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WSN Routing Algorithm Based on Routing Strategy with Ant Colony Optimization

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Abstract: To reduce the energy consumptions of wireless sensor network nodes (WSN), avoiding communication conflicts caused by different nodes simultaneously using shared channel, this paper proposes a dual-channel routing algorithm for sensor networks (CORA) based on Ant Colony optimization strategy. The algorithm can reduce the nodes mutual inhibition competition in channel contention by using dual channel communication model; compress the path finding ranger for ant colony through the maximum infection ball to reduce the energy consumption for network; propose a two-tier network with combined dispatching to effectively abate network congestion by means of layered graph. The simulation results show that compared with an energy-efficient routing algorithm based on Ant strategy and an energy-efficient routing algorithm based on Ant Colony optimization strategy, the CORA algorithm can lower down the network congestion to 17 % and reduce message conflicts between data packets and control packets, effectively reducing the energy consumption for average communicating time of packets and network. *Copyright © 2013 IFSA.*

Keywords: Dual-channel; Ant colony strategy; Wireless sensor network.

1. Introduction

WSN is composed by a large number of micro-sensor nodes deployed in the monitoring areas. These nodes have teamed up for collecting and integrating the information within the monitoring area, and then transmit the perceptions to the base station by multi-hop relayed-operation communicating to help monitor the area [3].

The Medium Access Control (MAC) in WSN is mainly for solving channel distribution between the nodes, preventing the communication conflicts caused by using shared channels and avoiding deteriorating network transmission. However, the message conflict between data packets and control packets is the main cause of communication conflicts; hence how to effectively address this conflict is a hotspot research in current sensor network.

The reference of [5] uses dual-channel communicating model to transfer separately data packets from control packets, in order to completely eliminate their message conflicts. The reference of [11] presents a cross-layer transport protocol (RCF) to effectively solve the data collision and multi-cast suppression, improving the network throughput. The RCF protocol designs a forwarding strategy for partial data packets which cannot balance consider the rest energy of the nodes, so it's hard to guarantee the selected route as the optimal route. Meanwhile, this forwarding strategy may put the path-finding into the routing void. While dealing with the void, it uses an approached way which regards the nearest neighbor node of the sending nodes as next hop forwarding node, can easily causing data flow backwards. The reference of [9] based on ant colony optimization proposes the routing algorithm, using self-organization and adaptive optimization

mechanism of ant colony for real-time network optimization. Nevertheless, none of these algorithms associates sensor network features, that is, using energy consumption mode of sensor nodes communications to find out the maximum area of the optimal route between the source node and goal node. And use this area to limit the node range in finding optimal path, reducing the energy consumption.

On account of the above research results, the author puts forward an optimal routing algorithm of dual-channel with WSN joint (CORA). The algorithm uses maximum infection ball to limit node range in finding optimal route, reducing the energy consumption and preventing the way-finding from the route void; and then uses the layered graph to simplify the channel transformation into the route, presenting a two-layer network joint dispatching to reduce network congestion.

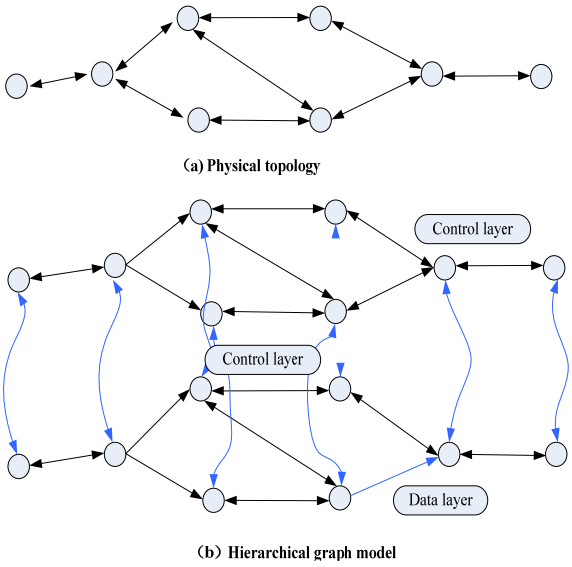

Fig. 1. Dual-channel communication mode.

2. CORA Routing Algorithm

2.1. Communication Energy Consumption Model

It uses the communication energy consumption model as [9] referred to analyze energy consumption between the nodes. While network topology control uses heuristic node awakening and sleeping mechanism, it can set the nodes to be a sleep node with nothing happens and to be automatically awake to arouse neighbor nodes when an event occurs, forming a data forwarding topology. Supposing that all nodes in the network have a only identification (ID) with two independent channels, respectively used for transmitting data packets and control packets; each node should establish a neighbor list of the contents including: (1) ID of neighbor nodes. (2) Neighbor node locations. (3) The pheromone concentration from nodes to its neighbor nodes. (4) The rest energy of node itself and its neighbor node.

2.2. Dual-Channel Communication Mode

It can simplify the dual-channel communication network into the route by using layered graph without considering channel distribution in WSN. Dual-channel communication places and transmits the control message in the control layer, and data message in the data layer, as Fig. 1 shows. This isolating and transmitting method can completely eliminate the message conflicts and effectively improve the network transmission performance. Maintaining a certain amount of ants in the control layer can update the neighbor list of each node for a real-time routing. At the same time, while there is an enough free resource, it can transfer the blocked path-finding in control layer to the data layer, to realize the joint operation of the two-tier network and reduce the network congestion.

2.3. The Maximum Infection Ball Theory

Supposing the sensor network diagram as $G(V,E)$, all edge weights as the square of the distance between the two endpoints of the edge, and supposing the father node as v and child node as u, the energy consumption of unit bits in the two nodes transmission as E_n^*. Starting from the node v, the route via node w and node u is vwu, if the energy consumption of unit bit transmission in route vwu is lower than E_n^*, then $d_{vw}^2 + d_{wu}^2 < (d_{vu})^2$. From the cosine theorem, it can know that $\angle vwu$ is an obtuse angle, so node w in the sphere as the diameter of vu which can be called the minimum infection ball of node v and node u. If the energy consumption of unit bit transmission is equal to E_n^*, then $d_{vw}^2 + d_{wu}^2 = (d_{vu})^2$, from the cosine theorem, $\angle vwu$ as a right angle, thus node w is on the minimum infection ball. While the energy consumption of unit bit transmission in route vwu is lower than E_n^*, node w is named as infection shortcut node. In the minimum infection ball, the diameter vu divides it equally into two semicircles; starting from the node v, the route from the shortcut node to the node u has the following characters.

Theorem 1: starting from the source node v, supposing the route from the shortcut node to goal node along one semicircle as $vw_1w_2\cdots w_hu$, the total energy consumption is lower than E_n^*.

Theorem proving: because nodes $w_1, w_2, \cdots w_h$ are all on the circumference of the semicircle, all $\Delta vw_1w_2, \Delta vw_2w_3, \cdots, \Delta vw_{(h-1)}w_h$ are obtuse

triangles. While Δvw_1w_2 is an obtuse triangle, it can obtain $d^2_{v,w1}+d^2_{w1,w2}<d^2_{v,w2}$ according to the cosine theorem. Similarly, from Δvw_2w_3, it can obtain $d^2_{v,w2}+d^2_{w2,w3}<d^2_{v,w3}$, that is $d^2_{v,w1}+d^2_{v,w2}+d^2_{w2,w3}<d^2_{v,w3}$, and then it has $d^2_{v,w1}+d^2_{v,w2}+\cdots+d^2_{w(h-1),wh}<d^2_{v,wh}$. In addition, because $\angle vw_hu$ is the angle of the circumference, then Δvw_hu is a right triangle, it can get $d^2_{v,wh}+d^2_{wh,u}=d^2_{v,u}$ by using the cosine theorem, and $d^2_{v,w1}+d^2_{v,w2}+\cdots+d^2_{w(h-1),wh}+d^2_{wh,u}<d^2_{v,u}$, therefore, the total energy consumption in route $vw_1w_2\cdots w_hu$ is lower than E^*_n.

Creating a minimum infection ball O_2 using infection shortcut node pair C_1D_1 in O_1 as diameter, supposing the distance between the longest node in O_2 and the centre o_1 of O_1 as E_1; H_1 is the distance of o_1E_1, when $C_1D_1=2^{1/2}r_1$, H_1 reaches the maximum value $2^{1/2}r_1$, and at this time, O_2 extends the diameter of O_1 to the longest with the external expansion $d_1=(2^{1/2}-1)r_1$. Similarly, creating a minimum infection ball O_3 using infection shortcut node pair C_2D_2 in O_2 as diameter, when $C_2D_2=2^{1/2}r_2$, H_2 reaches the maximum value $2^{1/2}r_2$ and at this time, O_3 extends the diameter of O_2 to $d_2=(2^{1/2}-1)r_2=(2^{1/2}-1)(2^{1/2}/2)r_1$. In sequence, if $C_2D_2\ldots$ and $C_nD_n\ldots$ are parallel, the total external distance will be the maximizing of $H=d_1+d_2+\cdots+d_n+\cdots=2^{1/2}r_1$.

If energy consumption in route $vw_1,\cdots,w_ku$ is not more than E^*_n, nodes $w_1,\cdots,w_k$ must be the centre of the ball as the midpoint of the two nodes in the maximum infection ball using the $(2^{1/2}+1)$ times of the distance between the two nodes as diameter. Hence, it can find out the optimal route of two nodes in the maximum infection ball, so as to reduce the path-finding range. Meanwhile, it also proves that corresponding to different route recession modes (regarding power of $q(2<q\le 4)$ side length as weight) can find out the optimal route diagram G^* which is the sub-graph of G when $q=2$. In this case, under the multi-route recession modes, the optimal route from source node to goal node is located in the maximum infection ball of G.

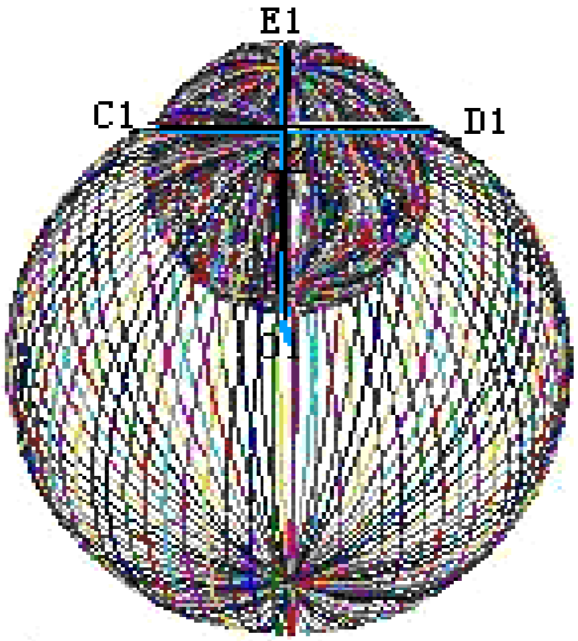

Fig. 2. The maximum extended diagram of radius of the minimum infection ball.

Theorem 2: the obtained optimal route diagram G^* under the multi-route recession modes is corresponding to the sub-graph of G when $q=2$.

Theorem proving: while proving G^* is the sub-graph of G, that is no new edges are added into the diagram G when G is transformed into G^*. Supposing the edge (v,u) has been added as the shortest path from node v to node u and the route $(v=v_{m0},v_{m1},\cdots,v_{m(n-1)},v_{mn}=u)$ in diagram G as the optimal path from node v to node u, it has contracted with

$$|v-u|^q=(|v-u|^2)^{q/2}\ge(\sum_{r-1}^{n}|v_{mr}-v_{m(r-1)}|^2)^{q/2}\ge$$

$$\ge\sum_{r-1}^{n}|v_{mr}-v_{m(r-1)}|^q,$$

so it proves. The diagram G^* is the sub-graph of G.

2.4. ACO (Ant Colony Optimization) Routing Policy

The ants randomly explore the regions around ant nest. Once finding out the food, it will access the food quality and quantity, and leave a volatile secretion of pheromone on the way back, while the

amount of pheromone depends on food quality and quantity. In the algorithm [2], ants will select next hop node at a certain probability. The probability of ant k on node i selecting node j in node i neighbor list as next hop node is:

$$p_{ij}^{k} = \lambda_1 \frac{(h_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_{j \in N_{ij}} (h_{ij})^{\alpha}(\eta_{ij})^{\beta}} + \lambda_2 \frac{(E_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_{j \in N_{ij}} (E_{ij})^{\alpha}(\eta_{ij})^{\beta}}, \quad (1)$$

From above, N_{ij} is the available neighbor node set of ant k on node i; h_{ij}, η_{ij} and E_{ij} are the pheromone level, heuristic information of energy consumption and the heuristic information of the rest energy from node i to node j respectively; while the parameters α and β are adjustable weights of pheromone level and energy heuristic information; λ_1 and λ_2 are non-negative bias parameters which reflects the degree of bias for pheromone level and the rest node energy.

If ant k on node i selects node j as next hop node, then after it transfers to the node j, firstly according to the below

$$h_{ij} \leftarrow (1-\xi)h_{ij} + \xi h_0, \quad (2)$$

To update local pheromone, in the above equation with $0 < \xi < 1$, h_0 is the initial value of pheromone. After arriving at goal node, it can calculate the optimal route.

After the ants all arriving at the goal nodes, choosing the minimum optimal route and directing the forwarding ants by using

$$h_{ij} \leftarrow (1-\rho)h_{ij} + \rho \Delta h_{ij}^{vu}, \quad \forall (i,j) \in T^{vu} \quad (3)$$

To update the overall pheromone, from the above equation, T^{vu} represents the minimum optimal route from source node v to goal node u; $\Delta h_{ij}^{vu} = 1/C^{vu}$ is the incremental pheromone and C^{vu} is the charge of optimal route; ρ stands for evaporation rate of pheromone.

3. The Description of CORA Routing Algorithm

In view of above ant colony optimization, in order to make full use of free sources in different layers, it proposes a path-finding with two-layer joint optimization. In mode 1, the path-finding operation in control layer only should transfer in this layer, if control layer hasn't enough channel sources, and then the operation will be rejected. It also presents the joint optimization of mode 2 for reducing congestion of control layer that is, when the control layer has enough free sources, which can transfer the congested path-finding down to the data layer, so as to realize two-tier network joint optimization.

Mode 1: the path-finding process of CORA routing algorithm in control layer as follows:

1) The source node v broadcasts the searching information to the control layer for the goal node u. After finding out the goal node u, by using the location of node u, node v can figure out the coordinate of the centre and diameter of the maximum infection ball determined by the two nodes.

2) Control layer is placed on m species of ants, each of which has n ants, and then direct an ant from node v to search for the route of node n every once in a while. The ant has the information including: the maximum infection ball information, ID and the rest energy of source node and all nodes via the route.

3) The ant k on node i firstly uses the information that carried with to revise the neighbor list of node i, deleting the nodes beyond the maximum infection ball and the nodes visited by ant k. Then, it selects next access node in the revised neighbor list with the pseudorandom rules. After reaching the next hop node j, it firstly updates the information that it carries with, and then the local pheromone based on the equation (2).

4) After an ant arriving at the goal node, it can calculate the optimal route according to the equation of [10]. After all species of ants arriving, selecting the minimum route and gathering in the optimal route, and updates the overall pheromone based on equation [3]. Then, starting the next specie path-finding, until all the ants have finished the routing, it can select the minimum route as the optimal route from source node to goal node.

Mode 2: the path-finding process for CORA routing algorithm under the two-tier network joint optimization, shown as follows:

1) The ant k is a real-time arrived path-finding operation in control layer. When the control layer has enough network sources, the ant k will start to find the optimal route in this layer on the basis of mode 1; otherwise, tuning to (2).

2) The ant k on node i will firstly scout the data transport layer to find out whether there is enough channel source for path-finding between the available nodes in node i and its neighbor list. If not, then the ant k will stop and refuse to carry out this path-finding operation; otherwise, turning to (3).

3) The ant k starts the path-finding on the data transport layer to find out the next hop node j based on the (3) of mode 1 for transmitting this operation. Arriving at the node j, the ant k will firstly to scout whether there is enough channel source between node j and its neighbor node in control layer to

carry out this operation. If not, the ant k will continue the operation, or back to the control layer and find the optimal route based on mode 1.

4. Simulation Experiment

Our algorithm and an energy efficient routing algorithm based on ant colony algorithm (EEABR) in reference of [10] together with an energy efficient routing algorithm based on ant colony strategy in reference of [9] are compared by simulation. It randomly deploys 160 nodes in 180 m × 200 m rectangular area; and the node initial energy is 5J, delivery power consumption 16 mw, reception power consumption 10 mw and MAC protocol IEEE802.11; the control and data channel bandwidth is respectively 0.4 Mb/s and 1.6 Mb/s; while in equation (1), the adjustable weight of pheromone level is $\alpha = 1$, and the adjustable weight of energy heuristic information is $\beta = 2$ as well as the non-negative bias parameter s of pheromone and heuristic information is respectively λ_1=0.6 and λ_2=0.4. At the same time, supposing the size of data packets as 350 byte, source node and goal node are respectively fixed on the opposite angles of the rectangle area, using statistical data analysis for about 20 times, and then regard these 20 times simulations as the experimental results.

Fig. 3 has described the algorithm related network congestion under the same network load. It can be seen from the Fig. 3 that when the packet generation rate is faster than 35 pack/s, the correspondence network congestion of EEABR and EEAWSN has risen sharply, while the CORA congestion increasing slowly. There are two main reasons for this phenomenon: one is because our algorithm uses a joint scheduling policy, effectively utilizing channel resources in different network layers to reduce congestion; the other is because CORA uses a dual channel isolation transmission mode, reducing the multi-cast suppression and communication conflicts, which improves the efficiency of data packet transmission and reduce the congestion. Fig. 4 describes the average time of transferring data packet from source node to goal node by running those three algorithms under the same network load. From the Fig. 4, it shows that CORA transmission uses the least average time, and with the increasing network load, the correspondent data transmission time of EEABR and EEAWSN had a higher rise than CORA. The reason for this is that both EEABR and EEAWSN adopt single channel communication mode, so the channel competition in high load network, the message conflicts caused by data packet and control packet is far more possible than CORA using dual-channel communication mode, consequently extending the packet transmission time.

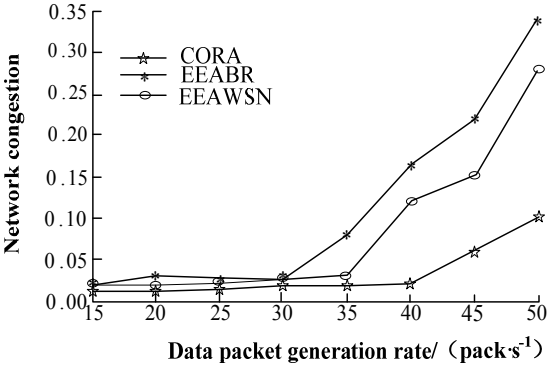

Fig. 3. Network congestion

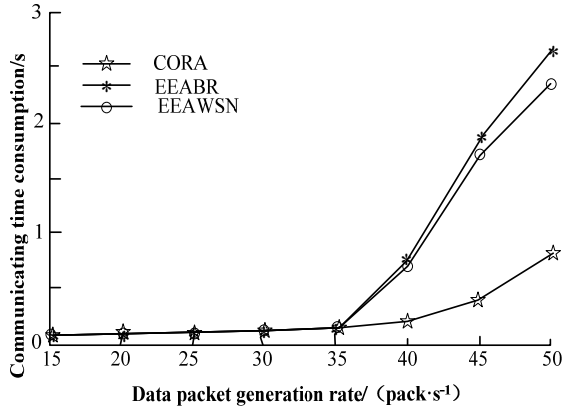

Fig. 4. The average time consumption of data packets transferring to goal node.

Fixing the location of source node at the left bottom, continuously moving the goal node and using CORA, EEAWSN and EEABR respectively to find out the related optimal routes; and then transferring 3500 bits of information to the respective optimal route, it can compare the total energy consumption of these three algorithms. It can be observed from Fig. 5 that the total net energy consumption of CORA is the lowest, especially when the source node is relatively close to the goal node.

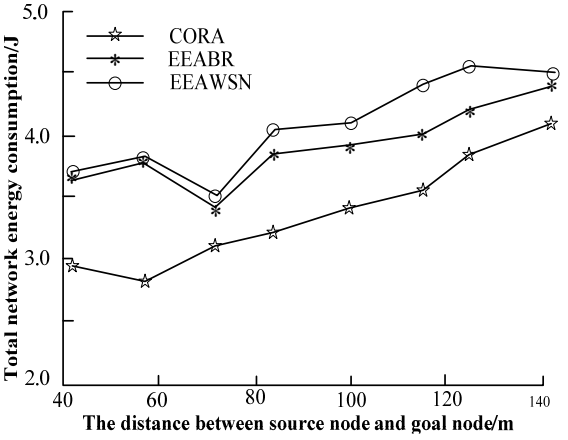

Fig. 5. Energy consumption of communication.

This is because the closer source node to goal node, the more visited nodes will be deleted by maximum infection ball policy and the smaller the sub-graph used to find out the optimal route. However, EEAWSN and EEABR look for optimal routes in the whole network, thus the energy consumption of these two algorithms will be higher than CORA.

5. Conclusions

Aiming at the mutual collision and inhibition of data packet and control packer in channel competitions, this paper proposes a CORA algorithm. It transfers these two packets in isolation, completely eliminating their message conflicts. In addition, the algorithm integrates the control layer and data layer into a network for joint scheduling. When the data layer has enough free sources, it can transfer the congested path-finding operations in control layer down to the data layer in real-time, reducing the network congestion. Meanwhile, the CORA algorithm also uses the maximum infection ball policy to narrow path-finding range, in order to reduce the energy consumption during this process, and also can prevent the path-finding from routing void.

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