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Energy-aware cluster head selection using particle swarm optimization and analysis of packet retransmissions in WSN

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Abstract

In sensor networks the maximization of network lifetime is a critical issue because the sensor nodes are characterized by restricted and non-replenishable energy supply. Therefore, proper organization of nodes (clustering) becomes one of the major techniques to expand the lifespan of the whole network through aggregating data at the cluster head. In this paper, Particle Swarm Optimization (PSO) approach is applied for producing energy-aware clusters with optimal selection of cluster head. The PSO ultimately reduces the cost of locating optimal position for the cluster head nodes. The PSO implementation is performed within the cluster rather than base station, which makes it a semi-distributed approach. The selection criteria of the objective function are based on the residual energy, minimum average distance from the member nodes and head count of the probable head nodes. Moreover, the effect of expected number of packet retransmissions is also demonstrated in our proposed energy model. The performance evaluation of our proposed technique is compared with the cluster-based sensor network protocols, LEACH-C and PSO-C respectively. The simulation results clearly reveal the effectiveness of our proposed work over its comparatives.

Keywords: Wireless Sensor Network; Particle Swarm Optimization; Energy-Aware Clusters; Packet Retransmissions.

1. Introduction

The sensor network is a wireless collection of portable devices that offers are a variety of services, including area and wildlife monitoration, etc. [1]. The wireless sensor networks (WSNs) have long been an attractive option to the researchers and scientists for its ease in deployment and maintenance. The battery-operated sensors are often deployed in unattended hostile region, which makes the power source of the sensors difficult to recharge. However, in the research there is number of relevant energy preserving techniques available, which tends to extend the network lifetime. In this paper, we consider one such Swarm Intelligence mechanism, known as Particle Swarm Optimization [2]. Particle Swarm Optimization

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(PSO) is an artificial intelligence technique which is motivated by the social activities of natural species, for instance - swarm of birds, etc. A novel cluster-based approach is introduced in [3] using PSO, which was found to function better than LEACH-C (Low-Energy Adaptive Clustering Hierarchy-Centralized) [4] protocol in terms of energy efficiency. Another improved PSO has been proposed in [5] for improving the performance of the optimization technique. In [6] another research work evaluates a routing optimization method on the basis of graph theory and PSO. Further, the authors in [7-9] have used PSO to optimize the location of the sensors with an objective to enhance the network coverage and connectivity. In this paper, we apply the swarm optimization to find optimized position of cluster head (CH) in order to reduce the overall energy consumption during packet transmission to sink. Further, we analyze the effect of link failure probability on transmission of packets and derive expected number of retransmission over a path in the sensor network.

2. Network Model & Assumptions

In this section we describe our network scenario (fig. 1). The assumptions made are as following:

- The sensor network is assumed to be a circular geographic region with the sink S, positioned at coordinate $(0,0)$, and radius R_S.
- The sensors are uniformly deployed in the sensing area A_S. Moreover, the number of sensor nodes is distributed according to 2-dimensional Poisson point process with ρ as the expected density of A_C.
- The cluster covers circular area with its cluster head at the center o with radius R.
- There are total k clusters in the sensor network. Further, owing to the uniform node deployment strategy, we can compute an approximation for the cluster radius, R:
  $$k \times A_C = A_S \Rightarrow k \times \pi R^2 = \pi R_S^2 \qquad \therefore R = R_s \big/ \sqrt{k} \tag{1}$$
- The base station (or sink) periodically sends a request to the cluster head to upload samples collected by the sensors (fig. 2). On receiving the request, the cluster head broadcasts a data-gathering-signal to all its cluster members.
- In our contribution we have applied swarm optimization in clustered sensor network, where the nodes are stationery. The basic aim is to find optimized position for cluster head, i.e. as close as possible to the center of mass (COM). The mass center of a cluster is the mid-position of the sensor distribution within the cluster. Such localization for cluster head would ultimately minimize the average distance covered by the sensors to transmit data to the cluster head. Therefore, the swarm intelligence considers *N* points or particles around the COM area and iterates in search of best location.
- Moreover, the velocity of the particle is assumed to be the rate at which the position of the particle is changed (shifted). Also, the sensor node nearest to any particle is associated with the node's residual energy (particle energy) and head count. These parameters are used during the evaluation of the objective function for each particle in all iterations.

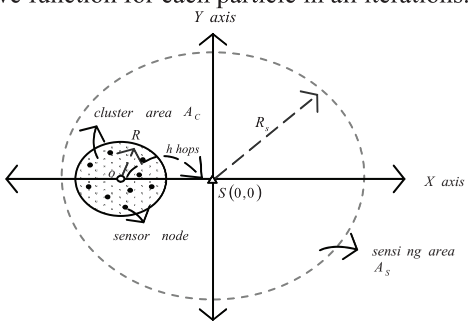

Fig. 1. Network scenario model

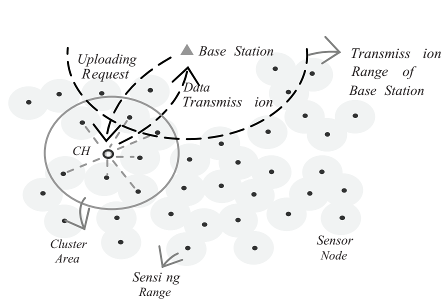

Fig. 2. Data uploading process

In PSO application a centralized coordinator is required to maintain several attributes of the particles for every generation. In order to accomplish the requirement, we randomly select a sensor node in every cluster and appoint it as *cluster assistant* (n_{CA}). The cluster assistant is assumed to maintain the local best position of every sensor along with other sensor characteristics, like - current position, particle energy, head count, global best solution and additional PSO parameter values. At the beginning of every round of cluster head selection, all the sensors in a cluster provides the initial location, energy and head count to the assistant node. The cluster assistant node is supposed be the local processing centre to a cluster.

3. Cluster Head Selection Using Particle Swarm Optimization

We assume S to be the swarm space ($S \subset R^2$) with $f : S \rightarrow G \subseteq R$ as the fitness or the cost function. The point coordinates (separated by predefined position shift) within the swarm region are considered as the population of points or particles. The fitness function is used to select the optimum position for the cluster head. The main objective of the function is to optimize the joint effect of average distance from the sensors in a cluster, residual energy and head count (i.e. number of times a sensor node served as cluster head). Let $\Sigma = \{x_1, x_2, ..., x_N\}$ be the set of all the particles considered for experimentation in the swarm S. There are N particles (candidate solutions) each having a position vector (x_i) and velocity vector (v_i) respectively.

$$x_i = (x_{i1}, x_{i2}, ..., x_{iM})^T \ , \qquad v_i = (v_{i1}, v_{i2}, ..., v_{iM})^T \tag{2}$$

where, $i = 1,2,...,N$ and M represents the dimension. Moreover, $x_{ij}(t)$ and $v_{ij}(t)$ signifies the i^{th} particle position and velocity in j^{th} dimension during the time instant . To track the global best positioning, n_{CA} maintains local (p_i) & global best (p_g) positions of the particles in set $\Pi = \{p_1, p_2, ..., p_N\}$ which contains the best positions of all the particles ever visited.

$$p_i = (p_{i1}, p_{i2}, ..., p_{iM})^T \ , \quad p_i(t) = \arg\min_t f_i(t) \ , \quad p_g(t) = \arg\min_i f(p_i(t)) \tag{3}$$

Finally, n_{CA} uses the following equations to update the particle position, velocities and local best value:

$$v_{ij}(t+1) = \omega(t) v_{ij}(t) + [c_{cog} r_1 p_{ij}(t) - x_{ij}(t)] + [c_{soc} r_2 (p_{gj}(t) - x_{ij}(t))] \ , \qquad x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \tag{4}$$

$$p_i(t+1) = \begin{cases} x_i(t+1), & if \ f(x_i(t+1)) \le f(p_i(t)) \\ p_i(t), & otherwise \end{cases} \tag{5}$$

Finally, we define the objective function $f(x_i(t))$ for the i^{th} particle in the following equation:

$$f(x_i(t)) = optimize \quad (\alpha_1 \chi_1 + \alpha_2 \chi_2 + (1 - \alpha_1 - \alpha_2)\chi_3) \tag{6}$$

$$subject\ to:$$

$$\chi_1 = \sum_{\substack{\forall n_j \in C_k \\ x_i \in S}} \left\{ \frac{\|n_j, x_i\|}{|C_k|} \right\} \ , \ \chi_2 = \sum_{\substack{i=1 \\ x_i \in S}}^{N} E(p_i) / \sum_{\substack{j=1 \\ n_j \in C_k}}^{|C_k|} E(n_j) \ , \ E_{\min} \le E(n_j) \le E_{\max} \ , \chi_3 = 1/H(p_i) \ , H(p_i) \ge 1$$

$0 < \alpha_1, \alpha_2 < 1$ *and* $\alpha_1 \le \alpha_2$. In the above equation $\alpha_1, \alpha_2, \alpha_3$ are the weightage parameters. Moreover, $E(p_i)$ and $H(p_i)$ represents the energy and head count associated with particle p_i. Also, n_j is the j^{th} node of k^{th} cluster (C_k) and $|C_k|$ denotes the total nodes in a cluster. The Euclidean distance between node n_j and particle p_i is represented by $\|n_j, x_i\|$.

4. Expected Number of Retransmission Attempts

Initially we assume that an aggregation tree exists in every cluster with the CH as the root. Moreover, within the cluster, transmission of data to the CH follows the path in the aggregation tree. We assume that there are h hops or links between the source node and CH. Also, every link (between two sensors) possesses *link failure probability* (p_{lk}). Clearly, for a tree of h links, the number of transmissions required for one successful sending of data to CH is also h. Now, the probability of h successful transmission for one successful end-to-end data delivery (towards CH) is $(1-p_{lk})^h$. Also, the probability of at least one failed transmission, leading to failed data delivery, is $1-(1-p_{lk})^h$. Let random variable Y which denotes the number of successful data delivery attempts. Further, $(\eta-1)$ failures followed by one successful attempt satisfy geometric distribution and is given by:

$$P[Y=\eta]=[1-(1-p_{lk})^h]^{\eta-1}\times(1-p_{lk})^h \tag{7}$$

Therefore, the expected number of attempts leading to a successful delivery of data is:

$$E[\eta]=\sum_{\eta=1}^{\infty}\eta\times P[Y=\eta]=\sum_{\eta=1}^{\infty}\eta\times[1-(1-p_{lk})^h]^{\eta-1}\times(1-p_{lk})^h = E[\eta]=\frac{1}{(1-p_{lk})^h} \tag{8}$$

5. Energy Consumption Model

The radio energy dissipated by a sensor node is mainly in form of electronics and amplifier energy. The energy expended in the radio electronics (E_{elec}) largely depends on how efficiently the signal is encoded, modulated and filtered. However, the energy dissipation rate in the radio amplifier (ε_{amp}) is directly proportional to d^{γ}, where d is the distance between the source (member node) and destination node (CH), and $\gamma=2$ is the path loss component. Therefore, the expected value of d^2, represented by $E[d^2]$ is obtained as following:

$$E[d^2]=\int\int(x^2+y^2)\rho(x,y)\,dx\,dy=\rho\int_0^{2\pi}\int_0^{R_s/\sqrt{k}}r^3\;dr\,d\theta=\frac{\pi\rho R_s^4}{2k^2}=\frac{R_s^2}{2k} \tag{9}$$

To transmit and receive an $m\text{–}bit$ packet over a distance d the energy used by a sensor node is given by:

$$e_{tx}(m,d)=\begin{cases} m\lambda E_{elec}+m\varepsilon_{fs}d^2 & d<\nu_o \\ m\lambda E_{elec}+m\varepsilon_{mp}d^4 & d\geq\nu_o \end{cases}, \qquad e_{rx}(m)=mE_{elec} \tag{10}$$

where ν_o is the threshold distance, beyond which the signal strength is affected by multi-path fading.

Finally the energy expended (ξ_{node}) by a sensor node to support transmission-reception operations as well as while in sleep mode, can be determined by the following equation:

$$\xi_{node}=(1-\beta_s)[e_{tx}(m,d)+e_{rx}(m)]+\beta_s e_{sp}$$
$$=(1-\beta_s)\left[m\lambda E_{elec}+\left(m\varepsilon_{fs}\times\frac{R_s^2}{2k}\right)+mE_{elec}\right]+\beta_s e_{sp} \tag{11}$$

Here, β_s is the sleep probability of a sensor computed on the basis of the outcome of randomized scheduler. Finally, the total energy in delivering a packet can be expressed as following:

$$\xi_{pkt}=h\times\xi_{node}\times E[\eta]=h\times\left\{(1-\beta_s)\left[m\lambda E_{elec}+\left(m\varepsilon_{fs}\times\frac{R_s^2}{2k}\right)+mE_{elec}\right]+\beta_s e_{sp}\right\}+\frac{1}{(1-p_{lk})^h} \tag{12}$$

6. Simulation Study

The proposed network scenario is designed and implemented using Network Simulator. In our 100-node network, there are specifically three categories of sensors (excluding the base station) - sensing nodes, assistant node and the cluster head node. All the nodes are homogeneous but are assigned different tasks to function. Such distribution not only coordinates and balances the operation load within a cluster, but also results in better management and extended network lifetime. The sensor network lifetime is evaluated in figure (3) in terms of number of alive nodes. The reason behind the significant achievement made by our protocol PSO-Semi Distributed (PSO-SD) is the optimized localization of the cluster heads by swarm optimization. However, PSO-C deteriorates because of the fact that the PSO operations are executed in an entirely centralized way at the base station. Moreover, LEACH-C suffers largely because of poor network clustering and cluster head selection. In figure (4) PSO-SD shows considerable increase in the average number of packets delivered. The trend increases till sec, after which it gradually drops due to energy insufficiency in the network. However, the rate of successful packet delivery still retains greater performance than its referenced counterparts. Finally, the graph in figure (5) clearly establishes the effectiveness of our protocol in delivering maximum sensor operations in an energy-efficient way.

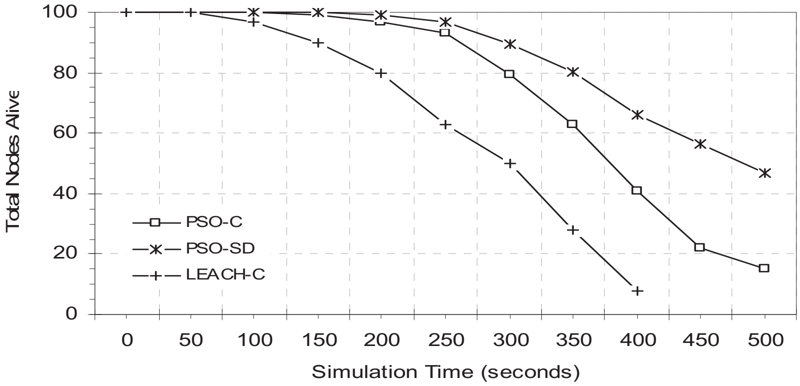

Fig. 3. Sensor network lifetime

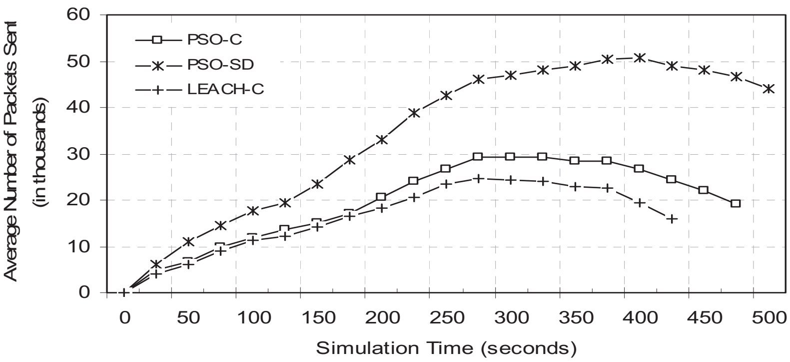

Fig. 4. Average number of packets transmission over simulated time frame

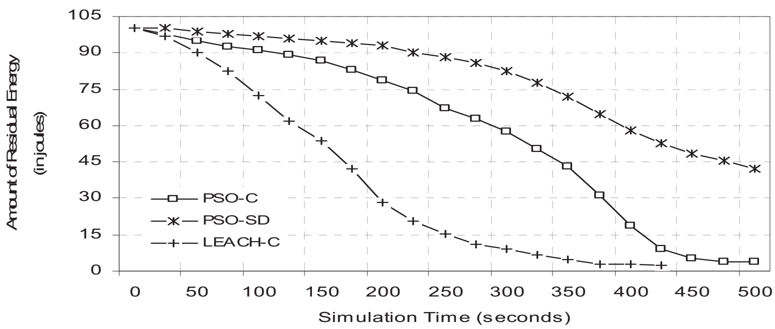

Fig. 5. Average energy consumption in the network

7. Conclusion

Particle Swarm Optimization (PSO) is a technique which is known for its easy implementation and fast convergence. In this paper, we have applied PSO for optimizing the cluster heads location on the basis of our objective function. The PSO ultimately reduces the communication distance by locating optimal position of the cluster head nodes in the cluster. Our proposed technique is implemented within the cluster rather than base station, which makes it a semi-distributed approach. Our proposed technique shows better performance in terms of network lifetime, average number of packets sent and energy consumption, than the LEACH-C and PSO-C protocols respectively. Further, our future work includes the implementation of sensor mobility in higher dimension region of interest and distributed PSO-application in heterogeneous wireless sensor networks.

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