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A Survey on Clustering Routing Protocols Based on PSO in WSN

Enyan Sun*, Chuanyun Wang, Feng Tian
School of Computer Science, Shenyang Aerospace University
Shenyang, China (+86)02489723892
*Corresponding author, e-mail: sunenyan418418@163.com

Abstract

LEACH is a traditional clustering routing protocol in wireless sensor network. When selecting the cluster head, Leach does not consider sensor nodes' energy and position information. It leads to uneven the distribution of cluster heads and uneven energy consumption of sensor nodes. Clustering routing protocols which are based on particle swarm optimization have been proposed to improve the performance of clustering routing protocols. This paper introduces and classifies the clustering routing protocols which are based on PSO and points the future direction.

Keywords*: wireless sensor networks, clustering routing protocol, PSO, LEACH*

1. Introduction

Wireless Sensor Networks (WSNs) is composed of a large number of sensor nodes which are randomly deployed either inside the phenomenon or very close to it. WSNs can perceive ambient environment and send these information to end users. WSN work as the sensing layer of Internet of Things (IoT) and have broad application domains [1-3]. Routing protocols are in charge of discovering and maintaining the routes in the WSNs. Routing protocols are key technology of WSNs [4]. Clustering routing protocols in wireless sensor network can extend the network lifetime through data aggregation at the cluster head. Clustering routing protocols have become the hotspot domain of WSNs and LEACH [5] is the traditional clustering routing protocol.

LEACH protocol is a distributed cluster-based protocol in which CHs are selected with some probability. LEACH divides sensor nodes into Cluster Heads (CHs) and Cluster Members (CMs). CMs collect data from ambient environment and send these data to their CHs. CHs are responsible for fusing these data from CMs within a cluster and directly fused data to the sink. CMs may be sleeping state when none works need be done. CHs undertake more workloads and consume energy more quickly. CHs go dead more quickly. LEACH rotates CHs among different sensor nodes. LEACH runs as a round. A round consists of a cluster head selection, cluster formation and stead-state phrase.

During the period of a cluster head selection, each sensor node produces a random number between 0 and 1. If the number is less than a threshold T(n), the sensor node n will become a CH for the current round. T(n) is expressed as the following Equation (1).

$$T(n) = \begin{cases} \dfrac{P}{1 - P \bullet (r \bmod {}^{1}\!/\!{}_{P})} & n \in G \\ 0 & else \end{cases} \quad (1)$$

P is the percent of CHs among all sensor nodes and r is the current running round. G is the set of sensor nodes which are not CHs for the current round. During the period of a cluster formation, each CH broadcasts an advertisement message (ADV). Each CM joins in a neighbor cluster according to RSSI of ADV. Each CH build TDMA schedule and notify CMs within a cluster. During the steady state phrase, CMs send their data to the CH in their allocated transmission slot. CH fuses these data and sends them to the sink. The steady state phrase is longest in order to save the energy consumption.

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2. Research Method

2.1. Disadvantage of LEACH

LEACH does not guarantee the desired number of CHs which is selected from sensor nodes.

When selecting CHs, LEACH does not consider sensor nodes' residual energy. Once these sensor nodes whose residual energy is less become CHs, these CHs may consume energy quickly and be dead. It shortens the network lifetime.

When selecting CHs, LEACH does not consider sensor nodes' position information. Those CHs which are selected from sensor nodes may disperse unevenly. It leads to too much communication cost between CHs and CMs.

The problem that m sensor nodes are selected to be CHs from n sensor nodes is NP hard problem. Particle Swarm Optimization (PSO) has proposed to solve the above problem [6]. The proposed protocols using PSO algorithm have higher efficiency and can achieve better performance.

2.2. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is an evolutionary computation technique which is developed by Kenney and Eberhart [7, 8]. PSO models social behavior of a flock of birds or fish. It consists of a swarm of s candidate solutions called particles. PSO must have a fitness function which evaluates the particles' position. The position with the best fitness function value in all particles is called the global best (Pg). Each particle keeps track of its best fitness function called the local best (Pl). PSO is an iteration-based optimal algorithm. The particle updates its velocity using formula (2) and its position using formula (3).

$$V_{id}(t) = wV_{id}(t-1) + c1 \bullet rand() \bullet (P_l - X_{id}(t-1)) + c2 \bullet rand() \bullet (P_g - X_{id}(t-1)) \quad (2)$$

$$X_{id}(t) = X_{id}(t-1) + V_{id}(t) \quad (3)$$

Where t is the number of iterations. Vid is the velocity for particle i and Xid is the particle position. w is the inertia weight. c1 and c2 are two positive constants. The function rand() will produce random numbers within rang [0,1].

3. Taxonomy of Clustering Routing Protocols

3.1. Consideration of residual energy of sensor nodes

M. J. Handy et al. [9] proposed Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection which is modified version of LEACH. To increase the network lifetime, the protocol considers the remaining energy level available in each node. T(n) is calculated by Equation (4).

$$T(n) = \begin{cases} \dfrac{P}{1 - P \bullet (r \bmod 1/P)} \times \dfrac{E_{n\_current}}{E_{n\_max}} & n \in G \\ 0 & else \end{cases} \quad (4)$$

En_current is the current energy and En_max is the initial energy of the sensor node. These sensor nodes whose residual energy is more have more opportunity to become CHs. The modification make sensor nodes consume energy more evenly and extend the network lifetime. Their simulations show that such a modification can increase the network lifetime for FND (First Node Dies) and HNA (Half of the Nodes Alive).

3.2. Equal Number of Sensor Nodes within a Cluster

Jason Tillett et al. [10] firstly made use of particle swarm optimization to solve the problem of clustering sensor nodes. Firstly, they use PSO to find a line dividing the sensor nodes into two regions which contain the same number of sensor nodes. The particle is defined as Equation (5).

$$P = (x, y, \theta) \quad (5)$$

x, y is a point on the line dividing the two regions and θ is the orientation of the line.

The above division continues recursively until M regions are created. These M regions contain almost equal number of sensor nodes.

Next, one CH will be selected from each region. The CH is the senor node which minimizes the mean distance between the CH and CMs.

3.3. Consideration of Location and Energy about Candidates and their Neighbors

Ying Liang et al. proposed PSO-Based Energy Efficient Gathering in Sensor Networks [11]. In the beginning, they use LEACH to cluster the sensor nodes. The CH collects the state information of CMs. These information are represented as the location P{p1, p2, … pn} and the residual energy E{e1, e2, … en}. CHs send the above information to the sink.

The sink use PSO to select next-round optimal CHs. The positions Xi which are calculated from PSO does not equal to the actual positions pi of sensor nodes. Xi includes x-location component Xxi and y-location component X_{yi}. Pi also includes x-location component p_{xi} and y-location component p_{yi}. The absolute value of the different between Xi and pi is calculated as Equation (6).

$$\Delta pi = \sqrt{(X_{xi} - p_{xi})^2 + (X_{yi} - p_{yi})^2} \quad (6)$$

The sensor node k whose Δpi is the lest is the searching node and the adjusted value is $X_{xi} \approx p_{xk}$ and $X_{yi} \approx p_{yk}$.

The fitness function considers the distance and residual energy factor and is defined as Equation (7).

$$f(k) = \eta e_k + \frac{\lambda}{n-1} \sum_{\substack{i=1 \\ i \neq k}}^{n} \frac{e_i \bullet r_i}{r_i + 1} \quad (7)$$

Where $\eta, \lambda \in [0,1]$ and $\eta + \lambda = 1$. k is the current sensor node and n is the number of sensor nodes. ri is the distance between the current sensor node and other sensor nodes. Select sensor nodes which have the biggest fitness value as the optimal CHs.

N. M. Abdul Latiff et al. proposed energy-aware clustering for wireless sensor networks using particle swarm optimization [12]. At the starting of each setup phase, all sensor nodes send information about their current energy status and locations to the sink. Based upon these information, the sink computes the average energy level of all nodes. These sensor nodes whose residual energy is above the average energy level are eligible to be CHs candidates for this round. Next, the sink runs the PSO to determine the best K CHs which can minimize the fitness function, as defined by Equation (8).

$$\cos t = \beta \times f_1 + (1-\beta) \times f_2 \quad (8)$$

$$f_1 = \max_{k=1,2,\cdots K} \left\{ \sum_{\forall n_i \in C_{p,k}} d(n_i, CH_{p,k}) \Big/ \left|C_{p,k}\right| \right\} \quad (9)$$

$$f_2 = \sum_{i=1}^{N} \mathrm{E}(\mathrm{n}_i) \Big/ \sum_{k=1}^{K} E(CH_{p,k}) \quad (10)$$

Where f1 is the maximum average distance of sensor nodes to their associated CHs and $|Cp, k|$ is the number of sensor nodes which belong to cluster Ck of particle p.

3.4. Unequal Size Clusters

JIANG Chang-jiang et al. proposed Energy-Balanced Unequal Clustering protocol for wireless sensor networks (EBUC) [13]. Figure 1 shows Unequal size clusters of EBUC.

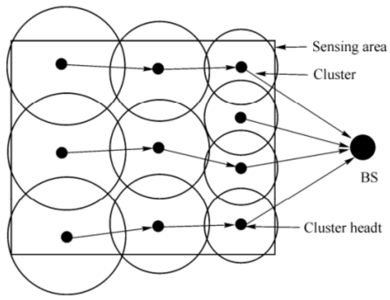

Figure 1. Unequal Size Clusters of EBUC

By using PSO algorithm, EBUC partitions all sensor nodes into clusters of unequal size, in which the clusters closer to the sink have smaller size. The CHs of these clusters can save some more energy for inter-cluster relay communication and the hotspots problem can be avoided. For inter-cluster communication, EBUC is different from LEACH and EBUC uses multi-hop routing.

3.5. Double CHs

HAN Dong-xue et al. proposed PSO-based Double Cluster-heads Clustering Algorithm for Wireless Sensor Network [14]. By using PSO algorithm, two sensor nodes are selected from one cluster. The optimal sensor node serves as the master CH and sub-optimal sensor nodes serves as the vice CH. The master CH is responsible for collecting and fusing data. The master CH sends fused data to the vice CH. The vice CH is responsible for communication with the sink. The fitness function is defined as Equation (11).

$$f = \varepsilon \times \left\{ E(H) \Big/ \sum_{i=1}^{m} E(n_i) \right\} + (1-\varepsilon) \times \left\{ (m-1) \Big/ \sum_{i=1}^{m} d(n_i, H) \right\} \tag{11}$$

Where ε is constant and $\varepsilon \in [0,1]$. E(H) is the residual energy of the CH and E(ni) is the residual energy of sensor node ni. m is the number of sensor nodes within a cluster. $d(n_i, H)$ is the distance between the sensor node ni and the CH H.

3.6. Optimal Number of Clusters

GUO Jian et al. proposed A Particle Swarm Clustering Protocol for Wireless Sensor Networks Based on Optimal Number of Clusters [15]. There exists the optimal number of clusters in wireless sensor networks. If the number of clusters is too small, the distance of CHs and CMs is far. It leads to consume too much energy. If the number of cluster is too big, too many CHs directly send data the sink. It cannot satisfy the expected purpose of the hierarchy routing protocol.

The optimal number of clusters is computed by Equation (12).

$$K = \sqrt{\frac{N\varepsilon_{fs}}{2\pi\varepsilon_{amp}}} \times \frac{a}{d^2} \tag{12}$$

Where N is the total number of sensor nodes. a is the edge length of square area. d is the distance between the CH and the sink. ε_{fs} and ε_{amp} is defined as reference [5]. The fitness function is defined as Equation (13).

$$f(i) = \eta e_i - \frac{\lambda}{n-1}\sum_{j=1}^{n}\sqrt{(p_{xj} - x_i)^2 + (p_{yj} - y_i)^2} \quad (13)$$

Where $\eta + \lambda = 1$ and $\eta, \lambda \in [0,1]$. ei is the residual energy of sensor node i. (p_{xj},p_{yj}) is the position information of the sensor node j.

3.7. A Ring-based Clustering Protocol

QIN Zhi-chao et al. proposed A Ring-Based Clustering Routing Protocol for WSN Using Particle Swarm Optimization [16]. The entire region is divided into a number of concentric circles with different intervals. Each ring is divided into many sectors. These sectors are defined as the basic units for a CH selection. CHs are selected by considering the distance to the center of sector and the sensor nodes' residual energy.

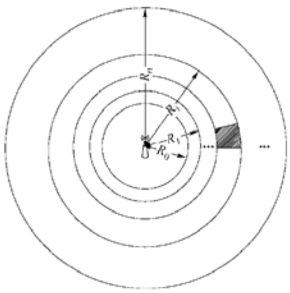

Figure 2. The Diagram of Ring Routing Protocol

3.8. Discrete Particle Swarm Optimization

ZOU Xueyu et al. proposed DPSO-Based Clustering Routing Approach for WSN [17]. DPSOCA uses discrete particle swarm optimization (DPSO) to cluster. The fitness function mainly considers location and residual energy of neighbor sensor nodes.

3.9. Chaos-PSO

LIU Zhikun et al. proposed A Clustering Protocol for Wireless Sensor Networks Based on Chaos-PSO Optimization [18]. PSO algorithm is easy to get the local optimal result. To solve the problem, chaos theory is introduce to PSO algorithm to improve the performance of pure PSO. Chaos has the characteristics of random, determination and regulation which benefits to optimization of PSO. After the algorithm runs for a fixed round, chaos search will be started. The current optimal result gbest will be operated by chaos calculation. The new optimal result g'_{best} will be created. Compare the fitness value of g_{best} with g'_{best}. If the fitness value of g'_{best} is better, g'_{best} will be uses as the global optimal result and iteration operations will continue.

3.10. QoS Routing Protocol

Xi-huang Zhang et al. proposed QoS Based Routing in Wireless Sensor Network with Particle Swarm Optimization [19]. Quality of Service (QoS) importantly affects the network routing protocol. The paper makes use of PSO algorithm to select the optimal path. The QoS metrics includes time delay, energy reserve, Signal Noise Ratio (SNR) and Bandwidth Efficiency Ratio (BWER). The QoS metrics is used as the PSO fitness function.

3.11. Multi-hop Routing Protocol Based upon Weighted Graph

Xianghong Cao et al. proposed Cluster Heads Election Analysis for Multi-hop Wireless Sensor Networks Based on Weighted Graph and Particle Swarm Optimization [20]. The protocol is based upon multi-hop communication. A directional, weighted and connected graph G(V,E) is used for description of a cluster of WSN. V(G)={V1,V2, … ,Vn} denotes sensor nodes and E(G) denotes the edge between two sensor nodes. The protocol proceeds to find the optimal spanning trees of weighted graph by using PSO. The optimal trees are selected based on the minimum distance. The best routing can be searched from the optimal trees by comparing energy consumption.

3.12. Hybrid Factor

Yubin Xu et al. proposed A Clustering Algorithm of Wireless Sensor Networks Based on PSO [21]. To equalizing the network consumption, the protocol uses the PSO algorithm to optimize clustering process by considering the energy, the communication costs, the load balance and other factors to determine the CH. If the particles location cannot corresponds to the sensor nodes location, they can find a nearest sensor node to replace. When considering the main disadvantages of LEACH, the fitness function is defined as Equation (14).

$$f(i) = \alpha \times f_1 + \beta \times f_2 + \gamma \times f_3 \quad (14)$$

Where $\alpha + \beta + \gamma = 1$ and $\alpha, \beta, \gamma \in [0,1]$. The fitness function f(i) mainly consists of three parts. Firstly, the higher residual energy sensor node has the priority to become a CH.

$$f_1 = \sqrt[Head\_num]{\prod_{i=1}^{Head\_num} (E_i - \overline{E})} \quad (15)$$

Head_num is the optimal number of clusters and Ei is the residual energy of the sensor node i. $\overline{E}$ is the average energy of sensor nodes of the entire network.

Secondly, the communication cost is minimal within a cluster.

$$f_2 = \sum_{i=1}^{Head\_num} \frac{Num_i}{Distance_i} \quad (16)$$

Where Num_i is the number of sensor nodes at the cluster i and $Distance_i$ is the sum distance from the CH to CMs.

Thirdly, the load-balance of a cluster is important to save energy.

$$f_3 = \frac{Head\_num}{\sum_{i=1}^{Head\_num} (Num_i - \overline{N})^2} \quad (17)$$

Where $\overline{N}$ is the average number of nodes of the entire network.

The greater value of the fitness function f(i) is, the more opportunity the sensor node i has.

4. Conclusion

Clustering routing protocol which is based upon PSO algorithm can balance energy consumption of sensor nodes of the whole network and extend the network lifetime. Compared to LEACH, these protocols have more performance. This paper surveys the clustering routing protocol which is based upon PSO algorithm and outlines the characteristics of these protocols. In the future, comparative studies of PSO and other swarm intelligence algorithms will go on.

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