

Research on Bus Joint Temperature Detection System Based on Wireless Sensor Network Node Energy Balance

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Abstract: This paper proposes a bus joint temperature detection system based on the balance of nodes energy consumption in wireless sensor network (WSN). The system supplies limited power to each node through batteries. Due to the imbalance of energy consumption on WSN nodes, some nodes in the network are "dead" too early, leading to the unreliable operation of the system. In order to solve this problem, energy consumption model is established by the analysis of the energy loss and one-way propagation characteristics of WSN applied to bus joint temperature detection. The strategy of WSN nodes energy balance is employed in multi-hop network to balance nodes energy consumption. Simulations demonstrate that it has a great help in WSN nodes energy saving and system lifetime extension.

1. Introduction

Bus bar as power transmission equipment, with its superior performance, high security, easy installation, wide current range, high line optimization and strong expansibility, has become one of the most important components of transmission lines[1]. However, the working performance of the bus bar is greatly affected by the temperature due to its own structural characteristics. In particular, a high-resistance connection in bus joint may cause overheating or even breakdown of the insulating materials, which brings a huge hidden danger to the operation of the power system[2]. Therefore, on-line monitoring of bus joint temperature is of great importance.

A bus joint temperature detection system based on the balance of nodes energy consumption in wireless sensor network (WSN) is proposed in this paper. The system uses batteries to supply power for WSN nodes, hence the energy consumption of nodes is directly related to the cycle of system battery replacement, which is also known as WSN life. Due to the large number and dense

distribution of nodes on the bus joint, the collected data are transmitted to the sink node in a multi-hop mode. In this process, the nodes near the sink node are dead too early due to forwarding a large number of data, which may cause WSN being divided or even failure[3]. This phenomenon of excessive energy consumption caused by unbalanced load distribution between nodes is called funneling effect[4], [5]. Funneling effect is an inherent problem of multi-hop WSN. Some solutions were put forward, such as configuration of the nodes transmitting distance[6], application of clustering algorithm[7], design of the load balancing routing protocol[8], etc., but these methods can only alleviate the funnel effect to a certain extent. In this paper, WSN nodes energy balance algorithm is employed according to the characteristics of the bus joint temperature detection system. It effectively improves the energy utilization of WSN nodes and prolongs the battery replacement cycle of the system.

2. Bus Joint Temperature Detection System

2.1. System Structure

Bus joint temperature detection system is composed of wireless sensor nodes, sink nodes and computers, as shown in Figure 1. The wireless sensor nodes from A(1) to A(n) are installed on the bus joint of trunk A, and from B(1) to B(m) are installed on the bus connector of trunk B. The WSN is formed by the wireless sensor nodes on the bus bar connectors of trunk lines in the process of information transmitting. Finally, the temperature and current information on each node is transmitted to the computer through the sink node.

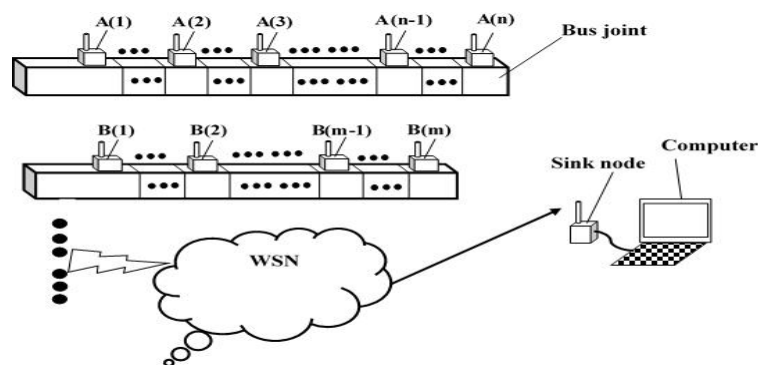


Figure 1: Structure of bus joint temperature detection system.

2.1. Node Structure

Figure 2 shows the structure of a bus joint temperature detection node. It mainly includes power module, STM32 control chip, temperature sensor and wireless communication module. In this node, DS18B20 is used as a temperature sensor for bus joint temperature collection, while CC2420 is applied as wireless communication module for the transmission of the collected bus joint temperature data to the next node closer to the sink node.

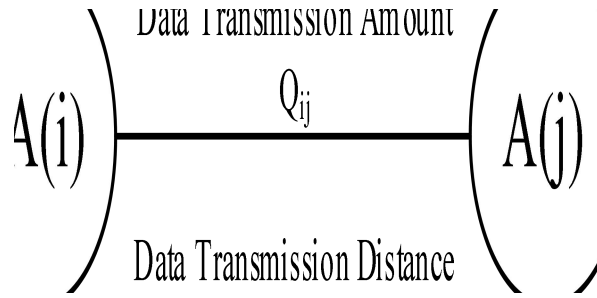


Figure 2: Structure of a bus joint temperature detection node.

3. Data Transmission Model and Node Energy Consumption Model

3.1. Data Transmission Model

According to the system structure shown in Figure 1, it can be seen that WSN applied to bus joint temperature detection is a typical linear network. Generally, $A(n)$ is considered to be the closest to sink node. For the trunk line of the bus, if $A(n)$ is closest to sink node, then $A(1)$ is furthest from sink node. The most common multi-hop information transmission mode of this linear WSN is $A(1)$ to $A(2)$, $A(2)$ to $A(3)$, . . . , $A(n-1)$ to $A(n)$. However, with the increase of the number of nodes, the power consumption of the subsequent nodes grows rapidly. The energy consumption of each node is unbalanced due to the imbalance of the amount of information transmitted by each node. It is shown that the distance of each hop and the number of multi-hops are closely related to the energy consumption of nodes by the analysis of the mode of information transmission. Since the data transmission direction of WSN applied to bus joint temperature detection is one-way, the node with small serial number must transfer data to the node with large serial number. That is, $A(i)$ and $A(j)$ are set as any two nodes in a bus trunk line. If $i < j$, $A(i)$ is the sending node and $A(j)$ is the receiving node. It is assumed that the distance between two adjacent nodes is equal, which is represented by L . The transmitting amount of node $A(i)$ is equal to the receiving amount of node $A(j)$, which is represented by Q_{ij} . The data transmission model for the bus joint temperature detection is shown in Figure 3.

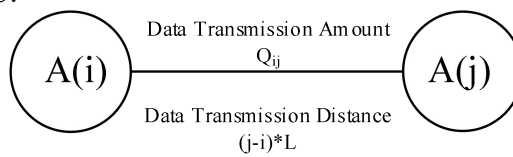


Figure 3: Data transmission model for the bus joint temperature detection.

3.2. Node Energy Consumption Model

Compared with the energy consumption of wireless communication, nodes processing energy consumption, sensing energy consumption and energy consumption in sleep state can be ignored[9]. Therefore, the node energy consumption model can be approximately as Figure 4. In this model, there are two cases: the transmitting data energy consumption E_{Tx} and the receiving data energy consumption E_{Rx} . Since the power attenuation of transmitted signal decreases exponentially with the increase of transmission distance in wireless transmission, the free space and multi-path attenuation model proposed in[10] is adopted as follows:

$$E_{Tx} = \begin{cases} cE_{elec} + c\epsilon_{fs}r^\alpha & (r < r_0) \\ cE_{elec} + c\epsilon_{amp}r^\alpha & (r \geq r_0) \end{cases} \quad (1)$$

where c is the number of perceived bits per second, E_{elec} is the energy consumed by a node to send or receive one bit, and r is the distance between a sending node and a receiving node. ϵ_{fs} and ϵ_{amp} are constants related to path loss index, which are generally 10 pJ/bit and 0.0013 pJ/bit, respectively. r_0 is the boundary distance value between free space model and multi-path attenuation model, which is generally 86.998m[11]. The path loss index α is related to the value of r . When r is less than r_0 , α is equal to 2. When r is greater than or equal to r_0 , α is equal to 4.

Meanwhile, the energy consumption of receiving information is only related to the amount of data, not to the communication distance. The energy consumption formula regarding receiving information is shown in (2).

$$E_{Rx} = cE_{elec} \quad (2)$$

For any node A(i) in WSN, its energy consumption includes transmitting energy consumption and receiving energy consumption. Therefore, the energy consumption of node A(i) can be expressed as follows:

$$E_i = E_{iTx} + E_{iRx} \quad (3)$$

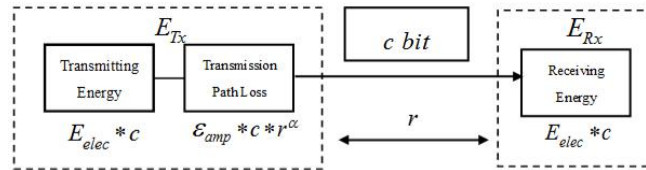


Figure 4: Node energy consumption model.

4. Node Energy Balance Algorithm and WSN Lifetime Analysis

4.1. Node Energy Balance Algorithm

In order to prolong the battery life on the WSN node of the bus joint temperature detection system as much as possible, the node energy balance algorithm proposed in[12] is adopted in this paper. By adjusting the jump distance and jump times of each node, the energy consumption on different nodes can be balanced. The specific implementation process of the algorithm is shown as follows:

4.1.1. Determine Bus Joint Node Location

The nodes on the same bus are sorted according to the distance away from the sink node. The number of the node furthest from the sink node is 1, while the node closest to the sink node has the maximum node number n . The distance between adjacent bus joint nodes on the same bus trunk may be unequal in application. In consideration of the transmission reliability, the longest distance between adjacent nodes on a bus trunk is chose as the standard value L in the model of Figure 3.

4.1.2. Establish Energy Consumption Constraints according to Data Amount and Jump Distance

Based on the data transmission model for the bus joint temperature detection in Figure 3, it can be seen that the node with small serial number can send data to any node with large serial number. The amount of data received and forwarded by the node can be indicated by X_{ij} . When $0 < i < j$, X_{ij} represents the amount of data sent by node i to node j . Conversely, when $0 < j < i$, X_{ij} represents the amount of data received by node i from node j . Each node receives data from the parent node and forwards the received data to the child node. Therefore, for any node, the amount of its receiving data must be equal to that of its forwarding data, as shown in (4).

$$\sum_{k=1}^i X_{ik} = \sum_{k=i+1}^n X_{ik} \quad (4)$$

When $0 < i < j$, E_{ij} indicates the data transmission energy consumption. The data transmission distance between node i and node j is $(j-i)*L$. If the amount of data to be transmitted in one second is n bit, then according to (1), the transmission energy consumption E_{ij} can be expressed as follows:

$$E_{ij} = \begin{cases} cE_{elec} + c\varepsilon_{fs}((j-i)L)^\alpha & ((j-i)L < r_0) \\ cE_{elec} + c\varepsilon_{amp}((j-i)L)^\alpha & ((j-i)L \geq r_0) \end{cases} \quad (5)$$

When $0 < j < i$, E_{ij} indicates the data receiving energy consumption. According to (2), the data receiving energy consumption E_{ij} can be expressed as follows:

$$E_{ij} = cE_{elec} \quad (6)$$

Using (3), (4), (5) and (6), the node energy consumption can be calculated as:

$$E_i = c \sum_{j=1}^{n-1} E_{ij} X_{ij} \quad (7)$$

4.1.3. Adjusting One-hop Distance and Data Forwarding Amount of Different Nodes for Equal Energy Consumption of the Whole WSN Nodes

Namely, the energy consumption of any node must conform to $E_i = E_{i+1}$, which ensures that the network lifetime of each forwarding area is the same.

4.2. WSN Lifetime Comparison of Two Algorithms

The WSN of the bus joint temperature detection system is a kind of linear network. When some nodes in WSN are dead too early due to energy exhaustion, WSN can not operate reliably. Therefore, it can be deduced that the unbalance energy consumption of nodes will directly decrease the life of WSN. The traditional continuous forwarding algorithm is transmitting the data to the adjacent nodes in sequence and finally to the sink node. The comparison between the node energy balance algorithm and the above traditional algorithm is carried out to analyze the respective lifetime of both nodes and networks.

Based on the node energy consumption model, it is assumed that the initial energy E_{init} of total nodes is 2000 J, the number of bus joint nodes is 30, the speed of data transmission is 40 bit/s, and the energy E_{elec} consumed by a node to send or receive one bit is 50 pJ/bit.

Figure 5 shows the lifetime comparison results of each node in two algorithms. Since the algorithm used in this paper makes all nodes on the same bus trunk consume energy evenly until they cannot transmit any data, the residual energy of each node is almost equal to zero. Correspondingly, the lifetime of each node is approximately equal. In the traditional algorithm, if the node is closer to the sink node, its service life is shorter, and the network service life is equal to the minimum lifetime of all the nodes on the same bus trunk.

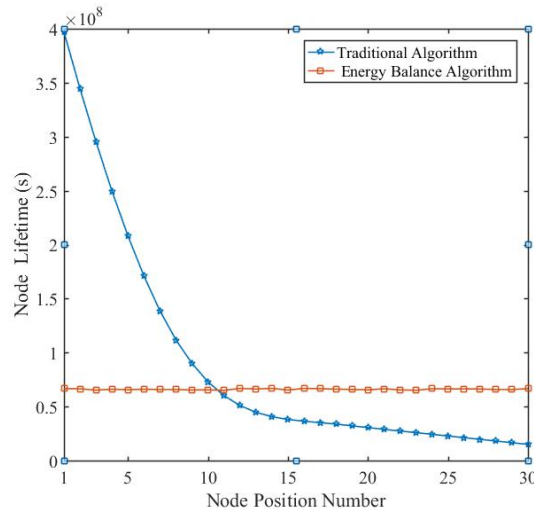


Figure 5: Lifetime comparison results of each node in two algorithms.

Figure 6 is a comparison of network life in two algorithms. As long as one node on the same bus trunk consumes all the energy, there will be data transmission problems in the network. Therefore, Figure 6 is obtained based on Figure 5 actually. It can be seen from the Figure 6 that the network life of the algorithm used in this paper is nearly three times longer than that of the traditional continuous forwarding algorithm. With the increase of the number of nodes on the bus trunk, the network life also grows several times.

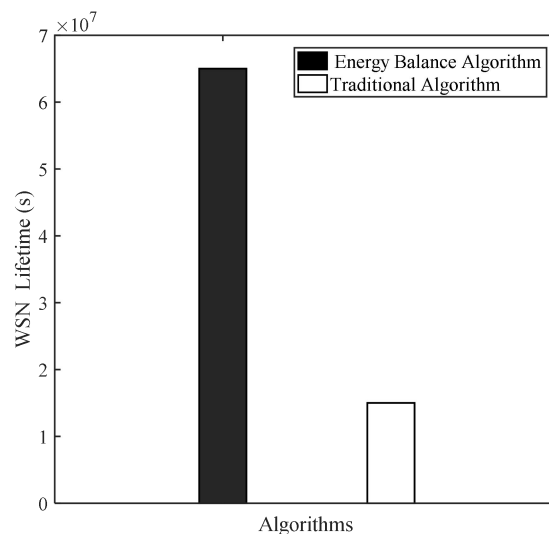


Figure 6: Comparison of network life in two algorithms.

5. Conclusions

In this paper, a bus joint temperature detection system based on the balance of nodes energy consumption in WSN has been proposed, which plays an important role in on-line monitoring of bus operations. Energy consumption model has been established by the analysis of the energy loss and one-way propagation characteristics of WSN applied to bus joint temperature detection. The algorithm of WSN nodes energy balance has been employed in multi-hop network to balance nodes energy consumption. Simulations demonstrate that this algorithm can greatly increase nodes energy efficiency and WSN lifetime in the bus joint temperature detection system.

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