

Research Article

An Energy Consumption Optimized Clustering Algorithm for Radar Sensor Networks Based on an Ant Colony Algorithm

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We optimize the cluster structure to solve problems such as the uneven energy consumption of the radar sensor nodes and random cluster head selection in the traditional clustering routing algorithm. According to the defined cost function for clusters, we present the clustering algorithm which is based on radio-free space path loss. In addition, we propose the energy and distance pheromones based on the residual energy and aggregation of the radar sensor nodes. According to bionic heuristic algorithm, a new ant colony-based clustering algorithm for radar sensor networks is also proposed. Simulation results show that this algorithm can get a better balance of the energy consumption and then remarkably prolong the lifetime of the radar sensor network.

1. Introduction

Radar sensor networks (RSN) [1] are the networks of distributed radar sensors which collaboratively operate and are deployed ubiquitously on airborne, surface, and unmanned vehicles in a large geographical area. Radar sensors have capabilities for radar sensing, signal processing, and wireless communications. In RSN, radar sensors are networked together in an ad-hoc fashion, that is, they do not depend on any preexisting infrastructure. In fact, they are self-organizing entities that are deployed on demand to perform various tasks such as surveillance, search and rescue, disaster relief, and so forth.

An RSN is organized into clusters, which are independently controlled and dynamically reconfigured to observe targets such as tactical weapons, missiles, aircraft, ships, and so forth, in the surveillance area. In a cluster, sensors receive the signals backscattered by targets in the presence of interference (e.g., clutter, jamming, interference between radar sensors) and noise. Then, the observed signals from all radar sensors are forwarded to a cluster head where received data set will be combined to perform fundamental tasks such as detection, localization, identification, classification, and tracking. After finished dealing with the data from the radar

sensors, the cluster head transmits the data to the sink node. In RSN, the cluster head must have a function such as data collection, fusion, transition, and so forth. The cluster head consumes more energy than the radar nodes. Hence, the algorithm of selecting the cluster head is very important for the life cycle of the radar sensor network.

The routing for wireless sensor network [2] (WSN) based on bionics heuristic algorithm has become one of the hot WSN research topics. Currently, ant colony algorithm [3], EEABR [4], MACS [5], and EPACOR [6] are utilized to find the best path from source to sink for wireless sensor network. In addition, ant colony optimization (ACO) [7], EAQR [8], QDV [9] not only solves the WSN network congestion, but also improves QOS and network security. Since the clustering algorithm has a good performance on the WSN routing, Salehpour et al. [10] proposed an efficient routing algorithm for large-scale WSN. This algorithm takes advantage of two routing levels. In the first level (intracluster), cluster members send data directly to their cluster head and the cluster head is selected by LEACH [11]. In the second level (inter-cluster), the cluster head uses ACO algorithm to find a route to the base station. ACDCHA [12] (Ant Colony-based Double Cluster-Heads Algorithm) is proposed by Su et al. through introducing the idea of ant colony algorithm.

A master cluster head and a vice cluster head are selected in each cluster according to the pheromone concentration. The tasks such as data collection, fusion, transition, and so forth, are allocated, respectively, to these two kinds of cluster head. Simulation results show that this algorithm can get a better balance of the energy dissipation and prolong the network lifetime than the traditional clustering algorithm. The benefit of this algorithm is that the master cluster head only sends the data to the vice cluster head within the cluster, then the vice cluster head sends the data to base station, thus saving the energy of the master cluster head. However, when the master cluster head and vice cluster head are selected, only the residual energy of the node is considered; the node's location information is not taken into account, so the distance between vice-cluster head and base station maybe greater than the distance between the base station and the master cluster-head, resulting in more energy consumption for vice cluster head.

Heinzelman proposes a "Low-Energy Adaptive Clustering Hierarchy" (LEACH) for WSN data gathering and communication [11]. In this protocol, the base station is assumed to be far away from the area where sensors are deployed. The WSN is clustered according to a certain rule and the cluster head collects data from all the sensor nodes within its cluster. Once the data from each sensor node are received, the cluster head aggregates and transfers them directly to the base station, meaning that being a cluster head cost much more energy than regular sensors. In order to make all the sensor nodes use up their energy approximately simultaneously, the role as the cluster head is randomly rotated among all sensor nodes in the same cluster. From this point of view, LEACH is a quite elegant protocol especially in terms of self-adaptive ability. But there are many disadvantages in traditional clustering routing algorithm LEACH. First of all, the cluster head is selected by probability model, so it possibly causes some cluster heads apart from each other or some nodes in part areas apart from cluster head, then transmission consumption of these nodes increases. Meanwhile, LEACH does not consider the residual energy of each node, so the nodes that have relatively small residual energy can be the cluster heads. This makes the network lifetime to be shortened. Secondly, the randomness of cluster head selection can cause that some cluster heads share burden of nodes unbalance and aggravate some cluster head node's burden. So the balance degree gets reduced. For these deficiencies, ESCAL [13] and NRSM [14] have improved this algorithm and effectively extend the network lifetime.

To overcome the defect of LEACH and ACDCHA, in this paper, the cost function for clusters is proposed based on radio-free space path loss for radar sensor network. The radar node joins the different clusters according to the values of cost function between this node and its cluster head, so the cluster structure is optimized. In the cluster head selection phase, the energy and distance pheromones based on the residual energy and aggregation of radar sensor nodes are proposed. Based on ant colony algorithm, we propose a new ant colony-based clustering algorithm (BACCA) for radar sensor network. Simulation results show that this algorithm

can keep a better balance of the energy consumption and prolong the life cycle of the radar sensor network.

The rest of this paper is organized as follows. Several concepts such as the cost function for clusters, energy pheromones, distance pheromones, and cluster head selection function are introduced in Section 2. The BACCA is described in Section 3. Simulation model and numerical results are discussed in Section 4. Finally, the conclusions are drawn in Section 5.

2. The Basic Concept of BACCA

2.1. Ant System and Optimization. In ant colony optimization (ACO), a colony of artificial ants is used to construct solutions guided by the pheromone trails and heuristic information [15]. ACO was inspired by the foraging behavior of real ants. This behavior enables ants to find the shortest paths between food sources and their nest. Initially, ants explore the area surrounding their nest in a random manner. As soon as an ant finds a source of food, it evaluates the quantity and quality of food and carries some of this food to the nest. During the return trip, the ant deposits a pheromone trail on the ground. The quantity of pheromone deposited, which may depend on the quantity and quality of the food, will guide other ants to the food source. The indirect communication between the ants via the pheromone trails allows them to find the shortest path between their nest and food sources. This functionality of real ant colonies is exploited in artificial ant colonies in order to solve optimization problem [15, 16].

2.2. Cost Function for Cluster. In the traditional clustering routing protocol, the radar node chooses to join the cluster head whose signal is strongest, according to the signal received from cluster head. However, it does not consider the residual energy of cluster head. Obviously, the structure of this cluster is irrational. To comprehensively consider the distance between the radar node and its cluster head, the residual energy of cluster head, and to further optimize the structure of cluster, we define the cost function for cluster, which is based on radio-free space path loss model. The radar node computes the values of cost function for clusters between it and cluster head, and chooses to join the cluster head whose values are maximum, so this structure of cluster will be able to better balance the network energy consumption.

In radar sensor network, the radar node transmits the radio in free space. The path loss model [17] is as follows:

$$P_r = \frac{P_t G_r G_t \lambda^2}{(4\pi)^2} \left(\frac{d_0}{d_{ij}} \right)^\alpha, \quad (1)$$

where P_t is radar node's transmission power, P_r is the radar node's received power, d_{ij} is distance between radar node S_i and S_j , and G_r and G_t are antenna gain of receiving antenna and transmitting antenna, respectively. λ is the wavelength of carrier. α is the path loss exponent which indicates the rate at which the path loss increases with distance; d_0 is the close-in reference distance which is determined from measurement close to the radar node transmitter.

Suppose transmission time T , then sending energy $W_t = P_t T$ and receiving energy $W_r = P_r T$. Formula (1) can be transformed by multiplying time T , then

$$W_r = W_t Q_c \left(\frac{d_0}{d_{ij}} \right)^\alpha, \quad Q_c = \frac{G_r G_t \lambda^2}{(4\pi)^2}. \quad (2)$$

From (2), the receiving energy W_r of receiving radar node S_j is proportional to the transmission energy W_t of transmission radar node S_i ; it inverses to the distance between S_i and S_j . Therefore, based on (2), we refer to ACO and define the cost function $P_{CM}(i, j)$ for a cluster as follows:

$$P_{CM}(i, j) = \frac{1}{[d_{toCH}(j)]^\beta} E_{rem}(j), \quad j \in G_{CH}, \quad (3)$$

where G_{CH} is set of cluster head, $d_{toCH}(j)$ are distance between radar node S_i and cluster head S_j , and $E_{rem}(j)$ is residual energy of cluster head S_j , β is adjustable weight of distance.

Clearly, the values of $P_{CM}(i, j)$ are proportional to the residual energy of cluster head and reverses to the distance between the radar node and cluster head. When $P_{CM}(i, j)$ is larger, not only the radar node is closer to its cluster head, but also the residual energy of this cluster head is greater. Hence, the node should choose to join the cluster head whose values of $P_{CM}(i, j)$ are maximum. Obviously, the cluster formed by this method, and not only the residual energy but also the energy attenuation of data transmission are taken into account.

2.3. Distance Pheromone. The location information of radar node's neighbor significantly influences the selection of cluster head for next round. When the distance between radar node and its neighbors is shorter, the aggregation of this radar node is larger, because this radar node is cluster head, and the cluster head is closer to its cluster members. The energy consumption of network can be reduced effectively. Referring to the pheromone model [3] of ant colony algorithm, we define the distance pheromone as follows:

$$r_m(i) = \frac{Q_d}{N_{neighbor}} (1 - \nu), \quad (4)$$

where ν is distance volatile factor, $\nu = (\text{dist}_{cluster} - \text{dist}_{neighbor}(i)) / \text{dist}_{cluster}$, and $\text{dist}_{neighbor}(i) = \sum_{j \in NBR} \text{dist}_{ij}$, $\text{dist}_{cluster} = \sum_{i \in cluster} \text{dist}_{toCH}(i)$, dist_{ij} is the distance between radar node S_i and radar node S_j , NBR is the neighbors' set of S_i , $N_{neighbor}(i)$ is the number of S_i neighbors, and $\text{dist}_{cluster}$ is the distance between all cluster members and cluster head; $\text{dist}_{toCH}(i)$ is the distance between radar node S_i and its cluster head, Q_d is adjustable weight of distance.

From (4), the value of $r_m(i)$ is proportional to the average distance between radar node and its neighbors. A small value of $r_m(i)$ indicates that the radar node aggregation is big, which brings that a great probability of this radar node is selected as cluster head.

2.4. Energy Pheromone. In addition, the residual energy of radar node's neighbor also significantly influences the

selection of cluster head for the next round. The higher the residual energy of the radar node is, the greater will be the probability of selecting this radar node as a cluster head. If this radar node is selected as the cluster head, it can afford the energy dissipation of collection data, fusion data in the cluster, and sending data to the base station. Referring to the pheromone model [3] of ant colony algorithm, the energy pheromone is defined as follows:

$$e_m(i) = \frac{Q_e}{\sum_{j \in cluster} E_{rem}(j)} (1 - \omega), \quad (5)$$

where ω is energy volatile factor, $\omega = (E_{init}(i) - E_{rem}(i)) / E_{init}(i)$, $E_{rem}(i)$ is the residual energy of radar node S_i ; $E_{init}(i)$ is the initial energy of radar node S_i , $\sum_{j \in cluster} E_{rem}(j)$ is the residual energy of all cluster members which cluster node S_i belongs to. Q_e is the adjustable weight of energy.

From (5), the larger the residual energy of the node is, the bigger $e_m(i)$ is. As a result, the energy of radar node volatile is smaller, and the probability of selecting this radar node as the cluster head is greater.

2.5. Cluster Head Selection Function. According to the transition probability [3], the ant selects next node (cluster head for next round) from this node (cluster head for this round). In order to select cluster head for next round effectively, we comprehensively consider the residual energy and aggregation of radar node (energy pheromone and distance pheromone). The novel transition probability is defined as follows:

$$P_{CH}(i) = \frac{[e_m(i)]^\eta \times [1/r_m(i)]^\mu}{\sum_{j \in cluster} ([e_m(j)]^\eta \times [1/r_m(j)]^\mu)} \quad i \in \text{cluster}, \quad (6)$$

where cluster is a set of cluster members, and $P_{CH}(i)$ is the probability values of radar node S_i , which is decided by the residual energy and aggregation of radar node. The radar node is selected as the cluster head for next round, whose value of $P_{CH}(i)$ is maximum. η and μ are the adjustable weights of $e_m(i)$ and $r_m(i)$, respectively. The selection of cluster head is related with η and μ . A higher value of η increases the chance for an ant to choose the radar node with more residual energy as the cluster head. A higher value of μ increases the chance for an ant to choose the radar node with bigger aggregation as the cluster head. Hence, the different cluster head is selected by dynamically changing the values of η and μ . When an RSN is not stable (the radar nodes move, so the distance between radar nodes is variable), a lower value of η and higher value of μ are generally preferred. This is because the distance pheromone has become more important for the cluster head selection. As an RSN becomes stable, a higher value of η is preferred. This is because a higher value of η means energy pheromone has become more important for the cluster head selection.

3. BACCA Algorithm

According to the above analysis, we are ready to get the BACCA algorithm for radar sensor network as follows:

- (1) first round, the cluster heads and the number of cluster heads are determined by LEACH;
- (2) those new cluster heads broadcast the cluster head message to all radar nodes around them;
- (3) the radar node S_i receives the message from the cluster head S_j , then computes the value of $P_{CM}(i, j)$ according to (3) and chooses to join the cluster head S_v while $v = \max(P_{CM}(i, j))$. This radar node becomes the cluster member of S_v ;
- (4) after all data transmission has been finished, cluster heads in this round compute their cluster members' distance and energy pheromones according to (4) and (5), then compute these nodes' value of cluster head selection function according to (6) and choose the S_w as the cluster head for next round while $w = \max(P_{CH}(i))$;
- (5) go to step (2) for next round of the loop until all radar nodes are dead.

Clearly, in this algorithm, when the new cluster head is chosen, both the residual energy and aggregation of radar nodes are taken into account. At the same time, when the radar nodes choose to join the corresponding cluster head to form the new cluster, both the residual energy of radar node and energy attenuation of data transmission are considered. Therefore, by using this algorithm, the radar sensor network lifetime can be prolonged effectively.

4. Algorithm Simulation and Analysis

4.1. System Model and Parameters. In order to verify the performance of this algorithm, we compare LEACH and ACDCHA with this proposed algorithm BACCA by simulation calculation for radar sensor network in MATLAB platform.

The difference between wireless sensor network and radar sensor network is that there is one more step in radar sensor network, which is radar scanning process; so we can deduce radar sensor network radio model from wireless sensor network radio model. In wireless sensor network, the radio model is the first-order model from the literature [18], thus we can get the radar sensor network radio model as follows:

$$E_{tx} = \begin{cases} l \times (E_{elec} + \varepsilon_{fs} \times d^2) + E_{radar} & \text{if } d < d_0, \\ l \times (E_{elec} + \varepsilon_{mp} \times d^4) + E_{radar} & \text{if } d \geq d_0, \end{cases} \quad (7)$$

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}. \quad (8)$$

Equation (7) represents the amount of energy consumption in the transmitting packet with l bits over d distance

TABLE 1: Parameters of simulation.

Parameter	Value	Parameter	Value
E_{elec}	50 nJ/bit	β	2
E_{DA}	5 nJ/bit/signal	μ	1
ε_{fs}	10 pJ/bit/m ²	Q_d	10
ε_{mp}	0.0013 pJ/bit/m ⁴	l	4000 bit
E_{init}	0.5 J	η	2
E_{radar}	50 nJ	Q_e	10

according to the first-order model. E_{elec} is the amount of energy consumption per bit to run the transmitter or receive circuitry. ε_{fs} and ε_{mp} are the amount of energy per bit dissipated in the RF amplifier according to the distance d_0 which can be obtained from (8). E_{radar} represents the energy consumption for scanning of radar sensor node in every round.

The amount of energy consumption in the receiving packet with l bits can be calculated as follows:

$$E_{rx} = l \times E_{elec}. \quad (9)$$

Simulation environment is 100 radar nodes random distribution in a square shape region A of 100 m \times 100 m; the base station is located at (50, 150); the application scenario is the periodic data collection. Here are some assumptions for our model.

- (1) Once the radar nodes in this radar sensor network are deployed, the radar sensor nodes do not move.
- (2) The RSN consists of the homogeneous radar sensor nodes which have the same initial energy and data fusion ability. Every radar node has the only identity (ID) and knows the other radar nodes' location information.
- (3) According to the distance between radar nodes, the radar nodes can adjust their transmission power to conserve energy consumption.
- (4) All radar nodes in communication range are not more than one hop.

Suppose the data of neighboring radar nodes have a high redundancy, the cluster heads can fuse the data from a cluster member into a fixed-length data packet, then send this fusion data to the base station. E_{DA} is the processing (data fusion) cost of a bit per report to the base station. The length of control information packets (such as the information of joining cluster head, etc.) is relatively smaller than the length of data packets (such as node collected data). In the simulation process, we ignore the energy dissipation of these information packages. The simulation parameters are shown in Table 1, where the parameters of energy consumption are as same as LEACH.

Before the simulation, we have to decide the value of P_{opt} used in LEACH for the first round of BACCA. According

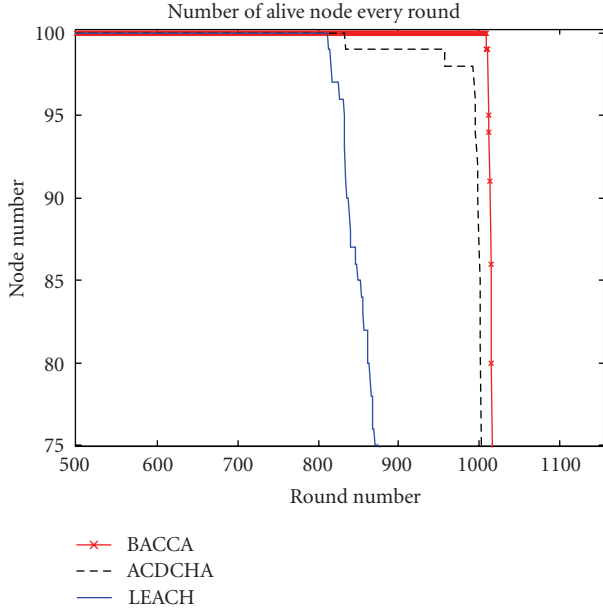


FIGURE 1: Number of alive nodes every round.

to (10) which is introduced in [19], we can get the P_{opt} as follows:

$$P_{opt} = \sqrt{\frac{n}{2\pi}} \cdot \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \cdot \frac{M}{d_{toBS}^2} \cdot \frac{1}{n}, \quad (10)$$

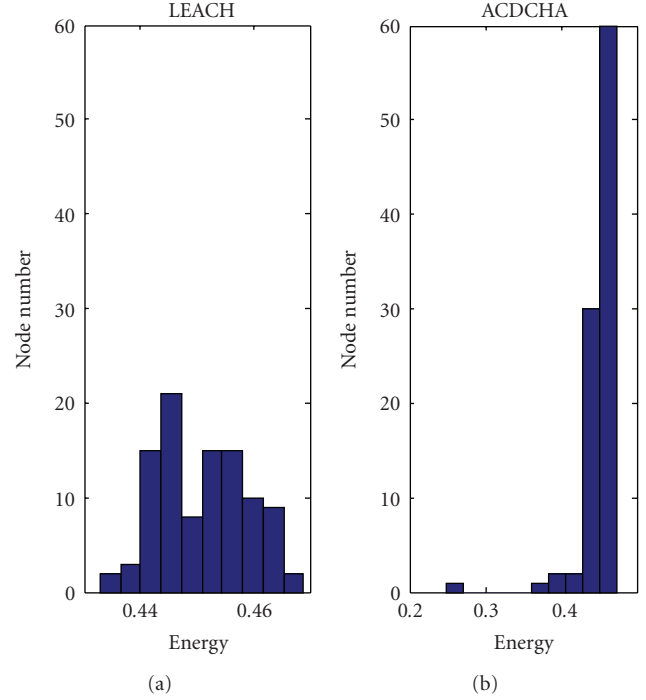
where n is the number of deployed nodes, M is the area of the RSN. d_{toBS} is the distance between radar node and base station.

4.2. Simulation Results and Analysis. When there are 10 dead radar nodes in the network, this round number is taken as the network’s life cycle. Figure 1 shows that the life cycle of BACCA is longer than LEACH and ACDCHA (in Figure 1, the cluster head number of BACCA and ACDCHA is 7). There are 10 dead nodes in 835 round for LEACH and in 993 round for ACDCHA; however, there are 10 dead nodes in 1014 round for BACCA. Obviously, this algorithm can prolong the life cycle of the network.

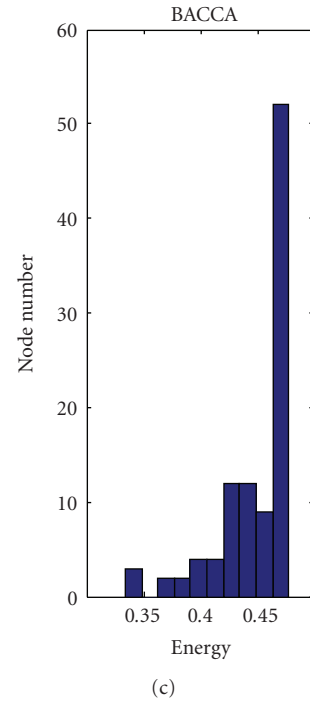
We compare these algorithms with average residual energy for 90~100 rounds. In Figure 2, the number of the radar nodes’ energy around 0.45 for BACCA is almost the same as ACDCHA, but it is more than LEACH. Obviously, this algorithm can reduce the energy dissipation of the radar sensor network. In addition, in the case of ACDCHA, some radar nodes’ energy is below 0.3, so they can die earlier. By contrast, the radar nodes’ energy is almost around 0.4, which indicates that BACCA can better balance the energy dissipation of radar sensor network.

In addition, the change of the number of cluster head can impact the round of the first radar node dead in the network. As Figure 3 shows, the performance of the radar sensor network is better while the cluster number is between 4 and 6.

We compare the energy dissipation for cluster heads in the first 70 rounds. In Figure 4, the cluster heads’ dissipation



(a) (b)



(c)

FIGURE 2: The energy of radar nodes.

for LEACH is not even in every round and the whole energy consumption for RSN is very large. However, in the ACDCHA, the cluster heads’ dissipation is more even and the whole energy consumption for RSN is less than LEACH. Lastly, the cluster heads’ dissipation for BACCA is the most even and the whole energy consumption for RSN is less than LEACH and ACDCHA. Therefore, the algorithm BACCA can more effectively reduce the cluster heads’ energy dissipation than LEACH and ACDCHA.

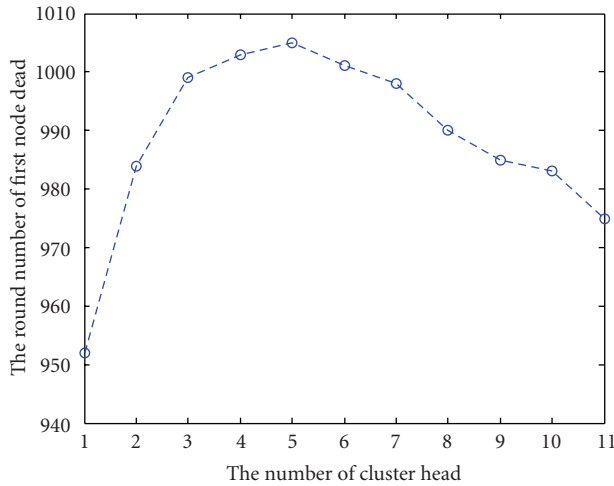


FIGURE 3: The dead radar node round via cluster head number.

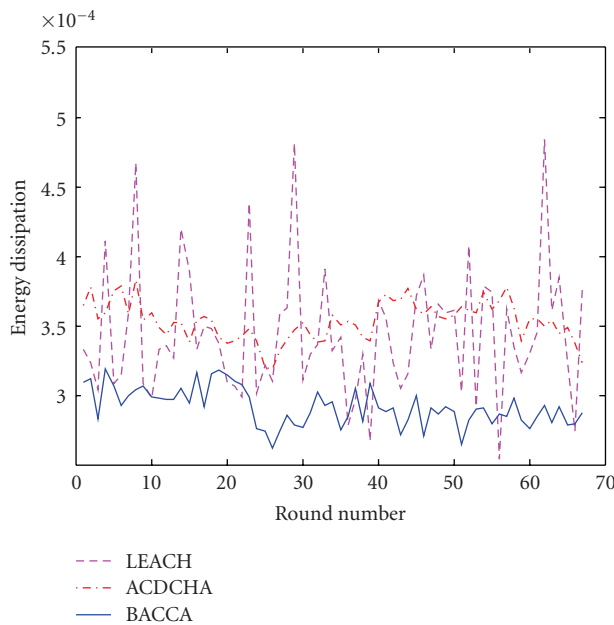


FIGURE 4: Energy dissipation for cluster head.

5. Conclusion

In this paper, the ant colony algorithm is applied to RSN clustering routing. The energy and distance pheromones which are based on the residual energy and aggregation of radar sensor nodes are proposed. We also propose the ant colony-based clustering algorithm (BACCA) for radar sensor networks according to the ant colony algorithm. Meanwhile, the cluster structure is optimized by the defined cost function for clusters. The simulation results show that this algorithm is better than LEACH and ACDCHA in that it can better balance the energy dissipation of the radar sensor network and extend the lifetime of the radar sensor network.

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