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Research of QoS routing protocol for underwater wireless sensor network

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ABSTRACT

QoS routing (Quality of Service) protocol is a routing mechanism which selects its path based on available network resouces and QosS requirements of business flow. It is also a dynamic routing mechanism which includes various Qos parameter. With underwater exploration activity continued to strengthen in recent years, the study of underwater wireless sensors sparked a research boom. In this paper, by setting the application of large-scale hydrological monitoring as its background, it analyzes the current QoS routing protocol of underwater wireless sensor networks. Moreover, it elaborats on the network topology structure, data forwarding mechanism and some other problems in the QoS protocol, and try to propose a way to improve the QoS routing protocol.

KEYWORDS

Underwater wireless sensor networks; Network topology structure; Hydrological monitoring; Quality of service; Routing protocol.

INTRODUCTION

In recent years, with the advance of science and technology and the extensive use of Internet, the study of detecting water environment has become a big new research focus. To monitor and protect water regime, people have come up with many effective ways. Among them, the underwater wireless sensor networks have become a new research hotspot because of its high scientific and real-time features, among which the study of routing protocol has become a top priority. However, the underwater wireless sensor network is not without any disadvantages, for example, it has a lower broadband wireless transmission, poor security system, and it is also susceptible to interference, etc., therefore, it is important to select a reasonable routing protocol. In recent years, scholars have proposed many routing protocols in studies[1], especially those based on geographic information system, but because of its high price, it is not widely recognized. Thus, the way of choosing routing protocols has become a major difficulty in studies, but it also enjoys very important significance.

THE UNDERWATER WIRELESS SENSOR NETWORK

Architecture

Generally, there are three basic types of wireless sensor network entities, namely target, sensor node and observer node. A typical wireless sensor system is shown as Figure 1. The target is the signal source, typically have one or more; the senor node is the observer of signals, usually connects each nodes in non-connected ways for wireless multi-hop, but also for one or plurality; the observer nod is the receiver and controller of signals, taking charge of monitoring and transmitting signals, as well as send requests to the network, but the number of active nodes is limited and will vary within a certain range of time and space. The routing which this paper focuses is on its information transmission process from effective nodes to observer nodes.

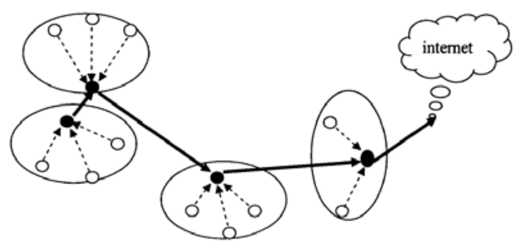


Figure 1 : Architecture Diagram of Wireless Sensor Network

There are two existing sensor nodes in network: one is the sink node[2], usually deployed in the water, it enjoys relatively strong capabilities in processing, storage and communication, and it can connect to sensor network and external network, while and at the same time release monitoring tasks and feed information back to external network; the other is the UW_sensor node, deployed in the underwater 3D areas which are labored to their interest, but its handling and storage capacity is relatively weak.

The hydrological monitoring network based on underwater wireless sensor

Hydrological monitoring network system is shown as Figure 2. The system is divided into three parts: data acquisition, data transmission and data processing. The realization of system function is mainly relied on the coordination and cooperation of senor nods, wireless communication networks and remote data server. The data acquisition of underwater monitoring is relied mainly on underwater sensor nodes. After collecting hydrological parameter data, it transfers data to sink node on the water through a multi-hop way. The realization of some functions of data transmission rely mainly one wireless communication networks and network routing algorithm. After intercepting sink node data, it carries out data fusion, and transmits data to server through wireless communication (internet or GPS). While the remote data server operates the data processing, after receiving monitoring data, it conducts data processing, and then provides relevant department with the hydrological monitoring data.

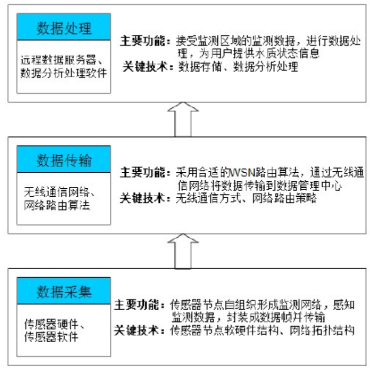


Figure 2 : Hydrological Monitoring Schematic Diagram based on Wireless Sensor

Routing protocol suitable to underwater sensor

According to the route discovery strategy, the wireless sensor routing is generally divided into active routing and passive routing[3]. The node of active routing periodically broadcasts routing information packets to exchange routing information. Based on the information, it takes the initiative to find the route. Therefore, when the node of active routing needs to send a data packet, it can quickly find the destination node, and then find the routing in a relatively less required delay. However, besides from its high costs, it will also result in resource waste because of those invalid routings being built or rebuilt. Thus, for now, the active route is not suitable for wireless sensor routing protocol. On the other hand, the passive route is based on the “labor-saving”principle. It only starts its routing discovery when there is no route destined for the destination node. The advantage of the passive routing is that there is no need to establish or rebuild an invalid routing, thus it saves resources. The passive route, however, also results in data latency, because it starts only when there is no destination node and has to wait in the middle. The use of the passive routing protocol based on the advantages of the passive routing is a unique type of routing protocol in ad hoc network. It enjoys advantageous in lowering routing consumption and increasing network throughput. Nowadays, the widely used wireless sensor routing protocols are mostly passive routing protocols. However, since the monitoring of large-scale hydrological environment requires strong real-time monitoring and small routing delay, so the underwater wireless sensor network is more appropriate to use the active route. Moreover, after taking into account of the limited energy of underwater nodes and the high communication consumption between underwater nodes, this paper introduces a distributed multi-hop network topology, and in accordance with the applicability of the algorithm, it selects the QoS routing protocol. It mainly studies the low-energy consumption routing protocols under the guarantee of QoS parameter in the underwater sensor network. And in order to verify the effectiveness of underwater sensor QoS protocols, this paper conducts a simulation.

MODEL OF QOS ROUTING NETWORK

Scholars define QoS routing as a routing mechanism based on available network resources and traffic flows to select a path; or as a dynamic routing protocol containing various QoS parameters[4]. In this study, QoS adopts the multi-hop distributed sink nodes with underwater sensor network topology structure. As shown if Figure 3, there are two kinds of effective network sensor nodes, one is the UW_sensor nod, distributing underwater 3D areas to be monitored, equipped with underwater acoustic modems to monitor regimen; the other is the sink nodes, locating on the water, using sink nodes to transmit data packets, equipped with RF modems and underwater acoustic modems. When the underwater monitoring environment is triggered, the image senor will collect the underwater environment data, such as pictures, video etc., back to sink sensor through the middle of the sensor in ways of multi-hop, and then to transfer data to the monitoring center through a communication satellite or internet; and finally, the monitoring center can take appropriate measures to deal with the regimen basing on the hydrological data returned, and ultimately it is able to control the regimen.

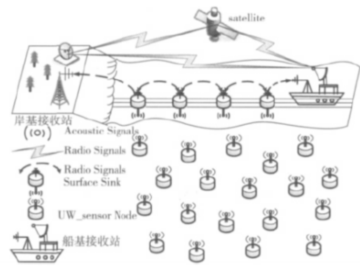


Figure 3 : Model of QoS Network; (shore-based station) (ship-based station)

QOS ROUTING ALGORITHM OF UNDERWATER SENSOR BASING ON ANT-COLONY

Basic ideas

The aim of this paper is on the application of underwater sensor on monitoring hydrological conditions, which requires strong real-time and high energy consumption. Therefore, in designing QoS routing protocols, we can measure the results from time extension as well as energy consumption. While the focus of this study –- ant-colony algorithm is the simulated swarm intelligence algorithm which evolves out of the collective behavior of real ants in nature. The basic principle relies on using artificial ant colony to simulate real ant colony, so as to release pheromones and to find a way forward. In addition, in accordance to the strength of the pheromone, it determines the positive feedback system of individual routing, and ultimately finds the optimal path through the swarm intelligence.

Since ant-colony algorithm is a simulation of ant colony behavior, it relies on swarm intelligence. Also, with the help of individual routing, it does not need the support of global information to solve problems. Ant-colony is very suitable to sensors for its unique dynamic, reliability and scalability. So it receives warmly attention in the field of sensor. Therefore, this paper conducts a study on the application of the ant-colony algorithm in underwater QoS routing algorithm.

Generally speaking, the sensor aims for the data transmission. When a source node needs to transmit data, it will generate an ant, which will find another ant (i.e. other underwater monitoring sensor nods in the underwater monitoring area) inside the area by using pheromone for data transmission. Such ants departing from the source node are known as predecessor ants[5], which primarily responsible for finding data of the transmission path and recording information of the traversed path. In this study, it uses overall information to update the pheromone. When an ant reaches sink node, the sink node can calculate the pheromone update of the entire path of the ant, as well as the pheromone update of another ant returning along the same route. And the later returning ant is called the descendant ant[6]. The data transfer method based on ant-group algorithm can effectively reduce calculated amount of the sensor nodes, so as to achieve the purpose of reducing energy consumption. In this paper, by using ant-colony algorithm, the probability function of the number k ant’s hop from node i to node j is as follows:

$$P_{ij}(k) = \begin{cases} \dfrac{(\tau_{ij}(t))^{\alpha} * (n_{ij}(t))^{\beta}}{\sum\limits_{h \in tabu_k} (\tau_{ij}(t))^{\alpha} * (n_{ij}(t))^{\alpha} * (n_{ij}(t))^{\beta}}; j \in tabu_k \\ 0; j \notin tabu_k \end{cases} \quad (1)$$

Among which, the calculation of the inspiration information:

$$n_{ij}(t) = \begin{cases} \frac{1}{E_{ij}}; & bandwidth(e_{ij}) \geq B_{min} \\ 0; & 其他 \end{cases} \quad (2)$$

Among which, the predecessor ants use the above equation (2) to calculate probability. The $\tau_{ij}(t)$ displays the intensity of the pheromone from node i to node j; α is the regulatory factor which selects the next hop node for pheromone; βis the regulatory factor which selects the next hop node between two nodes. After combining the two equations above, we can calculate the path of predecessor ants. Moreover, the calculation on the time delay from one end to another will be under the charge of the descendant ants. Thus, we have also to calculate the path of the predecessor ants. And the update calculation of pheromone of the descendant ants relies on the following formula:

$$\tau_{ij}(t+n) = (1-\rho) * \tau_{ij}(t) + \rho * \Delta\tau_{ij} \quad (3)$$

Among which, the account form of $\Delta\tau_{ij}$ is:

$$\Delta\tau_{ij}^{k} = \begin{cases} Q; delay > D_{max} \vee e_{ij} \in t \\ Q + \frac{1}{E_{park}(t)}; delay(r_k) \leq D_{max} \vee e_{ij} \in t \end{cases} \quad (4)$$

As we can see from equation (3) and equation (4), when the route of descendant ants from node i to node j does not meet the time delay requirements, we usually use a constant Q pheromone to update pheromone; on the contrary, when the route meets the time delay requirements, we use the overall inspiration information to update pheromone. Moreover, a combination of the two methods is able to avoid the loss of local information.

The description of QoS routing algorithm

In this paper, the study of the routing algorithm is based on the ant-group QoS routing algorithm. In the very beginning, every node in the sensor network acquires N routs with N neighbor node as a hop. The purpose of the QoS routing algorithm is to conduct a comprehensive evaluation of each path from these N routs, and to choose a transmission path which is most energetic and effective.

The basic steps of the optimized ant-colony algorithm in the underwater wireless sensor networks are as follows:

Step 1: NC=0, i.e. the initial search frequency is 0. The pheromone concentration of every route is the initial value. Then the individuals in the ant-colony start to find its routes.

Step 2: In the route seeking process of each ant k (k=1,2,...,m), we can calculate the probability from node i to node j by using the formula (1), and then add node j to $tabu_k$, so as to avoid repeating the same nodes and saving energy.

Step 3: When ants find sink node, we are able to calculate the pheromone of various routes by using formula (3). Thus, we can find the optimal solution, and then update the pheromone.

Step 4: Recording the optimal solution of the descendant ants in step 3, NC=NC+1.

Step 5: If we work out the optimal solution, then the process ends, and we can output the optimal value; however, if we do not work out the optimal solution, then we should go back to step 2 and repeat the process until we work out the optimal value.

Specific algorithm flow chart is as follows:

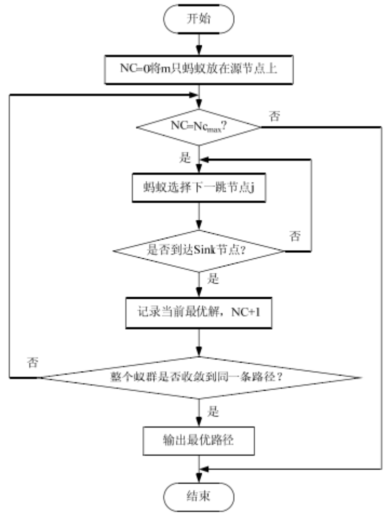
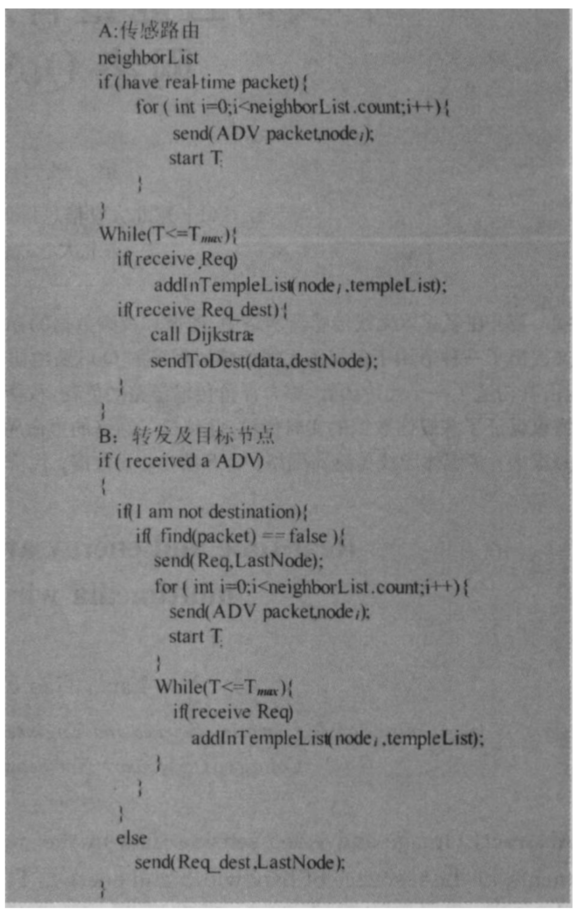


Figure 4 : The Optimized Ant-Colony QoS Routing Algorithm of the Underwater Wireless Sensor Flowchart

The pseudo-code implementation process of the optimized ant-colony QoS routing algorithm of the underwater wireless sensor is described as follows:



```
A:传感路由
neighborList
if(have real-time packet){
    for( int i=0;i<neighborList.count;i++){
        send(ADV packet,node_i);
        start T;
    }
}
While(T<=T_max){
  if(receive Req)
      addInTempleList(node_i,templeList);
  if(receive Req_dest){
      call Dijkstra;
      sendToDest(data,destNode);
  }
}
B: 转发及目标节点
if( received a ADV)
{
  if(I am not destination){
    if( find(packet) == false ){
      send( Req,LastNode);
      for( int i=0;i<neighborList.count;i++){
        send( ADV packet,node_i);
        start T;
      }
      While(T<=T_max){
        if(receive Req)
          addInTempleList(node_i,templeList);
      }
    }
  }
  else
    send(Req_dest,LastNode);
}
```

Figure 5 : The Pseudo-Code QoS Algorithm of the Optimized Ant-Colony

By using the QoS routing protocol based on ant-colony, we can not only achieve real-time hydrological monitoring, but also effectively reduce energy consumption, thus, improving monitoring efficiency.

SIMULATION VERIFICATION

In order to verify the effectiveness of the ant-colony QoS routing protocol of the underwater sensor, and to produce a significant effect, this study carries out a comparative experiment on QoS algorithm based on ant-colony, as well as simulation on SAR and SPEED. In the same experimental environment, therefore, we can compare these three algorithms by using the end-to-end time delay and energy consumption as measures[7].

The SAR algorithm creates multiple routes from source nodes to sink nodes[8]. Also, study of theories demonstrates that multiple mutually exclusive routes in source nodes are exist in the connected network, with the exclusive routes being able to reach the sink nodes. However, the SPEED protocol relies on the stateless and non-deterministic SNGF mechanisms to support the soft real-time communication services[9]. At first, the SPEED protocol carries out signal exchange between neighboring nodes to obtain information on transmission delay and network load, and then chooses the next hop node by using information on local geographic and transfer rates transmitted from the first node, and finally, by using neighboring feedback mechanism to ensure the smooth of the network transmission, so as to lessen routing delay and routing void.

Currently, though there are various kinds of wireless sensor network simulation and the simulated environment[10], this paper uses the NS-2 simulation tool to evaluate the performance of the simulated routing protocols of the wireless sensor. The experiment supposes there are 50 nodes which are randomly distributed in the monitoring area of 500 * 500, and then randomly selects source nodes and destination node among these 50 nodes. The node communication range is set to 60m, the initial energy is set to 10J, and the rate of each node to produce periodically packets is 10packet/s. Moreover, the energy consumption which nodes send packets is set to 0.009(J/Packet), and the energy consumption which nodes receive packets is set to 0.0013(J/Packet). Therefore, in this way, we can accurately compare the effect of the three protocols.

The experimental parameters are set as: α=l, β=2, Q=100, $\rho = 0.5$, $\tau_{ij}(0) = 10$; time delay is limited to 10-30ms; the number of the broadband link is at random among [1, 10]; the number of iterations are 200; and take an average after 200 experiments.

The experimental results of time delay as shown as Figure 6:

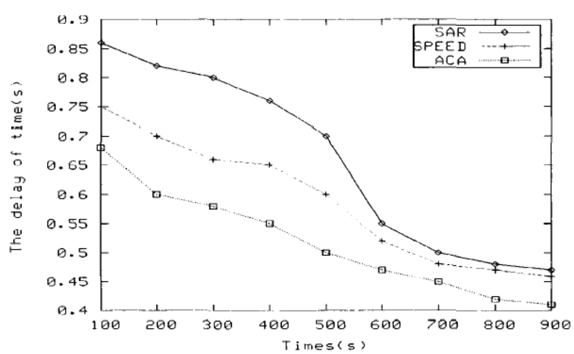


Figure 6 : The Contrast of Time Delay of the QoS Routing Algorithms

The experimental result shows that when the residence time is in the 500s, the QoS routing algorithm based on ant-colony enjoys more advantages in time delay when compared with SAE algorithm and SPEED algorithm. However, after the 500s, the three algorithms tend to have similar time delay. While in the 700s, the difference of the three is the smallest, and even in the 900s, the difference in time delay is below 0.45. Because In the ACA algorithm, while in the process of seeking sink node, its can quickly find various routings which meet the constraints of QoS by using pheromones and positive feedback mechanisms. And with the increasing of dwell time, the network topology structure in ACA algorithm is stabilized. Therefore, the mechanism no longer plays a significant role, and the average time delay becomes smaller and smaller.

Another aspect is the contrast of energy consumptions, and the results are as follows:

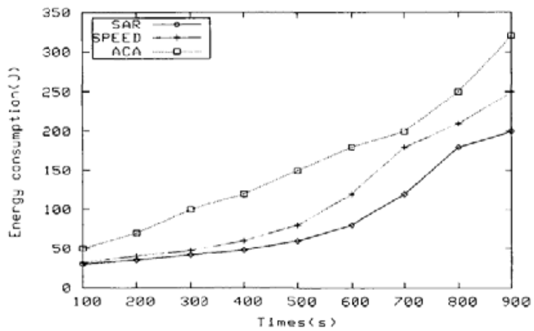


Figure 7 : The Contrast of Energy Consumption in QoS Algorithm

As shown in Figure 7, by contrast, ACA algorithm has higher energy consumption. Since at the beginning of work, ACA algorithm has to do a lot of extra work, thus, its energy consumption reaches to 58J, which is far higher than SAR algorithm and SPEED algorithm. Moreover, the process of ant-colony to find the optimal path is relatively long, which can not be accomplished in a short period. Therefore, the energy consumption of ACA algorithm remains stubbornly high, and results in a large gap compared with SAR algorithm and SPEED ACA. Also, it is one of the major tasks which need to be overcome in studies on underwater sensor QoS routing. To achieve hydrological monitoring, we need much smaller energy-consuming routing algorithm.

CONCLUSION

By studying the architecture and main features of the underwater sensor network, this paper puts forward the QoS routing protocol which is suitable to the application of underwater sensor network. Such QoS routing protocol is called ACA, which is based on ant-colony. Moreover, this paper makes a detailed description of the principles and models of QoS routing protocol based on ant-colony. Through theoretical analysis and simulation experiments, this paper makes a contrast among ACA algorithm, SAR algorithm and SPEED algorithm by using two measures, namely, time delay and energy consumption. After analysis, this paper finds that the QoS routing protocol based on ant-colony enjoys advantages in strong real-time and so on. However, inevitably, it has disadvantages in huge energy consumptions. Therefore, it is a big issue which should be overcame in future studies and should be developed in subsequent researches.

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