Wireless Sensor Networks Congestion Control Algorithm Based on Fusion Judgment

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Abstract. With the rapid development of sensor network, the network scale is expanding and nodes are deployed in a large amount. The dynamic change of wireless link quality and sudden traffic of sensor network are easy to cause network congestion, packet loss and waste of energy. In this paper, a congestion avoidance control algorithm (FJCA) for wireless sensor networks was proposed based on the fusion judgment method, and factors such as the distance from node to base station, the residual energy of node and the length of cache queue were considered. And compared it with TADR and MDD algorithms, the results show that the algorithm has higher energy efficiency and balance of nodes, which can improve network throughput more effectively, extended the life cycle of wireless sensor networks, and improve the service quality of network.

1. Introduction
With the rapid development of wireless sensor network technology, the data transmission volume of sensor networks has become more and more complex, so higher requirements are put forward for the transmission bandwidth, delay and reliability of communication networks. Due to the large-scale deployment of wireless sensor networks, and it is based on data-centric for many-to-one communication mode, when large-scale burst data flows to one or some sensor nodes, it will cause congestion due to the insufficient cache queue length and available bandwidth of the output stream of these sensor nodes, so that the incoming packets cannot be forwarded in a timely manner and will be discarded [1]. When congestion occurs in wireless sensor network, the network will continuously discard the data packets in transmission, increase the transmission delay and reduce the throughput of the network, and even cause catastrophic paralysis of the entire wireless sensor network, seriously affecting the quality of service and life cycle of the network [2]. Therefore, congestion control becomes one of the key technologies of sensor networks.

In recent years, domestic and foreign scholars have made a lot of tentative research on wireless sensor network congestion control, such as the literature [3], the author proposed a new congestion avoidance protocol (GMCAR). This protocol adopts the idea that the field of sensor network is grids. Different grids select different sensors as their primary nodes to transmit data. In [4], based on the use of RED algorithm in the network, a new congestion control algorithm is proposed. The algorithm uses congestion limit to control the data transmission of the network, and obtains better network performance by adjusting the congestion limit. Literature [5] proposed a distributed congestion control protocol (ALACCP), this algorithm adopts network congestion index and buffer management to control data transmission. It can avoid packet loss due to congestion and can reduce Node energy...
consumption and increased network throughput. Literature [6] proposes a congestion control algorithm that considers the quantum particle swarm of fairness. Particle swarm optimization is used to adjust the congestion of the network, and packet transport is used for data transmission in different network environments, which makes the algorithm have better network performance. The traffic-aware dynamic routing algorithm (TADR) proposed in [7] is to use multiple paths composed of idle or low-load nodes to spread too many packets, and to reduce congestion by dynamic routing technology to reduce the overhead of static multipath routing.

In this paper, a congestion control algorithm based on fusion judgment is proposed to solve the problems of dropping packets in transmission, increasing transmission delay and decreasing network throughput in sensor network congestion. The algorithm considers the distance from the node to sink, the residual energy and the queue length of buffer as evaluation criteria of the next hop of the route, establishes the membership function and performs the fusion judgment, and selects the next hop node according to the result of the judgment, and the node that makes the packet forward and avoids congestion node finally reaches sink finally. The algorithm can effectively avoid node congestion, improve the throughput of the network and balance the energy consumption of the nodes in the whole network, which is beneficial to prolong the life cycle of the wireless sensor network and improve the service quality of the network.

2. Congestion control algorithm

To solve the congestion problem, the occupancy of node buffer, residual energy and node to base station distance are the key factors to be considered in this algorithm. First, according to the buffer queue length of the neighboring node in the forward propagation direction, the residual energy and the distance to base station, the three next hop parameters are selected, and the appropriate membership function is established to normalize the three parameters. This makes it possible to visually reflect the decisive role of these indicators in selecting the next hop. Then, the membership function is used to fuse the membership function to obtain the final judgment reliability, and the next hop node of the route is determined according to the final judgment reliability. It is divided into three parts, which are neighbor node discovery, optimal path selection and data transmission.

2.1. Neighbor node discovery

Each node i in the wireless sensor network maintains a list of its information L(i), which includes the identifier ID(i) of the node i in the network, the current residual energy e(i) of the node i, and the distance d from the node i to base station, the current cache queue length s(i) of the node and the next hop neighbor list N(i) of node i.

The neighbor node discovery message broadcast is initiated by the sink, which includes the ID (s) and location information of the sink itself. After receiving any sink message, any node a updates its own message list, adds the sink ID to its own next hop neighbor node list, and then continues to broadcast the message containing its own ID. After any node b receives the message from the non-Sink node c, if d(b) is greater than d(c), it updates its own message list, and adds the message of c to N(b), that is, node c is the forward propagating neighbor node of b. The neighbor node continues to broadcast until all nodes receive the message and update, and the neighbor discovery phase ends.

2.2. Optimal path determination

The optimal path selection process is to select the next hop from the source node according to the fusion judgment result to determine the optimal path. When selecting the next hop node, the control algorithm will take the residual energy, the distance from the node to base station and the length of node cache queue as evaluation indicators. In the case where the residual energy of the node is the same, the smaller the distance from the node to base station, the smaller the energy consumed by the node to transmit data. Therefore, if the residual energy is same, the node close to base station is preferentially selected as the forwarding node. In the case that the distance of node to station is the same, in order to avoid the node with small residual energy failing first, the node with more residual...
energy is selected as the next hop first. However, under the condition that the residual energy and the distance of node to station are all the same, the node with small cache queue length has a light load, and the priority of choosing the node as the next hop can effectively avoid congestion. When considering the three evaluation indicators of the node at the same time, in order to eliminate the inconsistency of the three kinds of evaluation index to judge the result, the algorithm for a single index to establish membership function, reflect its influence to choose the next-hop judgment, then each evaluation index to determine membership function, reliability, get the final judgment and choose the most appropriate next hop node.

In the next hop node selection, the smaller the node cache queue length, the greater the contribution to becoming the next hop node. \( s(i) \) is the current cache queue length of node \( i \), \( s_{\text{max}} \) is the maximum cache of node \( i \), then the cache occupancy rate \( F_s(i) \) of the normalized node \( i \) is as follows.

\[
F_s(i) = \frac{s(i)}{s_{\text{max}}}
\]

(1)

The smaller the current cache queue length is, the smaller cache occupancy rate will be. This indicates that the node has a light traffic load and is not prone to congestion, which is suitable for packet forwarding as the node of the next hop of routing. Therefore, this control algorithm adopts Gaussian function to establish membership function for it, as shown in equation (2).

\[
G_s(i) = e^{-\frac{(F_s(i)-\mu)^2}{2\sigma^2}}
\]

(2)

Where \( \mu \) and \( \lambda \) are constant parameters that adjust the membership function, and these constants can be modified to control the membership function curve. In the algorithm, \( \mu=0.5 \) and \( \lambda=-0.1 \) are taken. The larger \( G_s(i) \) is, the higher the probability that the node belongs to the next-hop node is; otherwise, the lower the probability that the node belongs to the next-hop node is.

According to the energy model calculation formula, in order to reduce the consumed energy of network node, the node closer to base station is better when the next hop node is selected. Therefore, the closer the node is to base station, the greater probability that it becomes the next hop node. The distance value of node to station is normalized and the decision reliability becomes the probability of the next hop. The Gaussian function can also be used and the membership function can be established as follows.

\[
F_d(i) = \frac{d(i)}{d_{\text{max}}}
\]

(3)

\[
G_d(i) = e^{-\frac{(F_d(i)-\mu)^2}{2\sigma^2}}
\]

(4)

Where, \( d_{\text{max}} \) is the maximum distance. In order to balance the energy consumption of all nodes, the node with high residual energy will become the next hop. The residual energy value is normalized as the judgment reliability of the next hop possibility of the node. In order to meet the influence of the above two evaluation indicators on the membership degree of the node, let \( F_e(i) \) and \( G_e(i) \) be as follows.

\[
F_e(i) = 1 - \frac{e(i)}{e_0}
\]

(5)

\[
G_e(i) = e^{-\frac{(F_e(i)-\mu)^2}{2\sigma^2}}
\]

(6)

Where \( e_0 \) is initial energy and \( e(i) \) is the current residual energy.

The three evaluation indicators can be normalized into cost-type attributes. According to their influence on the judgment of the next hop, Gaussian functions are used to establish the membership
function. In order to better integrate the node cache queue length, the node-to-base station distance and residual energy as the next hop membership, this paper uses following formula to fuse it:

$$G(i) = G_c(i) + G_d(i) + G_e(i) - G_c(i) \times G_d(i) - G_e(i) \times G_d(i) \times G_e(i)$$

(7)

The above formula can achieve the enhancement and reconciliation of the three evaluation indicators and match the mapping $F$: $[0, 1]^2 \rightarrow [0, 1]$. Using the fusion result of equation (7) as the final judgment reliability, the node with the largest membership function value $G(i)$ is determined as the next hop node of the route.

2.3. Data transmission
When the data transmission of sensor network continues to increase, the congestion and residual energy will change. If the control algorithm is frequently executed to select the optimal path, excessive control overhead will be generated and energy will be wasted. Therefore, it is necessary to set a congestion threshold for nodes on the data transmission path. If the cache occupancy rate of any node $i$ on the transmission path exceed this threshold or fails due to energy exhaustion, the node will send a routine maintenance request and the control algorithm will restart the selection process of the optimal path immediately.

3. Simulation results and analysis
In wireless sensor networks, the reliability of data transmission is an important evaluation index of WSN, and the network throughput rate reflects the reliability of the network to a certain extent. The sensor node will cause data retransmission due to congestion, and when multiple data retransmissions are unsuccessful, the data packet may be discarded [8]. In addition, the life cycle of network and the average energy consumption of nodes are also important indicators to evaluate the performance of network congestion control algorithms. Some application scenarios allow some nodes to fail, while the death of any node in the application environment will have a critical impact on the network. In this paper, the number of data transmission when the first node dies is defined as the WSN network life cycle.

In this paper, MATLAB is used to simulate the experiment, and the algorithm is compared with TADR algorithm and Mobile agent-based directed diffusion algorithm (MDD) [9]. In the simulation, nodes are randomly and uniformly distributed in an area of $100 \times 100$ m. All nodes will not move once placed. The simulation parameters are shown in table 1. The sink is located at the origin of the coordinate axis, and the source node is at the region edge.

| Table 1. Simulation parameter |
|-------------------------------|
| **Item**                      | **Value** |
| Region                        | $100 \times 100$ m$^2$ |
| Number of nodes               | 100/150/200/250/300/350/400 |
| Sink coordinates              | (0, 0) |
| Node send radius              | 20 m |
| Initial energy of the node    | 0.5 J |
| $E_{elec}$                    | 50 nj/bit |
| $E_{fs}$                      | 100 pj/bit/m$^2$ |
| Source node packet rate       | 10 packets/s |
| Packet length                 | 500 bits |
| Buffer queue length           | 20 packets |
Perform the TADR, MDD, and FJCA algorithms separately to obtain the relationship between network throughput and nodes number, as shown in figure 1. As can be seen from the figure, as the number of nodes increases from 100 to 400, the network throughput of the FJCA algorithm is the highest, and the MDD algorithm has the worst performance due to the absence of congestion control mechanism. TADR algorithm considers the congestion state of the next-hop node, that is, detects congestion through the buffer queue length of the node. However, due to the limitation of linear weighting and the uncertainty of the weight coefficient selection, the network performance is limited. The establishment of FJCA algorithm is based on the membership function of node buffer packet queue length. This active traffic transfer routing strategy largely avoids congestion, reduces network packet loss rate, realizes congestion avoidance routing mechanism, and improves network throughput rate and other performance. The relationship between the network life cycle and the number of nodes is shown in figure 2. It can be seen from the figure that compared with TADR and MDD algorithm, FJCA algorithm can improve the network life cycle more effectively. When selecting the next hop node, FJCA algorithm combines three evaluation indexes to obtain the best congestion avoidance performance and the longest network life cycle.

Another important parameter for algorithm simulation evaluation is average node energy consumption, it measures the energy consumption in the process of network data transmission [10]. The average energy consumption of each node and each round when each control algorithm runs to the maximum life cycle number is analyzed and compared. The results of average node energy consumption are shown in figure 3. From the figure, compared with the TADR and MDD algorithms, the FJCA algorithm has the lowest node energy consumption. The data packet transmission under MDD algorithm is based on the query published by Sink, while the gradient field should be established in the process of query publishing by Sink. Due to the dynamic nature of the network communication state, it is impossible to ensure the optimal energy consumption according to the established path. As the network load increases, the packet loss rate will rise substantially. TADR algorithm is superior to the energy consumption of MDD, to gather in the WSN area according to the ordinary node communication distance will be divided into jump by increasing fixed area, this method makes the open by the potential energy field value is discrete, and every time when the deep change depth calculation cost is too big. In FJCA algorithm, membership function is established according to the distance from node to sink, which can more accurately and directly reflect the effect of distance on energy consumption. The TADR algorithm has a potential field that it is only a single guarantee for the establishment of the minimum hop count route, and it is easy to ignore the possible backhaul of the node.
Figure 3. Average node energy consumption.

Aiming at the balance of the overall energy consumption of the network, the establishment of the route in the FJCA algorithm enables the transmission of the data packet to be forward distance propagation, effectively avoiding problems such as node backhaul and local loop transmission, which reduces the overall energy consumption of network nodes, the network average node energy consumption steadily maintained at a lower level, and its performance is also minimally affected by changes in network size.

4. Conclusion

In this paper, a congestion control algorithm based on fusion judgment is proposed for the problem of packet loss, transmission delay and network throughput loss when the sensor network is congested. This algorithm takes the distance from the node to sink, the residual energy of the node and the queue length of the buffer as evaluation indexes, establishes the membership function and makes fusion judgment, and compares it with TADR and MDD algorithms. The results show that the FJCA algorithm has the highest network throughput and can effectively reduce the overall energy consumption of the network nodes, and its performance is minimally affected by the network scale change. The algorithm makes the network more energy efficient, making wireless the sensor network has a longer life cycle and can better improve the quality of service of the network.

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