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Intelligent Deployment Strategy for Heterogeneous Nodes to Increase the Network Lifetime of Wireless Sensor Networks

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Abstract: ***The applications of wireless sensor networks are increased day by day for different applications. Heterogeneous wireless sensor networks offer limitless possibilities because to their expandable capabilities, such as diverse computing power and sensing range, but they also represent significant issues due to the scarcity of energy, which is typically non-renewable. The node deployment, coverage area, connectivity, power depletion and network life time are major issues in wireless sensor networks. We have deployed heterogeneous sensor nodes on the basis of energy to design a heterogeneous network model and applied intelligent node deployment techniques by using metaheuristic algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO) algorithm to minimize the power depletion of sensor nodes for enhancing network life time using multi-hop transmission in this paper. The benefits of heterogeneity have been revealed by our experimental findings.***

Index Terms: Wireless Sensor Networks, Genetic Algorithm, Particle Swarm Optimization, Power Depletion, Network Lifetime

I. INTRODUCTION

Wireless Sensor Nodes are a network of interconnected sensor nodes that interact wirelessly to collect data from the environment, such as temperature, sound, pressure, motion, or pollutants, and send it to a sink where it may be viewed and processed [1]. One of the most significant issues faced by WSNs is power constraint. WSN nodes are typically powered since they are installed in remote regions such as deserts, woodlands, or combat zones. The deployment of sensor nodes is a basic but crucial factor that influences the performance of the WSN. Some nodes are scattered at random, while others are spread in a predictable pattern. In extreme environmental or hazardous settings, random node deployment is desirable. Connectivity, coverage, and energy consumption should all be considered while deploying nodes. WSNs face a number of issues, one of which being power constraint. Because WSNs are frequently installed in distant locations such as deserts, woodlands, and military zones, their nodes are typically powered by AA batteries with a short life span.

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It's possible that recharging such batteries won't be possible. Some of these nodes may be fixed, while others may be mobile. The lifetime of a sensor node is determined by its energy source. The lifetime of a network is defined as the time from death of first node deployment to the time till last node in the network dies. The battery in our sensor nodes is non-rechargeable. So, when a node dies, it causes an interruption in the sensor network. A lot of research has been done on WSNs. The challenge of node deployment, which entails identifying the best feasible site for such sensor nodes to cover n-target zones with the fewest possible nodes, has been shown to be an NP-complete problem. Scientists and researchers have come up with intelligent and efficient deployment and routing algorithms to increase the speed and efficiency of the network [2, 3]. Natural-inspired algorithms were created to overcome the deployment problem. One of these algorithms being investigated is the Swarm Intelligence (SI) approach, which uses efficient optimization to address WSN problems. They are particularly good at addressing complex problems with simple actions. The algorithms we consider are the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). These algorithms are chosen because they work very well with optimization problems. Genetic Algorithm (GA) is based on Darwin's theory of evolution. GA solves the problem by creating offspring with better fitness and evolving them to make even better solutions. Particle Swarm Optimization (PSO) solves a problem by iterating over candidate solutions. It has a population of particles and tries to find the best solution by moving the particles in problem space. This algorithm is inspired by the social behaviours of animals like a flock of birds or a school of fishes [5]. In heterogeneous WSNs different types of nodes are deployed. In our case, heterogeneity is in terms of power. So basically, we're adding some extra battery power to cluster heads [4]. The CHs only send data to sink. Hence, the CHs consume more energy. Our contribution in this paper is deploying number of heterogeneous sensor nodes, clustering, routing in the network using GA, PSO and multi-hop communication to improve life time of WSNs. The paper is organized as follows. In section 2, the related work is given. The preliminary of GA and PSO is mentioned in section 3. The system model, network model, energy model, problem formulation and mapping GA and PSO to our problem statement is described in section 4. The result analysis is described in section 5 and the conclusion is presented in section 6.

II. RELATED WORKS

The popular natured inspired algorithms ACO (Ant colony Optimization), PSO (Particle Swarm Optimization), BCO (Bee Colony Optimization) and GA (Genetic Algorithm) etc are used to design energy efficient protocols for WSNs.

PSO and GA are most popular optimization algorithms used in WSNs. In this paper both algorithms are used to enhance the life time of WSNs. PSO is better than GA for clustering in WSNs using some objective functions [5]. The authors designed EECMR protocol for routing data packets in under water wireless sensor networks. It is layer based multi-hop routing protocol which consumes less energy to improve network lifetime [6]. The authors are designed a hierarchical hybrid protocol based on GA and PSO for distributed clustering in WSNs. GA is used for global search and PSO is used for local search which is layer based energy efficient clustering protocol [7]. The authors are designed multi-hop energy efficient routing protocol which is graph based to extend life of WSNs [8]. The authors focus on solution of connecting and coverage issues in wireless sensor networks. To solve these problems classical and met heuristic methods are used [9]. The authors developed MOEA/D – DE, a multi-objective evolutionary algorithm (MOEA) that use decomposition methods to convert approximation issues into single-objective optimization problems. This is a more advanced variant of MOEA/D. To compare two solutions, a fuzzy pareto dominance technique is utilised. The new algorithms outperform all other algorithms in terms of output [10].

There are three different energy level sensors are used to design energy efficient heterogeneous WSNs. The cluster heads and member nodes are selected by weighted election probability and threshold functions. From the simulation, it is clear that the energy consumption of WSNs and total data packets sent to sink is based on number of rounds [11]. The authors have designed a routing protocol called EC-PSO which solves energy hole problems of clustering and applies energy protection mechanism to avoid low energy nodes to design heterogeneous energy efficient WSNs. This protocol provides better results than VD-PSO and Azharuddin [12]. For heterogeneous wireless sensor networks, the authors have suggested a routing system. To save energy and extend the life of HWSNs, a modified Grey wolf optimizer technique is used. It is obvious from the simulation that this protocol outperforms SEP, DEEC, FIGWO, and M-SEP [13]. The authors have proposed a multi-objective PSO and fuzzy based model to solve network coverage, network connectivity issues, extend network life and deployment of sensor nodes. This model produces better result than PSO based model [14]. To increase the life of WSNs, the authors presented an approach for relay node deployment that uses two evolutionary algorithms: GSA (Gravitational Search Algorithm) and DE (Differential Algorithm). This approach outperforms another algorithm based on the ABC (Artificial Bee Colony) technique, as demonstrated in the simulation section of this work. [15]. By using a probabilistic sensing model and a harmony search method in a heterogeneous wireless sensor network, the authors presented an effective solution to handle coverage problems, deployment costs, and network costs (HEWSN). In HEWSN and HOWSN, the proposed model outperforms GA (HSA) [16].

In this paper [17], the authors have proposed an energy efficient routing protocol for heterogeneous wireless sensor networks based on fuzzy model to control packet dropping, minimize delay, power consumption and stability of network. In simulation, the proposed protocol is compared with different parameters based protocols and proved its efficiency. The authors have presented a paradigm for wireless sensor network node deployment for environmental monitoring and post-accident evacuation emergencies. Different meta-heuristic algorithms are employed in simulation. This model can be used in real-time applications. [18]. The authors have solved coverage and connectivity problems by applying Genetic Algorithm (GA) for node deployment in target based WSNs. But the proposed algorithm is not energy efficient [19].

The authors have presented a model to address three WSN issues. They are the coverage issue, energy consumption, and message transfer delay. Random deployment, a square grid, and pattern-based Tri-Hexagon Tiling (THT) approaches are used to tackle these issues. THT outperforms the competition in terms of energy consumption and message transfer delay, according to simulation. However, a square grid is superior to others when it comes to solving coverage issues [20]. The node deployment is major challenge to design energy efficient WSNs. The authors have focused four methods for node deployment to solve coverage problems of WSNs and different simulators in this paper. Computational geometry-based approaches, force-based techniques, grid-based techniques, and meta-heuristic-based techniques are the four types of techniques [21]. In [22], the authors are purposed path planning model to localize different nodes in such a manner, there will no linearity. The purposed model is better than SCAN model.

III. PRELIMINARIES

A. Overview of GA

Genetic Algorithm (GA) is nature-inspired metaheuristic algorithm which can be used to solve optimization problems. GA is search method which can be applied easily to solve different applications such as Wireless Sensor Networks, Data Science, Machine Learning, Neural Network etc. GA is also used for scheduling to find near optimum solution in short time. There are five phases in GA. They are initial population, fitness function, selection, crossover and mutation.

B. Initial population

It is a set of randomly generated possible solutions of a problem. Each solution is set of chromosomes. Each chromosome is set of binary numbers or genes.

C. Fitness function

Each individual is evaluated by fitness function. It gives a fitness score. The next step of GA will be selected by fitness score.

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D. Selection

In this step, we select valid chromosomes by highest fitness value. The methods of chromosomes selection are Roulette-wheel selection, tournament selection, rank selection etc. The parents are selected by using one of these methods to produce better off-springs for next generation.

E. Crossover

In this step, the new off-springs are created from selected parents. There are different methods for crossover operation. They are one point crossover, multi point crossover, uniform crossover, Davis' over crossover and so on.

F. Mutation

In this step, the new DNA sequence is created for a particular gene to create new allele or new solution. There are many mutation operators such as bit flip mutation, random resetting, swap mutation and so on.

G. Overview of PSO

Particle swarm optimization (PSO) is population based algorithm which is inspired by social behaviour of birds, fishes, insects etc. PSO solves different types of optimization problems. A group of particles is known as swarm. The particles always move to collect foods in a group without colliding. They work collectively and follow each other. In initial stage of PSO, each particle is assigned with a random position and velocity to move in search space. Each particle provides a best solution for a problem. The solution is verified by a fitness function. The particle changes its own velocity and position to achieve the global solution by its own personal best and global best. The process will continue for certain steps to achieve the best solution for a problem.

This algorithm has following steps to solve a problem.

Step1: Initialization

Initialize parameters

Initial Population

Initialize Position (Xi) Randomly for each Particle

Initialize Velocity (Vi) Randomly for each particle

Step 2 Evaluate Fitness $f(x^t_i)$

Calculate Fitness value for each Particle

If Fitness value is better than Best Fitness value(gBest) then

Set new value as new (gBest)

Each particle with Best Fitness value as gBest

Step 3 For each Particle calculate velocity and position

Calculate particle position by: xi t+1 = xti+ vti * t

Calculate Velocity by: vik+1= wvik + c1r1(xBestti – xti) + c2r2(gBestti – xti)

Step 4 Evaluate Fitness f(xti)

Find the current Best (gBest)

Update t = t + 1

Step 6 **Output gBest and Xti**

IV. SYSTEM MODELS

A. Network Model

We assume, all sensor nodes are randomly deployed in the network field. All sensor nodes do not have similar energy level at the beginning stage. Each sensor node sense periodically and sends data to its cluster heads (CHs) or base station. The sensor nodes are communicated with each other within their communication range [23]. All sensor nodes are capable of processing, communicating and computing distance between each other. The cluster heads transmits the aggregated data to the base station. The sensor nodes in the network can be homogenous or heterogeneous.

B. Energy Model

Both free space and multipath fading channels are employed in this paper. The free space model is utilized if the distance (d) between the transmitter and receiver is less than a threshold value (d0), otherwise the multipath model is used [24]. The following equations calculate the total energy necessary for each node in the network to transmit an h-bit data packet.

$$ETX(h, d) = h.E_{elec} + h\,\varepsilon_{fs} d^2 \quad \text{if } d < d0 \quad (1)$$

$$h.E_{elec} + h\,\varepsilon mp d^4 \quad \text{if } d > d0 \quad (2)$$

In a free space and multipath fading channel, Eelec is the energy dissipated per bit to run the transmitter, and εfs, εmp is the energy required for both the electronics circuit and the amplifier.The energy necessary to receive h bit data packet by the following equation.

$$Erx(h) = h.E_{elec} \quad (3)$$

C. Problem Statement

SN: Sensor Nodes

HN: Heterogeneous Nodes

ESN: Energy of Sensor Node

EHN: Energy of heterogeneous Node

Our problem is deployment of n heterogeneous nodes in target area. Since we don't have any fixed network available, we'll generate one randomly.

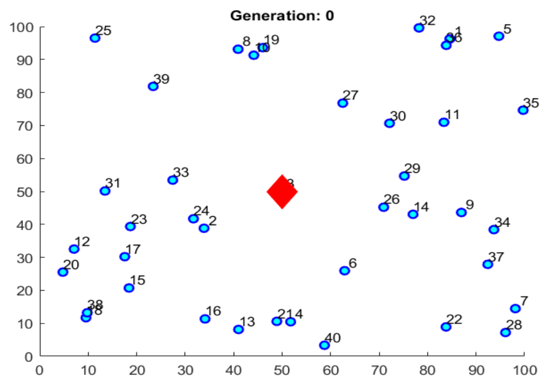

Fig.1 SN: 40, Sink @ center, Terrain Size: 100x100

We have a terrain size of 100x100 and deployed 40 sensor nodes randomly. We have to take care of the routing protocol. We're using direct as well as the multi-hop routing protocol. The cluster heads receives data from its sensor nodes, aggregates data and send data to the sink. Direct routing protocol means every node sends packets directly to the sink node. In this case, energy dissipation at each node is very high. In case of Multi-hop a sensor nodes forwards packets to its nearest node.

D. Mapping GA and PSO to our problem statement

We need to map our problem to GA and PSO. In GA we use integer representation for each variable.

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The size of each chromosome will be equal to the number of HNs to be deployed. Each variable in a chromosome would be a possible HN position. So each chromosome is a potential solution to our problem. Now we calculate lifetime as the objective function and we'll be minimizing the inverse of the objective function in turn increasing the lifetime. Parents are selected via Tournament selection (where randomly selected parents compete against each other in terms of fitness). We use the one-point crossover method (a random index is chosen and the tails are swapped) for our problem. In PSO, we find the solution sequentially. First, we search the space for the first node for optimal placement. When the position is found, we add the node to the network, and using the new network, we find the optimal placement for the second node. So, in general, we iterate over n heterogeneous nodes to find the best possible placements for all HNs.

V. EXPERIMENTAL RESULTS

A. Simulation Environment

The simulation works are done by using MATLAB (version 18b) on an Intel core i3 with 2.00 GHZ CPU and 4GB RAM running on the platform Microsoft Windows7. The simulations are executed with different number of sensor nodes with a single base station. In the simulation run, we have used following parameter values which are shown in tables.

Table I: Network parameters

Network Parameter for Simulation	
Parameter	**Values**
Network Field	100, 100
Sink Position	50, 50
Number of Sensor Nodes	100 , 150
Number of Heterogeneous Nodes	30
Message Size	2000 bits
Threshold Distance(d0)	87.7058m
Energy of Sensor node (Eo)	0.5 J
Energy of Heterogeneous Sensor node	1.5 J
ETx/ERx	50nj/bit
Efs	10 pJ/bit/m^2
Emp	0.0013 pJ/bit/m^4
Data Aggregation (Eda)	5nJ/bit/Signal

Table-II: GA Parameters

Parameter	Values
Population Size	1000
No. of Iteration	5
Cross over Probability	0.25
Mutation rate	0.1

Table III: PSO parameters

Parameter	Values
No. of Particles	150
C1	30
C2	30
W	15
Wdamp	9.9
No. of iteration	30

B. Performance metrics

We use following metrics to measure the performance of our proposed work.

Energy consumption: The node consumes more energy if it sends packets to sink directly and consumes less energy using multi-hop. The energy consumptions of sensor nodes depend on number of rounds.

Network lifetime: The life time of WSNs depends on lifetime of sensor nodes and deployment techniques of sensor nodes in target area. So we use intelligent node deployment techniques to improve the life time of WSNs

C. Simulation Outputs

This section deals with the simulation results obtained from the proposed work.

D. Direct Transmission

We have taken 30 SNs and 6 HNs in terrain size 100 x 100 square meters and the sink is at centre of sensing area. GA is used to deploy the HNs at different locations of sensing field. The red colour sensor nodes are HNs and rest are normal SNs in below figure 2. Here the nodes far away from the sink. So the nodes dissipate more energy.

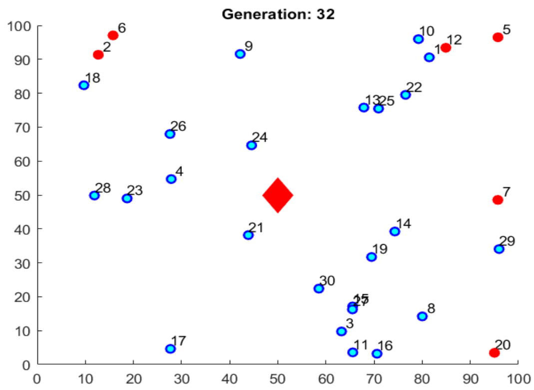

Fig.2 Direct output

E. Multi-hop transmission

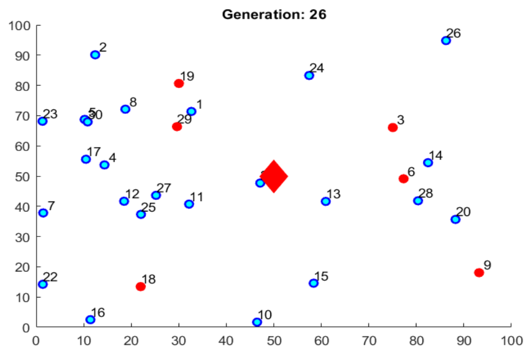

Fig. 3 Multi-hop output

We have taken 30 SNs and 6 HNs in terrain size 100 x 100 square meters and the sink is at centre of sensing area

SN: 30, HN: 6

Terrain Size: 100 x 100

The nodes closer (not always the closest ones) to the sink dissipates more energy because they will receive more packets from the previous nodes and GA placed the HN at these locations. The results are calculated for the following configurations.

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1. Varying SNs, keeping everything else constant.
2. Varying HNs, keeping everything else constant.

F. Varying SNs for Multi-hop routing protocol

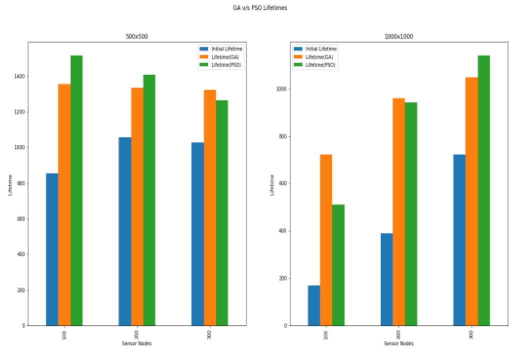

Fig. 4 HN: 30, ESN: 0.5, EHN: 1.5

In the figure 4, there are two different terrain size networks. They are 500 x 500 and 1000 x 100 square meters. There are thirty HNs and 300 sensor nodes. Each HN has 1.5J energy and each sensor nodes has 0.5J energy. The initial life time of sensor nodes are compared with the life time of sensor nodes after applying GA and PSO algorithms. We have observed that GA and PSO taking over each other when the number of sensor nodes is increased.

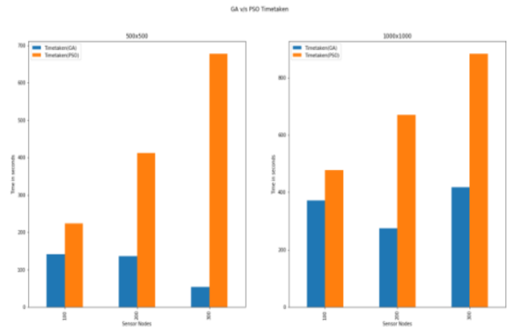

Fig.5 HN: 30, ESN: 0.5, EHN: 1.5

In above figure 5, there are two different terrain size networks. They are 500 x 500 and 1000 x 100 square meters. There are thirty HNs and 300 sensor nodes. Each HN has 1.5J energy and each sensor nodes has 0.5J energy. The time taken to get solution of GA and PSO algorithms are compared with each other. We have observed that GA is faster than PSO in reaching a solution.

G. Varying HNs for Multi-hop routing protocol

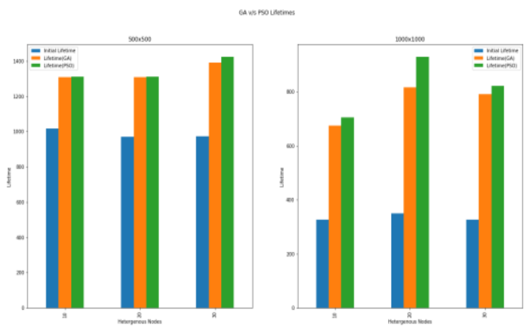

Fig. 6 SN: 150, ESN: 0.5, EHN: 1.5

In the figure 6, there are two different terrain size networks. They are 500 x 500 and 1000 x 100 square meters. There are thirty HNs and 150 sensor nodes. Each HN has 1.5J energy and each sensor nodes has 0.5J energy. The initial life time of HNs are compared with the life time of HNs after applying GA and PSO algorithms. We have observed that both GA and PSO perform comparably.

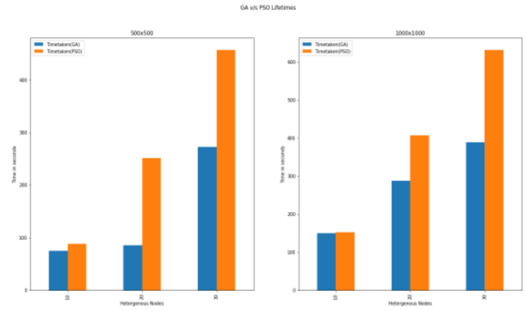

Fig. 7 SN: 150, ESN: 0.5, EHN: 1.5

In above figure 7, there are two different terrain size networks. They are 500 x 500 and 1000 x 100 square meters. There are thirty HNs and 150 sensor nodes. Each HN has 1.5J energy and each sensor nodes has 0.5J energy. The time taken to get solution of GA and PSO algorithms are compared with each other. We have observed that GA is faster than PSO in reaching a solution. PSO performs terribly in both cases.

VI. CONCLUSION

From the graphs, it is evident that both GA and PSO can increase the lifetime of the network up to 150% on average. PSO is slower because of it's the sequential calculation. We can find out that both the algorithms are leading to increased lifetime of WSNs. But the percentage of lifetime of WSNs will increase, if the terrain size of networks will vary.

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