A Data-aggregation Algorithm Based on Adaptive Ant Colony System in Wireless Sensor Networks

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Abstract

Data aggregation is an essential paradigm for energy efficient routing in energy constraint wireless sensor networks (WSN). Data aggregation in WSN can be treated as searching for the Minimum Steiner Tree (MST) including source nodes and sink node. In this paper, we propose a Data-aggregation Algorithm based on Adaptive Ant Colony System (AACS) algorithm. In this algorithm, Directed Diffusion (DD) is used to deliver interest message, and AACS algorithm is used to construct MST. The data sent by the source nodes is transmitted to the constructed MST and then is retransmitted to the sink node after aggregation. Compared with Destination Driven Shortest Path (DDSP) algorithm, NS2 simulation result shows that this algorithm can help reduce network energy consumption and prolong the life span of the network.

1. Introduction

Wireless Sensor Networks (WSN) have attracted more attention and got fast development for its high dependability, easily distributable and extensible features. Compared with traditional networks, WSN have great difference in data transmission:

(1) Node energy is limited and can be used for only one time. Therefore, energy saving has to be considered when doing network design.

(2) Each node's monitoring scope and its dependability are limited.

In order to increase the whole network's robustness and accuracy when receiving information, the monitoring scopes of each node have to be overlapped when distributing nodes. As a result, there will be some redundant data collected by nodes, leading to the increase of network load. Hence, the redundant data coming from different source nodes has to be processed in the network. Before retransmitting data, the first task of intermediate nodes is to integrate data through aggregation, take off redundant data and minimize the transmitted data volume with the application requirement satisfied. The amount of calculation of intermediate nodes is increased by applying data aggregation, but the redundant data has been greatly decreased when transmitting data, and the collision among information channels can also be decreased, which can help reduce communication energy consumption. Compared with the energy consumption in transmitting data, the energy consumption in processing data is much less. By combining routing protocol and data aggregation and by using data aggregation to balance each node's energy consumption in the network, the life span of network can be prolonged. Data aggregation plays an important role in the research of WSN [1].

Data aggregation in WSN can be treated as searching for the Minimum Steiner Tree (MST) including source nodes and sink node. Considering network energy saving, a data-centric routing protocol is proposed: a Data-aggregation Algorithm Based on Adaptive Ant Colony System (AACS) uses Directed Diffusion (DD) to distribute interest message and applies AACS algorithm to construct the MST. The data coming from the source nodes is transmitted to the constructed MST, and then is transmitted to the sink node after being aggregated, which can help reduce the amount of the transmitted data in the network. Compared with Destination Driven Shortest Path (DDSP) algorithm, it has been proved that this algorithm can efficiently save energy.

2. Data Aggregation in WSN

WSN includes more source nodes and fewer sink nodes, so the routing problem in WSN can be treated as searching for the optimal path from source nodes to sink node in the network. Suppose use the weighted connected graph $G = G(V, E, \omega)$ to represent the given WSN, in which V represents the assemblage of nodes, E represents the assemblage of links, ω: $E \rightarrow R^+$ is the cost of each link in E. For the two nodes v_k and v_l in WSN, only when they can exchange information, $e_{kl} = (k, l) \in E$. Owing to the limitation of the launching semidiameter and energy, normally each node can only exchange information with some nodes near it. Therefore, G is not a

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complete graph. Suppose $S \subset V$ is the assemblage of the source nodes, $d \in V$ is the only sink node in the network. Thus multisource and single destination routing problem can be seen as searching for the tree t_s including all of the nodes in $S \cup \{d\}$ in graph G, which can minimize the cost of the tree:

$$\omega(t_s) = \min \sum_{e \in t_s} \omega(e) \qquad (1)$$

It is clear that data aggregation in WSN actually is to search for the MST including source nodes and sink node [2].

3. AACS Algorithm

There are many algorithms centering on searching for MST. At present, the representative algorithms include Destination Driven Multicast (DDMC) algorithm, DDSP algorithm, Shortest Best Path Tree (SBPT) algorithm and Ant Colony Optimization (ACO) algorithm etc. Considering the practicability of algorithm in WSN, AACS algorithm is proposed to construct the MST.

By simulating ants' behavior of searching for food, ACO algorithm is a kind of heuristic and intelligent algorithm. It has been firstly and successfully applied in dealing with salesmen. It applies distributed parallel computing system, which has strong robustness. ACO algorithm description is as follows: Ants in the nature can give out a kind of pheromone on the path after walking when they are searching for food, which can help other ants within a certain range, perceive it and can affect their behavior. The more ants pass along some paths, the more pheromone is left on the paths, the higher the pheromone intensity will be. With the increase of the pheromone intensity, the probability for ants to select these paths is increasing, which can help further increase the pheromone intensity. Meanwhile, with time flying, the pheromone will dissipate in a certain proportion. The pheromone on the paths on which there are fewer ants passing will disappear gradually. ACO algorithm applies colony intelligence to set up path selecting system, which is very suitable for WSN with enormous nodes. But ACO algorithm still has some disadvantages. For example, it needs long time to do calculation and stagnation often happens.

AACS algorithm, which is designed to construct the MST, can efficiently avoid early stagnation caused by ACO algorithm. AACS algorithm originates from ant colony system (ACS) algorithm [4]. The chief concept of adaptive ant colony system algorithm is as follows.

3.1 Transition Probability

In this algorithm, suppose in iteration NO.m, ant NO.i, $A_i^{(s)}$ starts out from source node v_s and its current location is v_k, and in this iteration, the partial tree produced by ant NO.i starting out from source node NO.s-1 is $t_S^{s-1}(i)$, the partial tree branch produced by ant $A_i^{(s)}$ starting out from source node is $b_p^{(s)}$, and when $v_k \notin t_S^{s-1}(i)$, the probability of $A_i^{(s)}$ to select the next location v_l is as follows:

$$P_{k,l}\left(m, t_S^{s-1}(i)\right) = \begin{cases} \arg \max\limits_{v_l \notin b_p^{(s)} and (k,l) \in E} \left\{ \tau_{kl}(m) [\eta_{kl}]^{\beta} \right\}, & if \quad q \le q_0 \\ J, \ otherwise & \end{cases} \qquad (2)$$

In the above equation, $q_0 \in (0,1)$ is constant exponent, $q \in (0,1)$ is random number; $\tau_{kl}(m)$ represents the amount of pheromone on the link (k,l) in iteration *NO. m*; η_{kl} represents the heuristic information from node v_k to node v_l, normally $\eta_{ij} = 1/\omega(k,l)$, $\omega(k,l)$ represents the hop count from v_k to v_l; β represents the relative importance of the heuristic information η_{kl}. If $q > q_0$, the probability of $A_i^{(s)}$ to select the next location v_l is J:

$$J = \begin{cases} \dfrac{[\tau_{kl}(m)]^{\alpha} [\eta_{kl}]^{\beta}}{\sum\limits_{v_r \notin b_p^{(s)}, (k,r) \in E} [\tau_{k,r}(m)]^{\alpha} [\eta_{kr}]^{\beta}}, & v_l \notin b_p^{(s)} and (k,l) \in E \\ 0, \ otherwise & \end{cases} \qquad (3)$$

In the above equation, α represents the relative importance of pheromone $\tau_{kl}(m)$.

While when $v_k \in t_S^{s-1}(i)$, the probability of $A_i^{(s)}$ to select the next location v_l is as follows:

$$P_{k,l}\left(m, t_S^{s-1}(i)\right) = \begin{cases} \mathbf{1}, & v_l \ is \ the \ next \ node \ to \ v_k \ in \ t_S^{S-1} \\ 0, & otherwise \end{cases} \qquad (4)$$

Namely, in ant colony system algorithm, ants apply pseudo random proportional action choice rule to select the next node. That is to say, ant *i* located at node v_k moves to node v_l with the probability being q_0, in which v_l is the node to maximize $\tau_{kl}(m)[\eta_{kl}]^{\beta}$. This selection means that with the probability being q_0 and according to equation (2), ants select the most possible node to be part of the path constructed by ants. Apart from this, ants will select the next node according to equation (3) with the probability being $(1-q_0)$, in this algorithm, $q_0 = 0.9$.

3.2 Updating Rule of Pheromone

In order to make full use of circular optimal path and the found optimal path up until now, pheromone is regulated only on the optimal path after finishing iteration No. m. It can be the ant's pheromone updating of the current circular optimal path (local pheromone updating). It can also be the ant's pheromone updating of the optimal path from the beginning of the experiment until now (global pheromone renewal).

3.2.1 Local Pheromone Updating. The function of the local pheromone updating is to make the selected node bring little influence to the following ants which can make ants have stronger ability to explore the nodes which haven't been selected. In this algorithm, when ant moves from node v_k to node v_l , the pheromone on the link (k,l) will be updated according to equation (5):

$$\tau_{kl}(m+1) = (1-\lambda)\tau_{kl}(m) + \lambda \cdot \tau_0 \qquad (5)$$

In the above equation, τ_0 is constant exponent, $\lambda \in (0,1)$ is adjustable parameter. In this algorithm, $\tau_0 = 0.1$, $\lambda = 0.1$.

3.2.2 Global Pheromone Updating. Pheromone on the link which is included in globally optimal path can be updated according to equation (6):

$$\tau_{kl}(m+1) = \begin{cases} (1-\rho)\tau_{kl}(m) + \rho \cdot Q / \omega^{gb}, & (k,l) \in t_S^{*m} \\ (1-\rho)\tau_{kl}(m), & otherwise \end{cases} \qquad (6)$$

In the above equation, ρ is evaporation rate ($0 < \rho < 1$) , ω^{gb} represents the cost of the current optimal path, Q is the amount of the pheromone given out by ants.

Because of the existence of the evaporation rate ρ , the amount of information on the undiscovered path can decrease and even reach 0, which weakens the global searching ability of the algorithm; moreover, when ρ is exceedingly large, and the amount of information of the path is increasing, the explored path's possibility of being selected will be too high, which can affect the global searching ability of the algorithm. By reducing ρ , the global searching ability of the algorithm can be improved, but the convergence speed of the algorithm will decrease [5]. Therefore, in this paper ρ will be changed adaptively. When the optimal value got by the algorithm is not improved evidently in cycle No. m', ρ will decrease:

$$\rho(m'+1) = \begin{cases} \xi \cdot \rho(m'), & if\ \ \xi \cdot \rho(m') \geq \rho_{min} \\ \rho_{min}, & otherwise \end{cases} \qquad (7)$$

In the above equation, $\xi \in (0,1)$ is evaporation constraint rate, $\rho_{\min}$ is the minimum value of ρ , which can avoid the decrease of the convergence speed of the algorithm when ρ is too small. In this algorithm, $\rho(0)$ is the initial value of ρ and set $\rho(0) = 0.6$, $m' = 10, \xi = 0.9$, $\rho_{\min} = 0.1$.

4. Data-aggregation Algorithm Based on AACS in WSN

The data sent by source nodes in WSN corresponds to artificial ants. Hence, data aggregation in WSN can be treated as constructing the optimal path from source nodes to sink node under the condition of knowing sink node. The constraint condition is that the communication distance of nodes' each hop must be within set transmission range. Data aggregation algorithm based on AACS can be realized from three stages: interest message distribution stage, the MST constructing stage and data transmission stage.

4.1 Interest Message Distribution Stage

In WSN, source nodes can retransmit the corresponding data on the condition of knowing the required data type by sink node. Thus, the main task of this stage is that sink node distributes interest message (namely describing the attribute value of the target data) to the whole network. This algorithm applies DD to distribute interest message. Establishing diffusion gradient can make the nodes in the network know the data transmission direction and can know exactly the minimum hop count needed to reach sink node. After this stage, each node can know the data type needed by sink node.

4.2 The MST Constructing Stage

The MST proposed here is constructed according to AACS algorithm. Suppose there are n nodes in the network, among which there are one sink node and s source nodes. Put I ants on source node v_s. m is the iteration counter. The maximum iteration number is M. In each iteration, one ant will be let out in turn until all these I ants are let out. At this time I trees appear and pheromone updating begins and then the next iteration starts. The pseudo code of the MST algorithm based on AACS is as follows:

1. Initialization:
   Set m=0;
   For every link $(k,l)\in E$, set $\tau_{kl}(0)=\tau_0$, $\rho(0)=0.6$;
   Put I ants on source node v_s.
2. for m＝1 to M do
3. {for ant i＝1 to I do
4. {for source node s＝1 to S do
5. {set ant $A_i^{(s)}$'s present location k is on source node NO. s, namely v_s; meanwhile set ant $A_i^{(s)}$'s present tree branch $b_p^{(s)}$ is empty list;
6. While$((k,l)\in E, k\neq l)$
   {According to equation (2) ~ (4) , select the next node v_l with the probability $P_{k,l}$; Add the link(k,l) to the present tree branch$b_p^{(s)}$, shift ant $A_i^{(s)}$ to node v_l , and set $k=l$; }
7. Update $t_S^{s-1}(i)=t_S^{s-1}\bigcup b^s$;
   }
8. Record tree$t_S(i)$'s cost $\omega(t_S(i))$;
   }
9. Record the optimal tree t_S^{*m} found up until now, update the pheromone according to equation (5) ~ (6) ;
10. if （$m>m'$）and（$t_S^{*m'}=t_S^{*m-m'}$）
    Update ρ according to equation (7) ;
11. If (m<M) and (It is not all of the ants to select the same path) {
    m=m+1;
    Go to 2; }
    }
12. Export
13. End of program

4.3 Data Transmission Stage

When the MST constructing Stage finished, each source node will retransmit the detected data to the nodes on the Steiner tree. If this node has only one branch (subnode), it will retransmit the data to its leader node directly. If this node has many branches (subnodes), it will not be finished until all of the branches retransmit the data to it. Then this node begins to conduct data aggregation and retransmit the data to the leader node. This procedure will last until the data reaches sink node.

5. Simulation Experiment and Analysis

Simulation is based on NS-2 of CMU. All of the simulation experiments here are based in the same simulation environment: Nodes are distributed randomly in a 200m×200m sized area. The transmission range of the nodes is R=20m. The key parameters of the simulation are as follows, see table1:

TABLE I. KEY PARAMETERS CONFIGURATION TABLE OF SIMULATION

Mac Protocol	IEEE 802.11
Radio propagation	Two Ray Ground
Energy consumption of node sending/ receiving data	0.660W/0.395W
Node Initial energy	10J
Antenna model	OmniAntenna
Algorithm parameter weight	I=20, α=1, β=1.5, ρ_{min}=0.1, Q=10, q_0=0.9, τ_0=0.1, λ=0.1, ζ=0.9, M=20, m'=10

Simulation models of data aggregation are DDSP algorithm (DDSP-Steiner for short below) and the proposed algorithm (AACS-Steiner for short below). We evaluate algorithmic performance in two aspects: network energy consumption and network life span.

5.1 Network Energy Consumption Analysis

Set the number of nodes N in the network to be 100, the number of sink node to be 1 (fixed location), the number of source nodes to be 2、4、 6、8、10, and the running time of the network to be 100s. In the two algorithms, the changing tendency of the energy consumption of the whole network with the changing of the source nodes number is as follows: see figure 1. The figure shows that in the same simulation environment, in AACS-Steiner the energy consumption of the whole network is lower than that in DDSP-Steiner. What's more, with the increasing of the source nodes number, the superiority of AACS-Steiner is more evident.

5.2 Network Life Span Analysis

Set the number of nodes N in the network to be 100, the number of source nodes to be 6. The life span of the network can be represented by the average remaining energy of the nodes. Obviously, the higher the remaining energy of the network, the longer the life span of the whole network. In the two algorithms, with the changing of simulation time, the changing tendency of the average remaining energy of nodes is as follows: see figure2. It can be seen from the figure that in the same simulation environment, in AACS-Steiner, the average remaining energy of nodes is higher than that in DDSP-Steiner.

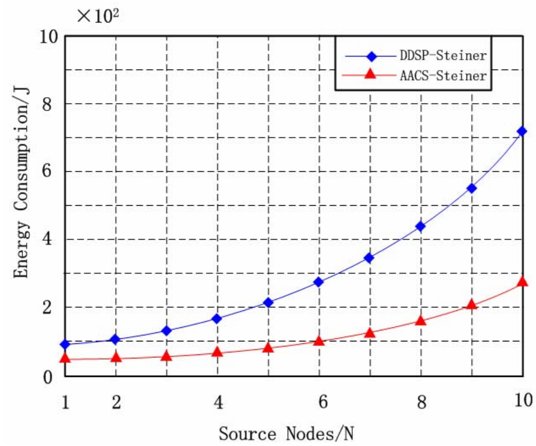

Figure 1. comparison of the energy consumption of the whole network in the two algorithms

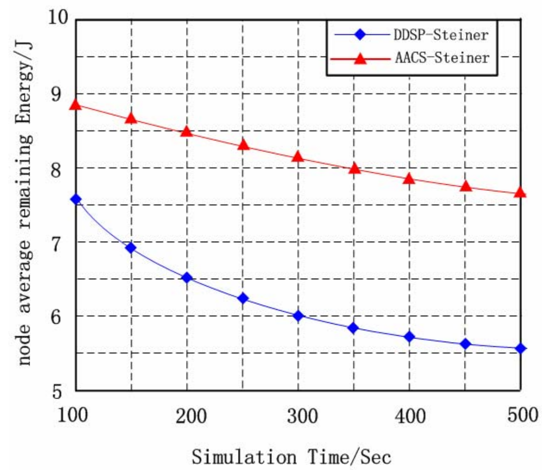

Figure 2. comparison of the average remaining energy of the node in the two algorithms

6. Conclusion

In WSN, proper data aggregation can help save energy and prolong the life span of the whole network. Data aggregation in WSN can be treated as searching for the MST including source nodes and sink node. A Data-aggregation Algorithm based on AACS in WSN proposed applies DD to distribute interest message and construct the MST through AACS algorithm. The data from source nodes is transmitted to the constructed MST and is retransmitted to sink node after aggregation. Simulation result shows that this algorithm is feasible and efficient.

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