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Study on an Energy-aware Routing Algorithm for Agriculture WSN

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Abstract

As precision farming requires real-time, accurate and sustainable monitoring of the biotope of the field, energy consumption and network delay constitute the major factors affecting the performance of ZigBee-based Wireless Sensor Network (WSN) applied in agricultural production. Based on the AODVjr algorithm, this paper presents a new algorithm, namely NS-AODVjr. Featuring emphasis on energy control and dynamic routing, as well as balance between energy consumption and shortest path routing, this algorithm realizes maximum service time of the WSN while ensuring timely and effective transmission of the data in the monitoring process. After a simulation experiment with the Network Simulator tool, results show that, compared to the original algorithm, although the packet delivery rate and network delay witness no improvement, the new algorithm not only significantly reduces the device energy consumption, but also effectively expand the service time of the network.

Keywords: *energy-aware, WSN, routing algorithm, AODVjr, agricultural*

1. Introduction

ZigBee routing protocol is suitable for small-sized and close-range data transmission, and most of the studies on ZigBee protocol-based routing algorithm [1] are focused on routing policy optimization. For example, the study on transmitting power optimizing is aimed at reducing energy consumption for the communication between short-distanced nodes, so as to realize better communication with lower transmitting power; the study on the topology features and address allocation mechanism of the ZigBee network is aimed at reducing the transmitting radius of the routing request packet through adaptive adjustments optimization, so as to realize lower power consumption.

For large-scale agricultural production, as the crop growth cycle is long and covers a wide area, the biotope monitoring system based on WSN has many disadvantages, such as the field impedance, high energy consumption, difficult maintenance, inequality of node energy consumption, short service time and other issues. The system often utilizes the ZigBee routing protocol-based AODVjr (Ad-hoc On-demand Distance Vector junior routing) which is more simplified and practical to realize communication between the nodes or between the nodes and the network [2]. Such a practice may result in the failure of a path or even crash of the entire network, as nodes with low energy may become invalid due to too much energy consumption. Considering the effectiveness and service time of the network [3], it is hard but necessary to find the best path [4] while taking into account the energy state of the node, so as to reduce the energy consumption of the whole network and prolong the network service time.

Considering the special features of large-scale [5] precision agricultural production, this paper, based on AODVjr, presents a new algorithm which combines path weights and dynamic routing. In order to balance the energy consumption of different nodes, and effectively transmit the data with limited energy, this algorithm takes into consideration the estimated remaining work time of the node device in determining the final datagram transmission path, realizing a durable and stable monitoring system for precision farming.

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2. Related Works

There are two routing algorithms in Zigbee NWK layer [6] .One is AODVjr, a modified Ad-hoc On-Demand Distance Vector (AODV), which is the default routing algorithm for ZigBee protocol. The other is a comparatively new algorithm called Hierarchical Routing Algorithm. The second algorithm can lead to unbalanced energy distribution in the network. What is more, some nodes require too much energy consumption [7], which may result in the crash of the whole network. Such a lack of stability makes it unsuitable for agriculture monitoring systems, which require long service time and high stability.

AODV algorithm has been widely applied in wireless ad hoc networks as a routing protocol for mobile nodes. As it was not designed for wireless sensor networks, it did not take into account the lower energy consumption requirement of wireless sensor networks [8]. Considering the fact that the nodes in a WSN are generally in fixed positions, the AODVjr algorithm is more concise and simplified than the AODV algorithm in terms of maximal reduction in node energy consumption. The AODVjr algorithm inherits only the dynamic routing feature of the AODV algorithm, and omits all optimization measures, such as Hello message, routing error message, and query serial number, etc., which are designed for better node mobility, realizing a maximum simplification of the AODV algorithm. Thanks to such a simplification, AODVjr algorithm performs much better than the AODV algorithm in energy consumption, and is widely used in various wireless sensor networks.

However, because AODVjr algorithm does not take into consideration energy control over the bottleneck node in the network, it still has potential to be further improved. The AODVjr algorithm determines the final routing path by comparing the weights of different paths. The path weight is the communication cost between two nodes, which is usually set as a constant value. In fact, the routing algorithm of AODVjr is a kind of Shortest Path Routing Algorithm.

The shortest path routing algorithm can effectively reduce network delay, as most of the network datagram can be transmitted along this path and arrive at the destination node quickly. But the price is that those nodes in the shortest path will consume a lot of power, leading to the failure of some key nodes because of insufficient power, which in turn leads to reduced network service time.

3. Improved AODVjr Routing Algorithm

All kinds of monitoring systems face the same problem of how to achieve balance between device energy consumption and network delay [9]. Therefore, we must choose appropriate routing algorithm or make further improvements according to different monitoring objects, different monitoring requirements and the reality. In agriculture WSN, device energy consumption is more important than network delay. So, the focus of this paper is on how to reduce the node energy consumption as much as possible and expand the service time of the network, while maintaining the normal performance of the monitoring system.

According to the above analysis, this paper presents a new AODVjr algorithm based routing algorithm, which combines energy control and dynamic routing. In routing, the new algorithm takes into consideration the estimated remaining work time of the node device in deciding the final datagram transmission path.

3.1. Calculation of Path Energy Weight

Many challenges, such as the huge number of device nodes, limited battery energy capacity, and insufficient bandwidth, call for energy control mechanism to reduce the node energy consumption and expand the service time of the network. The principle of the energy control mechanism presented in this paper is as follows: the final routing path is calculated according to the node energy weight, which represents the probability of the node being included into the routing set. The goal of this energy weight based calculation method, which is the core of our energy control mechanism, is to convert the remaining energy of the node device to its energy weight, which is a key reference for routing calculation. The mechanism is described as follows:

1) Let $E_{init}(i)$ be the initial battery capacity of node N_i at the time when it joins the ZigBee network, and the remaining battery capacity of node N_i is denoted by $E_{hold(i)}$.

2) In the course of each routing, each node N_i will record its energy consumption caused by transmission, reception, and monitoring activities in $\overline{E_i}(\Delta T_j)$, and then estimate the energy consumption for the next ΔT seconds by utilizing the Exponential Weighted Moving Average method:

$$E_i(\Delta T_j) = \alpha \times E_i(\Delta T_{j-1}) + (1-\alpha) \times \overline{E_i}(\Delta T_j) \tag{1}$$

Where $j \in \{0,1,2\ldots\}$, $0 < \alpha < 1$, α is a variable to adjust $E_i(\Delta T_{j-1})$ and $\overline{E_i}(\Delta T_j)$. $E_i(\Delta T_{j-1})$ represents the estimated energy consumption in the previous ΔT seconds, $\overline{E_i}(\Delta T_j)$ represent the energy consumption value in the newly ΔT seconds. For the initial value, $\overline{E_i}(\Delta T_j) = E_{init}(i) - E_{hold}(i)$.

3) Let L be the estimated number of residual working cycle of node N_i at time $j \times \Delta T$, meaning node N_i can also work for ΔT seconds. L is calculated as $L = \frac{E_{hold}(i)}{E_i(\Delta T_j)}$.

Fn_i represents the estimated lifetime of node N_i at time $j \times \Delta T$, Fn_i is calculated as follows:

$$Fn_i = \sum_{i=0}^{m-1} \overline{E_i}(\Delta T_j) \left(\frac{E_{hold}(i)}{E_i(\Delta T_j)} \right)^{\alpha} \tag{2}$$

According to Eq. 2, the longer lifetime of a node means the more number of working ΔT. The node with minimum Fn_i must be the bottleneck node of a route path, which is composed of N nodes. Once the battery of this node is depleted, this path becomes invalid and a new path should be calculated.

4) Assuming $P = \{P_i \mid i = 1, \ldots m\}$ as the set of all the possible routes between given source N_s and destination N_d. We use the minimal Fn_i for P_i to represent the maximal lifetime of this path, and the average maximal lifetime of set P is $\overline{Fn} = \frac{1}{m}\sum_{i=1}^{m} Fn(P_i)$.

We use $E_{sum}(P_i)$ to represent the total energy consumed by each node of path P_i for data transmission. If the power consumption of each node is fixed in the transmission process, we can use such a fixed value to multiply the number of nodes to get $E_{sum}(P_i)$. Similarly, the average value of energy consumption of set P is $\overline{E_{sum}} = \frac{1}{m}\sum_{i=1}^{m} E_{sum}(P_i)$.

For a given set P, each path weight can be calculated as follows:

$$Val(P_i) = val_1 \times \left(\frac{Fn(P_i)}{\overline{Fn}} - 1\right) + val_2 \times \left(\frac{\overline{E_{sum}} - E_{sum}(P_i)}{E_{sum}}\right) \tag{3}$$

Where val_1 and val_2 are both weight factors, $0 < val_1 < 1$, $0 < val_2 < 1$, and $val_1 + val_2 = 1$.

3.2. Implementation of the Dynamic Routing Mechanism

Appropriate routing request is prerequisite for due performance of the path energy weight. In old practice, the source node looks for new routing paths by periodically submitting routing requests. The source nodes do not usually consider whether there is bottle neck node in the network, or the influence some high-energy-consumption nodes. Because routing requests also incur energy consumption, more routing requests mean more energy consumption, therefore, it is not wise to apply such a practice in ZigBee network.

Based on AODVjr, this paper presents an improved dynamic routing algorithm, NS-AODVjr（New Save AODVjr）, which adjusts the routing request activity by introducing the concept of path energy weight. This dynamic routing mechanism is described as follows:

$$E_{rrep} \le \frac{1}{1-\beta} \times E_{sum} \tag{4}$$

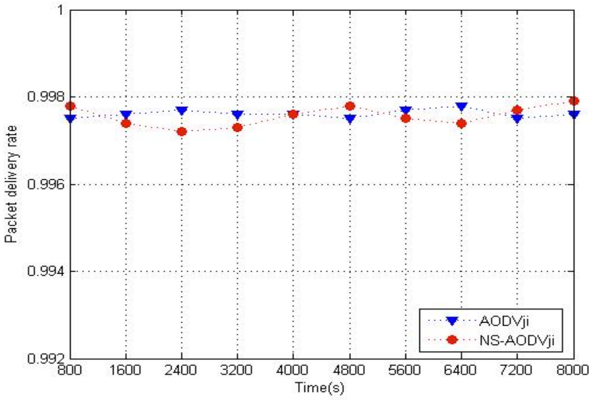

Figure 1. Packet delivery rate

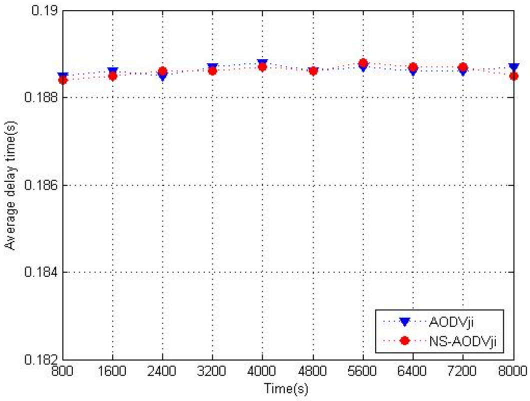

Figure 2. Average delay

Here E_{rrep} denotes the remaining battery capacity of the node while receiving RREP packets; $\beta\ (0 < \beta < 1)$ is a factor which can be set according to real traffic load situation. The implementation of the algorithm includes four steps:

1) Each node should store $E_i(\Delta T_{j-1})$ to calculate the value of $E_i(\Delta T_j)$ and Fn_i according to formula 1, 2 for every ΔT .
2) For the initial value, $\overline{E_i}(\Delta T_j) = E_{init}(i) - E_{hold}(i)$ is used only for the first ΔT second. For each following ΔT , we should save the previous variable $E_{hold(i)}$ in the variable $E_{oldhold(i)}$, and the value of $\overline{E_i}(\Delta T_j)$ is updated using $E_{oldhold(i)} - E_{hold(i)}$.
3) Adding the pathcost and hopcount to store the estimated lifetime of the path and routing

hop count respectively into RREP packet.

4) A E_{rrep} field is added into the route table. Upon receiving a RREP packet, update E_{rrep} according to the remaining energy of the node.

The detailed process of the four steps is shown as follows:

Algorithm 1:

```
Input: $\Delta T$
Output: $E_i(\Delta T_j)$ , $Fn_i$
if $\Delta T$ >= 0 then
    Calculate $E_i(\Delta T_j)$ and $Fn_i$;
if routetable!=NULL then
    if（4）is true then
        Update routetable;
    end
end
```

Algorithm 2:

```
Input: RREQ
Output: RREQ, Update routetable
RREQ->hopcount += 1;
if $N_i$ is dest node then
    for i=1 to m do calculate Val(P_i)
        Select a path P_i with maximal Val;
        Send a RREP according path P_i;
else if $Fn_i$ >0 then
    Build the reversal path;
    if RREQ->pathcost > $Fn_i$ then
        RREQ->pathcost = $Fn_i$;
    Update routetable of node $N_i$;
    Update RREQ;
    end
end
```

Algorithm 3:

```
Input: RREP
Output: $E_{rrep}$
Select a forward path;
if $N_i$ is not a source node then
    Update $E_{rrep}$ with $E_{hold(i)}$;
    Forward RREP;
if $N_i$ is a dest node then
    Send date packets;
end
```

Algorithm 4:

```
Input: packet
Output: $E_{rrep}$
Lookup the route table entry for the dest;
if routetable is Update then
    Forward the packet;
    Send RREQ;
    routetable->flags=RTF_UP;
else if routetable->flags=RTF_UP then
    Forward packet;
end
```

4. Simulation Experiment

In this paper, we refer to this new algorithm as NS-AODVjr (New Save AODVjr).This section will simulate the performance of both the old and new routing algorithms in Network Simulator environment, and present the comparison between NS-AODVjr and AODVjr in terms of packet delivery rate, network delay, and remaining device energy capacity after a certain period of operation. It is proved that, under equal network delay, NS-AODVjr algorithm is better able to balance the power consumption of each node in the network, effectively extending the network service time.

4.1. Simulation Model Setting

We installed 30 sensor nodes in the farmland (an area of 50*50m2). All these sensor nodes are Full Functional Device(FFD). Since our experiments are based on the JN5148 wireless microcontroller produced by Jennic, we set the transceiver power parameters of sensor nodes according to the manual instructions of Jennic. Set Init-Power is 2000J And 12 meter transmission range is adopted. Packet error ratio is set to 0.3% and the packet size is 300 bytes. The simulation time is 9000s.

4.2. Simulation Results and Discussion

Wireless sensor network for large area farmland information monitoring is sensitive to device energy consumption. Therefore, routing algorithms for such systems must balance the network performance and the device energy consumption. It must ensure the farmland information can be transmitted in a timely manner, at the same time, the network can work stably under unattended situation for a long period of time.

Therefore, when we compare the energy consumption of NS-AODVjr and AODVjr, we must make sure they have similar network performance. Based on the performance testing we carried out for NS-AODVjr and AODVjr comparison, packet delivery rate and the average delay (from 800s to 8000s) are shown in Figure 1 and Figure 2 respectively.

Figure 1and Figure 2 show that the packet delivery rate of NS-AODVjr algorithm is slightly lower than that of AODVjr in the latter stage of the simulation (from 800s to 8000s). The difference is so slight that it can not affect the performance of agricultural monitoring system. The average delay times of both algorithms are basically the same. Therefore, the NS-AODVjr algorithm is similar with AODVjr in packet delivery rate and average delay. They can meet the requirements of agricultural monitoring systems. In other words, both algorithms can guarantee the timely transmission of the data collected by the sensor node.

Figure 3 and Figure 4 show the remaining energy capacity of all the device nodes after 2500s and 5000s during the simulation.From Figure 3 we can see that every node (from 1 to 30) has roughly the same remaining energy. This is because the running time of the network is short and all the nodes still have sufficient remaining energy. Both algorithms use the same routing method, namely shortest path routing of AODVjr, for data routing.

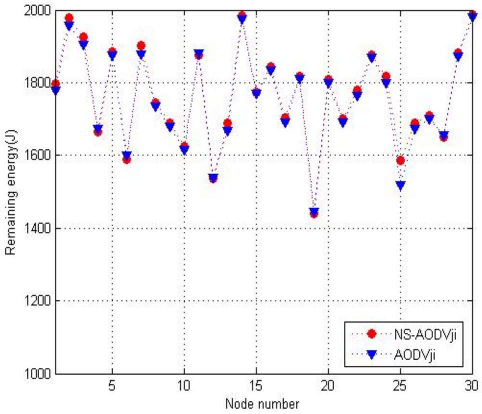

Figure 3. Remaining energy of nodes at 2500s

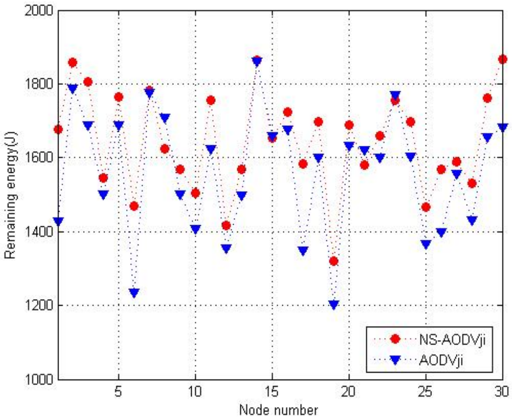

Figure 4. Remaining energy of nodes at 5000s

When the network running time is short, the nodes have sufficient remaining energy, the path-energy weight metric of NS-AODVjr has little influence on path routing calculation, so the NS-AODVjr and AODVjr algorithms have no significant difference in terms of energy consumption.

From Figure 4, we can see that NS-AODVjr algorithm is better than AODVjr algorithm in optimizing the remaining energy of the bottleneck node after 5000s in the simulation. The main reason is that with the running of system, the influence of energy weight on the calculation of path becomes more and more obvious, and the effect of the bottleneck node becomes more important. The NS-AODVjr algorithm can balance the energy consumption of bottleneck nodes according to network communication load and the device energy consumption factor, by adjusting the routes involving bottleneck nodes, replacing the bottleneck nodes by other nodes with more remaining energy, and effectively reducing the energy consumption of the bottleneck nodes.

As the simulation goes on, the bottleneck node in the AODVjr algorithm will stop running because its power is exhausted, then it becomes a ‘dead’ node in the network. The simulation experiment results show that the number of ‘dead’ nodes caused by AODVjr algorithm is more than that caused by the NS-AODVjr algorithm. Therefore, the lifetime of the network using NS-AODVjr algorithm will certainly be longer than that of the network using AODVjr algorithm.

The remaining power of the WSN is often a key factor affecting the assessment of the service time of the network. As more and more nodes become ‘dead’ with the decrease of the remaining power of the network, the WSN will continue to carry out reconstruction, and select a new routing, so as to ensure that the data of each node could be sent to the central node. In case the data of most of the nodes can not be reconstructed and sent through the network to the central node, the ZigBee network will be declared 'dead'.

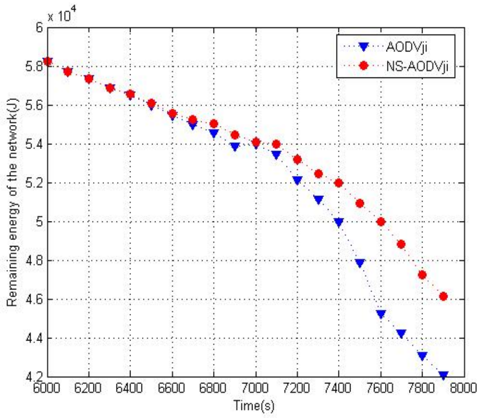

Figure 5. Remaining energy of the network nodes

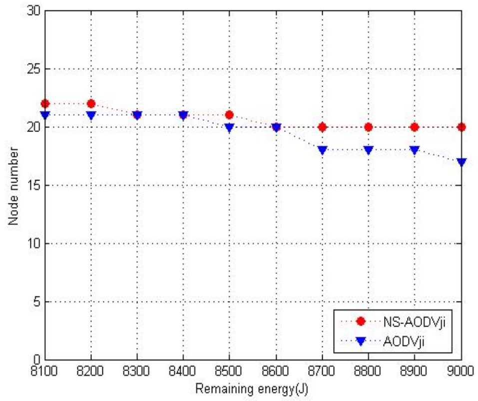

Figure 6. Remaining node number

Figure 5 shows different remaining energy of the same network under two different algorithms. And Figure 6 compare the remaining node number of two different algorithms. As the simulation progresses, the remaining energy of the network and remaining node number also changes. The remaining energy of the WSN under the NS-AODVjr algorithm is always higher than that under the AODVjr algorithm,Meanwhile the number of remaining nodes was increased, particularly, as the time goes, such an advantage of the NS-AODVjr algorithm becomes more notable, showing an longer service time of the network.

According to the simulation result, NS-AODVjr algorithm can expand the effective area of network coverage, and extensive farmland can be long-term monitoring with real-time and sustainability in the unattended environment.

5. Conclusion

This paper introduces a calculation method of path energy weight, which combines energy control and AODVjr algorithm. Based on the shortest path routing method applied by the original AODVjr algorithm, the new method decides whether to take a node into an active route or not according to the estimated remaining power of the device node. Based on the path-energy weight metric method and dynamic routing mechanism, this paper presents a new routing algorithm, which is adapted for the ZigBee agricultural monitoring system. Simulation experiments are conducted for the new algorithm, NS-AODVjr, in Network Simulator. The simulation results show that the lifetime of the ZigBee agricultural monitoring system using NS-AODVjr algorithm can be effectively expanded by expanding the lifetime of the bottleneck nodes in the network. The packet delivery rate and network delay can sufficiently meet the requirements of agricultural monitoring systems.

Acknowledgments

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