Prolong the Network Lifetime by Optimal Clustering based on Intelligent Search Algorithms in Wireless Sensor Networks

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Abstract **– In recent years, wireless sensor network (WSN) achieved many accomplishments in theoretical studies and practical applications. However, WSNs are facing with many challenges, one of the biggest challenges that the energy source is limited and difficult to recharge. Clustering is the efficient technique used to extend the network lifetime through data aggregation. In this paper, we propose a new approach by combining the stable cluster selection method with particle swarm optimization and intelligent searching to minimize the distance between the nodes in each cluster and reduce the number of dead nodes over time. The simulation results show that our proposed protocols have the lower energy consumption and longer lifetime compared to other protocols.**

Keywords— sensor network, energy consumption, cluster.

I. INTRODUCTION

With the rapid development of science and technology, especially in wireless communications technology and embedded device technology, the capacity of the sensors is being significantly improved while their cost is lower. The sensor nodes are designed very special to match the dense and random distribution in environment. Along with poor processing and storaging, each sensor is equipped with a limited energy resource and difficult to be replaced in most application environments. Therefore, when designing a WSN protocol, we always interested in energy efficiency. Clustering is the technique used very effectively to archive the energy efficiency in WSNs. One of the well known clustering protocol called LEACH has been introduced in [1]. In LEACH, sensor nodes elect themselves as cluster heads with some probabilities. The algorithm is run periodically and the probability of becoming a cluster head for each period is chosen. LEACH organizes its operation into rounds, where each round consists of a setup phase where clusters are formed and a steady state phase that consists of data communication process. LEACH provides significant energy savings and prolonged network lifetime over conventional multihop routing schemes. However, LEACH is obtained assuming that the nodes of the sensor network are equipped with the same amount of energy, and as a result, they can not take full advantage of the presence of node heterogeneity. Thus, the Stable Election Protocol – SEP [2]was introduced, it is a heterogeneous-aware protocol to prolong the time interval before the first node die. SEP is based on weighted election probabilities of each node to become cluster head according to the remaining energy in each node. Accordingly, the nodes are divided into advanced nodes and normal nodes. Advanced nodes will have the energy and the probability becoming cluster heads higher than normal nodes. Recently, an improvement over SEP protocol was introduced in [3] to reduce the number of clusters by merging nearby clusters. Hence, within a certain small geographic region, only one cluster is formed, which helps in overcoming redundancy over that region.

In recent years, swarm intelligence has attracted the interest of many scientists. Swarm-based methods which is inspired by searching for food of the natural creatures such as bees, ants or bats [4] offer many advantages compared to traditional methods. Many types of nature-inspired algorithms are introduced as Ant Colony Optimization (ACO) [5] and Artificial Bee Colony (ABC) [6]. However, they have the problems of complexity of algorithms as well as the convergence speed is very slow. Meanwwhile, Particle swarm optimization (PSO) first introduced in 1995 [7] is a popular multidimensional optimization technique which is a simple, effective, and computationally efficient optimization algorithm. It has been applied to address issues of WSN such as optimal deployment, node localization, clustering, and data aggregation. Authors in [8] have used PSO approach to obtain the optimum location of the sensor nodes for real time applications. An energy efficient layout with good coverage based on multi-objective PSO algorithm is proposed in [9]. In addition, a number of improved PSO algorithms applied for producing energy-aware clusters with optimal selection of cluster head were introduced in [10], [11]. In 2009, EsmatRashedi et al. introduced Gravitational Search Algorithm (GSA) in [12] for good convergence but long execution time, specially in the last iterators. Recently, a method combining the best of global searchability of PSO with a local searchability of GSA is called PSOGSA [13] which is based on the law of gravity and mass interactions.

The remainder of the paper is organized as follows. In section 2, we present paticle swarm optimization algorithm.

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Section 3 describes our proposal and corresponding algorithms. Section 4 provides simulation results in terms of energy efficiency and number of dead nodes. Finally, concluding remarks are given in section 5.

II. PSO ALGORITHM

Particle swarm optimization was developed by Kennedy and Eberhart in 1995, based on the swarm behaviour such as fish and bird schooling in nature. Though particle swarm optimization has many similarities with genetic algorithms and virtual ant algorithms, but it is much simpler because it does not use mutation/crossover operators or pheromone. Instead, it uses the real-number randomness and the global communication among the swarm particles.

In PSO, a set of potential solutions are called particles that are initialised randomly. Each particle will have a fitness value, which will be evaluated by the fitness function to be optimised in each generation. Each particle knows its best position *pbest* and the best position so far among the entire group of particles *gbest*. The particle will have velocities, which direct the flying of the particle. In each generation the velocity and the position of the particle will be updated [14]. In each iteration *k*, velocity *V* and position *X* are updated using (1) and (2). The update process is iteratively repeated until either an acceptable gbest is achieved or the maximum number of iterations is reached.

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 (pbest_i - X_i^k) + c_2 r_2 (gbest_i - X_i^k) \quad (1)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (2)$$

where ω is inertia weight ($\omega = 0.5\frac{iter_{max}-iter}{iter_{max}} + 0.4$, where $iter_{max}$ is the maximum number of iterations allowed, *iter* is the current iteration. ω affects the convergence of PSO. Large ω facilitates global search, whereas small ω facilitates local search), c_1 and c_2 are constants (acceleration coefficients), r_1 and r_2 are random numbers uniformly distributed in [0, 1], V_i^k is velocity of particle *i* at iteration *k*, V_i^{k+1} is velocity of particle *i* at iteration $k + 1$, X_i^k is current position of particle *i* at iteration *k*, $pbest_i$ is pbest of particle *i*, $gbest_i$ is gbest of the group, X_i^{k+1} is position of the particle *i* at iteration $k + 1$.

III. PROPOSED ALGORITHMS

Saving energy to prologing the network lifetime of WSN is very important issue and being studied. The algorithms have been proposed such as LEACH, SEP for energy saving and state stabling before the first node dies. Both algorithms have not yet shown the optimal allocation of nodes as well as the effective distribution of energy between normals and advanced nodes. Based on principles of organization and updating the velocity and position of individuals in PSO and PSOGSA, we proposed two impoved algorithms called SPSO (Stable PSO) and SPSOGSA (Stable PSOGSA) to find out optimal cluster heads which minimize the distance between the nodes in the cluster and reduce the number of dead nodes over time.

A. SPSO Algorithm

Operation of the proposed protocol based on stable clustering approach called SEP [2]. The algorithm is described as following steps:

Step 1: Network Initialization

Initialize the parameters and network topology;

Step 2: Choose advanced nodes and normal nodes based on fitness function (3), which is motivated in part by [15].

$$C_{ij}(x,y) = \begin{cases} 0 & if\ r + r_e \le d_{ij}(x,y) \\ e^{-\lambda\alpha^{\beta}} & if\ r - r_e < d_{ij}(x,y) < r + r_e \\ 1 & if\ r + r_e \ge d_{ij}(x,y) \end{cases} \quad (3)$$

where $d_{ij}(x,y)$ is Euclidean distance between sensor *s(x,y)* and grid point *P(i,j)*; *r* is detection range of each sensor node; r_e is a measure of the uncertainty in sensor detection; α, λ and β are parameters measuring detection probability when a target is at distance greater than r_e but within a distance from the sensor.

Because advanced nodes consume more energy than normal nodes, assuming that E_0 is the initial energy of the normal node, the initial energy of advanced node will be $E_0(1 + a)$.

Step 3: Probability computation and cluster heads election [2].

Probability of advanced node and normal node being cluster head are given by (4) and (5):

$$P_{nrm} = \frac{P_{opt}}{1+a\times m} \quad (4)$$

$$P_{adv} = \frac{P_{opt}}{1+a\times m} \times (1 + a) \quad (5)$$

where P_{opt} is the desired percentage of cluster heads, *m* is the fraction of advanced nodes and *a* is the additional energy between advanced nodes and normal nodes.

A normal node becomes a cluster head in the current round with following threshold:

$$T(S_{nrm}) = \begin{cases} \frac{P_{nrm}}{1-P_{nrm}(r\ mod\ \frac{1}{P_{nrm}})} & if\ S_{nrm} \in G' \\ 0 & otherwise \end{cases} \quad (6)$$

where *r* is current round; *G'* is the set of nodes that not have become cluster heads within the last $\frac{1}{P_{nrm}}$ rounds.

$T(S_{nrm})$ is threshold applied for $n\times(1-m)$ normal nodes. Thus, each round, there are $n\times(1-m)\times P_{nrm}$ normal nodes being cluster heads.

An advanced node becomes a cluster head in the current round with following threshold:

$$T(S_{adv}) = \begin{cases} \frac{P_{adv}}{1-P_{adv}(r\ mod\ \frac{1}{P_{adv}})} & if\ S_{adv} \in G'' \\ 0 & otherwise \end{cases} \quad (7)$$

Where G'' is the set of nodes that not have become cluster heads within the last $\frac{1}{P_{adv}}$ rounds.

$T(S_{adv})$ is threshold applied for $n \times m$ advanced nodes. Thus, each round, there are $n \times m \times P_{adv}$ advanced nodes being cluster heads.

So, there are $n \times (1-m) \times P_{nrm} + n \times m \times P_{adv}$ nodes being cluster heads each round.

Step 4: Clustering based on distance from cluster head to remaining nodes:

- Calculate distance $d(n_i, CH_k)$ between node n_i and all cluster heads .
- Assign node n_i to cluster head CH_k where:

$$d(n_i, CH_k) = min\{d(n_i, CH_k)\},\ i = 1,2\ldots N,\ k = 1,2\ldots C$$

where N is number of non cluster head; C is number of clusters; CH_k is cluster head of cluster k.

Step 5: Member nodes send data to cluster head and cluster head forwards the aggregated data to the base station.

Energy consumption is given by:

$$E(L,d) = \begin{cases} L \times E_{elec} + L \times \varepsilon_{fs} \times d^2 & if\ d \leq d_0 \\ L \times E_{elec} + L \times \varepsilon_{mp} \times d^4 & if\ d > d_0 \end{cases} \quad (8)$$

where E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit, ε_{fs} and ε_{mp} depend on the transmitter amplifier model we use, L is the message size, d is the distance between the sender and receiver nodes and $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$.

Step 6: Update position and velocity for every individuals based on (1) and (2). Position and velocity will affect to clustering and energy consumption in next rounds.

Repeat steps 2 through 6 until the maximum number of iterations is reached.

B. SPSOGSA Algorithm

SPSOGSA is an improved PSOGSA algorithm [13] by appling the stable clustering approach [2] to reduce the distance between cluster head and member nodes in each cluster for saving energy consumption and prolonging the network lifetime.

Operations of SPSOGSA from step 1 to step 5 are similar to SPSO algorithm.

Step6: Update accelerator for individual i at distance d given by (9), which is motivated in part by [13]:

$$a_i^d(t) = F_i^d(t)/M_i(t) \quad (9)$$

where $Fi^d(t)$ is total force that acts on the i^{th} individual at distance d; $M_i(t)$ is mass of inertia of individual i.

Step 7: Update velocity for individual i by (10):

$$V_i^{t+1} = \omega V_i^t + c_1 rand(ac_i^t) + c_2\, rand(gbest - X_i^t) \quad (10)$$

where V_i^t is velocity of individual i at the t^{th} iterator; $rand$ is random number uniformly distributed in [0, 1]; ac_i^t is acceleration coefficient of individual i at the t^{th} iterator; $gbest$ is the best solution for current.

Step 8: Update position of individual i by (11):

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (11)$$

Repeat steps 2 through 8 until the maximum number of iterations is reached.

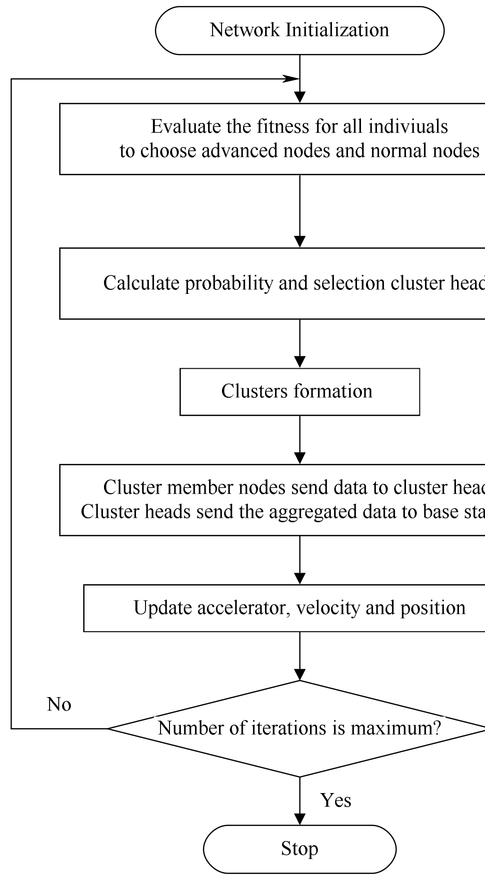
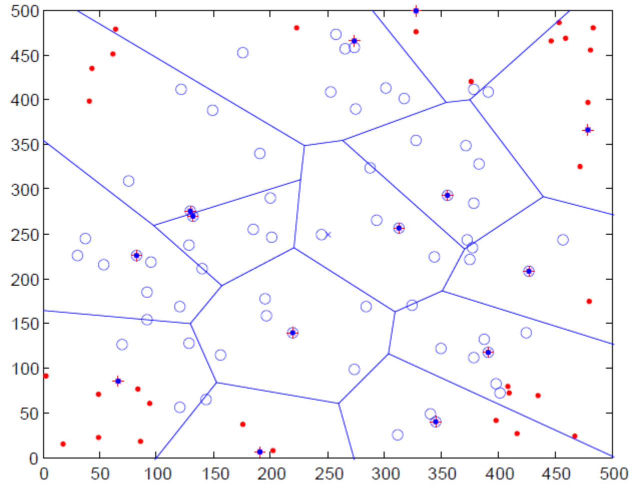


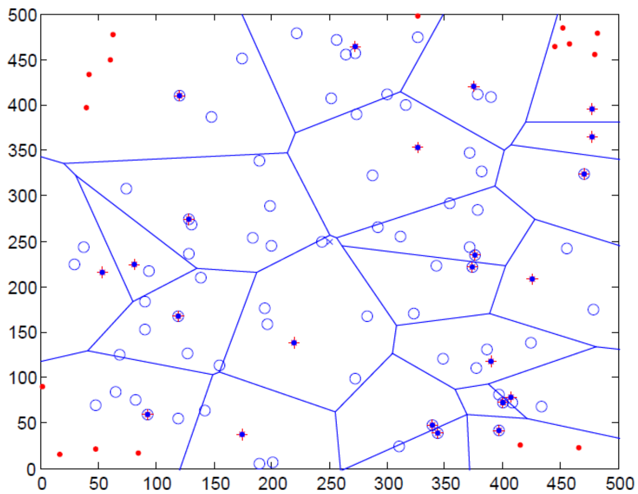
Fig. 1 Flowchart of SPSOGSA Algorithm.

IV. SIMULATION RESULTS

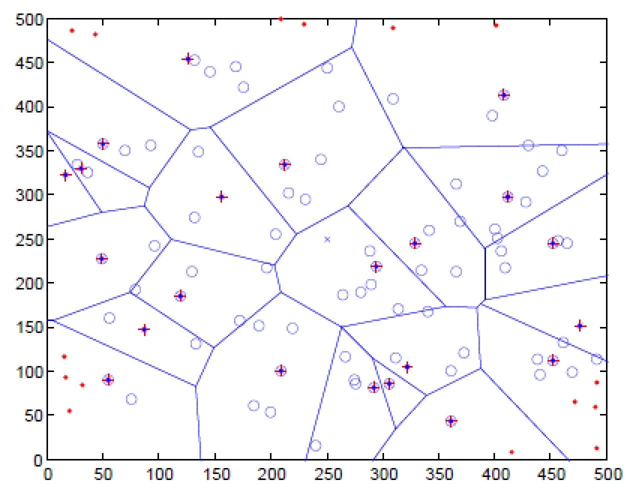
We simulate a clustered wireless sensor network for 100 nodes in a field with dimensions 500m×500m with unequal initial energy of nodes to show the effect of the different nodes' energy in the network. We set 10 percent of the total nodes to have 1 Joules of initial energy (i.e a = 1 and P_{opt} = 0.1) while 90 percent of remain nodes have 0.5 Joules of initial energy. Base station is located at (250, 250), the data message size was fixed at 500 bytes, maximum number of iterations = 100. For SPSO algorithm, we use parameters $c_1 = c_2 = 2$. For SPSOGSA algorithm, $c_1 = 0.5$ and $c_2 = 1.5$. We analyze performance evaluation compared with LEACH [1] and SEP [2] in terms of the number of nodes alive, total energy dissipated in the system over time.



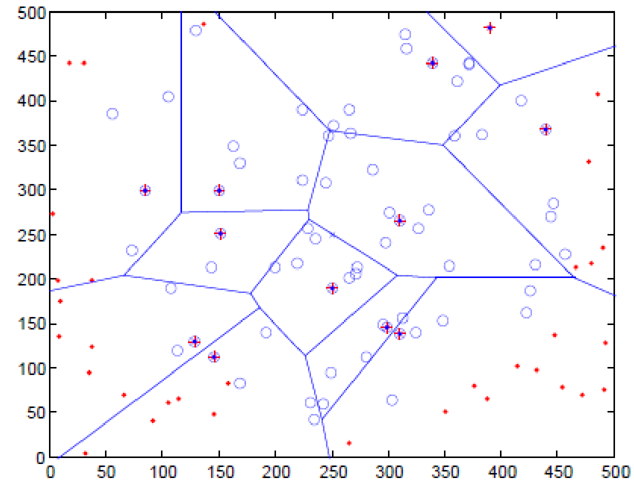
a) - LEACH



b) – SEP



c) SPSO



d) SPSOGSA

Dead node *Normal node* *Advanced node*
Normal node selected as cluster head
Advanced node selected as cluster head

Fig. 2 Results of network partitioning by different protocols.

Figure 2 shows the results of clustering for the 100 nodes network distributed randomly. Obviously, the proposed protocols (*(c)* and *(d)*) result in good network partitioning, where cluster heads are evenly positioned across the network and located near the centre of each cluster whereas LEACH and SEP (*(a)* and *(b)*) result in the uneven distribution of cluster heads throughout the sensor field. This is because a stochastic cluster head selection in LEACH will not automatically lead to a good network partitioning in which a cluster head may still be located near the edges of the cluster in a network.

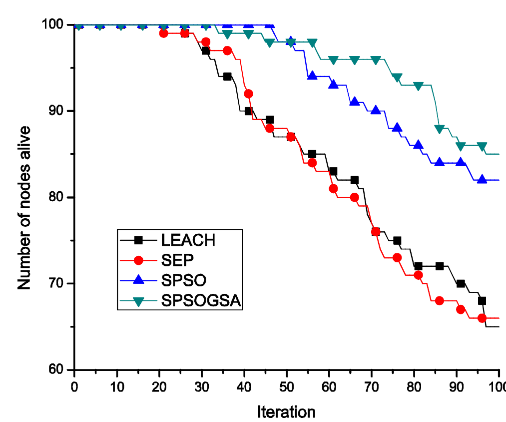


Fig. 3 Number of alive nodes over time.

Figure 3 illustrates the number of nodes alive over time for the simulation with the base station located at the middle of the network area. Clearly, SPSO and SPSOGSA prolong the network lifetime significantly compared to LEACH and SEP. This is because our improved algorithms minimize the distance between the non cluster head nodes to cluster head in each cluster while cluster heads are distributed optimally across the network.

Consequently, the total energy consumed by all nodes for communication is reduced since the distances between non-cluster head nodes and their cluster head are shorter. Figure 4 shows that the total consumpted energy of the entire network by SPSO and SPSOGSA is less than by LEACH and SEP over time.

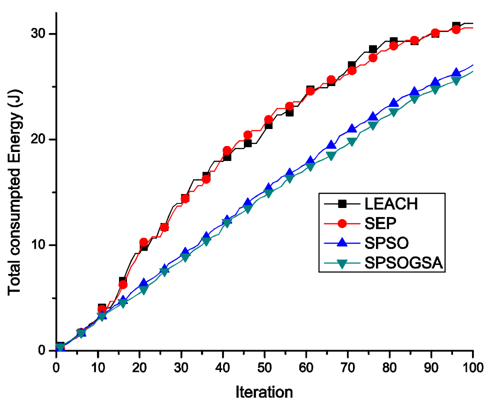


Fig. 4 Total energy dissipated over time.

V. CONCLUSIONS

In this paper, we have proposed two improved PSO algorithms to minimize the distance between the cluster head and non cluster head nodes in the each cluster by combining the stable cluster selection approach with particle swarm optimization methods. By simulation, we have shown the appropriateness of our algorithms evaluated againts LEACH and SEP protocols in terms of the number of nodes alive and the total consumpted energy in the entire network over time. Besides, our improved algorithms result in the better network partitioning where cluster heads are optimally distributed across the network.

We used the fitness function based on the distance between the nodes in each cluster for energy saving. However, in many applications that require the timely response of the system confronted with changes of the environment such as fire alarm systems, network delay is very important. Therefore, we are currently improving these algorithms to balance network delay and energy consumpion in WSNs.

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