Multicast Optimization and Node Fast Location Search Method for Wireless Sensor Networks Based on Ant Colony Algorithm

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ABSTRACT: Wireless sensor network is a new information acquisition and processing technology. A large number of sensor nodes form a network through self-organization including each node integrates sensing unit, processing unit, communication unit and energy supply. The protocol multicast technology of wireless sensor network routing is a means of group communication, which requires information from the source node at the same time sent to multiple destination nodes, routing as the core technology of multimedia networks, its scope of study is extensive, including routing protocols, routing strategy and routing algorithms. In this paper, we mainly study the multicast routing algorithm which is based on Quality of Service (QoS), and introduce the search strategy which is based on the shortest path of pheromone in the process of ant colony feeding. MATLAB ant colony algorithm is also used in the WSN routing protocol multicast problem in the application of the problem solving for local optimization. The result of computer simulation shows that the ant colony algorithm has a better effect on solving the multicast protocol of WSN, and the algorithm can realize the fast positioning and query of wireless sensor network routing nodes.

Subject Categories and Descriptors
[C.2.2 Network Protocols] ; Routing protocols: [C.2.1 Network Architecture and Design]; Wireless communication [I.1.2 Algorithms]

General Terms: Wireless Communication, Routing Protocols, Ant Colony Algorithm, Multicast Optimization

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1. Introduction

In recent years, with the development of microelectronics technology, sensor technology and communication technology, wireless sensor network technology has developed rapidly and progressed rapidly, and some concrete applications in military and civilian have also been successful. Its wide application makes the future of wireless sensor networks a bright future [1]. The wireless sensor network is a wireless network composed of many sensor nodes through wireless media connection. It uses Ad hoc to configure a large number of micro-intelligent sensor nodes to collect and process the target information in the network coverage area through the cooperative work of the nodes. Wireless sensor networks have a wide range of applications in environmental and military monitoring, seismic and climate prediction, underground, deep water and outer space exploration [2, 3]. It can be said that the wireless sensor network is a revolution in information perception and collection which is one of the most important technologies in the 21st century. The wireless sensor network consists of a number of wireless sensor nodes with the same or different functions. Each sensor
node consists of data acquisition module, data processing and control module, and communication module and power supply module composition [4-6]. A node can act as a data collector, a data transfer station or a group header, and a cluster head node role in the network. As a data collector, the data collection module collects data of the surrounding environment, and transmits the data directly or indirectly to the remote base station or sink node through the communication routing protocol. As a data transfer station, in addition to the completion of the acquisition task, the node helps to receive the neighbor node data, which also has forwarded to the base station closer to the neighbor node or directly forwarded to the base station or sink node, as a cluster head node, the node is responsible for collecting the cluster. The data collected by all nodes is sent to the base station or sink node after data fusion.

Unlike the traditional Internet, Wireless Sensor Network is task-based networks that cover data sensing, processing, and their QoS parameters which not only include a series of traditional Performance parameters, but also are related to energy consumption overhead, network life cycle, coverage, connectivity and other more extensive QoS indicators. Therefore, the traditional network QoS architecture is not directly applicable to the wireless sensor network [7]. On the other hand, the basic application types in the wireless sensor network include event-driven, time-driven and query-driven applications. The events of the wireless sensor network are more complex in the wireless sensor networks. Driven applications focus on real-time and reliability, data traffic has a certain degree of sudden. The time-driven applications commonly used in pre-defined rate of application scenarios, if the transmission of real-time data such as images or video, concerned about the transmission delay and throughput [8, 9]. If the transmissions of non-real-time data include temperature or humidity, the more concerned about the reliability of the query used for interactive applications moving scenes, the data transmission emphasis timely and reliability.

The QoS index is discussed from the perspective of network stratification, and the influence relation of each level QoS index is analyzed. On the basis of the traditional network level, the QoS index is often too focused and the content is trivial. In addition, the scheme mainly aims at providing real-QoS protection, the use of location-based attributes and timers to achieve the event registration and query, using the location of the identity of the transmission protocol, the location of routing protocols, the speed of monotonic scheduling strategy, and supporting the priority of the MAC protocol. This paper creatively put forward a Hierarchical QoS system framework to help guide the specific application of QoS protection technology, in which the ant colony algorithm using distributed parallel computing mechanism, with strong robustness, it is easy to combine with other algorithms [10]. The ant colony algorithm is not suitable for solving the continuous problem, an ant colony algorithm which is suitable for QOS routing multicast is proposed. Combined with the path search, it needs to achieve the algorithm at the same time in the field of the best ant ants to search and the cycle of the optimal solution as the next cycle of the starting solution search. By effectively expanding its search can range to avoid getting into the local optimal problem, the optimization quality and convergence efficiency of the ant colony algorithm are improved to a certain extent, and the algorithm is tested. The result proves the effectiveness of the algorithm.

2. The Relevant Knowledge

2.1 Basic Principles of Ant Colony System

When the ant group finds food, they always find an optimal path from food to lair. This is because the ants in the search path will be released in the path of a special pheromone. When they come across an intersection that has not yet passed, they randomly pick a path forward. At the same time, the pheromone associated with the path length is released. The path is longer, the release of the hormone concentration is lower. When the later ants hit the intersection again, the choice of hormone concentration higher path probability will be relatively large [11, 12]. This forms a positive feedback. The hormone concentration on the optimal path is increasing, and the hormone concentration is in the other pathways decreases with the passage of time. The final ant colony will find the optimal path [13]. In the whole routing process, although the ability of a single ants is limited, but through the role of hormones, the ant colony exchange of information is between the path and ultimately finding the optimal path.

During the process of ants \( k (k = 1, 2, \ldots, m) \), the direction of motion transfer is determined by the amount of information on each path. For the convenience of recording tabu \((k = 1, 2, \ldots, m) \) it can be used to record the ant \( k \) which has now walked through all the nodes, where the table can be said to store the table as a taboo. The collection of nodes will be with the movement of the ants’ dynamic adjustment. In the search process of the algorithm, the ants will intelligently choose the next step to go. The total number of ants is expressed as \( m \), and \( d_j(i, j = 0, 1, \cdots, n - 1) \) is used as the distance between node \( i \) and node \( j \). \( \tau_{ij}(t) \) represents the pheromone concentration \( ij \) at the time \( t \). At the initial moment, there are \( m \) ants which will be randomly placed, and the initial pheromone concentration on each path is the same. At time \( t \), the transition probability of the ant \( k \) from node \( i \) to node \( j \) is here.

\[
\begin{align*}
  p^k_{ij} &= \begin{cases} 
  \frac{\tau_{ij}^\alpha(t)\eta_{ij}^\beta(t)}{\sum_{k \in allowed_k} \tau_{ij}^\alpha(t)\eta_{ij}^\beta(t)}, & j \in allowed_k \\
  0, & \text{other}
  \end{cases} \\
  \end{align*}
\]

\( allowed_k = \{c - tabu_k\} \) means that the ant \( k \) next step can choose all the nodes, \( C \) is the set of all nodes, \( \alpha \) is the information heuristic factor, which represents the relative
importance of the trajectory in the algorithm, which reflects the influence degree of the amount of information on the path of the ant selection, and the other are the nodes [14]. The value is greater, the collaboration between the ants is stronger; it can be called the expected heuristic factor, in the algorithm $\beta$ represents the relative importance of visibility. $\eta_{ij}$ is the heuristic function, which is usually desirable in the algorithm to indicate the desired degree of transition from node $i$ to node $j$. Each ant will perform a search according to formula 1 when the algorithm is running.

2.2 WSN Communication Structure
The wireless sensor network can be regarded as an independent computer network, and its basic unit is the node. In different applications, the sensor network node composition is different, but generally consists of the sensing unit, the processing unit, communication unit and energy supply unit, as shown in Figure 1. Wireless sensor network works as follows, the use of aircraft will be a large number of sensor nodes which scattered to the region of interest, the node through the self-organization helps to quickly form a wireless network [15]. The node is both a collection of information and the sender also acts as the router of the information, and the collected data arrives at the sink node through multi-hop routing. The sink node as a special node, through the Internet, mobile communication networks, satellites and other communication center. You can also use the UAV leap over the network, collecting data through the sink node. With the application and architecture of the different, wireless sensor network communication protocol stack is not the same [16]. Figure 2 is the sensor node using the most typical protocol model.

![Figure 1. Components of nodes in WSN](image)

![Figure 2. The sensor node using the most typical protocol model](image)
The model not only refers to the architecture of the TCP/IP OSI model of the existing general network, but also includes the power management, mobility management and task management of the sensor network. Application layer for different applications provides a relatively uniform high-level interface; if necessary, the transport layer for wireless sensor networks needs to maintain data flow or to ensure that the Internet connection; network layer is mainly concerned with data routing; data link layer coordination of wireless media access to minimize the conflict when adjacent nodes broadcast; physical layer for the system helps to provide a simple, stable modulation, transmission and reception system. In addition, power, mobility and task management are responsible for sensing node energy, movement and task allocation monitoring need to help sensor nodes coordinate sensing tasks and minimize power consumption across the system.

3. Research on Multicast Routing Based on Ant Colony Algorithm in WSN

3.1 WSN QoS Routing

In recent years, a variety of routing protocols have been proposed for wireless sensor networks, but most have assumed that the service is based on a single best effort model. With the deepening of research and application, different services put forward different requirements for network quality of service (QoS), such as periodic monitoring and detection of key parameters in a military monitoring sensor network. The results require reliable transmission, and in event-driven enemy target recognition and tracking, real-time data transmission is very sensitive to delay and jitter [17, 18]. In the wireless sensor network, it is necessary to provide guaranteed differentiated services in the whole network. QoS routing is one of the key technologies to solve the problem.

Wireless sensor networks have three basic entities which are Target, Sensing Node, and Observer Node. The target is the application of the relevant signal source; the sensor node is the monitor of the target information, the number is large but the resources are limited, the nodes are connected by wireless multi-hop non-center; the observation node as the receiver and the controller, Listen and process network event messages, issue query requests to the network, or distribute tasks. In general, the target and the observing node in the network may be one or more, it also may be stationary or motion; the number of sensing nodes is large, usually stationary, where the effective node collecting the valuable information of the target is limited. A route is a process of transmitting valid node information to an observing node. In order to study the convenience, we make the following assumptions, the observation node energy is sufficient, and the sensor node specifications are the same, such as the effective transmission distance, carrying energy, nodes evenly distributed, end-to-end transmission delay can be used to estimate the number of hops; The change of the network topology is caused by the energy depletion failure of the sensor node. In addition, the network can be considered stable.

3.2 Policies Related to QoS Routing

- QoS Measurement Choice

Optional QoS metrics include latency, bandwidth, packet loss rate, and network throughput, its choice reflects the network characteristics and application requirements [19]. Here, the network lifetime is optimized, and the minimum residual energy, delay and delay jitter, and packet loss rate of the path node are selected as the QoS routing metric.

- QoS Routing Calculation

Multi-constrained QoS routing is usually NP-complete and can be used to measure correlation or a single metric helps to reduce computational complexity. In this chapter, the priority scheduling method is adopted for the multi-constraint metric, the selected QoS metric is prioritized according to the demand, and the path selection is carried out [20]. According to the priority, and the next level is calculated based on the subset of the path obtained by the previous level. In addition, the limited capacity of the sensor nodes rely on the neighbor node information distributed computing.

- QoS Routing Maintenance

The frequency of the route update and the size of the message should be in the routing overhead and the calculation accuracy on the compromise. The flooding range and the flooding frequency can be limited by other ancillary information such as geographic information or by setting an update threshold. The route establishment or maintenance opportunity is based on the on-demand drive mode to provide soft QoS guarantee when the connection is not interrupted [21]. When the link fails, the smooth transition of service quality is achieved through redundant path, and adaptive mechanism.

3.3 Model Establishment and Analysis

- Ant Colony Algorithm to Achieve Multicast Optimization

In the optimization function to solve a global extreme problem that is used to find a point \( x_{\text{opt}} \in S \), and used to meet the interval \( S \) in any point \( x \), they also have established \( f(x) \geq f(x_{\text{opt}}) \). The solution space is a regional representation, rather than a discrete point. Therefore, in the solution of continuous space optimization problem, the ant colony selection method is not based on the pheromone size of each point, but the influence of an area pheromone on the ants.

- Ant Colony Initial Position Determination and Pheromone Initialization

In this paper, the minimum value is taken as an example to improve the ant colony algorithm, and the optimization function is as follows: \( y = \min f(x), x = (x_1, x_2, ..., x_n), [S, E]_{m \times 2} \), the ant colony size is \( m \), and \( m \) ants are randomly placed in the optimization space as the starting point of each ant
search. When the number of ants is m, the length of each subinterval is as follows.

$$L(j) = \frac{E(j) - S(j)}{m}, j = 1, 2 \ldots n$$  (2)

The initial position of the ants $i$ is here.

$$x_i = (\text{rand}(S(1), E(i)), \text{rand}(S(2), E(2)), \cdots \text{rand}(S(n), E(n)))$$  (3)

The area of $\text{rand}(S(j), E(j))$ is a random data in $[S(j), E(j)]$.

According to the distribution of the ant location, the different optimization problems help to determine the initial pheromone size.

$$\Delta t(i) = ka^{-f(x_i)}$$  (4)

In the formula, the number $a, k$ is greater than zero. If the function of the minimum value is optimization, $a > 1$; if we get the maximum value of the function optimization, $0 < a < 1$. For the minimum optimization problem, the objective function value $f(x)$ is smaller, $x$ is the more pheromone left at the position; and the objective function value is larger for the maximum optimization problem, the pheromone left $f(x)$ at the position is more.

**Ant Move Rule**

In this paper, the ant colony algorithm is the optimal solution as the other ant next cycle of the starting position, ants moving rules are divided into two parts. First, the ant is not found in the last cycle to move the optimal solution to the optimal solution. The other part refers to the search of the ant in the optimal solution field in order to find a better solution. Here are the two moving rules.

**Rule 1:** After the completion of this cycle, the ants will be the last cycle to find the optimal solution of the ants to transfer. The transfer probability formula is as follows.

$$p(i, \text{best}) = \frac{e^{t(\text{best}) - t(i)}}{e^{t(\text{best})}}$$  (5)

$t(i)$ means the pheromone at the ant $i$, $t(\text{best})$ represents the ant pheromone at the optimal solution.

Ants in the process of moving to the optimal solution, may find a better solution, set the first $i$ ant to the best position to move the step size.

$$x_i = \begin{cases} x_i + \lambda(x_{\text{best}} - x_i), p(i, \text{best}) < p_0 \\ x_i + \text{rand}(-1, 1) \times L, \text{others} \end{cases}$$  (6)

$$0 < p_0 < 1, \ 0 < \lambda < 1$$

**Rule 2:** An ant $\text{best} x_{\text{best}}$ in the last cycle needs to obtain the optimal solution, in the context of the solution to search. If the new position is better than the original position, it will replace the original position with the new position [22]; otherwise, it will leave the original position. The search step $\omega$ should be reduced as the number of iterations increases so that a more accurate solution can be obtained in later searches. Move the formula as follows.

$$x_{\text{best}} = \begin{cases} x_{\text{best}} + \omega \times dx, \text{left} \\ x_{\text{best}} - \omega \times dx, \text{right} \end{cases}$$  (7)

$x_{\text{best}}$ represents the current optimal solution.

In the case, the step size is $dx$, after completing this search, $\omega = 0.1 \times \omega$, the search step is gradually reduced to improve the quality of the solution.

**2.3 Pheromone Update Rules**

After completing the above search, the pheromone at ant $i$ will be updated and the rules are updated as follows.

$$t(i) = \rho \times t(i) + \Delta t(i)$$  (9)

$\rho$ is pheromone volatilization coefficient, $0 < \rho < 1$, $\Delta t(i) = ka^{-f(x_i)}$.

**3.4 Performance Evaluation**

We use ant-cycle, ant-density, ant-density algorithm to access 30 routing nodes, for example, the use of Matlab in the pentium 550pc machine running through the parameters we have the following values were simulated $\alpha \in \{0, 0.5, 1, 2, 5\}, \beta \in \{0, 1, 2, 5\}, \rho \in \{0.3, 0.5, 0.8, 0.9\}$, $NC_{\max} \in \{100, 1000, 2000, 3000\}, Q \in \{1, 100, 1000\}$. A list of representative results is as follows.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\rho$</th>
<th>$Q$</th>
<th>$NC_{\max}$</th>
<th>Time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ant- colony</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>10</td>
<td>1000</td>
<td>193.437</td>
</tr>
<tr>
<td>ant-quantity</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>10</td>
<td>1000</td>
<td>199.569</td>
</tr>
<tr>
<td>ant-density</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>10</td>
<td>1000</td>
<td>208.758</td>
</tr>
</tbody>
</table>

Table 1. Ant colony algorithm results comparison table

Through a large number of experiments we draw the following conclusions.

(1) Ant- colony algorithm compared with the other two algorithms, with better optimization results;

(2) $\alpha$ determines the degree of influence which is the amount of information on the path selection, and $\lambda$ determines the degree of influence from the run to the time spent on the selection. It is found that a better solution
can be obtained when $\alpha = 1, \beta \in \{1,2,5\}$.

(3) The value of $Q$ does not have much effect on the results;

(4) The more the number of cycles, the better the results of optimization, but after 1000 times, the number of cycles in the increase is not too obvious impact.

When $\alpha = 1, \beta = 5$, as shown in the figure below, Figure 3 shows the optimal path curve when the optimization result decreases with the number of cycles, and when Figure 4 is $NC_{\text{max}} = 1000$.

![Multicast tree cost convergence curve](image)

(a)

![Path of the cost and delay changes](image)

(b)

Figure 3. The optimal path curve and path cost
Through the computer simulation, the wireless sensor network multicast routing optimization results and the average distance and the shortest distance, it is shown in figure 4.

Ant colony algorithm is superior to traditional algorithm in wireless sensor network multicast routing optimization and fast node location speed, and the result of optimization is smaller. However, the number of iterations can not
accurately reflect the search speed and effect of the algorithm [22, 23]. The ant colony algorithm can be optimized globally to avoid the early convergence phenomenon, so as to achieve better optimization results.

4. Conclusion

In recent years, with the development of the Internet, multicast technology with its unique superiority has been the industry’s attention. Because of the multicast network, the number of users doubted that the backbone network bandwidth does not need to increase. In addition, many of the current network requirements can not only transmit the conventional best-effort service, but also the requirements of different users need to transmit a certain quality of service real-time multimedia services, so the study of multicast routing algorithm has become an important field of network communications research problem. Because wireless sensor networks are used in many situations, such as natural disasters, battlefields, underground, and oceanic environments that cannot be difficult or difficult to build a basic network, considering the business load of a wireless sensor network, we focus on considering different applications, which are easy to lay the network.

In this paper, the concept, communication structure and characteristics of the wireless sensor network are introduced in detail. The simulation model and the path search method are established by using the distributed QoS routing ant colony algorithm which can fast search the information of the path nodes. Different proportions of mixed business model can be a good support for different business needs of the allocation of resources to achieve the whole network energy consumption balance, through a large number of simulation experiments verify the effectiveness and reliability of the simulation model. Multicast is the inevitable trend of the development of broadband services, the routing algorithm is the key to the realization of the business. However, it is a problem, we cannot use ordinary routing algorithm to solve. Although a lot of research has been done on the problem in recent years, there is no effective solution yet. Based on the study of multicast routing theory, routing model and classical algorithm, this paper proposes an improved ant colony routing algorithm based on ant colony algorithm and a fast location search method, which can effectively solve the network limitations and positioning slow search problem.

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