Energy-Efficient Clustering in Wireless Sensor Network: A Comparison between Genetic Algorithm and Bacteria Conjugation

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ABSTRACT

Wireless Sensor Networks are resource restrained in terms of energy consumption, lifetime, and processing speed. The prevalent goals of many types of research in Wireless Sensor Networks are to lessen the energy consumption among the sensor nodes and improve the life time of the network. Of all the measures, designing an efficient clustering protocol stands out. As a result, this research focuses on energy-efficient clustering in Wireless Sensor Networks. In this work, Genetic Algorithm is used to optimize clustering using the Mobile LEACH protocol. It is observed that Genetic Algorithm has been used to optimize LEACH in the previous works, but little attention is made on Mobile LEACH. LEACH and Mobile LEACH with Genetic Algorithm are implemented and simulated in MATLAB. The results show that the introduction of mobility and optimization using LEACH increases the stability period of the network. This accounts for about a 25% decrease in the energy consumed by the nodes of the network. It is therefore a rule of thumb in optimization that using algorithm A, successfully in a particular problem does not guarantee its effectiveness, it is then compared with other optimization techniques. As a result, adaptive clustering of Mobile LEACH optimized with Bacteria Conjugation Operator (BCO) is also implemented and the result obtained outperforms the adaptive clustering obtained with Genetic Algorithm.

Keywords: *Wireless Sensor Network (WSN) · Adaptive Clustering · LEACH-M (Less Energy Adaptive Channel Head-Mobile) · Genetic Algorithm (GA) · Bacteria Conjugation Operator (BCO).*

1. INTRODUCTION

Wireless Sensor Network (WSN) is a collection of small and tiny low-powered sensors with sensing, data processing, transmitting, and receiving abilities. These minute sensors collect sensed data from the environment or the application for which they are deployed, transmit, and relay the information to the sink. The base station is equipped with sink nodes that collect and aggregate the information from the sensors and a decision is made therein. WSN is a synergistic coupling of the sensor, network technology, and wireless communication [1]. The nodes are densely and randomly deployed with a battery as their source of energy. It is therefore impractical to recharge the sensor nodes owing to the inaccessibility of the distribution areas [2].

The energy consumption of each node has to be balanced to add to the longevity of the network [2]. So, energy is consumed in various ways, but heavily during transmission once the connection has been established. Consequently, designing a competent energy routing protocol is indeed necessary to increase the potential lifetime of the network.

Clustering is an important term in WSN that connotes the way the nodes present in the network organize themselves into clusters based on certain parameters. It applies to big networks especially ad hoc where the sensors are employed for sensing purposes. If the whole sensor nodes communicate with one another to transmit the sensed information to their destination, network congestion and collision will set in and eventually render the network less energy efficient due to limited resources. Clustering is one of the solutions that meet the effective resource utilization and load balancing in WSN. In a clustered network, the sensor nodes are arranged cluster-wise and one serves as the CH that oversees the activities of the cluster and the remaining nodes send data to it. The CH is charged with the responsibility of aggregating the data and sending it to the base station.

High-capacity node advertises themselves as the CH and others join in proximity. Instead, each node sends the data directly to BS over a large distance, it then transmits within the cluster over a short distance. Also, the periodic re-election of CH from residual energy guarantees balanced energy consumption within the cluster. The efficiency of data transmission is increased by clustering by aggregating the data within the cluster. Many hierarchical clustering algorithms have been presented in research and deployed for application based on some parameters. The selection is left with some open issues that need to be addressed especially with the advent of technologies like the Internet of Things (IoT), Vehicular Ad hoc Networks (VANET). As everything will be connected through the internet, sensor nodes will be employed to connect things wirelessly for data transfer. So, security, connectivity, retrieval, and storage of data are some of the challenges facing clustering techniques in WSN as the network operates in an open environment. This paper focuses on energy-efficient clustering with specific importance on optimizing energy consumption using Genetic Algorithm and Bacterial Conjugation Operator.

2. Theories and related works

2.1 Clustering algorithm in WSN

The LEACH is regarded as the first and furthermost prominent clustering algorithm in WSN. It is amenable to a homogenous sensor network. The basic concept is to form clusters based on the strong received signal strength (RSS) received from the head of clusters. This enables the cluster heads (CHs) to be used as gateways to reach the destination [3]. The sole aim of introducing LEACH is to reduce power consumption [4]. LEACH segments the network into clusters and each cluster has a leader that rotates roundly. CH sends data directly to the base station (BS) and uses a data aggregation technique to decrease the energy consumption of the nodes and extend the lifetime of the network. The operation of LEACH is performed in two stages: setup and steady-state phase. The cluster setup stage is the one in which each node decides on contending for CH. The decision depends on the desired percentage of CH in the network and the number of times a node has been a CH. Sequel to this choice, each node is randomly assigned a value between the values (0 and 1). The value is then compared with a threshold as in equation (1), if the threshold is greater than the value, the node is elected as the CH. Then, the CH invites the remaining nodes to join it by broadcasting advertising messages, and a cluster is made for the current round. The nodes will then be allowed to transmit data to CH by scheduling time division multiple access (TDMA). In the steady-state stage, data transmission starts and each sensor node sends according to the time slot. It can then be turned off and the CH should always be ON to receive data from the sensor nodes.

$$T(si) = \begin{cases} \frac{Pi}{1-Pi\left(r \bmod {}^{1}/_{Pi}\right)} & if\ s(i) \in G \\ 0 & otherwise \end{cases} \quad (1)$$

LEACH-M is a Mobile-WSN protocol that provides a highly flexible routing method to deal with CH selection and regular changes in topology. The implementation is based on the following equations

$$E_T(l,d) = E_{elec} * L + \varepsilon_{amp} * L * d^2 \quad (2)$$

$$E_R(l,d) = E_{elec} * L \quad (3)$$

The detection threshold is represented as P_{thresh}. The packet is discarded when the received power is lower than the threshold, because it cannot be detected and received. However, if the power obtained is higher than the threshold, the reception of the packet is successful. According to Kim etal., LEACH-M is used to confirm that a node is capable of communicating within the time slot allotted in TDMA. The main concept of LEACH-M is to check whether a mobile node is capable of communication with specified CH at TDMA. In LEACH, CH gathers the sensed info according to TDMA. There is a minor adjustment in the steady state to support mobility. As shown the fig2. below, CH first sends a request message to member nodes for data transmission. CH will include node time slot type when the data is sent by the nodes, which data is received by labeling the nodes from which data is received at the end of the data frame in the time slot. If at the end of the frame, the data is not obtained from the same node, it is removed from the cluster due to mobility. The node which is discarded or did not receive a request message for two successive frames should join a new cluster.

2.2 Optimizing Clustering using Genetic Algorithm

To build a well-functional design, optimization is needed according to the requirements. To achieve the desired objective of minimizing energy consumption or maximizing the existence of the network, network optimization is necessary. Energy consumption, security, network life, and packet delivery ratio are some routing challenges in a WSN.

Genetic algorithm (GA) is a computational model used to solve optimization problems by imitating genetic processes in the context of evolutionary theory. Genetic operators like selection, reproduction(crossover), and mutation are used to mimic biological evolution. In GA, a population is initialized and each individual symbolizes a possible solution. The important stage of the evolutionary process is using the fitness function to find individuals that are close to the best solution for the problem and with the help of crossover, individuals with the highest fitness are combined to form new individuals. It considers that the possible arrangement of a problem is an entity and that an arrangement of parameters may convey it. Parameters are seen as chromosome genes and can be organized in binary figures by a series of values. A positive value called fitness value is used to address the problem to represent the level of goodness of the chromosome, and this value is firmly identified with its objective value [5].

The best clustering strategy is very difficult to find in a large-scale wireless sensor network. In clustering protocols, meta-heuristic methods such as genetic algorithms, particle swarm optimization, fuzzy-based algorithms, and ant colony algorithms are also used. In this section, a comparative study of clustering, optimization-based clustering, and multi hop routing using Genetic algorithm is highlighted.

Research on energy-efficient adaptive clustering protocol based on Genetic Algorithm and Genetic Algorithm inter-cluster communication is presented in [6]. In the work, a comparison is made among LEACH, inter clustering in LEACH, and optimized LEACH using GA. The author uses the base station as the determinant to select the cluster head by introducing the preparation phase in the GA-based adaptive clustering to eliminate the effect of a probability value on the network performance. In [7], an energy-efficient GA method using Virtual Grid-based dynamic route adjustment is introduced. Total energy and total distance i.e., the location from the origin to the destination and energy of nodes form the fitness function. The best location for the highest fitness is represented by a line and the optimal route to reduce overhead. In [8], a hierarchical clustered sensor network is presented to select cluster heads with the help of GA. The Genetic Algorithm performs hierarchical clustering with parameters like distance, remaining energy, and concentration- to constitute the fitness function. Type-2 fuzzy logic is also used to achieve hierarchical clustering. The two methods are then compared in each cluster with equal and random distribution. The performance of the two methods is evaluated by considering the number of alive nodes, dead node counts, and residual energy. GA is also used with some adjustments for evaluation in the work presented in Multi-hop optimization in WSN using GA [9]. The distance and energy consumption are used to optimize the path to the nearest neighbour. One or more sinks are deployed with a variable number of sensor nodes for the sake of simulation. Enhanced GA energy efficient Multi-hop Path in WSN is proposed in [10]. The optimal multi-hop path between the source cluster heads and destination through the intermediate node is found using the new Optimal Multi-hop Path Finding Method (OMPFM). The approach also improves LEACH by modifying the CH selection and the chromosome is enhanced using GA. The following form the fitness function; the ratio of CHs included in the path (N_{par}) of the participating CHs and the average distance from the source, CH, and the intermediate node. In [11], GA-based optimized LEACH protocol for energy-efficient WSN. LEACH and GA are utilized for energy-effective routing.

LEACH executes the clustering and the data processing while GA optimizes the routing. The residual energy of the nodes is only the fitness function. It is also referred as OLEACH. The concept of a trusted route is presented to reduce the search time to store the route if the transmitted data repeats. Also, GA-based clustering approach for WSN to optimize routing techniques is elucidated in [12]. The cluster head establishes an equilibrium between the load and a suitable path between the sensor node and sink. The intermediate CHs and CH communicate in the chain-like system to reach the BS.
It is a point to observe that all the works presented in the section above used GA to optimize LEACH but few consider Mobile LEACH (LEACH-M). Despite the fact that the network is enhanced in several ways loopholes such as; insufficient to guarantee an optimal number of clusters, inability to select nodes based on energy and location cannot ignored [13]. Therefore, considering the speed of network execution, flexibility, and reliability of LEACH-M, the proposed work is based on optimizing the clustering of LEACH-M using GA and BCO.

2.3 The Proposed Work

The proposed work is centered on optimizing mobile clustering using GA. In this work, GA is used to select the best path to transfer the aggregated information from CHs to BS in a bid to reducee energy consumption and improve the lifetime of the network. The following; the average distance from the source CH and BS, the percentage of the participated CH from the CHs, and the total number of participations in the transmission path are considered to formulate the fitness function of the problem.

The work is done in two stages. The first stage focuses on the formation of mobile energy- efficient clustering using GA. LEACH-M clustering consists of a set up and steady-state phase. Stage 2 is the selection of the optimal path to send data to BS through CHs. As a result, GA is initiated in each round with the parameters in the fitness function.

Steps to implement the Proposed Work.

The steps to implement the proposed work optimized with GA are as follows:

1. Initialization of parameters
2. Energy parameters allocations
3. Generation of the initial population for CH selection
4. Evaluation of fitness function. The fitness function used is as follows:

$$F(c) = d(CHs, BS) + \left(\frac{Npar}{N}\right) + No\ of\ Part \quad (4)$$

   $d(CHs, BS)$ is the average distance between CH and BS,
   $\left(\frac{Npar}{N}\right)$ is the percentage of participated CH from all participated CH in GA
   $No\ of\ Part$ is the total number of participations in the transmission process [14]
5. The population is then updated.
6. The population fitness function is then replicated and then compared with the initial one.
7. If the successive fitness function is greater than the initial population, then it is considered and the next iteration begins. In that round, the best node is then chosen as the CH
8. Data is then transmitted between the nodes and CH, then between the CH and the sink
9. And, the final fitness parameters are estimated.
10. A comparison is made between the original population and the recent fitness function. Lower current fitness function will lead to an update in the population. This will continue until it becomes greater than the initial population.

The steps to implement the proposed work optimized with BCO are as follows:

1. The parameters are initialized
2. Allotment of energy parameters

3. The initial population of CH selection is generated
4. Initialize the positions
5. Prepare the fitness parameters
6. Evaluate the population
7. Sort the population
8. Store the best chromosome
9. Perform horizontal Gene Transfer and store the new chromosome
10. Calculate the number of similar genes
11. Repeat steps 5 and 6
12. Perform mutation
13. Repeat 5and 6
14. Sort the population
15. Store the best fit

3. Results and Discussion

3.1 Results of LEACH-M optimized with GA

Fifty nodes are dispersed in the field of 100m * 100m dimension. Some of the nodes are labeled as normal nodes and the others are advanced nodes depending on the energy of the nodes. The network is demarcated into clusters with the help of the Vinoroi diagram function in MATLAB and nodes in a particular cluster are differentiated with colors. The demarcation is done in such a way that if the threshold energy is greater than the energy of any node in a given cluster or CH within the cluster, the such node will be automatically discarded simply because demarcation changes at each round. In this case, 2000 is taken as the maximum round. While simulating the network, at the 200th round, a zero number of dead nodes are observed compared to LEACH where no node is with energy. Figure 1 shows the relationship between the number of dead and alive nodes at each round. It is observed that the lowest number of dead nodes is observed at the 500th round and at the 2000th round about 120 nodes have exhausted their energy. This indicates GA has lessened the energy consumption and also improve the lifetime of the overall network by increasing the stability period of the network.

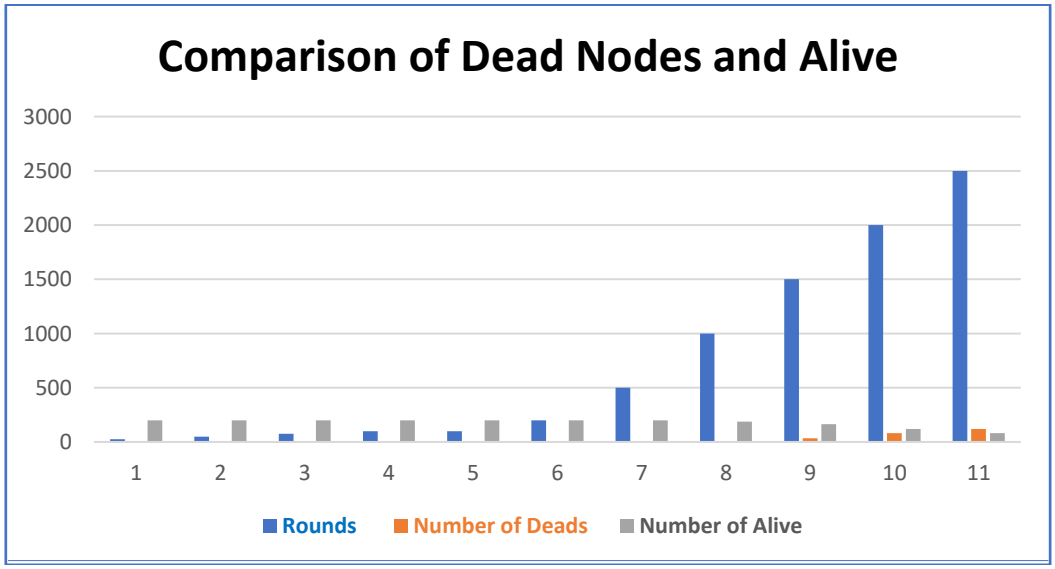

Figure 1. Comparison between Dead Nodes and Alive Nodes

3.2 Results of LEACH-M optimized with BCO

In this case, 200 nodes are dispersed in the field of 100m * 100m dimension. The first dead node is observed in the 1218th round and more than 20 dead nodes are observed in the 2000th round, while the 3000th round yields around 125 dead nodes. Figure 2 shows the relationship between the number of dead and alive nodes at each round. It is observed that the lowest number of dead nodes is observed at the 1500th round and at the 3000th round about 125 nodes have exhausted their energy. This means that with the introduction of BCO in LEACH-M, the energy consumption is reduced when compared with LEACH-M optimized with GA.

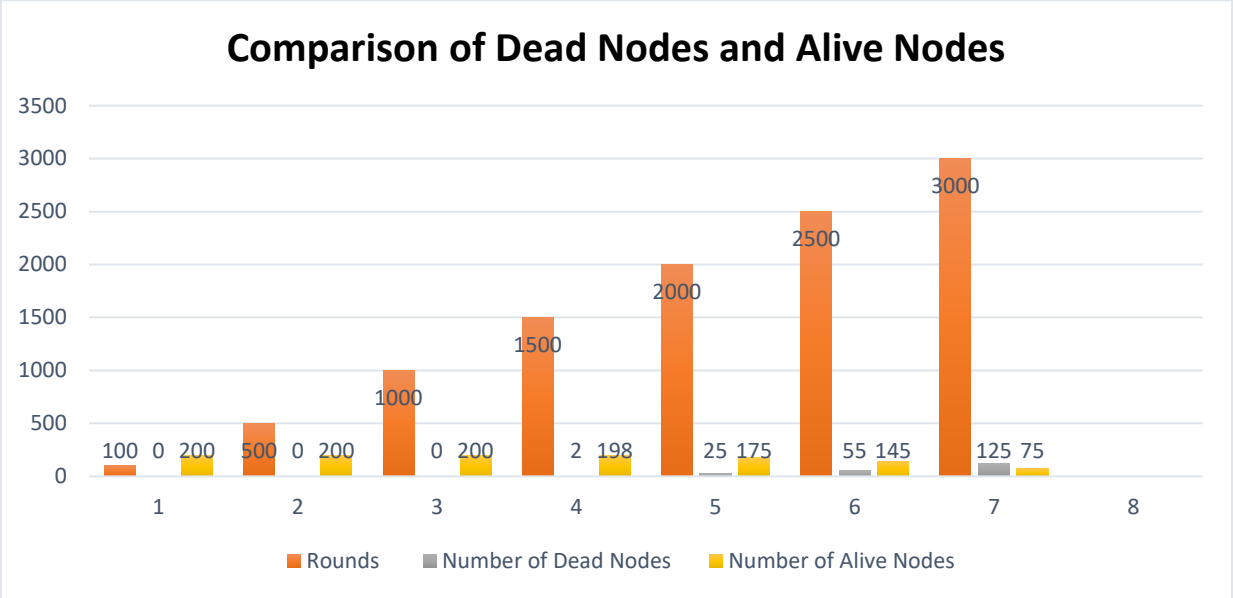

Figure 2. Comparison between Dead Nodes and Alive Nodes

Table 1. Comparison of Routing Protocols used in the proposed work.

Routing Protocol	Number of Nodes	Rounds	Dead Nodes	Alive Nodes
LEACH	100	20	20	80
		50	70	30
		140	0	100
LEACH-M optimized with GA	50	950	1	49
		1200	25	25
		2000	45	5
LEACH-M optimized with BCO	200	1218	1	99
		2000	20	180
		3000	125	75

4.0 Conclusion

A comparison between GA and BCO for energy-efficient clustering in wireless sensor network has been presented. Mobility of the channel head (CH) in the energy clustering (LEACH-M) has been given great attention due to its role in network stability. Therefore, LEACH-M has been optimized with two different algorithms; GA and BCO. It was found that optimization of LEACH-M with BCO outperformed in adaptive clustering than that with GA with less than 25% decrease in energy consumed by the nodes of the network.

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