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An Improved Genetic Algorithm with Clustering Techniques to Extend Network Lifetime in Homogeneous and Heterogeneous Wireless Sensor Networks

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Abstract: This paper presents adoption of genetic algorithm (GA) with clustering techniques to improve the lifetime for homogeneous and heterogeneous Wireless Sensor Networks. The newly proposed fitness threshold for these types of networks is able to select the most energy efficient nodes to become Cluster Heads every round. They are based on their residual energies during every round of the epoch. The proposed algorithms i.e., Improved GA Homogeneous and Improved GA Heterogeneous algorithms had shown better network lifetime with the help of new fitness threshold. They are also able to send more packets to BS as well as nodes to form cluster heads to more rounds with reduced energy dissipation in the network. The performances of these algorithms are compared with the two tier clustering algorithms to demonstrate that they have better network lifetime.

Keywords: wireless Sensor Networks; routing algorithms; network lifetime; clustering; energy consumption

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of large number of sensor nodes randomly deployed in a given area. These nodes collect, store and process the sensed information and communicate with other neighbouring nodes and send to Base Station (BS). WSNs provide observation of environmental systems through which monitoring and controlling the physical world makes more convenient [1].

Energy consumption is an important factor to determine the life of the sensor networks. These sensor nodes are driven by battery and have limited energy resources like battery power, communication bandwidth and transmission distances. Many researchers proposed several algorithms and extensive efforts had been made so far on routing problems. But still effective solutions related to these problems had become challenge in this field.

Many routing protocols for WSNs have appeared in the literature. In applications using direct transmission (DT) protocols [2], sensor nodes transmit their sensed data directly to a BS. Thus, the nodes located far from the BS will die quickly since they dissipate more energy in transmitting data packets. DT protocols are inefficient. On the other hand, minimum transmission energy (MTE) protocols [3] transmit data packets to the BS by way of multi-hop relay. As a result, nodes located near the BS die quickly since they end up relaying lots of data on behalf of remote nodes.

Grouping sensor nodes into clusters helps to achieve the network scalability. Every cluster would assign a leader called cluster-head (CH). Many techniques involve node reach ability, route stability, network longevity and coverage. Clustering can also conserve communication bandwidth with inter-cluster interactions to CHs and avoid redundant exchange of messages among sensor nodes. Moreover, clustering can stabilize the network topology. Sensors would care only for connecting with their CHs and would not be affected by changes in their CHs. The CH also utilizes optimized management strategies to further enhance the network operation and prolong the battery life of the individual sensors and the network lifetime. Sensors can be engaged in a round-robin order and the time for their transmission and reception. Furthermore, a CH can aggregate the data collected by the sensors in its cluster and thus decrease the number of relayed packets [4].

Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the first clustering protocols proposed for routing in WSN which is designed by Wendi B. Heinzelman [5]. The authors have studied multi-hop clustered networks and used a randomized clustering scheme to organize the sensors. They provide methods to compute the optimal values of the algorithm parameters. Most of the clustering algorithms, such as LEACH, Power Efficient Gathering in Sensor Information Systems (PEGASIS) [6] and Hybrid Energy Efficient Distributed (HEED) [7] protocols are meant for homogeneous networks.

Stable Election Protocol (SEP) is for heterogeneous networks in which election probabilities are weighted by the initial energy of a node relative to that of other nodes in the network [8]. This prolongs the time interval before the death of the first node known as stability period, which is crucial for many applications where the feedback from the sensor network must be reliable. SEP provides longer stability period and higher average throughput than current clustering heterogeneous oblivious protocols.

The focus of proposed work is based on the optimization properties of genetic algorithm (GA). However, GA is used to determine the energy efficient clusters and then cluster heads choose their associate nodes for further improvement. To increase the overall performance, simple heuristics are used to retain a few energy efficient clusters for a longer duration than the other ones.

II. THE PROPOSED 'IMPROVED GA HOMOGENEOUS' ALGORITHM

The WSN nodes are represented as bits of a chromosome. A chromosome is a collection of genes and represents a data aggregation tree for a given network. Each chromosome has fixed length size, which is determined by the number of nodes in the network. The head and member nodes are represented as 1s and 0s respectively. The fitness of a chromosome is determined by parameters such as distance and energy consumption. A population consists of several chromosomes and the best chromosome is used to generate the next population. For the initial population, a large number of random cluster heads are chosen. Based on the survival fitness, the population transforms into the future generation. A network of 'n' nodes is represented by a chromosome of n bits. The fitness of a chromosome is designed to minimize the energy consumption and to extend the network life time.

The proposed function fitness for the network is improved from [8] and given by

$$Fitness = \sum_{CH=1}^{m} (\sum_{i=1}^{n} \frac{E_{residual}}{d_{ij}}) + Distance \quad (1)$$

where

m indicates the number of nodes associated to the Cluster heads

n represents the number of nodes in the network

d_{ij} is the distance between nodes and Cluster head nodes

Distance is the distance between Base Station and Cluster head

$E_{residual}$ is the energy left after consumption during previous rounds

According to radio energy dissipation model [9] to achieve signal to noise ratio in transmitting *k* bit message over a distance *d*, the energy expended by radio is given as

$$E_{Tx(k,d)} = E_{elec} * kbit + E_{fs} * kbit * d^2 \quad (2)$$

Where *Eelec* is energy dissipated per bit to run transmitter or receiver circuit, *kbit* is the control packet length for every time, *Efs* depends on the transmitter amplifier model, *d* is the distance between sender and receiver.

To receive a *k* bit message the radio expends energy given as

$$E_{Rx(k,d)} = E_{elec} * kbit \quad (3)$$

Assume an area over which 'n' nodes are uniformly distributed. If we assume sink is located at any place in the field, and distance of any node to the sink less than d_o i.e. $d_o = \sqrt{(E_{fs})/(E_{ms})}$.

The energy transmission for non cluster head is obtained as

$$E = E_{elec} * kbit + E_{fs} * kbit * d^2 \quad (4)$$

d = distance between sensor nodes and its cluster head

Then the energy transmission for cluster head is given by

$$E = EDA * totalbit + E_{fs} * kbit * d^2 \quad (5)$$

totalbit = packet length

d= distance from cluster head to node

The proposed genetic algorithm parameters determine the energy consumption and therefore extend the lifetime of the network. There is a trade-off between energy consumption and distance parameters because making large numbers of clusters shortens the distance between the sensor member nodes and also corresponding CH. Creating many clusters increases energy consumption level rather than decreasing of distance. Due to this, the ratio of total energy consumptions to the total distances of nodes is used in order to get average amount of used energy for every node.

III. THE PROPOSED 'IMPROVED GA HETEROGENEOUS' ALGORITHM

For the heterogeneous networks, the fitness function is given by

$$Fitness = \sum_{CH=1}^{m} (\sum_{l=1}^{n} \sum_{i=1}^{n} \frac{E_{residual}}{d_{ij}}) + Distance \quad (6)$$

Where *l* is the nodes which have more energy than remaining other nodes, *i* is the normal nodes and other parameters are same as in Eq. (1).

The energy dissipated in the cluster head node during a round is given by the following formula [8]:

$$E_{CH} = \left(\frac{n}{c} - 1\right) kE_{elec} + \frac{n}{c} kE_{DA} + kE_{elec} + k\varepsilon_{fs} d_{toBS}^2 \quad (7)$$

Where *c* is the number of clusters, *EDA* is the processing cost of a bit per report to the sink, and d_{toBS} is the average distance between the cluster head and the sink.

The energy used in a non-cluster head node is equal to:

$$E_{nonCH} = kE_{elec} + k\varepsilon_{fs} d_{toCH}^2 \quad (8)$$

Where d_{toCH} is the average distance between a cluster member and its cluster head and if we assume area of the field is *A* x *A* . Then

$$d_{toCH}^2 = \frac{A}{2\pi k} \quad (9)$$

The total energy dissipated in the network is equal to:

$$E_{total} = k\{2nE_{elec} + nE_{DA} + \varepsilon_{fs}(Kd_{toBS}^2 + nd_{toCH}^2)\} \quad (10)$$

The average distance from a cluster head to the sink is given by

$$d_{toBS} = 0.765 \frac{A}{2} \quad (11)$$

The optimal probability of a node to become a cluster head *p* can be given by

$$p = \frac{K_{opt}}{n} \quad (12)$$

$$\text{where } K_{opt} = \sqrt{\frac{n}{2\pi}} \frac{\varepsilon_{fs}}{\varepsilon_{mp}} \frac{A^2}{d_{toBS}^2} \quad (13)$$

The optimal construction of clusters which is equivalent to the setting of the optimal probability for a node to become a cluster head is very important.

IV. SIMULATION RESULTS AND ANALYSIS

Consider a wireless sensor network with *N* = 100 nodes randomly distributed in a 100m x 100m field. Assume that the base station is in the center of the sensing region. The lifetime of the network is measured by the number of rounds until one node dies. In this situation, it is much more important to minimize the energy dissipation of the most heavily loaded nodes than to decrease the average energy dissipation. Both the cluster routing protocols are implemented in MATLAB.

The above mentioned two algorithms have been implemented with the same parameters all through the simulations shown and features of them have been compared.

The parameters [10] of the algorithm are shown in Table I below:

Table: 1 Parameters used in Simulations

Parameter	Value
Size of Network	100m X 100m
Bandwidth	1Mb/s
E_{elec} (Radio electronics energy)	50nJ/bit
E_{amp} (Radio amplifier energy)	100pJ/bit/m^2
E_{init} (Initial energy of node)	0.5J
Number of nodes	100
Data Aggregation(EDA)	0.5nJ/bit
ctrPacket Length of EDA	2000 bytes
Packet length	200 bytes

Here p=0.05, where p is the probability to become cluster head per every round.

Table: 2 GA Parameter Values

Parameter	Value
Length of chromosome	8
Crosover rate	0.5
Mutation rate	0.1
Iteration rate	200

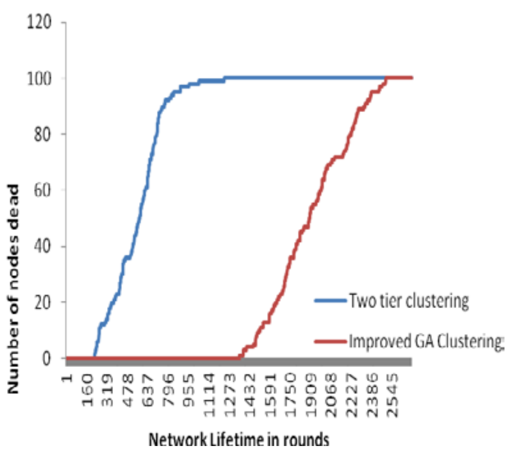

Figure 1. Comparison of Network lifetime between proposed algorithm and two tier clustering.

From the Fig. 1, it can be inferred that proposed algorithms have shown better performance than the two tier clustering algorithm. The Improved GA Homogeneous and Improved GA Heterogeneous algorithms extend the network lifetime better and reduce the energy dissipation as well as transmission from sensor nodes to base station. The death of first node occurred at 252 rounds for two tier clustering while the same for proposed algorithms occurs at 1256 and 1656 respectively. All nodes in them die at 2210 and 3268 respectively for the proposed algorithms. Simulation indicates that the proposed algorithm has more than 54% extension of network life for homogeneous networks compared with the two tier clustering algorithm.

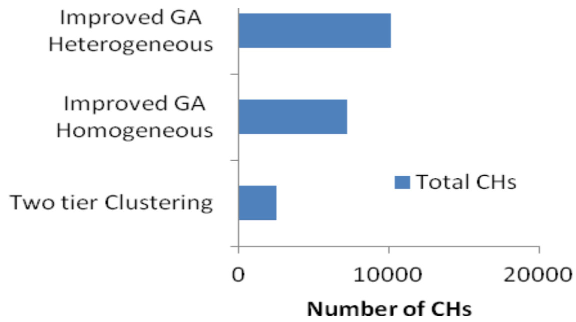

Figure 2. Comparison of CHs formed during entire lifetime

Fig. 2 depicts the comparison of the total number of CHs formed in every round in their entire lifetime. It states that 7218 and 10090 CHs are formed during their entire network lifetime in total rounds considered for the proposed algorithms i.e., Improved GA homogeneous and Improved GA heterogeneous algorithms respectively. However for the two tier clustering algorithm 2488 CHs are only formed.

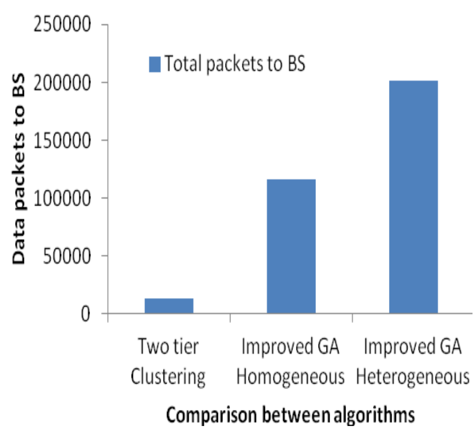

Figure 3. Comparison of data packets sent to BS for two algorithms

Fig. 3 gives the comparison of data packets sent to BS from the above mentioned algorithms. From this result, it can be understood that Improved GA heterogeneous sent more packets to BS than the two tier clustering algorithms. It transferred 2.0 x 10^5 data packets to BS compared to 1.3 x 10^4 data packets that had been received from their respective CHs during its entire lifetime for two tier clustering. Therefore it can be said that Improved GA heterogeneous had transferred 1.1 x 10^5 more data packets to BS.

From the above statistics taken from Figs. 1, 2 and 3 the proposed algorithms showed better performance from all the aspirants compared with the normal two tier clustering algorithms. This infers that Improved GA homogeneous and Improved GA heterogeneous are the appropriate and highly suitable energy efficient clustering algorithm proposed for Wireless Sensor Networks.

The Table III gives the performances of all the three algorithms during their entire lifetime observed from the simulations with respect to the issues concerned above. Hence, from the statistics mentioned in the Table, proposed Improved GA homogeneous has 54% more energy efficiency than the two tiered clustering algorithm and also extended to heterogeneous networks also.

Table: 3 Comparison of all the algorithms

Algorithm	**FND**	**LND**	**Total CHs formed**	**Packets sent to CH**
Two tier clustering	252	1005	2488	1.3×10^4
Improved GA Homogeneous	1256	2210	7218	1.1×10^5
Improved GA Heterogeneous	1656	4268	10090	2.0×10^5

The Table 3 gives the performances of all the three algorithms during their entire lifetime observed from the simulations with respect to the issues concerned above. Hence, from the statistics mentioned in the Table, proposed Improved GA homogeneous has 54% more energy efficiency than the two tier clustering algorithm and also extended to heterogeneous networks also.

V. CONCLUSIONS

The proposed Improved GA homogeneous algorithm performs better than some traditional cluster based protocols. The simulation results have shown that using a GA based CH formation extends the network lifetime between energy consumption and distance parameter. The proposed algorithms have improved the process of cluster head selection and the network lifetime, data packets transmission to both BS and reduced energy dissipation among the nodes in the network. Further the algorithms with new evolutionary algorithms will be considered and improved the performance of these routing protocols.

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