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Simulated Annealing algorithm for Data Aggregation Trees in Wireless Sensor Networks and Comparison with Genetic Algorithm

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***Abstract*—**In ad hoc networks, the main issue about designing of protocols is quality of service, so that in wireless sensor networks the main constraint in designing protocols is limited energy of sensors. In fact, protocols which minimize the power consumption in sensors are more considered in wireless sensor networks. One approach of reducing energy consumption in wireless sensor networks is to reduce the number of packages that are transmitted in network. The technique of collecting data that combines related data and prevent transmission of additional packages in network can be effective in the reducing of transmitted packages' number. According to this fact that information processing consumes less power than information transmitting, Data Aggregation has great importance and because of this fact this technique is used in many protocols [5]. One of the Data Aggregation techniques is to use Data Aggregation tree. But finding one optimum Data Aggregation tree to collect data in networks with one sink is a NP-hard problem. In the Data Aggregation technique, related information packages are combined in intermediate nodes and form one package. So the number of packages which are transmitted in network reduces and therefore, less energy will be consumed that at last results in improvement of longevity of network. Heuristic methods are used in order to solve the NP-hard problem that one of these optimization methods is to solve Simulated Annealing problems. In this article, we will propose new method in order to build data collection tree in wireless sensor networks by using Simulated Annealing algorithm and we will evaluate its efficiency whit Genetic Algorithm .

***Keywords*—**Data aggregation, Wireless sensor networks, energy efficiency, Simulated Annealing algorithm, Genetic Algorithm

I. INTRODUCTION

RECENT developments in MEMS have made these tiny sensor nodes available in large numbers, to be used in a wide range of applications: military, environmental monitoring, etc. A wireless sensor network operates in an unattended environment, with limited computational and sensing capabilities capable of sensing, computing and wirelessly communicating. In order to effectively utilize wireless sensor nodes, we need to minimize energy consumption in the design of sensor network protocols and algorithms. Since the sensor nodes have irreplaceable, batteries with limited power capacity, it is essential that the network be energy efficient in order to maximize the life span of the network.

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Large number of sensor nodes have to be networked together, direct transmissions from any specified node to a distant base station is not used, as sensor nodes that are farther away from the base station will have their power sources drained much faster than those nodes that are closer to the base station. On the other hand, minimum energy multi-hop routing scheme will result in rapidly drain energy resources of the nodes, since these nodes engage in the forwarding of a large number of data messages (on behalf of other nodes) to the base station. Thus solution is to use multi-hop communication within network aggregation of correlated data. In this, sensor nodes collect, processes, and forward the data from all the sensor nodes to BS. The application of an aggregation approach helps reduce the amount of information that needs to be transmitted by performing data fusion at the aggregate points before forwarding the data to the end user. The remainder of this paper is organized as follows. In this paper Section II explains Simulated Annealing algorithm and our method and Section III describes Genetic Algorithm (GA) Section IV shows Simulation and Section V Conclusion the paper.

II. SIMULATED ANNEALING ALGORITHM AND OUR METHOD

A. Demonstration of Response Structure

Response structure demonstrates one point of a feasible space of a problem, so that the way of its demonstration in every super-innovative approach is important. The response structure we have considered is as following:

1	2	3	4		98	99	100
5	**6**	**21**	**100**	**…..**	**2**	**54**	**43**

Fig. 1 demonstrates response structure

Figure 1 demonstrates response structure, so that indices of array indicates ID nodes and content of array represents parent of each node, and ID parents of everyone is specified; for example, parent of No.4 node is No.100 node. Another one is No.1 which we have considered it as "sink", or in another terms, as a root of tree.

B. Selection of Primary Response

Selection of a proper primary response highly increases convergence speed toward global optimal response. To increase efficiency of algorithm, primary response is controlled, whether it is acceptable or not. To be acceptable means that it has the characteristics of a tree (connectedness and without circle). Figure 2 shows pseudo-code control of a tree.

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Fanction Control (Solution)
Flag = False
While flag
        Create (Tree) ;
        Control (Loop & Connectivity)
        If Control = OK then flag = True
        END
```

Fig. 2 pseudo-code control of a tree

C. Mechanism of Creating Neighbor Response

To survey in a feasible space, we need to produce another response by changing the current one, which is referred to as "neighbor response". The mechanism which we have chosen for producing neighbor [response] is that two nodes are selected randomly and parents of them is exchanged; feasibility of response is then studied. There is no guarantee that the produced neighbor is certainly a tree. If the obtained response is not confirmed, it is eliminated and another one is produced. Figure 3 shows Mechanism of Creating Neighbor Response.

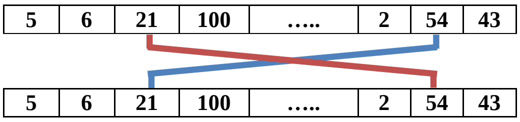

Fig. 3 Mechanism of Creating Neighbor Response

D. Selection of Primary Temperature

Determination of primary temperature value of a system (T0) has obvious and direct contribution to acceptance or refusal of responses, because in high primary temperature state, system energy is also high, and it is a desirable state to find best path to reduce temperature in attaining a stable state (most stable energy level). When primary temperature is selected to be low, it is unlikely that worse response became acceptable and the system may remain in optimal local state.

E. Fitness Function

We have considered fitness of any response as energy consumption of every tree. It is also calculated on the basis of energy principle (Heinzelman et al, 2005).

F. Mechanism of Reduction in Temperature

It is used formula (1) for measure of reduction in temperature and moving toward system cooling, where α represents coefficient of reduction in temperature, it is constant of <1. Its values usually considered 0.8, 0.9, and 0.95. Parameter of n demonstrates the system's number of reductions in temperature level. It is also used as measure to halt SA algorithm .

$$T_i = \alpha T_{i-1} \ \forall \ i = 1, \ldots, \ n \qquad (1)$$

G. Markov Chain Length

One of the important parameters to determine the quality of resulting responses from SA is the number of searched points in the space of problem response in any temperature. We refer to the number of these responses as Markov Chain Length. It is necessary to determine this parameter in order to ensure that close search has been performed to all possible responses. The simplest suggestion to determine the value of Markov Chain Length in SA is to choose a constant value, which is independent of primary temperature, which according to white, it must be close to the value of the problem as far as possible.

H. Standards to Halt SA Algorithm

In SA algorithm some standards are:

- The number of reductions in temperature level.
- The successive number in cooling process, which is not resulted in improvements in target function.
- Accessing to desirable lower temperature level.

III. Genetic Algorithm (GA)

GA is commonly used in applications where search space is huge and the precise results are not very important [5]. As GA is relatively computation intensive, it is executed only at the base station. GA is used to generate balanced and energy efficient data aggregation spanning trees for wireless sensor networks. A chromosome represents a data aggregation tree where gene index determines the node and the gene's value identifies the parent node. The next generation is obtained using standard genetic operations such as single-point crossover, mutation, tournament selection, and eliticism. Further, the population size and the number of generations are based on the number of nodes.

A. Gene and Chromosome

The gene index represents a node identification number (ID) and gene value provides the node's parent's ID. 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.

1	2	3	4		98	99	100
5	**6**	**21**	**100**	**…..**	**2**	**54**	**43**

Fig. 4 Chromosome Example

Figure 4 shows a chromosome representation for a network of 32 nodes. The first node's ID is 0 and its parent's ID is 20. Similarly, the last node's parent ID is 25. Although the gene value is denoted as decimal, it can be represented in binary format. For instance, the chromosome given in Figure I can be represented as 10100, 10010, 00101 ... 1000 1, 1100 1. However, regardless of decimal or binary representation, for all genetic operations, the entire gene value is treated as atomic. Further, a chromosome is considered as invalid chromosome if there are direct or indirect cycles (loops).

B. Population

A population is a collection of chromosomes. In other words, a population is a collection of possible aggregation trees. For the initial population, the parent nodes are selected arbitrarily and validity of chromosomes is also maintained.

C. Generation

A new generation is created using crossover and mutation operations. Tournament selection is used to select chromosomes for crossover. A single point crossover is performed between two parent chromosomes to produce a pair of children. Further, the best chromosome (parent) survives for the next generation, by using eliticism selection. Moreover, the population size remains same for all the generations. In crossover operation, the crossover point is randomly selected and the gene values of participating parents are flipped to create a pair of child chromosomes. Figure 5 shows the crossover operation between participating parents of a network size of 5 nodes. The vertical dark bar shows the crossover point. The pair of children is produced by flipping the gene values of the parents after the crossover point. In this example, the last two genes are flipped.

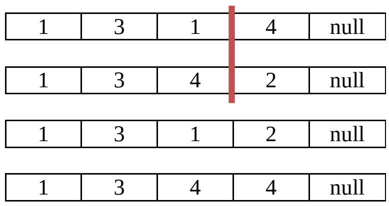

Fig. 5 Crossover Example

D. Repair Function

Notice that the crossover operation between two valid chromosomes may produce invalid chromosome(s). Figure 6 illustrates the creation of an invalid chromosome. As shown in Figure 6, Child 1 is invalid chromosome because there is a cycle (loop) in the network. A repair function is used to identify and prevent the inclusion of invalid chromosomes for the new generation. Figure 7 shows a pseudo-code for the repair function. For each gene in the chromosome, it checks whether the gene

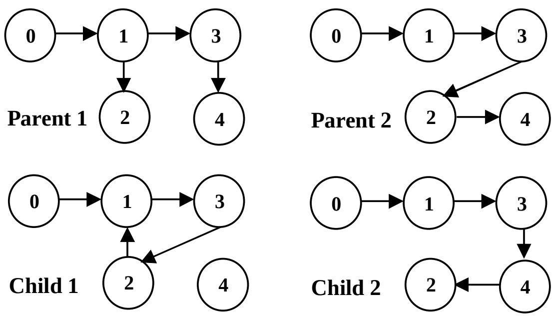

Fig. 6 Illustration of invalid chromosome

Illustration of invalid chromosome forms a cycle or not. If a cycle is found, a random node is selected as a potential parent. If the potential parent also forms a cycle, the process of finding new parent continues until the end of chromosome is reached.

```
Procedure Repair Function (chromosorne)
1:  For each gene in chromosome do
2:  While gene, creates a cycle do
3:  Randomly select a new parent for gene
4:  End while
5:  End for
```

Fig. 7 Chromosome Repair Function

Figure 8 shows that the repair function can modify the invalid chromosome to produce a valid chromosome. For instance, the crossover operation of Figure 2 causes a cycle in Child 1. The repair function traverses all the genes (nodes) in the chromosome and detects a cycle at node 3. Finally, a valid chromosome that is free of cycles is produced, as shown in Figure 8.

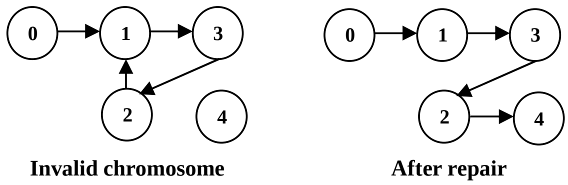

Fig. 8 Invalid chromosome after repair

E. Mutation

The mutation adds variation in the next generation. In mutation, a node is randomly picked and its parent ID is reselected randomly. Similar to crossover, mutation operation may produce an invalid chromosome, which is also fixed using the repair function.

F. Evaluation and Fitness

We have considered fitness of any response as energy consumption of every tree. It is also calculated on the basis of energy principle (Heinzelman et al, 2005).

IV. SIMULATION

For simulation experiments, we assumed that there are sensor nodes distributed randomly in a 100m×100m square region. All nodes have the same transmission range. There is a single sink node located at coordinates (10, 10) of the wireless sensor networks, which receives the data of all source nodes for all the simulations.

TABLE I
SIMULATION PROPERTIES

A	Area	(100*100)
N	Number of sensor nodes	100 - 50
S	Number of source nodes	5 - 20
R	Transmission range	10
α	Parameter for temperature decrease	0.98
T	Initial temperature	20000
E	Initial energy of sensor nodes	0.25J

Fig 9 is temperature reduction. This event is very importance in SA algorithm. We considered T0=20000 and α=0.98. If temperature reduction happens very slowly, probability of best solution will increase.

If temperature reduction happens very fast, SA will tarp in local solution.

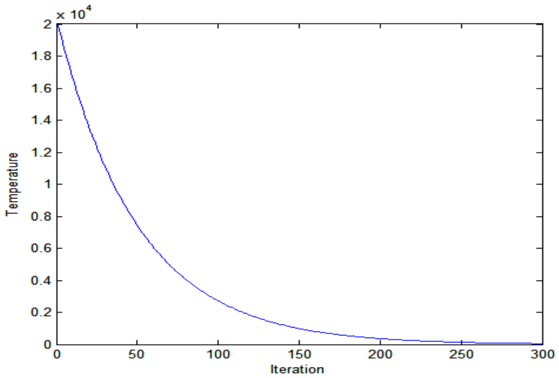

Fig. 9 temperature reduction

The first set of experiments is carried out to investigate the total energy consumption and fig.10 shows that. The axis X shows the number of runs and the axis Y shows fitness function. Fitness function chooses path which consumes low energy. It's clear that SA is getting convergence to improvement tree with lowest consumption energy because of this diagram is descent.

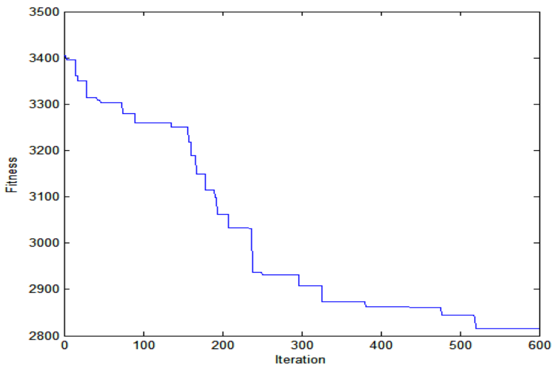

Fig. 10 fitness function calculates total energy consumption

Fig. 11 denotes the average data delay of network under different scale of nodes.Compared with the simulation results of two algorithms.

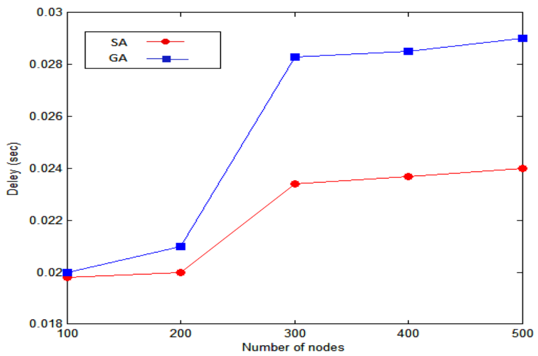

Fig. 11 Average delay

For further comparison the impact of two algorithms on the energy cost for network, we simulation calculated the average energy consumption in network nodes under different scale of nodes, as shown in Fig.12 Compared with GA

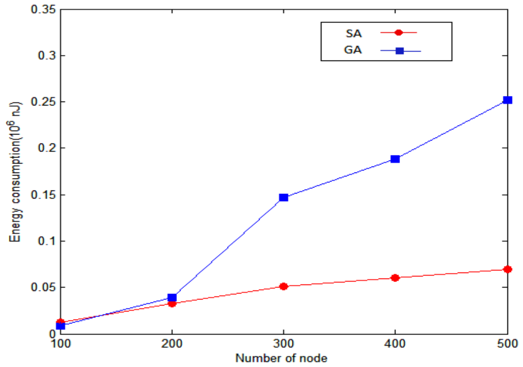

Fig. 12 Average energy consumption

V. Conclusion

One of the existing problems in data aggregation algorithms is that in these algorithms the shortest path between starting an ending node is always selected for transmission between the two nodes, which makes selected energy nodes to be evacuated rapidly. Particularly this problem shows itself when our network has great scale and the rate of data being transferred from a distinct region is relatively high, which is quite possible in sensor networks. The other negative point which worsen this problem is that if a path is evacuated, mostly the other shortest path, which typically is near this one, is selected; especially when the distance between starting and ending point node is farther, it can gradually cause different parts of network to be separated. Therefore, we need a method able to distribute equitably traffic of transmitted data between starting and ending points among path nodes. Performed simulations indicate that we can access such a tree using Simulated Annealing algorithm.

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