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Reduce Energy Consumption and Increase the Lifetime of Heterogeneous Wireless Sensor Networks: Evolutionary Approach

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Abstract: Heterogeneous wireless sensor networks consist of sensor nodes with different capability, such as different computing power, amount of energy and sensing range. One of the most important issues in heterogeneous wireless sensor network is the energy consumption that has the important effect on the lifetime of the network. In this paper the evolutionary approach to decrease the energy consumption and increase the lifetime of the heterogeneous wireless sensor network is introduced. The main achievement of this method is to reduce the execution times of algorithm.

Keywords: Wireless sensor network, energy consumption, lifetime, genetic algorithm

I. INTRODUCTION

Wireless Sensor Networks provide a new technology which is consisted of several nodes that enables the monitoring and control of physical and environmental variables, such as temperature, sound, light, vibration, pressure, movement, and pollution [1]. A variety of wireless sensor networks are used for environmental monitoring, blood pressure monitoring [2], plant control, monitoring of traffic, roadway safety warning [3], industrial sensor [4], remote patient monitoring [5], habitat monitoring [6], smart classroom [7], etc.

Energy consumption is a one of the most important issue in wireless sensor network because the nodes are energy constrained, and battery replacement is almost impracticable. However besides energy consumption, hardware complexity is another feature that needs to be considered in network designing [8].

However it is desirable to ensure that all the nodes run out of their battery at about the same time, so that very little residual energy is wasted when the system expires. One way to ensure this is to rotate the role of a cluster head randomly and periodically over all the nodes as proposed in LEACH [9]. However the downside of using a homogeneous network and role rotation is that all the nodes should be capable of acting as cluster heads, and therefore should possess the necessary hardware capabilities.

In a heterogeneous wireless sensor network two types of nodes with different battery energy, communication range and functionality are used. These types are: the high-end ones have higher process throughput and longer communication range; the low-end ones are much cheaper and with limited computation and communication abilities [10].

In heterogeneous wireless sensor networks many methods for data collection are exist. The very simple method is direct transmission, where each sensor directly sends collected data to the base station [11]. When the sensor nodes use direct transmission to reach the cluster head, the nodes that are farthest from the cluster heads always spend more energy than the nodes that are closer to the cluster heads.

One of the difficulties of this method is a scalability problem where the number of sensors can be potentially enormous. Also, in this method the sensing nodes must be able to reach the base station. This method also called single hop routing.

The second method is indirect transmission or multi-hoping, which has been widely studied for ad hoc routing networks and wireless sensor networks [12], [13] and [14]. This method can be designed to obtain different purposes, such as minimize energy consumption. The communications are mostly all-to-one or all-to-few.

A third method is clustering, where one of the sensors in the cluster will be chosen as a cluster head and be responsible for gathering data from each sensor nodes in the cluster to the base station. This method is more scalable; but the cluster heads will consume more energy and thus die sooner [15]. LEACH [15], PEGASIS [16], TEEN [17] and APTEEN [18] are the most important method that acts based on clustering algorithms. Clustering in heterogeneous wireless sensor network has some advantages as follows:

A. Clustering reduces the size of the routing table stored at the individual nodes by localizing the route set up within the cluster [40].
B. Clustering can conserve communication bandwidth since it limits the scope of inter-cluster interactions to cluster heads and avoids redundant exchange of messages among sensor nodes [41].
C. Clustering cuts on topology maintenance overhead. Sensors would care only for connecting with their

cluster heads [42].

D. A cluster head can perform data aggregation in its cluster and decrease the number of redundant packets [43].
E. A cluster head can reduce the rate of energy consumption of sensor nodes.

In this paper the new method based on genetic algorithm to determine that which nodes must be cluster heads is introduced. This method acts in a manner that reduces energy consumption and increases the lifetime of networks.

The rest of the paper is organized as follows: Section 2 provides an overview of related work. Section 3 briefly describes the genetic algorithm. Section 4 describes the network model and describes the problem. Next, the proposed method and are presented in Section 5. The simulation results are provided in Section 6. We conclude the paper in Section 7.

II. RELATED WORKS

In [19], the authors propose the power aware dynamic source routing protocol for enhancing the traditional method with power awareness.

In [20] a new consumed energy type aware routing method was introduced which discourage some active node in participating in routing process in order to save their energy.

T. Kim and et al. in [21] present a distributed low power scheduling algorithm for wireless sensors to determine their active time slots in a TDMA scheme operating on a slotted CSMA network.

In [22] the authors propose the Particle Swarm Optimization (PSO) method to classify a sensor node field into groups of equal sized groups of nodes. This method enables the network to balance the energy consumption of cluster heads; but is not applicable to some where nodes are not evenly distributed.

In [23] a framework for managing the QoI offered by a shared WSN using negotiation techniques between application tasks and network resources and real-time estimates of the network’s total QoI capacity is presented.

The energy optimization with multi-level clustering algorithm for wireless sensor networks is presented in [24].

In [4] the results show that when the network lifetime is over, up to 90% of the total initial energy of the nodes is left unused if the nodes are usually distributed in the network.

There are other extensive researches on energy aware routing [25-28] and improvement in lifetime [29-32].

III. GENETIC ALGORITHMS

Genetic algorithms are the heuristic search algorithms that are used to solve a variety of optimization problems which uses the idea of natural biological evolution [33]. GA was invented by John Holland in 1975 [34]. The genetic algorithm has great application to optimize the complicated problems particularly in where is inadequate information about search space. Each cycle in GAs produce a new generation of possible solutions for a given problem. To solve any problem by GA, nine terms must be defined [35, 36]:

A. ***Representation:*** representation defines each chromosome in the real world by using chromosome. A chromosome is a set of parameters which define a proposed solution to the problem that the genetic algorithm is trying to solve [36].

B. ***Fitness Function:*** These function shows the fitness of each chromosome and is defined by the user. The fitness function is used in the process of evolution to determine survival probability of a chromosome [40].

C. ***Population:*** The role of the population is to hold possible solution [36]. The size of a population depends on the complexity of the problem in research [40].

D. ***Parent Selection Mechanism:*** The role of parent selection is to distinguish among individuals based on their quality, in particular, to allow the better individuals to become parents of the next generation [36].

E. ***Reproduction:*** The reproduction operator is based on the Darwinian notion of "survival of the fittest". Individuals taking part in successive generations are obtained through a reproduction process or evolution operation. Individual strings are copied into a mating pool according to their respective fitness values. The higher the fitness values of the strings, the higher the probability of contributing one or more offspring in the next generation [36].

F. ***Crossover Operators:*** Recombination operator selects two or more chromosomes and then produces two new children from them. It aims at mixing up genetic information coming from different chromosomes to make a new individual [36].

G. ***Mutation Operators:*** Mutation operator selects one chromosome and then produces one new child from it by a slight change over the parent [36]. It is an operator that introduces diversity in the population whenever the population tends to become homogeneous due to repeated use of reproduction and crossover operators. Mutation may cause the chromosomes of individuals to be different from those of their parent individuals [37].

H. ***Survivor Selection Mechanism:*** The role of survivor selection is to distinguish among individuals based on their quality. This mechanism survives the individual among the passing from one generation to the next generation [36].

I. ***Termination Condition:*** Termination Condition is the condition that ends the running of genetic algorithm when specified condition occurred [36].

IV. NETWORK MODEL

In this paper the number of cluster head in heterogeneous wireless sensor network are C and the number of sensor nodes are S that $S<<C$. Only sensor node-

cluster head communications are considered. The network topology is represented with an undirected weighted graph $G=(V, E, c)$ in the two dimensional surface, where $V=\{n_1,n_2,\ldots,n_S,n_{S+1},\ldots,n_{C+S}\}$ is the set of nodes, and E is the set of edges, $E=\{(n_i,n_j)|dist(n_i,n_j)\leq R_{max}\}$, where $dist()$ is the distance function. The first C nodes in V are the sensor nodes, and the last S nodes are the cluster heads. The cost function $c(u,v)$ represents the power requirement for both nodes u and v to set up a bidirectional communication between u and v. Each node has a unique id such that each node is able to collect its own location information by using one of the localization techniques for wireless sensor networks [38]. The reachable neighborhood is the set of nodes that node s_i can reach by using the maximum transmission range R_{max}.

For a sample heterogeneous wireless sensor networks, to find the optimal number of cluster head and their locations is difficult; for example a 80-nodes, to perform an exhausted search of all possible solutions requires $C^1_{80}+C^2_{80}+\ldots+C^{80}_{80}=2^{80}-1$ different combination; therefore his problem is one of the NP-Hard problems.

V. PROPOSED METHOD

As shown in section4, the cluster head placement problem in heterogeneous wireless sensor network is NP-Hard problem. The evolutionary algorithms to sole these types of problems are appropriate. In this section the genetic algorithm as one of the evolutionary algorithm to solve this problem is proposed.

As mentioned in section 3 to solve any problem with genetic algorithm nine components must be defined. The rest of this section describes these components.

A. Representation:

To represent individual the binary representation is used in this method. Each bit corresponds to one cluster head or sensor node. A “1“ means that corresponding sensor is a cluster head and a “0“ means that corresponding sensor is a sensor node. In the figure 1 one example of the chromosome illustrated.

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	0	0	1	0	0	1	0

Figure 1. one chromosome with three cluster heads

Nodes S1, S4 and S7 are cluster nodes and S2, S3, S5, S6 and S8 are sensor nodes.

B. Fitness Function:

A fitness function evaluates individuals, and reproductive success varies with fitness. The energy consumption is the main factor to need to minimize. Each individual is evaluated by the following combined fitness components [39]:

$$Fitness = (w\times (D-I) + (1-w) \times (N- S_i)) / 100$$

$$I = I_n + I_s$$

Where D is the total distance of all nodes to the target node; I_n is the distances from sensor nodes to cluster head. I_s is the sum of the distances from all cluster heads to the target node; S_i is the number of cluster heads; N is the total number of nodes; and w is a pre-defined weight. Except for I and Si, all other parameters are fixed values in a given topology. The shorter the distance, or the lower the number of cluster heads, the higher the fitness value of an individual is.

The value of w ($0\leq w\leq 1$) is application-dependent. It indicates which factor is more important to be considered: distance or the cost incurred by cluster heads. If w=1, we optimize the network only based on the communication distance; if w=0, only the number of cluster heads is considered.

C. Population:

A population is the search space for a GA. The initial population consists of randomly generated individuals. The population size is varied and determined based on the number of nodes in the network. In this method the population size considered equal to the number of nodes.

D. Parent Selection Mechanism:

In this method to select the parent, parent selection mechanism evaluates the fitness of each chromosome; then selects fifteen chromosomes randomly, then for mutation operating this method selects the five best chromosomes, and then selects one chromosome randomly. For crossover operating, this method select one chromosome from 5 best chromosomes randomly and another chromosome selecting from 9 remaining chromosome randomly.

E. Reproduction:

The reproduction determines how the next generation is created from the current generation. Reproduction selects good strings in a current population and forms a mating pool. The idea of reproduction is that the above average strings are picked from the current population and their multiple copies are inserted in the mating pool in a probabilistic manner. There are many methods to implement a reproduction operator. One commonly studied implementation is fitness proportionate selection that each individual has an associated fitness value. The genetic algorithm generates new populations by reproducing chromosome under weighted probabilities in proportion to their fitness. Thus, a higher fit chromosome is more likely to survive from generation to generation.

F. Crossover Operators:

A crossover operator is used to recombine two individuals to get a better individual. In this method two points crossover is used. The crossover operation takes place between two consecutive chromosomes with pc = 80%. These two individuals exchange portions that are separated by the crossover point. For example suppose that two chromosome that specified in figure2 selected for crossover.

First Parent	1	1	1	0	0	1	0	1
Second Parent	1	0	1	1	1	1	1	0

Figure 2. two candidate chromosomes for crossover operation.

In this step two chromosomes exchange the genes base on the crossover point and two children produced. Figure3 illustrates these children.

First Child	1	1	1	1	1	1	1	0
Second Child	1	0	1	0	0	1	0	1

Figure 3. two produced children after the crossover operation.

After crossover, if a sensor node becomes a cluster head; all other sensor nodes should check if they are nearer to this new cluster head; if so, they switch their membership to this new cluster head. If a cluster head becomes a sensor node, all of the nodes that communicate with this cluster head must find new cluster head. Every node is either a cluster head or a sensor node in the network.

G. Mutation operators:

Mutation adds new information to the genetic search process randomly and avoids getting trapped at local optima. The mutation operator is applied to each bit of a chromosome with p_m = 1.5% and p_{gf} = 1/n where n is the length of chromosome or number of the nodes in the network. The bitwise mutation is used in this method. The p_{gf} when applied, a bit whose value is 0 is mutated into 1 and vice versa. An example of mutation is in figure 4. In this figure the chromosome that illustrated in figure 3 mutated.

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	0	0	**0**	0	0	1	**1**

Figure 4. the mutated chromosome

As shown in figure 6 the genes that placed in the 4th and 8th place, flipped. After mutation, if a sensor node becomes a cluster head; all other sensor nodes should check if they are nearer to this new cluster head, they switch their association to this new cluster head. If a cluster head becomes a sensor node, all of the nodes that communicate with this cluster head must find new cluster head.

H. Survivor Selection Mechanism:

The 20% of the best chromosome of the old population directly copped to the new population after that the mating pool size is the 80% of the population size. The remaining chromosome, 80% of population size, replaced with the new chromosome from the middle population.

I. Termination Condition:

In this method, our algorithm running until no improvement in the fitness of the best member of the population has been observed for 20 generation.

VI. SIMULATION

In this section the simulation results are presented. Suppose that the number of sensor is 80, the area that the sensor nodes are deployed is 30×30. Table1 shows the simulation result when w = 1 and the target sensor is located at the (15, 15).

In table1 the node# indicates the sensor number, X and Y show the location of sensor in the network, the SN# shows the sensor node number that the node belonged to it and type indicates the type of sensor. This table show that 12 cluster heads needed for 80 nodes in 30 × 30 area. The other nodes by considering the minimum power connected to one of the cluster heads.

Table I. Simulation Results for 80 Nodes

Nod	X	Y	S	Type	Nod	X	Y	S	Type
1	1	1	---	Target	41	8	1	58	Sensor
2	1	2	20	Sensor	42	2	1	8	Sensor
3	1	3	50	Sensor	43	5	1	29	Sensor
4	1	2	8	Sensor	44	1	8	50	Sensor
5	3	1	38	Sensor	45	1	2	67	Sensor
6	1	2	20	Sensor	46	1	4	74	Sensor
7	1	9	50	Sensor	47	4	2	58	Sensor
8	1	2	---	Cluster	48	2	7	62	Sensor
9	4	5	16	Sensor	49	5	1	31	Sensor
10	2	0	74	Sensor	50	1	8	---	Cluster
11	5	1	58	Sensor	51	1	2	31	Sensor
12	1	1	67	Sensor	52	2	9	38	Sensor
13	1	2	8	Sensor	53	1	2	67	Sensor
14	1	1	8	Sensor	54	2	1	8	Sensor
15	6	9	58	Sensor	55	1	4	61	Sensor
16	3	2	---	Cluster	56	1	2	20	Sensor
17	1	2	8	Sensor	57	2	6	74	Sensor
18	1	2	67	Sensor	58	6	1	---	Cluster
19	2	2	8	Sensor	59	1	1	20	Sensor
20	1	1	---	Cluster	60	1	2	67	Sensor
21	2	1	38	Sensor	61	1	2	---	Cluster
22	1	1	29	Sensor	62	1	1	50	Sensor
23	1	4	74	Sensor	63	2	1	38	Sensor
24	1	1	20	Sensor	64	1	2	31	Sensor
25	1	1	8	Sensor	65	2	2	74	Sensor
26	1	2	67	Sensor	66	7	3	31	Sensor
27	6	1	31	Sensor	67	1	2	---	Cluster
28	4	1	58	Sensor	68	2	6	74	Sensor
29	3	1	---	Cluster	69	1	2	8	Sensor
30	9	1	58	Sensor	70	1	1	20	Sensor
31	6	2	---	Cluster	71	0	8	16	Sensor
32	2	1	74	Cluster	72	1	5	61	Sensor
33	1	1	50	Sensor	73	2	8	74	Sensor
34	1	3	8	Sensor	74	2	4	---	Cluster
35	5	2	31	Sensor	75	1	1	38	Sensor
36	2	1	8	Sensor	76	8	1	58	Sensor
37	1	1	61	Sensor	77	5	1	31	Sensor
38	2	6	---	Cluster	78	7	3	16	Sensor
39	8	7	16	Sensor	79	1	2	20	Sensor
40	2	3	74	Sensor	80	1	7	80	Sensor

As shown in table I the sensor nodes is belong to one cluster head as a manner to reduce the energy consumption of the whole networks.

VII. CONCLUSION & FUTURE WORK

Heterogeneous wireless sensor network is a network which is consists of several nodes with different capabilities. The most important challenge in this network is power consumption. In this paper the new method based on evolutionary algorithm for reducing the energy consumption and increasing the life time of network is introduced.

As future works we can use other method such as fuzzy algorithm, ant colony, bee colony and compare with each other.

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