Research on the Reliability of Internet of Things Information Transmission for Bus bar Operation on-line Monitoring

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Abstract. Aiming at the problem of packet loss in information transmission for on-line monitoring of bus bar operation status, the factors influencing the reliability of information transmission are analyzed from three aspects: The physical structure of monitoring system, communication protocol and the topological structure of information transmission network. A routing quality evaluation model is constructed, and a highly reliable path selection algorithm for information transmission is proposed. The results show that the model and algorithm proposed in this paper not only can greatly reduce the packet loss rate in the Internet of Things, but also effectively solve the problem of information transmission reliability of on-line monitoring system for bus bar operation status. Furthermore, an example of reliable information transmission for other Internet of Things applications is provided.

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. Due to the stability of bus bar directly determining the operation status of the power system, bus bar failures often cause huge losses to industrial production and normal operation of power system [1]. With the development of Internet of Things (IOT) technology, the on-line monitoring of bus bar operation has become an important field in the application of IOT technology.

Bus bar is the conductor used to collect current-carrying branches in distribution devices, which plays the role of collecting, distributing and transmitting electric energy. The connection between bus bar units is called bus bar connector, which is usually fixed by bolts, as shown in Figure 1. The connection mode and structure of connector will have an important impact on the stable and reliable operation of bus bars. In the long-term operation of the equipment, bus bar connector is the weakest link of the power supply line. Every year, hundreds of accidents occur due to the high temperature of bus bar connector, which is an important cause of bus bar failure. Therefore, on-line monitoring of bus bar joint temperature is the main problem regarding bus bar operation supervisory control.
At present, the main methods of bus bar connector temperature detection are manual point-by-point measurement, optical fiber temperature measurement and wireless temperature transmission automatic detection, etc. The manual point-by-point measurement method is characterized by high labor intensity, high dispersibility and low efficiency. As the occurrence of thermal faults is occasional and intermittent in the process of temperature rising, it is difficult to detect hidden faults in time by manual point-by-point measurement method, and there are phenomena of missed detection and false alarm. Fiber optic temperature measurement method has the disadvantages of high cost, large investment, complex optical fiber lines, easy surface contamination and difficult removal, which limit the application and popularization of optical fiber temperature measurement method. In recent years, with the maturity of wireless communication technology, microelectronics technology and the continuous progress of sensor technology, wireless transmission temperature automatic detection method has gradually developed. Especially with the development of IOT technology, more and more wireless transmission chips and the continuous improvement of low power sensor technology, this method has broad prospects due to its unique advantages. However, as bus bar installation is generally indoor, different building structures such as walls have a great impact on the reliability of wireless information transmission, it is difficult to apply and popularize bus bar operation condition monitoring technology.

The key technology of on-line bus bar operation monitoring is how to automatically select the information transmission path of wireless sensor network (WSN) to improve the reliability of information transmission. In this paper, the link quality indication (LQI) value information contained in IEEE802.15.4/Zigbee protocol of 2.4 GHz is used to establish a path reliability evaluation model to evaluate the transmission reliability of each path. Choosing the best quality path for information transmission makes the packet loss rate of data transmission the lowest, which effectively solves the reliability problem of information transmission of on-line monitoring system for bus bar operation condition.

2. Reliability Analysis of Information Transmission in Monitoring System

2.1. Physical Structure and Communication Protocol of Monitoring System

Bus bar running condition on-line monitoring system is composed of wireless sensor nodes, sink nodes and computers, as shown in Figure 2. 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.
The main core chip of WSN communication node is CC2430 produced by Chipcon. This chip supports IEEE802.15.4/Zigbee protocol of 2.4 GHz. Data frame format for transmission is shown in Figure 3 [2]. The last two bytes of MAC layer data frame are used for frame checking, that storing CRC redundant code when sending data, storing RSSI value, CRC value and LQI value when receiving data. Therefore, by reading the last two bytes of the MAC layer data frame and extracting the LQI value, the wireless link quality monitoring from the transmitter to the receiver can be realized.

| Prefix Code | Frame Control | Address | Load | Frame Check Sequence |
|-------------|---------------|---------|------|----------------------|
| MAC Header (MHR) | MAC Load | MAC Footer (MFR) |
| 4 | 1 | 1 |
| PHY Layer | 5+ (0 to 20 +n) |

| Bit | RSSI Value | LQI Value |
|-----|------------|-----------|
| 7-0 | 7 | 6-0 |
| RSSI.VAL | CRC | LQI.VAL |

**Figure 3.** The position of RSSI&LQI in IEEE802.15.4 frame format

### 2.2. Topological Structure of Information Transmission Network

The WSN regarding bus bar connectors includes three kinds of nodes: sensor node, transfer node and base station. Sensor node is responsible for collecting temperature data; transfer node collects and forwards temperature data; base station receives data information from all other nodes and sends it to PC monitoring system through serial port. Base station is located in the terminal of linear network. After wireless sensor node collects bus bar joint temperature information, it will send the information to base station by multi-hop mode. Nodes far from the base station first send data to the nodes near the base station, and then forward it to the base station. Therefore, the closer the node is to the base station, the greater the amount of forwarding must be borne, thus consuming more energy. From the foregoing, when the bus bar current is low, the node will turn to lithium battery power supply. However, the capacity of lithium battery is limited, the node with the largest energy consumption will take the lead in the problem of insufficient power supply. Therefore, if the maximum node energy consumption could be decreased, the capacity requirements of lithium batteries would be reduced, and the safe and stable operation of WSN could be ensured. How to reduce the maximum node energy consumption in the bus bar WSN and guarantee the balance of node energy consumption is a vital research direction of this paper.

Aiming at the research object, this chapter adopts a node jump scheduling optimization scheme. By analyzing the principle and characteristics of energy consumption of wireless communication nodes, the communication path and traffic volume of nodes are optimized, and the communication management of WSN is carried out. In this way, the energy consumption of nodes is balanced and the stable operation of the network is guaranteed. A linear network model is established for bus bar WSN. Nodes in the WSN are evenly deployed according to the joint distribution, hence the distance between adjacent nodes is equal to the unit length of the bus bar. The length of bus bar line is set to L, the distance between communication nodes is expressed by r, while N is used to indicate the total number of nodes on the bus bar and the number of forwarding areas. The label of a Node $G_i$ in the network is expressed by $G_i$. From the bus bar side to the base station side, all the node numbers are expressed by 1 to N in turn and the last node $G_N$ is the base station. When $j=i-1$ is satisfied, it means that node $G_j$ is the source node of node $G_i$, and node $G_i$ is the destination node of node $G_j$. When $j>i$, data is transmitted from $j$ to $i$. At this time, node $G_i$ is called the descendant node of node $G_j$, and node $G_j$ is called the ancestor node of node $G_i$. For any node $G_i$, only the data of the ancestor node will be received, and the data in the current node is only sent to the descendant node. The self-detected data and the received data are sent directly or indirectly to the base station $G_N$, that is, the data transmission is one-way. Base station $G_N$ communicates with other nodes $G_i$ through multi-hop mode, in which the distance of each hop and the number of multi-hops may be different. The network topology of base
station $G_n$ is shown in Figure 4. $X_{(i,j)} \ (i<j)$ in the graph indicates the amount of data that node $G_j$ receives from $G_i$.

\[
\begin{bmatrix}
0 & X_{1,2} & \cdots & X_{1,n-1} & X_{1,n} \\
0 & 0 & \cdots & X_{2,n-1} & X_{2,n} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
0 & 0 & \cdots & 0 & X_{n-1,n} \\
0 & 0 & \cdots & 0 & 0
\end{bmatrix}
\]

**Figure 4.** Topology structure of bus bar networks

The link matrix between nodes is as follows:

2.3. Analysis of Influencing Factors on Reliability of Information Transmission

In the transmission process of WSN, there are many factors affecting LQI. In the on-line monitoring system of bus bar operation, the factors affecting the reliability of information transmission include antenna of CC2430 node and its transmitting power, obstacles in transmission and communication distance [3], etc.

2.3.1. Antenna Anisotropy

The intensity of radio frequency signal in space has a great correlation with the angle of antenna, and there is a multipath effect in transmission, which makes the intensity of signal vary greatly in all directions. The antenna of CC2430 node in transmission system is integrated by PCB, which is sensitive to the change of direction.

2.3.2. Transmitting Power

It is well known that power will affect the communication radius of nodes. The transmission power not only directly affects the received signal strength, but also the stability of link quality.

2.3.3. Obstacle

Obstacles in transmission cause reflection and scattering of signals, which results in multipath fading and affects link quality.

2.3.4. Communication Distance

In the free space, the radio signal decreases inversely as the distance increases, while in the actual propagation environment, the path attenuation factor is generally 2-4, which greatly rises the attenuation speed of the signal intensity leading to reducing the propagation distance of the signal. With the increase of communication distance, the link quality and stability between nodes becomes worse.

3. Routing Quality Assessment and Reliable Transmission Path Selection

As the transmission distance and accuracy of single hop are limited, it can't meet the requirement of long-distance transmission in bus bar operation condition monitoring system, multi-hop is used to realize information transmission. Due to various interference factors, the link quality of a hop or several hops in the path will often be affected and deteriorated. The multi-hop path for data transmission will become unreliable and even unpredictable packet loss will occur [4]. Therefore, it is necessary to evaluate the quality of communication routing and to select reliable transmission paths.
3.1. Communication Routing Quality Assessment

According to the definition in IEEE802.15.4, LQI is used to indicate the strength and quality of received data packets, which can be measured by energy detection of receiver and signal-to-noise ratio estimation [5, 6]. However, LQI is not constant at different times and has certain fluctuations. When different factors influence the link, LQI value decreases and fluctuates greatly. Therefore, it is not reliable to measure the link quality by a single LQI value. In this paper, a routing metric based on LQI mean and Coefficient of Variance (RMBLQICV) is proposed. The routing metric model can be obtained by combining LQI mean with Coefficient of Variance, which can be used to dynamically evaluate the merits and demerits of transmission paths in the network. Routing metric $P$ can be expressed as follows [7]:

$$ P = \alpha P_{cm} - (1 - \alpha)CV $$

Where $\alpha$ is a weighted value, $P_{cm}$ represents Probability of Closing to the Max, and $CV$ is Coefficient of Variance.

3.2. Information Reliable Transmission Path Selection Algorithms

As the density of nodes deployed in the data acquisition area is often very high, the neighbour nodes may receive more than one routing request information, which results in forming multiple multi-hop transmission paths. Therefore, it is very critical to select a path with high reliability for data acquisition and transmission. CC2430 produced by Chipcon supports 2.4 GHz IEEE 802.15.4/Zigbee protocol, which can obtain LQI directly through wireless hardware measurement [8, 9]. Based on above CC2430, [7] and [10] adopt LQI mean as path selection for data transmission, and have achieved good results. [11] evaluates both paths and links by LQI mean. However, without considering bottleneck links in [11], data packet loss will occur in communication links if the load exceeds the rated load capacity. The bottleneck link in this paper mainly means that in a communication path, although the quality of other links on the path is good, the data transmission quality of the whole path may be affected by the poor quality of one hop or several hops links, resulting in unreliable data transmission. In view of the above problem, RMBLQICV can effectively avoid bottleneck links in the path. In order to select a path with good link quality and stable performance for data transmission, the evaluation of path quality is based on the quantitative dynamic weighting of LQI mean and $CV$, which can effectively reduce the probability of bottleneck links, prolong the network life cycle and greatly improve the quality of reliable data transmission.

The specific selection algorithm of reliable information transmission path is as follows:

1) Number all transmission paths between the information originating node and the information receiving node: 1, 2... N.
2) Get the LQI values of each link of transmission path $k$ and calculate $P_{cm}$.

$$ P_{cm} = e^{-\frac{(110-\mu)^2}{110-50}} $$

Where $\mu = \frac{1}{n} \sum_{i=1}^{n} X_i$ (where $X_i$ is the LQI value of each node on the whole path)

3) Calculate $CV$

$$ CV = \sigma / \mu $$

Where $\sigma$ is the standard deviation of LQI values for each link in the path, that

$$ \sigma = \left( \frac{1}{n} \sum_{i=1}^{n} (X_i - \mu)^2 \right)^{\frac{1}{2}} $$

4) Calculate $\alpha$

$$ \alpha = \begin{cases} 1 & \mu \in (101, 110] \\ e^{-0.02}\sigma & \mu \in (91, 100] \\ 0.5 \times \frac{\mu}{110} & \mu \in (71, 90] \\ 0 & \mu \in [0, 70) \end{cases} $$

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5) Calculate Routing metric $P_k$ for the Path $k$ using Formula (1), starting from the first path, namely $k = 1$.
6) Choose the next path, that $k = k + 1$, repeat step 2) to step 5) and get routing metric values of $P_1$, $P_2$, ..., $P_N$, select the path with the largest route metric value as the reliable transmission path.

4. Reliability Experiment and Analysis of System Information Transmission

4.1. Experimental Configuration

In order to verify the correctness of reliable transmission path selection, four groups of experiments were set up. Each group sent 1000 fixed number of data packets from the source node to the destination node, but the data transmission paths for 4 groups were completely different. 4 groups transmitted data packets from path A, path B, path C and path D respectively. According to the indoor transmission characteristics of bus bar joint detection information, the LQI values of each transmission link were different by changing the factors affecting the reliability of information transmission. There were 4 nodes, $G_1$, $G_2$, $G_3$ and $G_4$, $G_1$ was the source node and $G_4$ was the destination node. 4 transmission paths from the source node to the destination node were established: (1) The first was direct transmission, which was defined as Path A and contains a link $L(G_1, G_4)$; (2) The second was relay transmission through $G_2$, which was defined as Path B and contains two links $L(G_1, G_2)$ and $L(G_2, G_4)$; (3) The third, defined as Path C, was relay transmission through $G_3$, including two links $L(G_1, G_3)$ and $L(G_3, G_4)$; (4) The last, defined as Path D, had two relay nodes $G_2$ and $G_3$, including three links $L(G_1, G_2)$, $L(G_2, G_3)$ and $L(G_3, G_4)$.

4.2. Experimental Results and Analysis

According to the frame format of IEEE802.15.4/Zigbee protocol data transmission, the LQI values of each communication link are read from the communication nodes of WSN. The LQI value of link $L(G_1, G_4)$ in Path A is 88.56, and those of link $L(G_1, G_2)$ and $L(G_2, G_4)$ in Path B are 95.18 and 90.27, respectively. Meanwhile, the LQI values of link $L(G_1, G_3)$ and $L(G_3, G_4)$ in Path C are 100.49 and 105.54, and finally those of link $L(G_1, G_2)$, $L(G_2, G_3)$ and $L(G_3, G_4)$ in Path D are 95.18, 89.37 and 105.54, respectively. Packet loss rates measured in Path A, Path B, Path C and Path D are 29%, 5%, 2% and 12%, respectively. According to the selection algorithm of reliable information transmission path in Section 3.2, the Routing metric $P$ of the 4 paths is 0.3543, 0.9204, 0.9865 and 0.8783, respectively. The relationship between the experimental results and the Routing metric $P$ is shown in Table 1.

| path object | Path A | Path B | Path C | Path D |
|-------------|-------|-------|-------|-------|
| Link 1      | 88.56 | 95.18 | 100.49| 95.18 |
| Link 2      |       | 90.27 | 105.54| 89.37 |
| Link 3      |       |       | 105.54|       |
| Routing metrics $P$ | 0.3543 | 0.9204 | 0.9865 | 0.8783 |
| Packet loss rate | 29% | 5% | 1% | 12% |

According to Table 1, it can be seen that path A and path D have bottleneck links, therefore packet loss occurs several times on the data transmission path. Path C has the highest Routing metric $P$ and the lowest data loss rate in the data transmission path. From above analysis, it can be indicated that bottleneck links can be effectively found by RMBLQICV, which has great practical value in application of bus bar operation on-line monitoring.
5. Conclusion

Reliability of information transmission is a key problem of on-line monitoring system for bus bar operation condition. Based on the analysis of factors affecting the reliability of node information transmission in WSN, an algorithm for selecting information transmission path by using routing quality evaluation method named RMBLQICV is presented, which improves the reliability of information transmission in the process of system operation. The following two conclusions can be drawn from the research of this paper:

(1) In the application of the IOT, the reliability of information transmission is closely related to the selected transmission path. As long as the information transmission path is selected properly, the packet loss rate of the data transmission will decrease significantly.

(2) The choice of information transmission path is neither single-hop nor multi-hop, but based on the LQI of IEEE802.15.4/Zigbee protocol. With the help of link quality evaluation method, information transmission paths with relatively few bottleneck links can easily be selected, and reliable transmission of information in the IOT can eventually be realized as well.

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