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A SINR-AODV Routing Algorithm for Wireless Sensor Networks

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***Abstract*—A distance vector routing algorithm based on node interference factors is proposed to aim at the problems of node wireless interference and energy limitation in wireless sensor networks. The algorithm introduces the signal-to-interference-to-noise ratio (SINR) value into the routing request (RREQ) control message. During the route discovery process, it establishes a SINR optimal route between the source node and the destination node. This method can effectively reduce the influence of node interference factors and improve the communication quality of wireless sensor networks. In addition, the proposed distance vector routing algorithm based on signal-to-interference noise ratio (SIN R-AODV) is compared and analyzed with the classical AODV routing algorithm. The simulation results show that the proposed routing algorithm is significantly better than the classical AODV algorithm in terms of average delay, data transmission success rate and network throughput performance.**

Keywords*—*wireless sensor network; wireless interference; AODV; SINR

I. INTRODUCTION

Wireless Sensor Network (WSN) is a multi-hop self-configuring, dynamically routed, distributed, and autonomous wireless network. It can be used in several application areas, such as emergency rescue, bio-detection, environmental measurement, and real-time monitoring [1, 2]. In WSNs, sensor nodes are spatially distributed and work in concert to communicate through wireless links collecting information from the monitoring field, and data are collected by different nodes and sent to the receiver. In WSNs, the routing algorithm is the key to the proper operation of the communication network and directly determines the performance of the communication network operation. Therefore, a proper routing algorithm is essential to improve network performance. For Ad hoc On-demand Distance Vector Routing (AODV) in wireless sensor networks, many researchers have improved and developed this classical algorithm based on different metric values in the routing process. In [3], the authors proposed an algorithm called Ad hoc On-demand Multipath Distance Vector Routing Protocol (AOMDV), which reduces the average transmission packet delay and improves the network throughput by selecting multiple paths between the source node to the destination node. In [4], authors proposed an energy-efficient enhanced AODV routing algorithm to reduce the energy consumption of nodes in the network by selecting energy-optimal routes, thus effectively extending the network life cycle.

In [5], a probabilistic message forwarding scheme is proposed to limit the routing message overhead by reducing the redundant broadcasts from nodes with a predetermined forwarding probability, thus reducing the power consumption and extending the network node lifetime.

It should be emphasized that when data are transmitted simultaneously on multiple paths that are physically close to each other, routing coupling caused by node interference can degrade data transmission quality to some extent, for the problem of node interference in wireless sensor networks [6], a multipath energy-efficient routing algorithm is used to reduce the impact of node interference, improve the quality of wireless communication, and balance the node energy cost of the entire wireless network[7]. An Interference-minimizing multipath routing based on a congestion control algorithm[8] is proposed to solved the data retransmission and energy consumption problems caused by wireless interference, while improving network throughput. In [9], authors established a total routing power consumption model under wireless channel quality constraints. They proposed a hybrid data aggregation strategy by deriving the optimal number of hops; the routing power efficiency is improved to maximize the wireless channel throughput and routing lifetime, significantly reduce the network's total energy consumption, and reduce the computational overhead.

In [10], authors introduced game theory into WSN topology control to establish a game model. They used a Markov lifetime prediction model for each node to achieve real-time prediction of the node life cycle. It saves energy by adjusting the transmitting power of nodes, introducing SINR into the mode transition probability of nodes, reducing communication interference between nodes, reducing concurrent transmission, and at the same time, reducing energy consumption. In [11] ,the paper investigated the SINR-based adaptive transmission power with scheduling in WSNs. Under the signal-to-noise ratio constraint in WSNs, the algorithm allocates minimum power to each sensor node at each transmission link's scheduling time slot. It maximizes the number of concurrent transmission links in each scheduling time slot, effectively reducing energy consumption and minimizing inter-node interference. In [12], the authors proposed a spatio-temporal diffusion-assisted transmission algorithm, which improves the network throughput and reduces the network's required energy consumption, mainly by minimizing the interference and reducing the energy required for interference due to the superposition of sensor decisions.

According to the above research status, for the problems of node energy limitation and node interference routing coupling in wireless sensor networks, this paper proposes a SINR-AODV routing algorithm based on wireless interference factors to reduce routing cost, improve routing transmission efficiency and link transmission quality, as well as save network energy consumption.

The paper is organized as follows; Part II gives the energy consumption model; Part III describes the routing algorithm considering wireless interference in wireless sensor networks; Part IV conducts simulation experiments on the proposed algorithm, it analyzes and discusses the experimental simulation results. The fifth part draws conclusions based on the analysis and simulation results.

II. ENERGY CONSUMPTION MODEL

In this paper, the initial conditions of wireless sensor network nodes are set as follows: (1) randomly distributed network nodes; (2) all nodes have limited initial energy and use node IP addresses as unique identifiers for nodes; (3) each node is isomorphic, and all nodes are identical in terms of maximum communication radius, signal reception sensitivity, and ability to process and forward information; and (4) the communication distance between nodes is adjustable.

The energy consumption model for wireless communication is described as follows [13]. The sensor node energy consumption is divided into two main parts: the energy consumption required by the node to transmit signals to other nodes and the energy consumption the transmitted signals require to enter the amplification circuit.

Set the energy consumption equation of a node when sending a packet of k bytes to other nodes at distance d as shown in (1), and the energy consumption equation of other nodes receiving the packet from the node, as shown in (2).

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx-elec}(k)+E_{Tx-amp}(k,d) \\ &= E_{elec}\times k+\varepsilon_{amp}\times k\times d^{n} \end{aligned} \tag{1}$$

$$E_{Rx}(k)=E_{Rx-elec}\times k \tag{2}$$

where $E_{Tx-elec}$ is the energy consumption required to transmit the signal, E_{Tx-amp} is the energy consumption of the amplifier, and $E_{Rx-elec}$ is the energy consumption required to receive the signal. Depending on the distance, the transmission model is divided into the free-space transmission model and multi-channel fading model [14], and the threshold distance is set as:

$$d_0=\frac{4\pi\sqrt{L}h_r h_t}{\lambda} \tag{3}$$

where L is the path loss generated in transmitting data, h_r is the antenna height of the received signal, h_t is the antenna height of the transmitted signal, and λ is the fixed setting of the wireless wavelength. When the communication distance of nodes transmitting data is less than d_0 ,the free-space transmission model is used and set to 2; when the transmission communication distance is larger than d_0 , the multi-channel fading model is used and set to 4.

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx-elec}(k)+E_{Tx-amp}(k,d) \\ &= \begin{cases} E_{elec}\times k+\varepsilon_{amp}\times k\times d^{2} & d<d_0 \\ E_{elec}\times k+\varepsilon_{amp}\times k\times d^{4} & d>d_0 \end{cases} \end{aligned} \tag{4}$$

III. METHODS

A. AODV Routing Algorithm

The AODV algorithm [15] is a responsive routing algorithm that builds routes to destinations on demand. It works in a reactive manner, which means it determines and establishes a route once the data is transmitted between the sender and receiver. As shown in Figure 1, when node A needs to transmit data to node F, first node A needs to check whether there is an available route in the routing table to reach node F. When it does not exist, node A sends a Route Request (RREQ) control message to node C and node B and sends the RREQ message for broadcast. When node B and node C receive the route request control message, they first judge whether the IP address of the destination node in the route request control message is the same as the IP address of this node, and when it is different, they continue to forward the route request control message to their neighbor nodes D, E, and G. When the route request control message is forwarded to the destination node F, node F sends a Route Reply (RREP) control message to node A. When the route request control message is forwarded to destination node F, node F sends a Route Reply (RREP) control message to node A to form the shortest path available route.

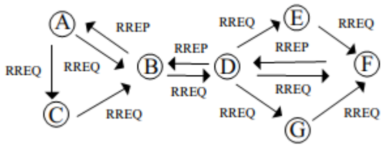

Fig. 1. AODV route discovery process

B. SINR-AODV Routing Algorithm

This paper introduces SINR metrics to improve the AODV routing mechanism for selecting paths with good signal quality and low interference. The SINR parameters from the physical layer are added to the routing tables of the AODV RREQ packets and nodes in the selected paths [16]. The SINR parameters are calculated as shown in (5).

$$SINR = \frac{P_r}{\sum_{i \neq r} P_i + N} \qquad (5)$$

where P_r is the power of the received frame, P_i is the individual received power of other frames received by the receiver simultaneously, and N is the effective noise at the receiver.

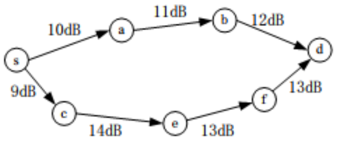

Fig. 2. Two routes between the source and destination nodes

Fig. 2 labels the SINR values between each node, showing the required SINR values for two paths from the source node to the destination node, respectively, and expresses the SINR values in dB. For example, the SINR value from source node s to node a is 10 dB.

During the route discovery phase, the source node s broadcasts RREQ control messages along path 1 (source node s → node a→ node b → destination node d) and path 2 (source node s → node c → node e → node f →destination node d) transmission. When using the classical AODV algorithm， the source node s selects path 1 with fewer hops; if using the SINR-AODV algorithm proposed in this paper, the source node s selects path 2 with the largest SINR value. Path 2 is stronger than path 1 in terms of routing quality, ensuring a more robust end-to-end packet transmission.

The SINR-AODV routing algorithm proposed in this paper mainly consists of route discovery and route maintenance, and the flow chart of the algorithm is shown in Fig. 3.

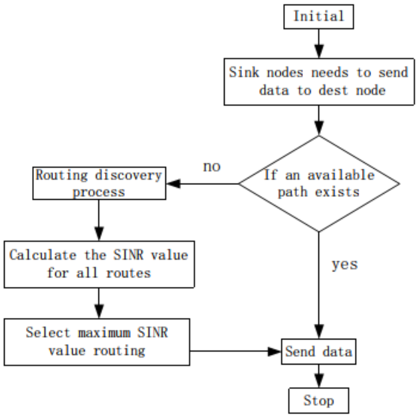

Fig. 3. SINR-AODV Routing algorithm flowchart

- Routing Discovery: As shown in Fig. 4, SINR-AODV has a newly defined SINR value in the first 8 bits of the RREQ header field. Except for this 8-bit field, the other fields have the same definitions as in the AODV algorithm.

Type 8 bits	Flag 5 bits	SINR 8 bits	RESERVE 3 bits	Hop Count 8 bits
RREQ ID 32bits				
Source Address 32bits				
Source Sequence 32bits				
Dest Address 32bits				
Dest Sequence 32bits				

Fig. 4. RREQ Control message settings

The SINR-AODV routing algorithm proposed in this paper mainly consists of route discovery and route maintenance, and the flow chart of the algorithm is shown in Fig. 4

The route discovery process in SINR -AODV is similar to the route discovery process in basic AODV, where each node of the routing algorithm records the SINR value from some source node to the current node. The SINR value determines the probability of successfully receiving a signal for an RREQ control message.

The SINR-AODV routing algorithm processes RREQ control messages as follows:

(1) When the RREQ control message arrives, first, it determines whether the current node generates the RREQ message by comparing whether the source ID of the current node is the same as the source ID field in the RREQ message. If it is the same, the RREQ control message is judged to be generated by the current node and discarded directly; if it is not the same, go to step 2.

(2) Determine whether it is already a destination node. If it is a destination node, start the delay waiting mechanism, calculate the SINR value in all RREQ messages on the destination node, and select the link with the largest SINR as the reverse path for the RREP control message corresponding; If not, the current node is an intermediate node, which is processed in step 3.

(3) First, the reassignment process is performed to determine if the RREQ message is received repeatedly based on the RREQ ID and Source ID field in the RREQ control message. If the RREQ message is received repeatedly, go to step 4; otherwise, update the SINR value in the node routing table and broadcast the RREQ control message.

(4) Since RREQs are flooded network-wide, nodes may receive multiple copies of the same RREQ. After receiving the first RREQ, intermediate nodes receive and collect copies of subsequent RREQs for a specified waiting period. Intermediate nodes update the node routing table based on the control message with the largest SINR value.

- Routing Maintenance: Node failures and link breaks can disrupt the routing path being used. In wireless sensor networks, network links are more likely to be disconnected due to the mobility of nodes. When such a link break occurs, the node upstream of the broken link (the next node to the forwarding source node) invalidates all destinations that have become unreachable due to the break in its routing table. It creates a Route Error message (Route Error, RERR) listing each lost destination and sends it back to the upstream node to the source node. If multiple previous hops are utilizing the link, the node broadcasts the RERR. Once the source node receives the RERR, it can re-initiate route discovery if it still needs the route.

IV. RESULTS AND DICUSSION

In this paper, the algorithm's performance is simulated using Matlab software. Under the same simulation environment, the number of network nodes is set to start from 50 nodes, and the number of nodes is increased by 50 nodes each time until 500 nodes. The performance indexes of average delay, packet transmission success rate, and network throughput are compared and analyzed between the SINR-AODV and classical AODV algorithms.

The average delay refers to the time when the packet arrives at the destination node minus when it is sent from the source node during the network operation as the delay of the packet [17]. The network average delay is obtained by averaging the sum of the delays of all packets received by the destination node. The calculation method is shown in (6):

$$averagedelay=\frac{1}{N}\sum_{i=0}^{N}(T_{end_i}-T_{start_i}) \tag{6}$$

where N denotes the total number of packets received by the destination node, T_{end_i} denotes the time when the destination node received the last packet sent, and T_{start_i} denotes the time when the source node started sending the first packet.

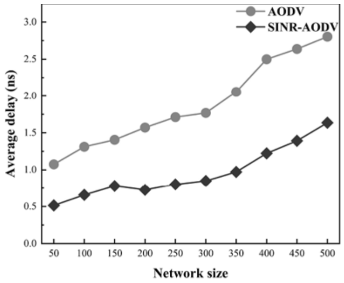

Fig. 5. Comparison of average network latency

The average network delay is calculated according to (6), and a comparison graph of the two algorithms is obtained, as shown in Fig. 5. It can be seen that the average delay of SINR-AODV transmitting data is about 50% lower than that of AODV. This is mainly because SINR-AODV selects paths with less interference and has a higher probability of successfully sending data; thus, the average network delay is lower than that of the classical AODV routing algorithm.

The packet transmission success rate refers to the ratio of the total number of packets received by the destination node to the total number of packets sent by the source node [18]. It is calculated as shown in (7):

$$packetdelivery=\frac{Size_{dest}}{Size_{source}} \tag{7}$$

where $Size$ denotes the total number of packets received by the destination node and denotes the total number of packets sent by the source node.

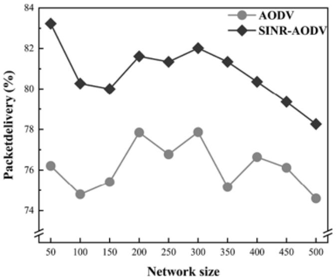

Fig. 6. Comparison of network data transmission success rates

The network data transmission success rate is calculated according to (7). The comparison graph of the two routing algorithms is shown in Fig. 6. The data transmission success rate of SINR-AODV is about 80%, which is 4% higher than the average of the classical AODV. The reason is mainly that the likelihood of link breakage becomes larger due to node interference. SINR-AODV has more reliable routing and less overhead.

Network throughput [19] refers to the total number of packets sent from the source node to the destination node in a given time period and is calculated as shown in (8):

$$throughput=\frac{\sum_{i=0}^{n}Size}{T_{\mathrm{end}}-T_{start}} \tag{8}$$

where $Size$ denotes the size of the first packet at a given time.

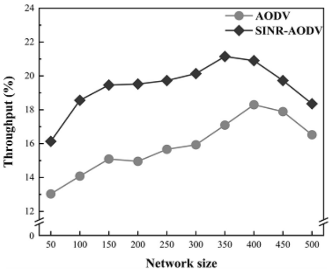

Fig. 7. Comparison of Network throughput

The network throughput is calculated according to (8), and a comparison graph of the two routing algorithms is obtained, as shown in Fig. 7. During the network operation, the network throughput of SINR-AODV with different numbers of nodes is in the range of 16%-21%, which is 3% higher than AODV on average. When more SINR values are in the node routing table, the more inter-node interference information can be detected, the higher the probability that the nodes can communicate with each other, and the higher the network throughput.

V. CONCLUSION

Exploring the routing algorithm based on node interference factors is crucial for improving the performance of wireless sensor networks. This paper introduces noise and node interference parameters in the route discovery process to propose an SINR-AODV routing algorithm based on the signal-to-interference plus noise ratio. Unlike the classical AODV routing algorithm, the SINR-AODV routing algorithm resets the RREQ control messages by introducing signal-to-interference plus noise ratio. The routing path is constructed by tracking the process of broadcasting RREQ messages, which can effectively reduce the influence of node interference during data transmission. Simulation results show that the proposed SINR-AODV routing algorithm significantly outperforms the AODV algorithm in terms of average delay, data transmission success rate, and average throughput. The performance improvement is especially more significant as the network size increases.

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