Research on an Intelligent Routing Strategy for Industrial Internet of Things

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Abstract. The Industrial Internet of Things is considered to be an important cornerstone of future industrial development and has broad development prospects. It is being deployed to the society on a large scale. Sensor nodes in the Internet of Things will inevitably face many challenges. Due to the limitations of the existing sensor nodes, the traditional energy measurement methods for wireless sensor networks have been difficult to meet. Therefore, this article proposes a new routing protocol for low-power and low-power networks (RPL). The routing measurement method EEM meets the requirements of low-power lossy networks for link quality and energy consumption, and then uses the modified simulation software to test the EEM routing measurement, and performs performance verification on the packet loss rate and network load. The experimental results show that EEM retains the requirements of ETX routing metrics for link quality, realizes the awareness of node energy consumption, and optimizes network load.

Keywords: Wireless sensor network · RPL · Routing metrics · Industrial internet of things

1 Introduction

The RPL routing protocol is an IPv6-based distance vector protocol for low-power lossy network design and development. In a low-power lossy network, the environment faced by the links between nodes is often harsh, and the information processing capabilities and energy of the nodes themselves are limited, and the limited energy and processing capabilities of the nodes need to be self-organized. networking. In the RPL routing protocol, nodes broadcast control messages to each other to establish a DODAG structure, collect information from sink nodes intermittently, and are compatible with IPv6. These features make the RPL protocol a perfect fit for the development needs of the future industrial Internet of Things. And because of the objective function and the reference of routing metrics, the RPL protocol has extremely high modularity and plasticity, so it has great research value in the field of industrial Internet of Things.

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2 Research Background

At present, the RPL protocol mainly uses two objective functions to complete the network topology construction, namely OF0 and MRHOF. OF0 is the metric selection based on the number of hops from the node to the root node. The smaller the number of hops from the candidate parent node to the root node, the higher the probability that it will be the parent node. OF0 is the simplest basic objective function and is used in small-scale deployment networks. Often performance is excellent, but this routing strategy cannot consider the link quality between nodes. When the communication quality between nodes is poor, it will cause a large number of backhauls between nodes and cause energy consumption problems, which will compress the network life cycle. A large number of practices use the MRHOF objective function based on the ETX routing metric, and the objective function can take a variety of routing metrics, including Hops, Latency, etc., among which ETX represents the quality of the communication link between nodes. Therefore, based on the in-depth study of ETX in the RPL protocol, this article considers ETX alone as a routing metric that cannot meet the needs of the industrial Internet of Things model, and then introduces a routing strategy EEM (ETX and Energy) based on link communication quality and energy balance. balanced Metrics), and used the API provided by the objective function in the RPL protocol to implement and verify the strategy.

3 Industrial IoT Model

The industrial IoT system architecture is mainly divided into three levels, namely the perception layer, the transmission layer and the application layer. This paper focuses on the routing strategy of the sensor network in the transmission layer of the Industrial Internet of Things, so this article uses the Industrial Internet of Things model shown in Fig. 1 to study the routing strategy.

In Fig. 1, the root node with a stable power supply is used as a border router to allocate the IP addresses of other child nodes, and centrally process and transfer the information collected by the sensor nodes to the information processing center. The sub-nodes composed of sensors respectively include mobile nodes and fixed nodes, and their communication distances are limited and because they are powered by batteries, the energy of the sub-nodes is limited. The child nodes have a certain storage space and limited transmission distance, and have the ability to collect information and send information. The control messages and trickle mechanism introduced in Sect. 2 are used between the nodes to build and maintain the topology structure. The control messages contain the information of the node. Energy information, Rank value, etc., and finally the information collected by the child nodes are transmitted to the root node in a multi-hop manner. In this model, the information collected by the node needs to be gathered at the root node.

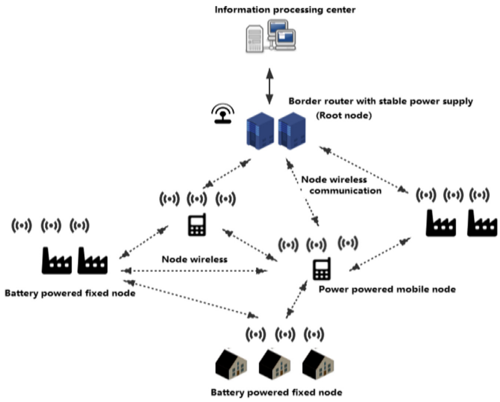


Fig. 1. Industrial Internet of Things research model

3.1 Model Structure Analysis

In this paper, the Packet Loss Ratio (Packet Loss Ratio) indicator is used to measure the cognitive function of the node on the link quality. The use of this index mainly considers that the packet loss rate is closely related to the link quality. If the link quality between nodes is poor and the routing strategy does not realize the cognitive function of the link quality, it will inevitably lead to an increase in the packet loss rate., and a large number of retransmissions will lead to an increase in the cost of control messages and an increase in the duty cycle of node monitoring and sending, which makes the node's excessive energy consumption and death time earlier, which is fatal for the sensor network. This article defines the packet loss rate as follows:

$$PLR = \frac{\sum_{n} \frac{P_{received}(i)}{P_{send}(i)}}{N_{total}} \tag{1}$$

$P_{received}(i)$ represents the number of data packets sent by the node that the root node has successfully received, $P_{send}(i)$ represents the number of data packets sent by the node to the root node, and N_{total} represents the number of child nodes in the entire network topology.

Aiming at the problem of node energy consumption, this paper proposes a model of computing node energy consumption:

$$E_{consumption} = \sum_{M,S} P_{M,S} \cdot T_{M,S} \tag{2}$$

Where $P_{M,S}$ represents the power of the M module in the S state, and $T_{M,S}$ represents the working time of the M module in the S state.

Through the above analysis, calculate the energy of the processor and wireless communication modules that consume a lot of energy:

$$Power = P_{cpu} \cdot T_{cpu} + P_{lpm} \cdot T_{lpm} + P_{rt} \cdot T_{rt} + P_{rl} \cdot T_{rl} \tag{3}$$

Where P_{cpu}, T_{cpu} represents the power and time of the processor module in full-speed operation; P_{lpm}, T_{lpm} represents the power and time of the processor module in low-power consumption mode; P_{rt}, T_{rt} represents the power and time of the wireless communication module in the sending state; P_{rl},T_{rl} represents the wireless communication module Monitor the power and time. The working voltage of the node and the current in different modes are usually fixed constants. In this way, it is only necessary to measure the working time of the node in different states to calculate the energy consumption of the node.

3.2 Quality Analysis of Node Communication Link

The purpose of the introduction of ETX is to measure the reliability of the link. In practical applications, nodes use the MAC layer to receive transmission or ACK messages, collect neighbor node information, determine and calculate the ETX value between nodes. ETX calculation methods are diverse. One of the most widely used is the EWMA (Exponentially-Weighed Moving Average Function) algorithm, whose formula is as follows:

$$new\_ETX = \alpha \cdot recorded\_ETX + (1 - \alpha) \cdot packet\_ETX \tag{4}$$

If the node does not receive neighbor node information at the MAC layer, *packet_ETX* will be set to the maximum value, which can be adjusted for different network conditions. On the contrary, if the node receives neighbor node information, the maximum value will be decremented. *packet_ETX* can reflect the link quality between nodes. It is characterized as the link metric value of the neighbor node, and the new ETX value is assigned to *link_metric* after the calculation is completed.

4 Research on Intelligent Routing Strategy

MRHOF adopts the ETX measurement while considering the hysteresis phenomenon. Although the introduction of the ETX concept realizes the node's cognitive function of the link quality between nodes, a single cognitive function is difficult to adapt to the complex environment. Therefore, this article A routing metric EEM that integrates two cognitive functions is proposed:

$$EEM = Algorithm(ETX, Node\_Energy) \tag{5}$$

In the above formula, ETX characterizes the link communication quality between nodes, which is calculated by formula (4), and Node_Energy represents the total historical energy consumption value of the candidate parent node, which is calculated according to formula (3). The specific principle of EEM metric is shown in Fig. 2. When a node selects a parent node, it will first give priority to the parent node's ETX value. If the candidate parent node's ETX is within the allowable range, it will continue to consider the historical total energy consumption of the candidate parent node. If a node's historical energy consumption is higher If it is smaller, the node will be selected as the parent node first. If the ETX value difference between the candidate parent nodes is too large, the node with the best link communication quality will be selected first as the parent node. In this way, EEM integrates ETX and node energy consumption measurement, and realizes node energy load balancing while ensuring the communication link.

4.1 Routing Metric EEM

Introduce the EEM routing metrics into the MRHOF objective function. The MRHOF objective function mainly provides four program interfaces, which can be used to optimize MRHOF. The four program interfaces are the best directed acyclic graph (Best Dag), the best parent (Best Parent), the calculation of the Rank value (Calculate Rank), and the update of control information (Update Metric Container). The functions of the above four program interfaces are:

(1) Optimal directed acyclic graph. The API selects the DAG with the best candidate parent node based on OF and joins it. Different OFs will consider different selection strategies, such as whether the DAG is connected to an external network, DAG rank value and version number, and the order of DIO messages.

(2) The best parent node. The API selects the best parent node based on OF. In MRHOF, compare the ETX value of the candidate parent node. If the ETX value is within the allowable threshold, the parent node will not be changed. Otherwise, a new parent node will be selected based on the routing metric. The purpose of this is to avoid network conditions. The resulting ETX gap leads to frequent replacement of parent nodes by nodes, which leads to changes in the network topology and brings huge costs. If the two ETX values exceed the threshold, the node with the smallest ETX is selected as the default next hop according to the ETX information of the parent node.

(3) Calculation of Rank value
This interface calculates the rank value of a node based on OF, and the rank value between parent and child nodes is an increasing relationship. The calculation formula is:

$$Rank_N = Rank_P + Rank\_Increase \tag{6}$$

In MRHOF, *Rank_Increase* is the *link_metric* value of the parent node, and the value of *link_metric* is the same as the ETX value between nodes, that is, the node Rank value reflects the information of the node's ETX value.

(4) Update of control information
In the DIO control message of the RPL protocol, the interface appends the updated routing metric information of the node to the DIO control message, and broadcasts it in the network along with the DIO message. The updated routing metric message must conform to the DIO control message format, such as the node's ETX Value or energy information occupies the option field in the DIO

control message. Other nodes select the parent node by extracting DIO information of neighbor nodes.

4.2 Optimization Strategy

In order to ensure that the optimized objective function has the route establishment process and maintenance mechanism of the RPL protocol, and avoid the generation of loops, this article retains the original optimal directed acyclic graph of the RPL protocol and the method of calculating the Rank value during the implementation of the EEM., It is mainly updated for the two interfaces of the optimal parent node, namely the control information update. The updated part is as follows:

(1) Optimal parent node
The pseudo code for selecting the optimal parent node is shown in the following table:

Table 1. SCM routing metrics Best Parent pseudo code

Algorithm 1	Best Parent
Input:	Alternative node P1, alternative node P2
Output:	Best Parent
1:	**if** P1->ETX – P2->ETX <mindiff && P1->ETX – P2->ETX>-mindiff **then**
2:	**If** P1->energyest < P2->energest **then**
3:	return P1
4:	**else** return P2
5:	**end if**
6:	**end if**
7:	**if** P1->ETX <P2->ETX **then**
8:	**return** P1
9:	**else return** P2
10:	**end if**

the above pseudo code, mindiff represents the preset ETX threshold. If the candidate node is within the threshold, the optimal parent node is selected according to the node energy. energest represents the total energy consumption of the node, which is equivalent to Node_Energy in formula (5). Under the premise of ensuring the quality of the communication link between nodes, the less historical energy consumption of the candidate parent node, the higher its priority.

(2) Update of control information
The pseudo code of the DIO control message update part is shown in Table 2:
In the following pseudo code, if the rank value of the root node of the DAG graph contained in the original DIO control message is 0, which means the root node, the energy information part of the new DIO is set to 0. This approach is to increase the priority of the root node, If there is a root node in the candidate parent node list of a

node, the node will preferentially select the root node as its own parent node, otherwise it will record the energy value of the local node and update the value to the new DIO and forward it.

Table 2. SCM routing metric Update Metric Container pseudo code

Algorithm 2	Update metric container
Inout:	oldDIO
Output:	newDIO
1:	**if** oldDIO->dag->root->rank == 0 **then**
2:	newDIO->mc.energest-> ==0
3:	**else**
4:	power = cpu + lpm + rl + rt
5:	newDIO-> mc.energest-> == power
6:	**end if**
7:	return newDIO

After completing the above two parts, use EEM routing metrics to re-plan the network deployment in Fig. 2. The simulation results are shown in Fig. 3:

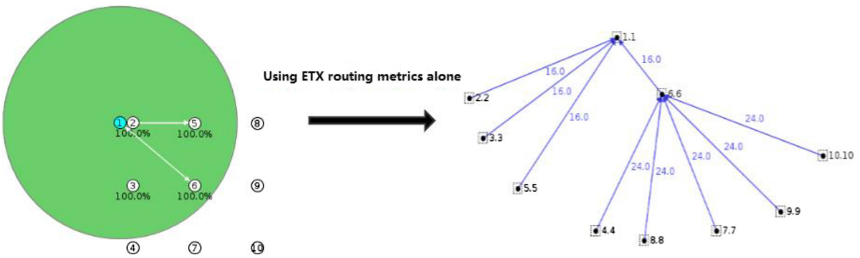
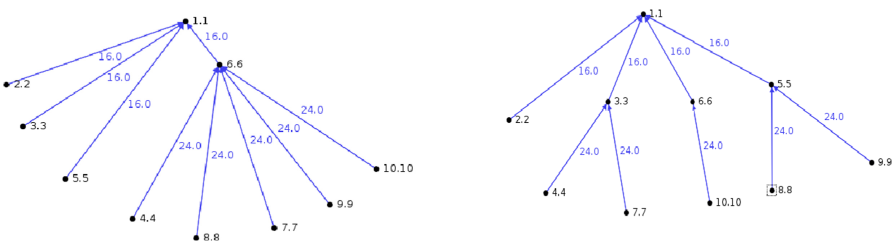


Fig. 2. ETX routing metrics



（a）Network topology based on ETX （b）Network topology based on EEM

Fig. 3. Comparison of ETX and EEM routing metric topology structures

The EEM routing metric avoids the problem of multi-node selection of node 6. It can be found that nodes 4, 7, 8, 9, 10 avoid the centralized use of 6 as its parent node, 4, 7 selects node 3 as the parent node, and 8 and 9 select Node 5 is the parent node, while node 10 retains 6 as the parent node. By using the EEM metric, the selection of the child nodes to the parent node is more balanced, and the entire topology is more dispersed. Through the analysis of the topology, it can be qualitative It is believed that EEM has completed the load balancing task of nodes in the network under the premise of ensuring the link quality.

5 Experimental Simulation

The Contiki operating system and Cooja simulation software are used to simulate and verify the routing metric and perform performance analysis to investigate the difference in packet loss rate and energy load compared with the original routing metric.

5.1 Simulation Environment

The Contiki operating system is an open source multitasking operating system. The interface is shown in Fig. 4. The uIP protocol stack implemented inside the Contiki operating system supports the TCP/IPv6 communication protocol, which enables a large number of embedded devices to achieve complete IP access, networking and communication with relatively few resources, and greatly reduces With the complexity of communication between embedded devices and Internet devices, people can use a unified IP perspective to quickly and flexibly develop various sensor network and Internet of Things applications.

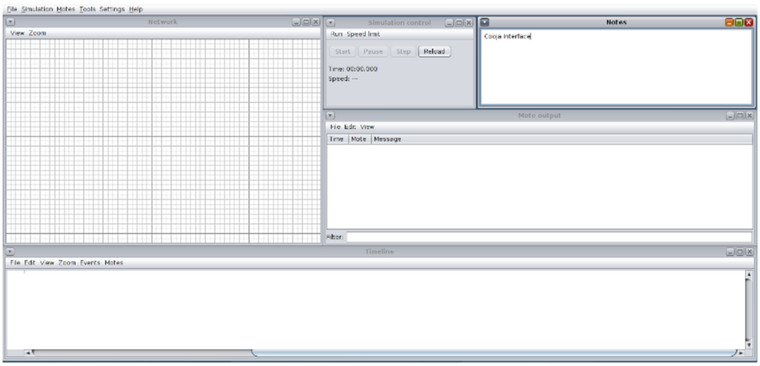


Fig. 4. Cooja simulation software operation interface

The routing strategy proposed in this paper needs to have a cognitive function on the link quality of neighbor nodes. In order to verify whether the EEM routing metric has the same link quality perception effect as ETX, this paper considers the performance of both from the perspective of packet loss rate. The experiment is based on two deployment scenarios, linear deployment and random deployment, corresponding to Fig. 4 (c) and (d). By comparing the packet loss rate data of ETX and EEM routing metrics under different packet flows, it is verified whether EEM retains the cognitive function in ETX. In the experiment, each child node sends data packets to the root node independently and regularly. If the root node successfully accepts and returns a successful acceptance message, this process is counted as a successful packet reception, otherwise it is counted as a packet loss. In the experiment, by changing the child node timer setting The number changes the node data packet flow. The simulation results are shown in Fig. 5.

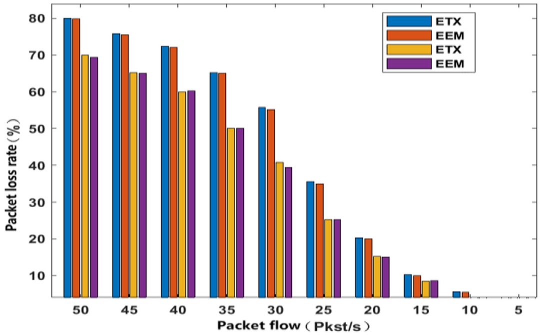
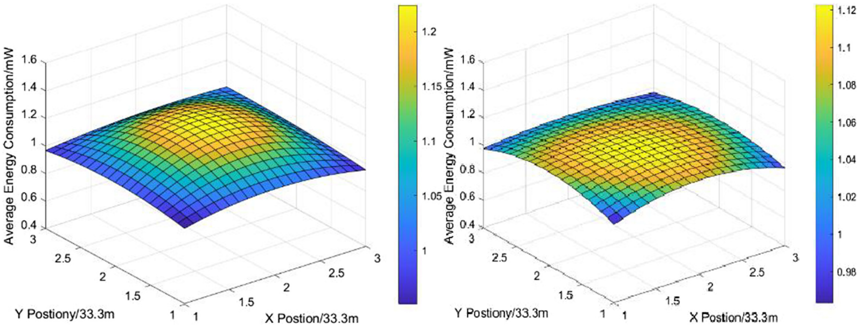


Fig. 5. Comparison of ETX and EEM packet loss rate

It can be found that with the increase of data packet traffic, the packet loss rate based on ETX and EEM routing metrics increases. When the data packet traffic is lower than 10Pkst/s, both perform well in data packet transmission. When the data packet traffic is greater than 15Pkst At/s, the packet loss rate increases significantly, and in general, the randomly deployed network structure is better than linear deployment in terms of packet loss rate. The packet loss rate performance of the two routing metrics is similar under different packet flow and topology. Based on the above results, a preliminary conclusion can be drawn that in terms of packet loss rate performance, ETX and EEM achieve the same performance effect.

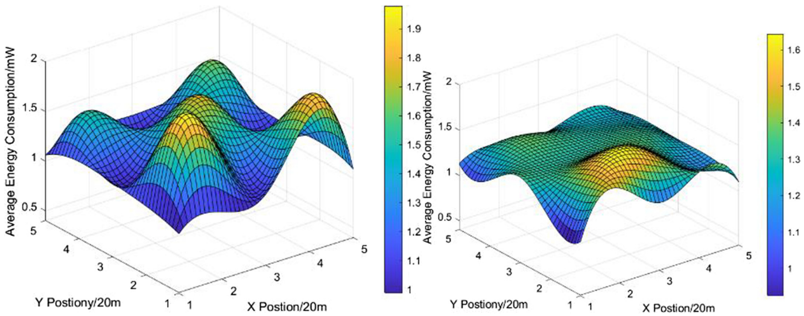
EEM is more "dispersed" for the establishment of DODAG topology, and the average number of child nodes of the parent node is less than the ETX routing metric. Therefore, it is necessary to continue to verify the energy cognitive function of SCM and compare its performance on network load balancing capabilities.

Figure 6 and Fig. 7 reflect the network load situation using different routing metrics in the two deployment scenarios. There are obvious poles in the network based on the ETX standard, and the energy consumption of nodes in the entire network is not evenly distributed. Under the EEM standard, the load situation of the entire network is relatively balanced, there is no or no obvious extreme point, and the energy consumption of nodes in the entire network is relatively flat. Through experiments, it can be concluded that in terms of network load balancing, EEM has completed the expected energy cognition function, optimized network energy distribution, and realized the task of load balancing.



(a)ETX network load (b) EEM network load

Fig. 6. 10-node linear deployment network load situation



(a)ETX network load (b) EEM network load

Fig. 7. 26-node linear deployment network load situation

6 Conclusion

This paper studies the routing strategy of the Industrial Internet of Things, and expands on the basis of the widely used RPL routing protocol in the field of Industrial Internet of Things. It discusses the node attributes that need to be considered for the future deployment of the Internet of Things to the society, and proposes a node For the dual functions of link quality and energy perception, a new routing metric quasi-EEM combining ETX and energy perception is designed based on this. Combined with the research platform Contiki and simulation software Cooja, the routing metrics are the packet loss rate and node energy consumption. And the network load capacity was evaluated experimentally, which verified that EEM realized the perception of node energy while retaining the cognitive function of ETX, optimized node energy consumption, and balanced network load.

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