Dynamic Routing Algorithm Based on the Channel Quality Control for Farmland Sensor Networks

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Abstract—This article reports a Dynamic Routing Algorithm for Farmland Sensor Networks (DRA-FSN) based on channel quality control to improve energy efficiency, which combines the distance and communication characteristics of farmland wireless sensor network. The functional architecture of the DRA-FSN algorithm, routing establishes the mechanisms, the communication transmission mechanism, the global routing beacon return mechanism, abnormal node handling mechanism and sensor networks timing control mechanisms were designed in detail in this article. This article also evaluates and simulated the performance of DRA-FSN algorithm in different conditions from energy efficiency, packet energy consumption and packet distribution balance by comparing DRA-FSN algorithm with DSDV, EAP algorithm. Simulations showed that the DRA-FSN was more energy efficient than EAP and DSDV, the DRA-FSN algorithm overcame the shortcoming of capacity and bandwidth of the routing table correspondingly increase as more and more nodes joining the network. It has better performance in scalability and network loading balance.

Index Terms—Wireless Sensor Networks; Dynamic Routing Algorithm; Channel Quality; Energy Efficiency

1. INTRODUCTION

Wireless sensor networks (WSNs) are providing tremendous benefit for a number of industries. The ability to add remote sensing points, without the cost of running wires, results in numerous benefits including energy and material savings, process improvements, labor savings, and productivity increases. Power cast takes the capabilities of wireless sensors a step further by allowing them to be powered without wires and without the need to change batteries [1, 2]. Wireless sensors networks are being widely deployed and power cast’s technology can provide benefit for many applications including: Farms, forests, mountains, oceans, and so on [3, 4].

In WSNs, information is transmitted through the wireless radio channel which is susceptible to signal attenuation, noise, reflection, diffusion, and other factors. These factors result in the signal transmission distance and the packet loss rate and the error rate is very unstable, so that the application of wireless sensor networks subject to considerable restrictions [5, 6]. Wireless sensor channel more vulnerable to the impact of changes in the external environment than wired networks. Ananstasi’s studies confirmed that the communication distance of wireless sensor influenced by rain and fog [7, 8, 9]. The transmission distance of Mica2dot node was 120m in 2.4GHz frequency tests, but the transmission distance is only about 10m in fog and heavy rain test. Kang et al tested the transmission of wireless sensor signals influenced by the weather situation. They pointed out that the wind can make the antenna vibrate, and thus the signal was impacted significantly. Also they pointed out that rain, snow and fog signal cannot be ignored [6]. Information is vulnerable to outside interference in the process of information transmission in the wireless sensor, and an error occurs. Jeong J, et al. carried out two types of experiments indoor and outdoor, and found the wireless sensor error bit is mostly one and two bits. Also they pointed out that the scheme of 1 and 2-bit linear error-correcting codes is efficient because the multi-hop nature of information transmission in wireless sensor error correction code method the proportion of passes to save energy [10, 11]. Ahn et al also designed a method of data error correction on FECA algorithm for mobile wireless networks from the packet error rate distance function [12, 13].

In farmland sensor network environment, there are many uncertain factors, such as lower communication quality and higher error packet. Based on these considerations, this paper drew on the idea of directed diffusion protocol and the Destination Sequenced Distance Vector (DSDV) algorithm [14, 15], combined with the characteristics of farmland wireless sensor network communication channel quality. In order to improve the effectiveness of network energy, this paper proposed an energy efficient farmland dynamic routing algorithm (DRA-FSN) for farmland wireless sensor networks. The DRA-FSN routing has been simplified initialization phase algorithm for the fixed characteristics of the location of the base station. The DRA-FSN algorithm took into account the channel quality of communication between nodes, the global routing information, the remaining nodes energy, and a number of factors, so that the next hop node had the dynamic and strong channel adaptability for prolonging the network life cycle. The DRA-FSN had better scalability, for its non-corresponding increase in capacity and bandwidth of...
the routing tables while more and more nodes joined the network.

The rest of this paper is organized as follows, section 2 gives Functional architecture of the DRA-FSN algorithm, section 3 describes The establishment mechanisms, the communications transport mechanism, the global routing beacon return mechanism and time control mechanism of the sensor network, the section 4 simulates the performance comparisons evaluation of the DRA-FSN algorithm with DSDV and EAP routing algorithm from the energy efficiency, the average energy consumption of the packet and the packet distribution.

II. THE FUNCTIONAL ARCHITECTURE OF DRA-FSN ROUTING ALGORITHM

There are six functional modules in the DRA-FSN routing algorithm, Which are the Route Setup Module (RSM), the Data Transmission Module (DTM), the Next Hop Selection Module (NHSM), the Global Route Beacon Module (GRBM), the Packet Handle Module (PHM) and Table Handle Module (THM) shown in figure 1. The DRA-FSN routing Algorithm layered sensor network in the whole network flooding Hello packets to establish the gradient field and obtain the node information from a neighbor.

The responsibility of the RSM was initiating routing. The PHM was responsible for construction data packets and communication between nodes. The THM mainly used for recording node information and providing data processing for a neighbor node. The DTM drove moisture packet sending. When the local node clock Threshold arriving or receiving water packets from the neighbor, the DTM wake up the next hop, constructs packets and sends out. The GRBM’s main function was to complete the global routing beacons collections, when the water packets reached the base station node, the base station node would send a global routing beacon, and the beacons reversed transmission along the transmission route of the water packets. The NHSM was the core of the DRA-FSN routing, the module NHSM gave full consideration to various factors including the status of the quality of communication between nodes, node moisture data packet transmission to the base station node capacity which expressed as the number of global routing beacons, nodes bear the ability to send tasks, and the next hop node to acted as likely to transit nodes.

The key characteristics of DRA-FSN routing didn’t require the base station node while processing node abnormalities. The NHSM adopted the historical value of the N rounds. The historical value of the abnormal nodes within the past N round would be zero if some node fails. So the NHSM could avoid these abnormal nodes while choosing the next hop. Over a period of time, the terminal could find those abnormal nodes because there were no packets from them.

III. DETAILED DESIGN OF DRA-FSN ROUTING ALGORITHM

This section described the details of DRA-FSN routing in establishing mechanisms, transmission mechanism, the global routing beacon post back mechanism and a sensor network timing control mechanism. The processes of the various mechanisms were specified one by one.

A. Routing Establishment

Route establishment process was shown in Algorithm 1:

*%Algorithm1: DRA-FSN routing establishment algorithm %

Step1: In the system initialization phase, the sink flooded hello packet in the whole network through its closed node \( a_{00} \), and built networking gradient level field. At first, the initial state of the sink node was “\( \text{Level} = 0 \)”. All other nodes of the network level were initialized as “\( \text{Level} = \infty \)” and were set in the receiver model, and all entries in the neighbor node information table of the node neighbour_nodeInfo were not activated. The sink node broadcasted Hello packets in the form of flooding that contained the node level, node ID number, the node number of global routing beacon, residual energy and the maximum possible number of network layers.

Step2: If the node clock reached the sleep time, then turned to step 12.

Step3: If the node clock reached the time of send packets or received packets from other nodes, then turned to step 11; if node clock has reached to the time of sending Hello packets, then turned to step 9.

Step4: If the node \( a_{ij} \) hadn’t received a hello packet from the other node \( a_i \), then turned to step 2.

Step5: The node checked the destinations ID number of the Hello packet reception, if the destination ID was not its own ID number, then turned to step 2.

Step6: First of all, find corresponding node of \( a_{ij} \) entries in the information table neighbour_nodeInfo in the neighbors of \( a_{ij} \), according to the node ID number. If these corresponding entries were found, then updated this entry node level, the number of the node global routing beacon, the remaining energy and other information, and activated these entries. If did not find the appropriate entries, then created a new entry into this table, recorded the node level of the node \( a_{ij} \), level, node ID, the number of the node global routing beacon, residual energy information and activate this entry.

Step7: if \( \text{Level}_{zw} > \text{Level}_{ij} + 1 \), then set \( \text{Level}_{zw} = \text{Level}_{ij} + 1 \), recorded the time of receiving Hello packet time \( t_{zw} \), calculated the node Hello packets sending delay \( t_i \)
using the formula (1), and turned to step 9. if Level \( \leq \text{Level}_j + 1 \), then turned to step 8.

\[
t_s = \text{Mod}(t_i, C_0) * T
\]

(1)

where, \( t_f \) was the transmission delay, \( T \) was a constant which means the maximum delay according to the size of the network setting by the system, \( C_0 \) was a constant, \( t_d \) was the ID number of the node, and a transmission delay was obtained through the remainder.

Step 8: \( a_{\text{zw}} \) did not send Hello packets, and discarded the Hello packet.

Step 9: if the node clock time \( t < (t_i + t_j) \), then turned to step 3.

Step 10: updated \( \text{Level}_{\text{zw}} \), and wrote it into Hello packet, and then broadcasted Hello packet, turned to step 3.

Step 11: The Hello packet would stop flooding after a certain delay. In all the active entries of \( a_{\text{zw}} \)’s neighbor nodes in table neighbour_nodeInfo, all nodes that satisfied \( \text{Level} = \text{Level}_{\text{zw}} - 1 \) or \( \text{level}=\text{Level}_{\text{zw}} \) would be as a next hop candidate nodes.

Step 12: The initialization phase algorithm was ended, all nodes began to sleep.

In addition to the sink node broadcasted a Hello packet when the system began running, the other source nodes broadcasted Hello packets only when their levels were updated. The update of the level was no infinite loop because of its monotonically decreasing. If there were some nodes with communication delay, the nearest node of the sink would be conducted to the level gradient field, and each node could build its level gradient field only sending a Hello packet. With the operation of the network, the node communication capability decreased with energy reduction. After a certain operating time, re-create network routing process may be necessary.

B. Routing Transmission

The farmland sensor has its own characteristics, such as the majority of information is periodically collecting. The time delay \( t_2 \) of the node transmission packet data was calculated by the formula (2).

\[
t_2 = (M - N + 1) \times (M - 1) \times T
\]

(2)

where, \( M \) represented the maximum number of layers of the whole network. It was obtained by the sink node which usually was greater than or equal to the maximum number of layers of the actual network. \( N \) was node gradient layers. \( T \) was same as formula (1), which means that the delay maximum. The whole data transmission process was described in Algorithm 2:

* Algorithm 2: DRA-FSN routing transmission algorithm

Step 1: After a certain delay, the whole Hello data packet turned to the end of the flooding. The node \( a_{\text{zw}} \) began collection data, and calculated transmit packet delay \( t_2 \) according to the equation (2).

Step 2: If the node clock arrived time \( t_0 + t_2 \), then turned to step 8.

Step 3: If the node clock reached the sleep time, then turned to step 9.

Step 4: If the network nodes \( a_{\text{zw}} \) hadn’t received a packet from the other node \( a_{ij} \), then turned go to step 2.

Step 5: If the gradient layer of node \( a_{ij} \) was the same with the other same layer’s gradient layers, then turned to step 7.

Step 6: Ignored all nodes in activated table neighbour_nodeInfo all entries in the same layer and all the nodes of the lower layer calculated their values \( P \) by equation (3). The maximum \( P \) value of the node was selected as the next hop, and modified the data packets.

Step 7: Forwarded the data packet, recorded source node ID number, serial number and the ID number of the node \( a_{ij} \), and turned to step 2.

\[
P = \alpha_1 A_{\text{row}} + \alpha_2 A_{\text{route}} + \alpha_3 E + \alpha_4 C + \lfloor \alpha_5 \rfloor
\]

(3)

Step 8: Recording source node ID number, serial number and \( a_{ij} \) ID number of the data packet.

Step 9: Node \( a_{\text{zw}} \) calculated the \( P \) value for all activated neighbours node of table neighbour_nodeInfo in the same layer and the lower layer of nodes by the formulas (3), and selected the node with maximum \( P \) value as the next hop.

Step 10: Constructed the structural data packet and sent out, then turned to step 2.

Step 11: Turned to sleep node.

C. Global Routing Beacon Return

The routing algorithm usually route in accordance with two types: based on the global information and based on local information.

DRA-FSN routing algorithm was based on local information. In order to increase the global performance of the DRA-FSN routing algorithm, the DRA-FSN routing algorithm used global beacon nodes to estimate. If \( a_{ij} \) received more global routing beacon, then the node has better global routing performance. It stood for \( a_{ij} \) had the higher successful rate to the sink.

There were two fields of ID number and serial number of the source node in packets. The source node was responsible for collecting the packet that was the original sender of this packet. The serial number was an incremental source node label which means the number of rounds in information collection. Two fields were uniquely identifies in a data packet, and these two fields would not change during the transmission in the entire sensor network.

The global routing beacon return included following steps, shown by algorithm 3.

*% Algorithm 3: DRA-FSN routing beacon return algorithm

Step 1: The sink would obtain sending node ID, source node ID number, and serial number, after it received a data packet. Then the sink constructed a global routing beacon packet and sent to the destination node with ID number of the sending node.

Step 2: If the node \( a_{ij} \) received a global routing beacon packet, and the destination node ID was not equal to its ID number, then accepted this beacon packet. Or the node \( a_{\text{zw}} \) would discard this global routing beacon packet, then turned to step 7.
D. Abnormal Node Handling

When wireless sensor networks appeared, the failed node, such as energy depletion, failure, etc., was not working properly. In addition to collecting error data, the presence of the failed node would make the node not working normally if it was as the next hop node. If the failure node was responsible for forwarding a large number of nodes, so that the affected nodes would be more. Therefore, how to deal with the problem of the failed node was an important issue to be considered in the routing algorithm.

DRA-FSN routing algorithm was based on local information and judgment for abnormal nodes was also based on local information. There are two reasons for the node $a_{iw}$ if it had not received a single-hop response packet during last $N$ times from the node $a_{ij}$ data packets. One was the poor quality of the communication channel resulting in the loss of data packets, the other was nodes abnormal. The $A_{one}$ parameters in the formula $(3)$ could show whether the node the $a_{ij}$ was abnormal in a certain extent, but it was not absolute. Whatever the reason, the node $a_{iw}$ should not be the next hop of $a_{ij}$. In DRA-FSN routing algorithm, the node $a_{iw}$ could judge whether the node was abnormal from its local collected information. Therefore, it could avoid the abnormal nodes, and reduced unnecessary data transmission to save energy.

E. Timing Control Mechanisms

Farmland wireless sensor networks has its particularity such as many farmland data was periodically transmitted. So the network nodes should be in a dormant state to conserve energy in the non-working period. In the routing initialization phase, the sink estimated the maximum gradient of the number of layers for the entire network, and sent out by the Hello packet. All nodes receiving hello packets calculated sending delay within a maximum delay value $T$. Many time delay parameters could be obtained by following status.

1. The sink node sent hello packets in $t_{init}$ so that the nodes in the first layer could receive this package at time $t_{init}$.

2. The nodes in the second layer could receive this packet between time $t_{init}$ and $t_{init} + T$.

3. The nodes in the $m^{th}$ layer could receive the hello packet between time $t_{init}$ and $t_{init} + (m-1)T$.

The routing initialization phase would end no later than $t_{init} + (m-1)T$. Due to the low-level node would be used as a forwarding node for the upper node, so the node number of $n^{th}$ layer could send its own data packet after time $(m-n+1)(m-1)T$. Totally, the entire network could send out all packets during $t_{init} + m(m-1)T$. After that, the entire network at the moment entered into sleep mode until the next round of transmission.

IV. DRA-FSN ROUTING ALGORITHMS SIMULATIONS

In this paper, the simulation environment was set to $N \times N$ nodes in the network that the entire network into a square distribution. In this section, a comparative evaluation was conducted among DRA-FSN, DSDV and EAP [13] routing algorithms from energy efficiency, single data packet average power consumption and the packets distribution balance.

The energy of the base station was supposed to infinite, the base has no longer received any packet as the basis for wireless sensor networks death. The simulation results on various aspects of the network were run multiple times. The average of the obtained data was used to estimate by the simulation program. Energy efficiency was expressed by the number of packets which could be handled in a limited energy condition. The most important task in farmland water sensor networks is to maximize the water data collected from each node. The base station node receives the more packets, the more strong ability of the routing algorithm to transfer data packets.

A. Simulation of Energy Efficiency

Because the EAP routing was a clustering protocol and it would cause increasing packet length while fusing cluster data. Additional operation of the DSDV routing was to exchange routing table between the nodes, the larger the network size, the greater the routing table, so the more the extra energy consumed. DRA-FSN routing took full advantage of the characteristics of the farmland sensor network. It simplified the network initialization process, deletion of unnecessary operations, made an additional reduction in energy consumption, thereby enhancing the effectiveness of the network energy. An experiment in figure 2 showed that the DRA-FSN route was better than the EAP routing, and EAP route was better than DSDV routing. Additional operating in the DRA-FSN routing were the return packet broadcast Hello packets periodically and global routing beacons. Clustering would bring additional consumption.

The numbers of packets received by the three kinds of routing algorithm base station node were shown in Figure 2 without node abnormalities. From the horizontal view in figure 2, the number of packets received from the base station node was less affected by the size of the network. The received packet number was about 35,000 by the base station under different network size in running DRA-FSN routing protocol. The packet number was...
about 12000 in DSDV routing protocol and was about 29000 in the EAP routing protocol.

B. The Average Energy Consumption

Except for the energy consumption for the normal transmission of moisture packets, there were a series of auxiliary operations, such as the establishment of routing, packet acknowledgment, packet retransmission, packet transfer, and so on. These additional energy consumptions also related to the performance of the routing protocols. The average energy consumption of a single packet of routing protocols can reflect this performance to some extent, and its formula was given by equation (4).

\[
E_{\text{packet, ave}} = \frac{E_{\text{total}}}{N_{\text{receive}}}
\]

where, \(E_{\text{packet, ave}}\) was the average packet energy consumption, \(E_{\text{total}}\) was total energy consumption, \(N_{\text{receive}}\) was the number of packets received in base station node.

The total energy consumption of the network was the total energy consumption of all nodes until the base station node could not receive packets in the network. The average energy consumption of the three routing protocols in a single package was shown in Figure 3 under different network size.

The average energy consumption of a variety of routing algorithm was increased with the network size increasing in Figure 3.

Figure 3 indicated that the routing would be collected away from the base station node data back to a base station to consume more energy. Under different network size, the average energy consumption of a single packet the DRA-FSN route than the other two routing protocols. In the case of 1000 nodes, the average energy consumption of the DSDV routing a single packet rose rapidly, this is the result in the routing table increases due to the node increased between nodes exchange the sake of increased energy consumption of the routing table. This article by farmland sensor network deployment model analysis shows that all nodes in the data simply transmitted to the base station node, and do not need to know the routing of the other nodes. And farmland sensor networks take full advantage of the many-to-one feature to simplify the initialization process of the DSDV routing.

C. Packets Distribution Balance

The packet transmission can not guarantee without error, so the packets by multi-hop transmission were easy to lose. Data was difficult to reach the base station from the away moisture node, so that the packets distribution balance of moisture packets could be used as the routing protocol performance evaluation. The better balance of the routing protocol showed its better network performance. The packet distribution was shown in Figure 4, 5 in network size of 100, 300 nodes. In testing, data packet distribution had the biggest variable in the EAP route, and the DSDV routing had the smallest variance. This analysis showed that DRA-FSN routing in the node layer within a single hop factors played a role in.
From Figure 4, although the number of packets in the EEDRP - FMSN protocol was less than the EAP protocol, EAP routing protocol packets was over-concentrated in certain node. Most nodes appeared packet loss in the network in EAP protocol, so its balance was poor. In the farmland sensor network, the EAP routing protocol is the most desirable of the three routing protocols, and the DRA-FSN protocol was better than DSDV protocol under the same conditions. The DRA-FSN protocol extended the network life cycle than DSDV protocol.

V. CONCLUSIONS

In this paper, a Dynamic Routing Algorithm for Farmland Sensor Networks (DRA-FSN) was reported basing on channel quality control to improve energy efficiency, which combines the distance and communication characteristics of farmland wireless sensor network. The functional architecture of the DRA-FSN algorithm, routing establish the mechanisms, the communication transmission mechanism, the global routing beacon return mechanism, abnormal node handling mechanism and sensor networks timing control mechanisms were analyzed in detail in this article. The experiments showed that the DRA-FSN routing algorithm had high energy efficiency while reducing the average energy consumption of the data packet. The DRA-FSN routing algorithm was suitable for application farmland sensor network environment.

However, simulations were supposed to an agreed mode in transmitting power and error rate. Some deviation may be related to the real environment. So carrying out the DRA-FSN application into the real farmland will be the next major work of this project. And how to further improve the routing algorithm balance performance of the DRA-FSN routing is also an important work according to the operation of the network environment in the future.

REFERENCES


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