An Improved Routing Algorithm Based on Energy Efficient Ant Colony

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Abstract

For the problem that the existing multi-path routing protocol in the MANETs can't offer high-quality services with increasing the number of nodes and speed, an improved algorithm is proposed based on Energy-Efficient Ant-Based Routing Algorithm (EEABR) through Ant-Colony algorithm (ACA) in this paper. The improved algorithm makes improvement on packet structure and the way of updating pheromone. In order to save the energy consumption caused by the field redundancy in EEABR, based on the different tasks of the forward ant and the backward ant, the algorithm proposed in this paper designs two kinds of reasonable packet structures. The pheromone updating is added to the tasks of the forward ant in this algorithm to speed up the convergence rate.The path length is considered when pheromone updating is executed by the backward ant, the ants release more pheromones on the node which is closer to the destination, which makes the destination node is more likely to be found and speeds up the convergence rate. The improved algorithm shows higher superiority on energy consumption and prolonging the network lifetime than EEABR.

Keywords: Ant-Colony, EEABR, Wireless sensor network, Routing

1 Introduction

The battery is the energy source of sensor nodes in wireless sensor network [1], but because of the limitation of their own size and the environment, the nodes' computing and storage ability is very limited. And it is difficult to supplement power to the batteries when the network structure is complicated. At the same time, the highly dynamic of the network, the energy depletion of a single node, as well as the increase of nodes and the harsh environment will lead to the change of the network structure. Therefore, it has become one of the core issues to design a good routing protocol to extend the network lifetime in the area of wireless sensor network [2-3].

Wireless sensor network belongs to Ad Hoc network. However, it is quite different from the traditional Ad Hoc network. Ant colony algorithm is a new method that is proposed based on the biological phenomenon to solve the combination optimization problems heuristically. It has been demonstrated that Ant-Colony algorithm (ACA) has good performance and huge development potential. ACA has distributed computation ability, which means that in ACA, the action of one ant is simple but very complicate tasks can be accomplished by the cooperation of each ant in a whole colony, which makes ACA attract wide attention of researchers. And it has gradually become the research hotspot in the field of wireless sensor network in recent years.

The remaining of the paper is organized as following. Section 2 describes routing protocol based on ant colony. Section 3 introduces EEABR algorithm. Section 4 describes the proposed algorithm improving EEABR. We introduce the improved data packet structure and pheromone update mode. The computation is completed inside the nodes to reduce the burden in the data transmission phase, and different data packet structures are designed based on the different tasks of forward ant and backward ant. The simulation and verify the effectiveness of the improved algorithm is shown in Section 5. Section 6 concludes the work. To save the energy consumption caused by the field redundancy in EEABR, the proposed algorithm designs two kinds of reasonable packet structures to prevent ants from going back and increasing the search efficiency.

The notations used in this paper are shown in Table 1.

Table 1. Notation

Notation	Abbreviation
Wireless Sensor Network	*WSN*
Ant-Colony algorithm	*ACA*
Energy-Efficient Ant-Based Routing	*EEABR*
Mobile Ad-hoc Networks	*MANET*
Distributed Ant Routing	*DAR*
Ant-Colony-Based Routing Algorithm	*ACRA*
Ant routing algorithm for mobile ad-hoc	*ARAMA*
Ant cycle system	*ACS*
Ant destiny system	*ADS*
Ant quantity system	*AQS*

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2 Routing Protocol Based on Ant Colony Algorithm

Ant colony algorithm is a bionic optimization algorithm based on the simulation of intelligent behavior of ant colony. When the ant is looking for food, the movement of individual ant is blind, but the ant colony has amazing self-organizing ability and can always find the shortest path between the nest and food. By observing the foraging behavior of ants for a long time, bionics learn that during looking for food, ants release chemical hormone on the path [4] to exchange information with others, through which the ants will find the food location accurately. In the initial phase, there is no chemical hormone on the path, and ants find food in a random way. In the process of moving forward, ants release chemical hormone on the link between nodes to guide the other ants to move in the right direction. The path that has more chemical hormones attracts more ants to choose it. However, as time goes by, the chemical hormone will volatilize and become weaker.

AntNet protocol is proposed firstly in [5], it's the first time to apply the ant colony algorithm to establishing network routes. There are forward ants and backward ants set in the routing algorithm. The forward ant chooses the next hop based on the pheromones and some heuristic information. When the forward ant reaches the destination node, it will convert into the backward ant, returning to the source node over the same route and releasing pheromones. AntNet protocol has a strong adaptive capacity to the changing network, but it does not take the energy state of the nodes into consideration, may cause network paralysis because of the depletion of some nodes. Besides, this algorithm can only be applied to the wired network.

Based on AntNet, many researchers and research institutions both at home and abroad introduced the ant colony algorithm to the wireless sensor network, proposing an algorithm called Ant-Colony-Based Routing Algorithm (ACRA), which balances the energy consumption of the main path and other paths. And the routing table updates based on node state in ACRA.

ACRA algorithm applies ACA to mobile ad hoc network successfully [6]. During data transmission, only the packet sequence number, source address and destination address are sent in *ACRA*, which means the cost of ACRA is small. What's more, the pheromones update both when ants head to the destination node and when an ant returns to the source node in this algorithm.

Ant routing algorithm for mobile ad-hoc (ARAMA) protocol adds the information collection of the link, such as the remaining energy of nodes and queue delay, to the tasks of the forward ant [7]. The concept of gradient is firstly proposed in *ARAMA*. And the value of the gradient is calculated and saved by the backward ant base on the information collected by forward ant. When arrives at a intermediate node, the backward ant will update the pheromones on the link based on the value of the gradient. And the bond of the pheromone is limited because of its character of volatilization.

Distributed Ant Routing (DAR) protocol is an on-demand routing protocol [8]. Compared with the active routing protocol, it can reduce the network load during routing. In this protocol, forward ants choose the next node only based on the pheromones and only pay attention to the cross-nodes. And the backward ant releases a certain quantity of pheromones when it comes back to the source node. In DAR protocol, a single ant needs to save the ID of all ants, so the protocol is not suitable for the large-scale network.

Caro proposed AntHotNet algorithm, which is a hybrid algorithm that combines AntNet and ACRA protocol [9]. Thus this protocol has the characteristics of both on-demand routing protocol and active routing protocol, discovering the route on demand and maintaining the route actively. *AntHotNet* consists of four phases: establishing the path on-demand, transmitting data randomly, maintaining the path actively and processing the failure data. A lot of ants are needed to maintain the route in this protocol. Furthermore, each node is supposed to store the information of all nodes that can be reached, so *AntHotNet* is not suitable for the large-scale network.

Wu put forward the HopNet, which is a hybrid routing protocol that has the merits of ARP and DSR. HopNet divides the network into several areas, adopting a proactive routing protocol [10]. In this protocol, the ant can move very quickly from one node to the other nodes at the same area. Besides, the size of each area is not big generally, which can't cause the heavy network load.

The protocols mentioned above mostly do not take into the energy conservation account. The purpose of the ant colony algorithm is to find the shortest path between the nest and the food, and all the data streams will be aggregated on one path finally. However, the energy of the node in WSN is very limited and the nodes on this path may run out of power and stop working. In this case, the ant colony algorithm could not be directly applied to WSN. Hence, an improved algorithm based on Energy-Efficient Ant-Based Routing (EEABR) is proposed in this paper, making improvement on packet structure and the way of updating pheromone.

3 EEABR Algorithm

One of the most important goals of WSN is to save the energy consumption of nodes and alleviate the network congestion to prolong the network lifetime [11]. The main task of the ant colony algorithm is to find a shortest way between the source and the destination node, and save the information of the path by the way. It's found that the data transmission consumes more energy than the internal calculation and memory management of nodes [12]. Thus, the computation should be completed inside the nodes as much as possible. In ant colony algorithm, the IDs of all the nodes that have been visited are recorded in the data packet. However, in the large scale network, with the increase of the amount of nodes in the path, the memory list in packet will grow bigger and the data packet will be larger and larger, which will increase energy consumption of data transmission and reduce network lifetime.

Aiming to solve the excess energy consumption caused by the field redundancy in EEABR, the data package will be redesigned in the paper. For the purpose of that the computation should be completed inside the nodes as much as possible to reduce the burden in the data transmission phase, different data packet structure are designed based on the different tasks of forward ant and backward ant: Pheromone updating is added to the tasks of the forward ant and the update strategy is improved in the proposed algorithm in this paper.

The remaining energy of the neighborhood nodes is taken into consideration when the task of pheromone updating is executed by forward ant leading the later-coming ants move to the nodes with more energy. The energy consumption of the nodes on the path searched by ants is also taken into account. From a global point of view, the improved algorithm shows higher superiority on energy consumption and prolonging the network lifetime.

4 Improved Algorithm Based on EEABR

4.1 Improved Data Packet Structure

In EEABR protocol [13], the packet structure of forward ant can only be distinguished from the packet structure of backward ant by the Boolean field "toSinkNode", which is certain to cause the fields redundancy and waste of energy. In order to solve this problem, the improved algorithm proposed in this paper makes improvement on packet structure of forward ant and backward ant. Different data packet structure is designed based on the different tasks of forward ant and backward ant, only carrying some necessary fields. In the improved packet of forward ant, the "antpath" and "toSinkNode" fields are removed and the "node_all" and "TTL" fields are added meanwhile. The "hp_type" field means the packet type and there are three predefined types: "type_Hello" means the Hello packet, "type_Fnt" means a forward ant and "type_Bak" means a backward ant. "Pkt_src" records the start time of the procedure, "seqno" is used to store a serial number of each forward ant, <pkt_src, seqno> can be a unique identification of a single ant. "E_{sum}" means the total energy consumption on the path searched by the forward ant. When a front ant arrives at a intermediate node, the energy consumption of the node will be added to E_{sum}. "lenFromSrc" records the path length, using the hop counts as the metric. If the TTL value is zero, the ant will stop working and be discarded. "Vis_node" is used to record the visited nodes. The packet structure of the forward ant is shown in Table 2.

Table 2. The forward ant packet structure

hp_type	pkt_src	seqno	node_all	Esum	Vis_node	lenFromSrc	TTL

During the searching process, when a forward ant visits a node that has been visited, the ant will be discarded, which means that there has the loop in the network and the route searching fails. However, in a large scale network, there are a lot of nodes, increasing the probability of the existence of the routing loop in the network, which means a lot energy cost and low success rate of route searching. In order to solve the problem above, the "node_all" field is added to the packet of the forward ant. "node_all" is an address array used to store all of the neighbor nodes of the current node that is being visited. When an ant arrives at an intermediate node, the ant will choose the node that has not been recorded in the "node_all" as the next hop based on the probability. In this case, the ant can be prevented from going back, which increases the search efficiency.

In the backward ant packet, the "E_{sum}" and "E_{min}" fields are removed; "pt_phe" is added to store the pheromone value. "Pkt_src" means the starting address of the forward ant. And "lenFromSrc" is the path traveled by the backward ant as shown in Table 3.

Table 3. The backward ant packet structure

hp_type	pkt_src	seqno	pt_phe	lenFromSrc

"Neighborhood table structure" will be adopted in each node to store the information of the neighbor nodes. In this structure, the "nb_addr" means the addresses of the neighbor nodes, "egy" represents the remaining energy of the neighbor nodes, "phe" is the pheromone on the link between the current node and one of its neighbor nodes. "Hops" is used to record the hop counts from one of its neighbor nodes to the destination node. And "last_update_time" represents the latest updating time of the Neighborhood table as shown in Table 4.

Table 4. Neighborhood table structure

Nb_addr	egy	phe	hops	Last_update_time

4.2 Improved Pheromone Update Mode

In ant colony algorithm, different models (ACS(Ant cycle system), ADS(Ant destiny system), AQS(Ant quantity system)) adopt different pheromone update strategy respectively. ACS uses global update strategy; the pheromone will be updated after the ant completes the current round. ADS and AQS use local update strategy, which means the pheromone will be updated after the ant gets to the next node from the current node.

The ant colony algorithm uses the local or global updating strategy to update pheromone independently. In EEABR, the global updating strategy is adopted, and the pheromone updating process is not performed when the forward ant is searching the route from the source node to the destination node. *Yang* found that the convergence rate of the algorithm will be speeded up if the pheromone updating is added to the tasks of the forward ant [13]. Therefore, the improved algorithm in the paper performs the pheromone updating process when the route searching is performed by the forward ant. The forward ant and the backward ant will update the pheromone according to (1).

$$T_k(r,s) = (1-\rho) * T_k(r,s) + \Delta T_k(r,s) \quad \textbf{(1)}$$

The task of the forward ant is collecting the node information and finding the shortest path from the source node to the destination node. Therefore, in the improved algorithm, the value of the pheromone on the link released by the forward ant $\Delta T_k(r, s)$ is calculated as following.

$$\Delta T_k(r,s) = \frac{[E(j)]^x}{[E_{sum}]^y [PL_k]^z} \quad \textbf{(2)}$$

E(j) is the remaining energy of the neighbor nodes of the current node. E_{sum} is the energy consumption on the path from the source node to the current node. PL_k is the path length from source node to the current node. *(x, y, z)* is the weight of the three parts, reflecting the relative importance of them.

As shown in (2), at the beginning of the proposed algorithm, the path searched by the forward ant is very short and the energy consumption is little, so the forward ant will release more pheromones.

As the path searching continues, the pheromone released by the forward ant will be reduced gradually. Because of the pheromone's character of volatilization, the improved pheromone updating strategy has the ability of balancing the distribution of pheromones on path from a global perspective, breaking away from the local optimum. The amount of the remaining energy of the neighbor nodes was considered, which can lead the later-coming ants to move to the nodes which has more energy. And the energy consumption on the path is also taken into account from a global point of view, which can balance the energy consumption and prolong the average lifetime of the network [14-17].

The value of the pheromone on the link released by the backward ant $\Delta T_k(r, s)$ is calculated as following.

$$\Delta T_k(r,s) = \frac{[E(j)]^a}{[BL_k]^b} \quad \textbf{(3)}$$

When the backward ant is returning to the source node, the path length is not only considered but also the remaining energy of the neighbor nodes. The backward ant releases more pheromones on the node which is closer to the destination node, which makes the destination node is more likely to be found by ants and speeds up the convergence rate of the algorithm.

4.3 Algorithm Description

Step 1. in the initial phase, hello packets are broadcasted to establish relationships between each node and its neighbor nodes. The value of the amount of pheromones on the link between two adjacent nodes is initialized to a constant.

Step 2. For the nodes that need to send the data, a forward ant for each one of them is generated independently and synchronously. Then the routing table of the node that needs to send the data will be checked to see whether there is a direct route to the destination node, and if so, the data will be transmitted along the path in the routing table. Otherwise the next hop will be selected according to the state transition formula to send the data.

Step 3. If a data packet is received by an intermediate node, the packet will be processed according to its type.

Step 4. If the packet type is *type_HELLO*, which means the packet is sent from a neighbor node: If the information of the neighbor node already exists in the neighborhood table of the current node, the table will be updated, If not, the information of the neighbor node will be added to the table.

Step 5. If the packet type is *type_Fnt*: if there has a loop, the packet will be discarded. If the current node is the destination node, then a backward ant will be generated. If the current node is an intermediate node, the packet will be forwarded: If the *TTL* value of the packet is more than zero, the next hop will be selected according to the state transition probability to send the packet. Then the fields in the packet will be updated, and the pheromone will also be updated according to Equation (1) and (2). Finally, go to the third step.

Step 6. If the packet type is *type_Bak*, which means the forward ant has already reached the destination and is dead, a backward ant has been generated, in this case: If the current node is an intermediate node, the fields in the packet will be updated, and the pheromone will also be updated according to (1) and (3). Then the information in the neighborhood table recorded by the forward ant will be deleted, and the packet will be forwarded along the same path. Finally, go to the third step. If the current node is the source node, which means a path from the source node to the destination node has been found successfully, the information recorded in the list by the forward ant will be deleted, then the backward ant will die.

5 Simulation Analysis

5.1 Simulation Platform

In the paper, the *NS2* is adopted to do the experiment [18-19]. To verify the validity of the improved algorithm based on *EEABR*, simulation experiments were done on *NS2* to compare the proposed algorithm with *EEABR* and *IEEABR* [20].

5.2 Simulation Analysis

In this paper, each parameter of the wireless sensor is shown in Table 5.

Table 5. Parameter setting of wireless sensor node

Parameter	Value
Channel type	WirelessChannel
MAC type	802.11
Wireless signal transmission model	TwoRayGround
Drop type	DropTail
Energy mode	EnergyModel
Link layer	LL
Antenna type	Antenna/OmniAntenna
Routing protocol	Antsense

The value is as following: *m=30, α=1, β=4, ρ=0.7*. In order to assess the effectiveness of the proposed algorithm, the proposed algorithm, *EEABR* and *IEEABR* are compared from two aspects: the network energy consumption and network lifetime [21-22].

5.2.1 Network Energy Consumption

In *WSN*, energy consumption is an important indicator of the evaluation of algorithm's performance. Through viewing how the node energy consumption changes with increasing time, the superiority of the improved algorithm is verified. In this experiment, there are 100 selected nodes, and the simulation had been done 30 times to get the average value. *EEABR* and the algorithm proposed in this paper are compared in terms of network energy consumption shown in Figure 1.

From Figure 1, at the beginning, the hello packets are broadcast to establish relationships between each node and its neighbor nodes, the energy consumption of the proposed algorithm and *EEABR* protocol are both large. As time goes by, the energy consumption in *EEABR* is tending towards stability quickly, but the energy consumption is still larger than the proposed algorithm. It can prevent the ant from going back, which can cause that the destination node will be found more quickly, speeding up the convergence rate.

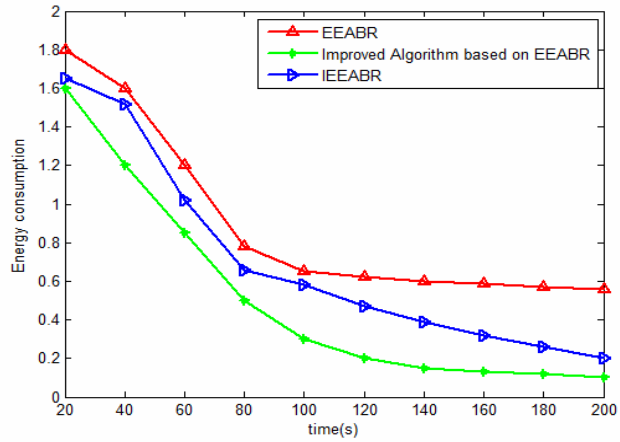

Figure 1. The relationship of network energy consumption and simulation time

When the forward ants find the destination node, the number of the forward ants will be reduced, thereby reducing the average energy consumption of the nodes. However, in *EEABR* algorithm, the routing loop can't be avoided effectively. Hence, compared with the improved algorithm, the convergence rate of *EEABR* is slower, and the amount of the forward ants is relatively large, thus the energy consumption of *EEABR* is more than the proposed algorithm [23-24].

5.2.2 Network Lifetime

Network lifetime can depend on the death time of the first node, the sooner the first node dies, the shorter the network lifetime. Also network lifetime can be determined by the number of the survived nodes in the network, the more survived nodes there are, the longer the network lifetime is. In this paper, based on the two ways to determine the network lifetime, two experiments were done to compare the network lifetime of the proposed algorithm, *EEABR* and *IEEABR*. In the first experiment, the node number is from 50 to 500. 50 nodes were added every time, and each experiment was done 30 times to get the average value shown in Figure 2.

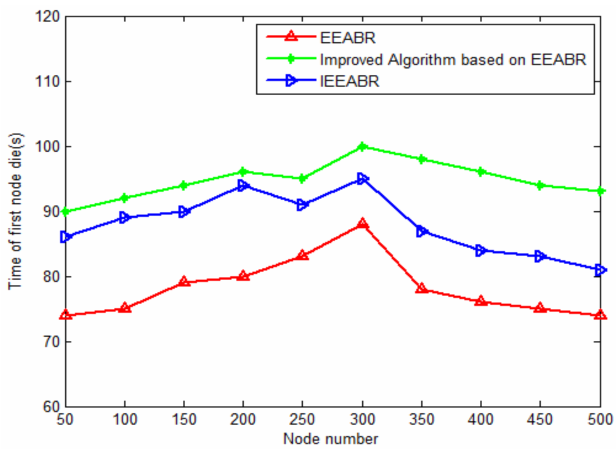

Figure 2. The relationship between the first node death time and node quantity

From Figure 2, the death time of the first node of the proposed algorithm is later than that of *EEABR* and *IEEABR*. The network lifetime of the proposed algorithm is longer than that of *EEABR* and *IEEABR*. In a small scale network, as the path searching continues, the energy consumption for data transmission will be increased, reducing the network lifetime. In a large scale network, there are a lot of nodes, the amount of the hello packet will be increased, and the ants will spend more time to find the destination node, thus the energy consumption will be increased, which makes the network lifetime shorter.

In the second experiment, there are 100 nodes in the network, and 20 seconds are added to the simulation time every round. Each simulation was done 30 times. The relationship between the number of the survived nodes and simulation time is as shown in Figure 3.

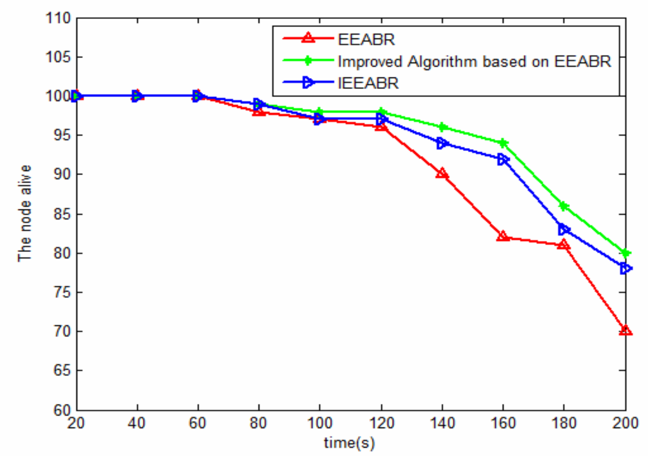

Figure 3. The relationship between the survived node quantity and simulation time

From Figure 3 that within 100s of simulation time, there is no death node in the network in the improved algorithm, but when the simulation time is increased to 85s, there have some death nodes in the network in *EEABR*. When the simulation time is increased to 200s, in the improved algorithm, the number of the survived nodes is still about 80, while in *EEABR*, the number is only about 70.

The network lifetime of the propsoed algorithm is significantly longer than that of *EEABR* and *IEEABR*. This is because the proposed algorithm removes the redundant fields from the data packet, reducing the additional energy consumption and preventing the ants from going back. Besides, the pheromone updating is added to the tasks of the forward ant to speed up the convergence rate. And the path length is considered when pheromone updating is executed by the backward ant. It can reduce the energy consumption, and prolong the network lifetime well.

6 Conclusion

In the paper, the new algorithm is proposed based on *EEABR*. The proposed algorithm makes improvements on packet structure and updating pheromone. To save the energy consumption caused by the fields redundancy in *EEABR*, the proposed algorithm designs two kinds of reasonable packet structures, preventing ants from going back and increasing the search efficiency. In addition, the proposed algorithm also makes improvement on the update strategy of pheromone: The task of updating pheromone is also executed by the forward ant, and the update strategy for the forward ant not only takes the remaining energy of the neighbor nodes into account, but also considers the energy consumption of the whole path, balancing the energy consumption of the network and prolonging the network average lifetime. While the update strategy for the backward ant takes the path length and the remaining energy of the neighbor nodes into consideration, speeding up the convergence rate of the algorithm. In this paper, the proposed algorithm make the computation be completed inside the nodes as much as possible, reducing the burden in the data transmission. Besides, the proposed algorithm simplifies the packet structure, reducing the network energy consumption. The proposed algorithm is simulated on *NS2*. The proposed algorithm shows higher superiority on energy consumption and prolonging the network lifetime than *EEABR*.

Acknowledgments

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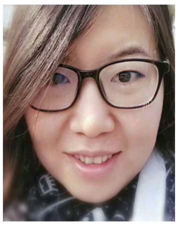

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