and test a real WSN application, then Contiki is the best choice.

1.1 The Motive Behind the work

The model proposed (SA–LEACH) is measured and simulated on the protocols LEACH, EE–LEACH and Simulated Annealing algorithm.

LEACH (Low Energy Adaptive Clustering Hierarchical) routing protocol (Figure 1) is TDMA–based MAC protocol which is a blended with clustering and is the easiest protocol of WSN[11]. The motive of the LEACH protocol is to minimize the energy consumption needed for building and retaining the clusters in order to improve the lifetime of WSN. The task of the LEACH protocol is to gather the information received by the cluster head from various nodes and then accumulate and compress the information and transmit it to the sink (base station). All the nodes in WSN apply stochastic algorithm for ascertaining whether they can become the cluster head for that round. The LEACH algorithm infers a node can reach the cluster head by itself using the power or energy associated with it. But the disadvantage is that it utilizes the total energy associated with the node and would waste the energy. The nodes in WSN are elected as CH per round. A node gets the opportunity of becoming a CH with a probability $\frac{1}{P}$, where P is the percentage of CHs. During each round, a node that is not a CH joins a cluster near to it. Then the CH will prepare a schedule for each node to broadcast the information. There are two phases called setup and steady phases in LEACH protocol. During the setup phase, one node in a WSN behaves as a CH and accepts information from all the other sensor nodes and broadcasts the information to all the sensor nodes. After that cluster is established and a CH is elected from all the nodes who are part of the cluster. During the steady phase, all the sensor nodes pertaining to a cluster transmit the information to CH. Then the cluster head transmits the data to all the sensor nodes in the cluster. The process of electing the CH is carried out randomly, without considering the location of the nodes or its associated energy. For being elected a CH, the node has to produce any number in between 0 and 1. The **Equation 1** gives the produced threshold value. This is given by T(S). After all the nodes get their values, an appropriate CH is selected. The Figure 1 shows the LEACH protocol design.

$$T(S) = \begin{cases} \dfrac{P}{1 - P * \left(rmod\left(\frac{1}{p}\right)\right)} if\ n\ \epsilon\ G \\ 0\ \ otherwise \end{cases} \tag{1}$$

Where, the probability of a node being chosen as part of the cluster is defined by p, the number of times information is broadcasted is denoted by r.

Radio transmission also called radio wave or radio frequency transmission model is a mathematical formula for description of radio wave transmission which is a function of frequency, distance or other constraints. It is the base for calculation of energy consumption of a node. The energy associated in between the source and destination nodes can be known using energy consumption model[12]. **Equation 2** describes the energy consumption model. Let us consider the bits being transmitted be represented by H. Let E_{TX} be the total energy exhausted by a node while transmitting a message to its neighboring sensor node and ε_{fs} represent the loss of energy in space. Let ε_{amp} represent energy diffusion for the amplifier and E_{elec} represent

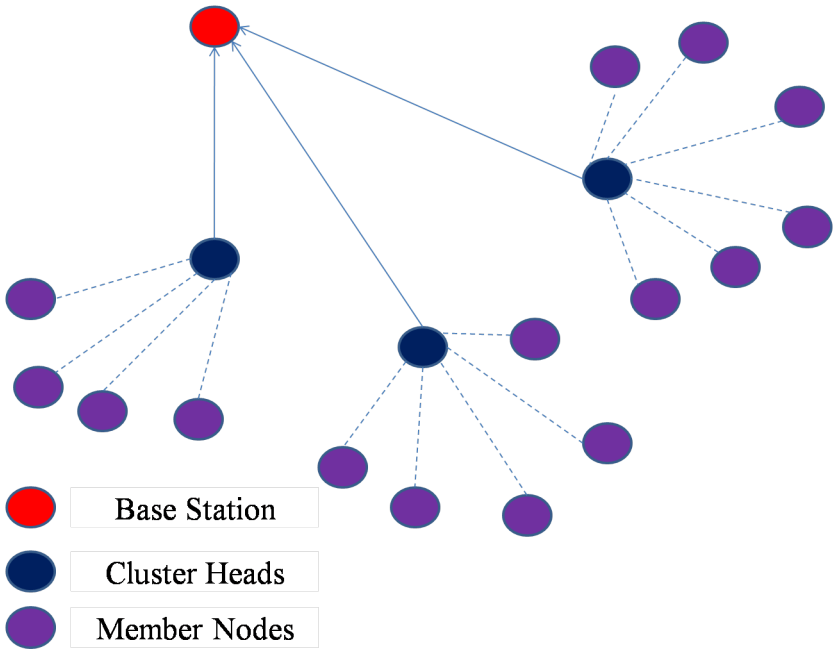

Fig 1. LEACH Model

the total energy exhausted while transmitting one bit from the sender to the receiver. Let d represent the distance between the any two adjacent nodes. The value for d is evaluated using Euclidean distance. Further, let d^2 and d^4 represent the loss incurred by power in vacuum and loss incurred due to fading of power respectively.

$$E_{TX}(m,d) = \begin{cases} mE_{elec} + m\varepsilon_{fs}d^2 d < d_0 \\ mE_{elec} + m\varepsilon_{amp}d^4 d \geq d_0 \end{cases} \tag{2}$$

Let d_0 represent the range between the receiver and transmitter. The value of d_0 can be obtained from **Equation 3**.

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \tag{3}$$

Energy Efficient LEACH (EE–LEACH) is an enhancement of the LEACH protocol. EE–LEACH protocol employs Gaussian distribution for estimating the lifespan and scope of covering the neighboring nodes of a sensor node is evaluated. The information about the neighboring nodes of any sensor node is performed using a sorting algorithm based on the amount of energy associated with each node. In order to conserve energy of each node, the data is collected by accumulating the information from each node. If the sink node is at a farther distance, then clusters are formed within limited space. Each cluster elects a CH to decrease the wastage of energy associated with each node and to maximize the usage of resources. Energy–efficient routing is accomplished by those nodes that have excess energy in them. Thus, those nodes are opted for transmitting data to the sink nodes. The EE-LEACH protocol helps in attaining improved delivery ratio with minimal utilization of energy[12].

1.2 Meta–heuristic approaches

These approaches are intended to find a better solution rapidly when compared to the conventional techniques. The conventional techniques are slow and produce results that are nearer to the solution under specific circumstances, when the desired results cannot be achieved. The meta–heuristic algorithms apply heuristics techniques for achieving the nearest solution by examining the set of solutions rather than examining the complete set of solutions for producing an optimal solution. Most of the heuristic approaches are considered to be on a trial–and–error basis. The most commonly used meta–heuristic algorithms in research include Gravity algorithm[13], Genetic algorithms, Artificial Bee Colony algorithm and PSO (Particle Swarm Optimization) algorithm. Heuristics algorithms are mainly employed in industrial and scientific problems for producing better results. They

are used for improving the energy efficiency by considering certain parameters that could show better results. Over the past few years, meta–heuristic algorithms have gained widespread recognition in many areas. This led to the emergence of many meta–heuristic algorithms that could be applied in various fields of research.

1.3 Simulated Annealing (SA)

One of the meta–heuristic algorithms is Simulated Annealing[14]. It is inspired by the physical process of annealing, in which a material is gradually cooled to form a crystalline structure with a minimum energy state. SA emulates the movement of atoms in a solid in the course of annealing process. It is a thermal process that is employed to attain the lowest energy for a material. The annealing process works by iteratively adjusting the temperature of the system or rejecting candidate solutions based on a probability function that depends on the current temperature and the change in the objective function value. At high temperatures the algorithm accepts solution with a worse fitness to explore the search space and avoid local optima. As the temperature decreases the algorithm becomes more selective and converges to a better solution. The cooling schedule determines the rate of temperature reduction and plays an important role in the algorithms performance. Monte Carlo approach is mainly used in annealing process. Monte Carlo is mathematical approach with probability techniques for annealing process. It is used for detecting the minimal energy power among the ideal solutions. Initially the algorithm acquired only minimal energy power but later due to the Metropolis strategy, it acquires maximum energy power too.

In SA, temperature decay function also called cooling schedule is an important part of the algorithm. The cooling schedule controls the temperature parameter on how the temperature decreases eventually which affects the algorithm's capability to expand the search space, so that the algorithm can converge to an optimal or nearby optimal solution. The temperature decay function is a mathematical formula that decreases the temperature during the progress of the algorithm. It is the temperature that regulates the probability of accepting worse solutions. When the temperature is high it permits for more exploration and low temperature aims at exploitation. When the cooling decay function is too fast, there is a possibility that the algorithm gets stuck with local minima and if the cooling decay function is too slow, the algorithm takes longer time to converge. In WSN, the choice of decay function is critical because it maintains the balance between the quality of the solution and computation time.

Figure 2 depicts the process of Simulated Annealing. When simulated annealing procedure is chosen for solving problems, which constitutes of numerous solutions, the exploration starts for an appropriate solution. The search starts by looking around the neighboring solutions all over while considering the maximum temperature and slowly reducing the temperature values. Whenever a solution is found, it is compared with the recent solution to discover if it is a better solution. For minimization problems, the search is done for minimal value. The search process is continued, whenever a bad solution is found. A solution is bad when the results are compared to the nearest neighboring solution. Each solution is evaluated for its acceptance probability. **Equation 4** is used for evaluating the acceptance of the solution. When an optimal solution is found, it is considered as an objective function. Finding an optimal solution at the first instance is not the objective of acceptance probability. Acceptance probability does not mean to refrain from finding solutions once a minimal value solution is found. In the process of finding the lowest value obtained by the algorithm, the lowest solution found is considered to be the best one. Once the lowest value acquired is considered to be the best solution, the probability of attaining a good solution can be avoided if the previous solution is having a higher value. The algorithm cannot always give the best solution but however the search process always tries to achieve the lowest temperature value.

In Simulated Annealing, the temperature doesn't have a physical unit such as Celsius or Kelvin. Temperature is an abstract and dimensionless quantity which is used as a control parameter in the optimization purpose. The inspiration of SA was from annealing in metallurgy, where the physical temperature does not have units. However, in the algorithm, if the cost function has units then it is necessary that temperature should also have the same units for canceling out. Normally, both cost function and temperature are considered to be pure numbers, hence there is no unit explicitly defined.

$$X_{i+1} = \begin{cases} X_{new} \exp\left(\dfrac{-\Delta f}{T}\right) > r \\ X_i \; otherwise \end{cases} \tag{4}$$

In Wireless Sensor Networks, Simulated Annealing is helpful because SA is a probabilistic optimization algorithm. It is suitable for tasks related to energy optimization, clustering and routing. The SA algorithm's computational overhead can affect the performance of resource-constrained environments in different ways.

- **Computational Complexity:** The SA algorithm goes through a number of iterations for possible solutions which refines by accepting better solutions and sometimes uses worse solutions in order to avoid local minima. Because of its iterative nature SA is slower than greedy algorithms. The execution time is affected due to the number of iterations and temperature.

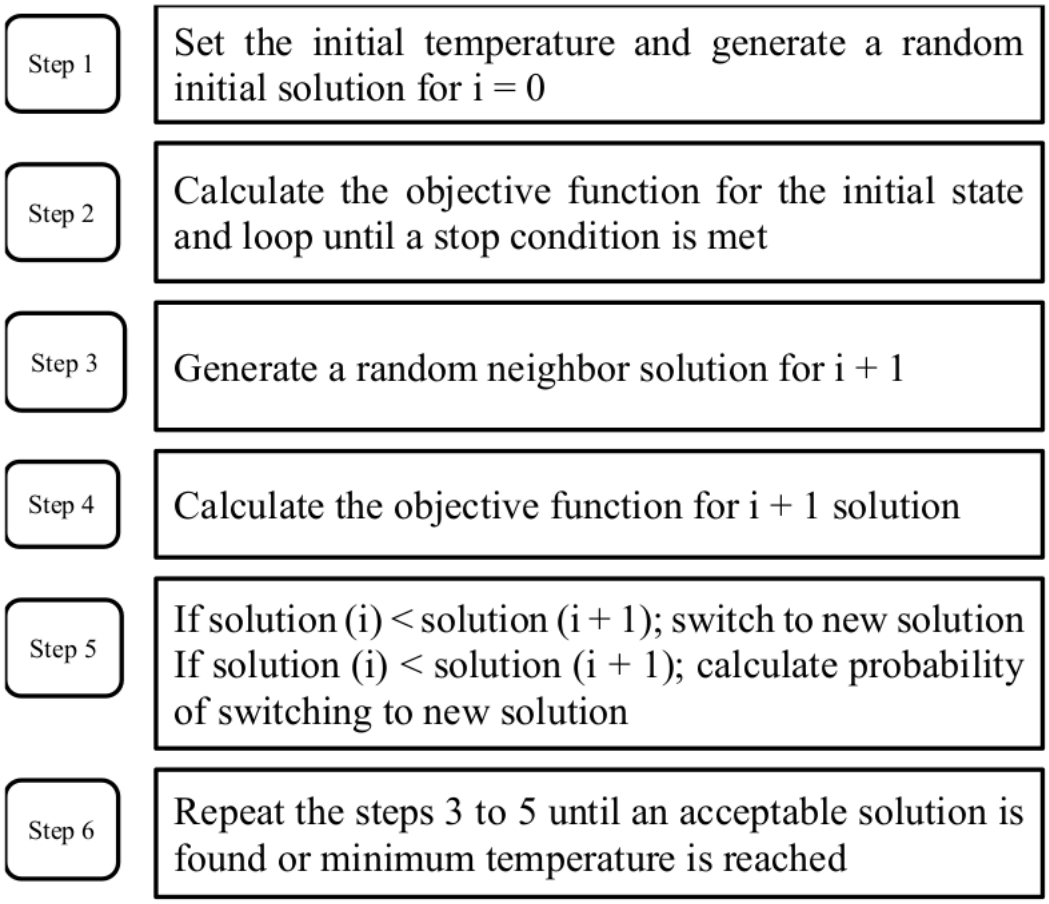

Fig 2. Steps involved in Simulated Annealing algorithm

The computational power is also affected because SA is run on sensor a node which leads to the exhaustion of the lifetime of battery quickly.

- **Latency and Real-Time Constraints:** The SA algorithm cannot meet deadlines due to decision-making delays. In a dynamic environment of WSN, there is a trade-off between accuracy and speed. The long cooling schedule may give better optimization but leads to higher latency.
- **Memory and Processing Constraints:** Due to the limited CPU power associated with a sensor node, complex computations are not feasible.

To improve the efficiency of WSN, SA can be integrated with heuristic methods. Another way to improve WSN is to distribute the computation among more powerful nodes than burdening the individual nodes. The optimization can be stabilized by improving the cooling schedule depending on the real-time constraints.

1.4 Comparing the Prominent Meta-heuristic Optimization Techniques Genetic Algorithms, Ant Colony Optimization and Particle Swarm Optimization with Simulated Annealing Approach

The key dimensions on which the comparisons can be performed include Optimization Performance, Algorithm Behavior, Parameter Sensitivity, Computational Cost, Scalability, Application Suitability and Complexity. Table 1 depicts the comparison of the metrics used.

Simulated Annealing is lightweight and works well when the number of resources is limited. A genetic algorithm is reliable but is considered to be slower and requires fine tuning of the parameters. Ant Colony Optimization is better for routing but is slower to converge. Particle Swarm Optimization can be a better choice for Wireless Sensor Networks because of its faster convergence.

Table 1. Comparison of the metrics

Metric	Simulated Annealing	Ant Colony Optimization	Particle Swarm Optimization	Genetic Algorithms
Convergence Speed	Medium	Slow	Very Fast	Fast
Quality of the Solution	High	Medium	High	Medium
Parameter Sensitivity	Low	High	Medium	High
Memory Requirement	Low	High	High	High
Complexity involved in the implementation	Low	High	Medium	Medium
Parallelizability	Low	High	High	High

2 Methodology

2.1 The Proposed SA-LEACH Method

Let us first design a Wireless Sensor Network for implementing LEACH protocol by creating GUI of WSN with 100 sensor nodes using MATLAB. WSN is modeled by randomly placing sensor nodes in a 100m x 100m area. At the center we place a device that works as a gateway. During each data transfer, a new network topology establishes clusters for the LEACH protocol. Based on the LEACH protocol, a cluster head CH is chosen during each cycle for transmitting data. All nodes in the cluster transmit information to CH. It then transmits the information gathered to the sink node. Table 2 depicts the parameters used for the simulation which are considered to evaluating the energy consumption during each cycle of data transfer.

Table 2. Simulation Parameters

Name of the Parameter	Value
Starting Energy (E_0)	0.5 Joule / node
Transmitter's Energy (E_{elec})	75 nJoule / bit
Receiver's Energy (E_{elec})	75 nJoule / bit
Size of the data packet (h)	5000 bits
Coefficient of the energy transfer (E_{fs}) for $(d < d_0)$	15 pJoules / bit / m^2
Loss of energy (E_{amp}) for $(d > d_0)$	0.0015 pJoules / bit / m^4
Cluster ratio (p)	0.1

Once the cluster head CH is established, Simulated Annealing algorithm is applied. The algorithm tries to improve the efficiency of the energy by probing into the network. Hence, this approach is referred to as SA-LEACH. There is a difference between LEACH and SA-LEACH protocol. The choice of the cluster head CH and nodes to be included in each round for data transfer is performed by the LEACH protocol whereas the SA-LEACH protocols reconstitute the nodes selected for transmission with other nodes that could minimize the consumption of energy during transmission. The **equation 5** computes for each sensor the amount of energy leftover once the transmission of data is completed.

$$f(x_i) = f(x_{i-1}) - \sum_{i=1}^{CH_n} E_{TX(S_i \to CH_n)}(m,d) + \sum_{i=1}^{CH_n} E_{CH_i} + E_{TX(CH_n \to SN)}(m,d) + \sum_{i=1}^{C} E_{TX(Si \to SN)}(m,d) \quad (5)$$

In the above equation, CH_n represents the cluster heads. The total energy exhausted by a sensor node i while transmitting data to a cluster head CH is represented by $E_{TX(S_i \to CH_n)}$. The amount of energy exhausted by a cluster head CH is represented by E_{CH_i}. The amount of energy exhausted by cluster head CH while transferring the data to the sink node is represented by $E_{TX(CH_n \to SN)}$. The sensor nodes that are not a part of the any cluster are represented by C. The amount of energy exhausted by a sensor node while transferring the data to sink node is represented by $E_{TX(Si \to SN)}$.

There are number of limitations to be used in WSN while minimizing the efficiency of energy. The limitations imposed when SA algorithm is used include the following

- N be the set of sensor nodes with node CH being a member of the set $N(CH \in N)$, where CH is the cluster head.
- A new sensor node selected as cluster head CH, cannot be included into a set M, where M a set of is already selected nodes CH. The set M cannot be an empty set $(M \neq \emptyset)$.
- The selected node should have energy level more than $0(E > 0)$.

Table 3 illustrates the simulation parameters utilized in Simulated Annealing process by the SA-LEACH technique.

Table 3. Parameters considered for SA-LEACH technique

Parameters considered	Values
Initial temperature (T_{start})	110000
Final temperature (T_{end})	0.1
Coefficient (sk)	0.99

The algorithm for SA-LEACH efficiently uses Simulated Annealing for improving the process of selecting the CH and clustering to optimize the use of energy in a Wireless Sensor Network and generating a good solution space. Figure 3a and Figure 3b show the process of implementing the SA-LEACH for optimization of energy.

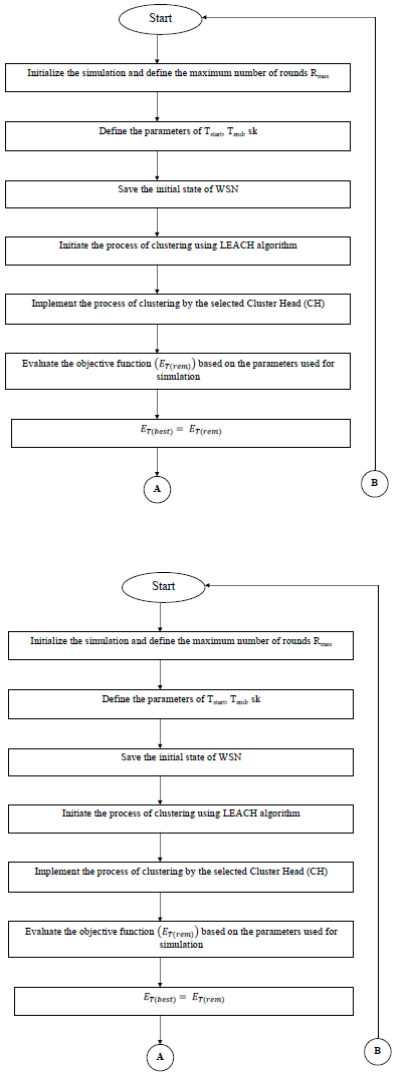

Fig 3. Energy Optimization Flow Chart with SA-LEACH

2.2 Algorithm for SA-LEACH employing Simulated Annealing for WSN Energy Optimization

The following is the algorithm for the effective implementation of SA-LEACH with Simulated Annealing approach.

1. Initializing the Simulation of WSN

- Initiate the process of simulation by defining the maximum number of rounds that the simulation should run

2. Defining the Parameters used in Simulated Annealing

- Initialize initial temperature as T_{start}, final temperature as T_{end} and cooling coefficient as sk

3. Save the Initial State of WSN

- For the purpose of comparison and recovery, record the current status of WSN

4. Process for the Selection of Cluster Head (CH)

- Choose the Cluster Heads (CHs) for the N clusters. The CHs are selected based on the percentage value obtained from the sensor nodes
- Ensure that these CHs are distinct from those in the M cluster simultaneously

5. Process of Forming Clusters

- Based on the recently selected CHs, new clusters are formed in WSN

6. Evaluating the Initial Energy Consumption

- Using **Equation 5**, the energy consumed by the clusters is evaluated based on the given objective function

7. Adjusting the Initial Best value

- The energy consumption calculated using **Equation 5** is set as the initial best value

8. Applying Iteration to Simulated Annealing

- For each iteration:

- Replace the existing CH with the newly selected neighboring node as a new candidate for CH
- Reconstruct the network with the present nodes and form new clusters. Evaluate the current energy consumption
- Compare the new energy consumption value with the current best value:

- **If the new value is better than the current best value**:

- Restore the CH list and save the new energy consumption value

- **If the new value is worse than the current best value**:

- Generate a random number r
- Adopt the bad solution with a probability $\exp\left(-\Delta\frac{E_{T(rem)}}{T}\right)$
- Otherwise, consider the new situation as the current state.

9. Check Termination Condition

- If the temperature T has cooled to T_{end} , exit the loop and finalize the WSN state with the least energy consumption found
- Otherwise repeat the process

10. Update WSN Configuration

- Once the loop exits, update the WSN with the optimal configuration that minimizes energy consumption.

3 Results and Discussion

The trials were done to show how better the proposed approach SA-LEACH would outperform the other approaches. The approaches LEACH and EE-LEACH were considered to display the improvement when compared to SA-LEACH approach. The measures considered for assessing improvement include End–to–end Delay, Packet Delivery Ratio, Throughput, and Average Consumption of energy are depicted in Figure 4, Figure 5, Figure 6 and Figure 7 respectively. It is observed that the proposed approach yields minimal time for transferring the data from the sender to the sink node than the existing LEACH and EE-LEACH protocols. It shows enhancement of 28.57% and 300.1% when compared to EE-LEACH and LEACH protocols respectively. The proposed SA-LEACH is more efficient than the existing protocols. There is an approximate increase of 2.08% and 3.15% increase in the successful transmission of data when compared to EE-LEACH and LEACH protocols respectively. There has been an enhancement of throughput by 5.25% and 30% for EE-LEACH and LEACH protocols respectively. The amount of reduction is approximately 11.15% when compared to EE-LEACH protocol and 23.07% when compared to LEACH protocol.

The parameters used for simulation of the network model are indicated in Table 1. The starting energy of all nodes in the network is assumed to be 0.5 Joules. Thus, the overall energy for a total of 100 nodes in the network is 50 Joules. Nevertheless, the amount of energy present in a node decreases during every cycle of transferring data and ultimately the energy associated with each node reduces to 0 (zero). From the simulation, it is observed that the overall energy prior to the transfer of data in the network for given state is 40.145 Joules. Hence it is appropriate that while forming a cluster; it is desired to design in such a way that the amount of energy consumed is minimal. The proposed algorithm SA-LEACH calculates the best value by running the algorithm for 2000 iterations. The results during the simulation have shown that at $x = 311$, maximum energy is recorded with $y = 40.14$ in all iterations. The value was observed to remain constant during the entire data transfer cycle. However, because of the peculiar characteristic of SA algorithm, the graph exhibits worst result after each iteration. This is because there is a possibility of achieving better result after every worse result. The simulation was performed on the test model and the process is performed again during the next cycle of the data transfer. With this approach, a perfect cluster could be established with the remaining nodes that would exhaust minimal energy.

The parameters indicated in Table 1 are used for the simulation of the suggested SA-LEACH technique. The results of the simulation are examined in contrast to the existing protocols LEACH and EE-LEACH. The proposed algorithm is compared using throughput, end-to-end delay, and average consumption of energy and packet delivery ratio parameters.

3.1 End-to-end delivery

The results of the comparison between the proposed approach SA-LEACH and LEACH and EE-LEACH are shown in Figure 4. It is observed that the proposed approach yields minimal time for transferring the data from the sender to the sink node than the existing LEACH and EE-LEACH protocols. It shows enhancement of 28.57% and 30.01% when compared to EE-LEACH and LEACH protocols respectively.

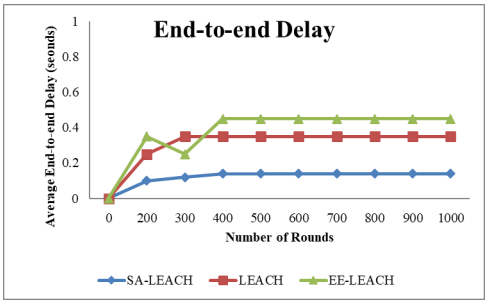

Fig 4. End-to-end Delay comparison of SA-LEACH, LEACH and EE-LEACH

3.2 Packet Delivery Ratio

Packet Delivery Ratio is the defined as the amount of data that has been successfully transmitted to the sink node. The Figure 5 depicts the results of the simulation applied on the proposed and the existing approaches. It can be seen that the proposed approach is more effective in terms of successful transmission of data when compared with the existing protocols. SA-LEACH algorithm chooses the optimal path to reach the sink node considering the cluster head (CH). Hence, SA-LEACH is more

efficient than the existing protocols. There is an approximate increase of 2.08% and 3.15% increase in the successful transmission of data when compared to EE-LEACH and LEACH protocols respectively.

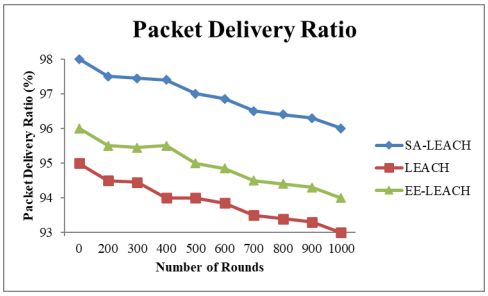

Fig 5. Packet Delivery Ratio comparison of SA-LEACH, LEACH and EE-LEACH

3.3 Throughput

The Figure 6 depicts the comparison for the throughput obtained for the proposed approach and the existing protocols. The result from the graph depicts that SA-LEACH approach has shown substantial improvement in terms of throughput when compared to the other protocols considered for comparison. This is because the proposed approach has shown consistent consumption of energy and has been able to transmit the data successfully to the sink node over all the clusters. There has been an enhancement of throughput by 5.25% and 30% for EE-LEACH and LEACH protocols respectively.

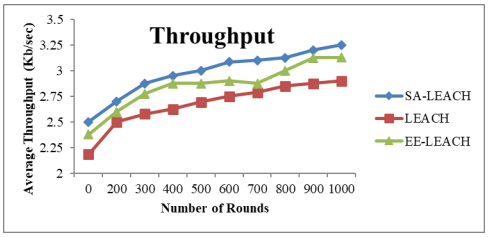

Fig 6. Throughput comparison of SA-LEACH, LEACH and EE-LEACH

3.4 Average Consumption of Energy

The average consumption of energy in Wireless Sensor Network by any node is depicted in Figure 7. The graph indicates that the proposed approach SA-LEACH performs better than the existing protocols. The SA-LEACH approach selects the optimal node for transmitting the data. From the results of the simulation, we can see that there is a considerable minimization in the consumption of energy by a node. The amount of reduction is approximately 11.15% when compared to EE-LEACH protocol and 23.07% when compared to LEACH protocol.

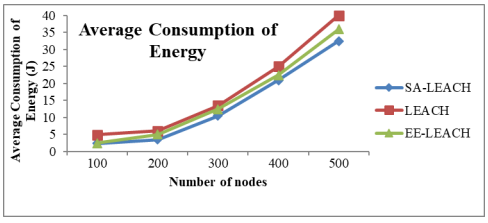

Fig 7. Average consumption of energy comparison for SA-LEACH, LEACH and EE-LEACH

The proposed SA-LEACH improves the conventional LEACH technique blended with an optimization algorithm for providing energy-efficient routing in WSNs and a mechanism for selecting an appropriate cluster head. The effectiveness and

uniqueness of the proposed SA-LEACH approach is supported by comparing the performance of the proposed approach with LEACH and EE-LEACH protocols. The metrics used for demonstrating the efficacy and novelty include end-to-end delay, packet delivery ratio, throughput and average energy consumption.

The SA-LEACH approach minimizes the end-to-end delay by electing an optimal CH that reduces the intra-cluster distances and improves the routing paths to the base station. The average reduction in delay of LEACH protocol through simulation is between 25–35%, for large networks. The use of SA's probabilistic search, the approach prevents suboptimal cluster head replacements that cause congested paths. The novelty of the approach is that it limits in the selection of CH randomly.

The SA-LEACH approach attains higher Packet Delivery Ratio throughout the lifetime of the network and simulation shows that 95% packet delivery is maintained throughout. The novelty in the proposed approach is SA-LEACH technique uses cost function which balances the energy and node connectivity which leads to an efficient, consistent and reliable communication. The conventional LEACH technique incurs the drawback with uneven CH selection.

The SA-LEACH when compared to LEACH has an increase of 25-40% in terms of packets being delivered efficiently at the sink node. The efficient role of CH increases the throughput and hence better utilization of the channel. The use of Simulated Annealing ensures that the nodes with higher energy levels are preferred for CH selection thereby maximizing the data transmission before a node exhausts it energy.

The SA-LEACH significantly reduces the energy consumption up to 20% and increases the lifetime of the network. This is achieved because of the balance in maintained while selecting CH. The cost function used by SA helps in adjusting the energy levels. The conventional LEACH protocol does not support this approach. This mechanism helps in balancing the energy levels of the network nodes.

4 Conclusion

There are a variety of ways for establishing routing protocols in WSNs for the minimizing the consumption of energy by a sensor node. Basically, protocols are meant for enhancing the performance of the network. It is very difficult for finding an efficient routing protocol that could optimize the consumption of energy in a WSN. Since it is very difficult to change or recharge the battery of the sensor always, it is necessary to design a protocol that could minimize the energy consumption. This topic has been in research for a long time and thus many protocols and algorithms have been proposed for designing an efficient routing protocol which would aim to minimize the usage of energy by a node while transmitting the data from a node to its cluster head and then back to the sink node. There are some problems in most of the existing works such as inconsistency in the process of clustering, less lifespan of the network, excess loss of data, insecurity, increased response time.

The proposed approach SA-LEACH is one of the meta-heuristic algorithms. The main objective of the approach is to minimize the consumption of energy thus enhancing the energy efficiency of a Wireless Sensor Network. The proposed approach aims to enhance the process of selecting a cluster head (CH) by incorporating LEACH protocol with Simulated Annealing. In the proposed approach the members of the cluster select a cluster head. The selection process is performed by way of the LEACH protocol. Then the cluster head collects the data from each of its members during the cycle. Later all the neighboring nodes are assessed for replacing the current cluster head with a node that could reduce the consumption of energy. This is achieved by the using Simulated Annealing algorithm.

Through simulation it is observed that SA-LEACH approach in comparison to the LEACH and EE-LEACH has shown better performance in terms of end-to-end delay, consumption of energy, throughput and packet delivery ratio. The drawback with LEACH approach is that it can cause instability in the cluster head selection while selecting the nodes randomly. The EE-LEACH approach gives better possibility coverage and uses the Gaussian distribution. This approach gives good results when the topology of the network is very small. The proposed approach SA-LEACH performs better when the size of the network is large. This approach performs better than the other two approaches based on cluster head selection. The SA algorithm restores the selected cluster head node based upon their energy consumption while transmitting the data. From the results of the simulation, we can see that there is a considerable minimization in the consumption of energy by a node. The amount of reduction is approximately 11.15% when compared to EE-LEACH protocol and 23.07% when compared to LEACH protocol. There has been an enhancement of throughput by 5.25% and 30% for EE-LEACH and LEACH protocols respectively.

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