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Design of the State Monitoring System of Power Cable Outer Sheath Based on the DigiMeshi Network

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Abstract

With the development of power grid intellectualization, real-time state monitoring of power cable outer sheath is becoming more and more important. Monitoring and test of the cable outer sheath currently being used are time consuming and inflexible. To this point, a DigiMesh network based wireless monitoring solution is proposed in this article. The sensor node is mainly composed of main control chip Msp430F169 and XTend module based on DigiMesh network. It is being used to receive, store and transmit the collected data and information, and pass back the outer sheath state monitoring data through multiple hop transmission. During this process, the multi-channel and multi-data source parallel transmission mechanism is applied to reduce the route hop number and lower the network load. The proposed solution was experimental simulated, which proved to be practical and had a good real-time performance. This solution is also applicable to state monitoring of cable outer sheath in areas which are not covered by telecom signals, and it is helpful to discover and handle the cable line fault and reduce safety hazards.

Keywords: *DigiMesh network, cable outer sheath, XTend module, system design, node clustering*

1. Introduction

Intelligent power grid is now regarded as the direction of development and construction of the power grid system. The state of all equipment in this system should be monitored in real time for timely maintenance and repairing. Power cables being used to distribute and transmit electric energy are a very important component of the power system. Practice has proved [1] that a lot of faults were caused by the failure of outer sheath of cables and any cable failure may lead to massive loss. At present, the power cable state data collection technology [2] has been partly realized and applied. However, there has by now been no effective solution to real-time state monitoring of power cable outer sheath and transmission of state data. The core question is how to build reliable, low power consumption, low cost and highly flexible communication system for the power transmission line to realize wireless transmission of information.

Currently the following two methods are being used for transmission of power cable state monitoring data: general packet radio service (GPRS) and wireless sensor network (WSN). Communication service should be obtained from the telecommunication service suppliers for a long time to support GPRS monitoring system, and this means remarkable expenses. Furthermore, its data transmission bandwidth is limited and it also poses data information security issues [3]. WSN is one of the hot topics in the field of wireless network research. In the past few years, actual application of WSN is mainly reflected by the ZigBee wireless sensor network based on IEEE 802.15.4 standard. ZigBee is a

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wireless network technology of low complexity, low power consumption and low cost. However, the transmission distance between nodes of ZigBee network is quite limited. When the transmission distance is extended to hundreds meters, the power amplifier will be needed, which will also increase the power consumption of communication device.

In view of the above problems in the current power cable state monitoring system, a monitoring solution combining state information collection of power cable outer sheath and DigiMesh communication technology is proposed in this article. The solution is based on multi-hop pass-back of real-time data, and is applied to measure the cable state data in real time using the data collector, and then transmit the data through the communication network. It is effective, reliable and low power consuming. In addition, it enjoys a high emergency communication capacity in case of disasters, and could transmit the monitored state to the nearby monitoring stations in a timely manner. The monitoring stations or analyzing center will process the data and determine the state of the outer sheath based on the processed data. This is very important for timely maintenance and repairing of power cables and helps reduce safety hazards along the line.

2. Introduction to Wireless Mesh network

The Wireless Mesh Network (WMNs) is a ‘multi-hop’ network, which is developed from AD HOC network. It serves as a key technology for broadband wireless access of the last 1km and is expandable and dynamic network architecture. It can be used in combination with other network protocols, such as 802.11, 802.16, 802.20 and 3G mobile communication technology for cooperative communication [4]. All nodes within the network are equal and could all served as routes and terminals. Any two nodes could be wireless-connected [5].

In the actual application of power transmission line monitoring, WMNs enjoys the following advantages:

Self-organized network: Wireless Mesh node is able to automatically search for nearby nodes and organize networks with them when powered on, which noticeably simplifies the networking procedures.

Automatic heals: When one node is removed from the Wireless Mesh network, the network is able to automatically discover the topological changes and start the searching program, and find the optimal transmission path by adjusting the communication route.

High broadband utilization ratio: Each node of WMNs serves as an access point (AP). When the utilization ratio of an AP drops, the data will automatically choose another AP for transmission. The networking method is very flexible which greatly improves the network utilization ratio.

Considering the requirements of the power cable line monitoring system on the equipment stability and power consumption, DigiMesh network technology is chosen in this article as the communication basis. DigiMesh network is one of the Mesh networks, and enjoys a farther transmission distance and lower power consumption compared with Wireless HART, Z-Wave and other Mesh networks. Communication equipment based on this technology could operate for a prolonged period in depopulated zones with severe climate and ambient, and could transmit the monitored data to the monitoring station reliably.

3. Design of Power Transmission Line Monitoring System

3.1. Long-chain tree-type System Structure

According to the distribution characteristics of power cable lines, a long-chain tree-type distribution model of sensor nodes is proposed in this article. The sensor nodes are composed of data collector and communication nodes, and are placed at the segment points along the long-chain power cable lines. An aggregation node is set to the point nearby the monitoring station on each cable line to collect all monitored data along that line. The aggregation node is connected with the central server of the monitoring station at the line terminal. A tree-type topological structure is formed by a number of long chains with the aggregation node as the root, and each long chain represents one power transmission line. The structure is shown in Figure 1.

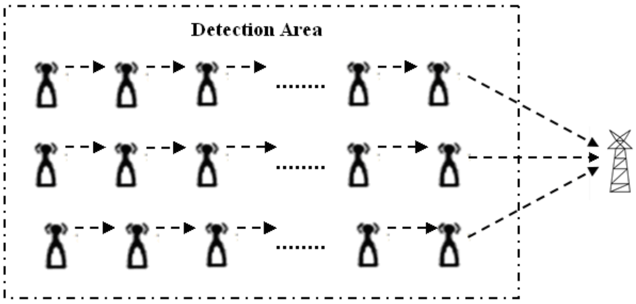

Figure 1. The Long Chain Tree-like WMNs Topology

The system enjoys the following characteristics,

(1) In the long-chain tree-type topological structure of WMNs, the data information on the chains will be transmitted to the aggregation node in a multi-hop manner.

(2) The data collectors and communication nodes at each segment point have a unique ID number for easy marking and locating of the passed-back images. The nodes will not move any more after deployment.

(3) Timing sampling by data collector: The data transmit speed of Msp430F169 and emission rate of XTend module should be adjusted during data transmission to ensure the former is not greater than the latter, so as to preventing data flooding and loss.

(4) Power to the sensor nodes is supplied by solar power and batteries [6]. To reduce power consumption, the communication equipment along the line will be in a dormant state when there is no data transmission, and will be awakened as scheduled before data transmission to transmit and receive data [7].

3.2. Multi-channel Data Transmission

The XTend module communication distance was tested respectively under the conditions that the vertical elevations of the two communication parties were both 35 meters and that the elevation difference between the two parties was 45 meters (the elevation of 220 kV line iron tower was about 23 meters). The 7db omnidirectional antenna was used for the test. The result indicated that, the XTend module could be used for wireless communication in the one-to-one communication mode at a distance of 3.5 km. In different areas, the communication distance might be different. However, if the location for data collection was properly selected, the optimal effect can be achieved. One fixed node communication could cover several data collection points, and the interconnection between nodes could form a network to ensure the stability of data transmission. But the pass-back of information data via communication nodes on each level would increase the equipment power consumption and network load, and result in waste of resources.

For long-chain tree-type WMNs, the parallel transmission solution of a multi-data source and multi-channel is proposed in this article [8, 9]. This solution could reduce the route hop number of data, processing time delay and channel interference, so as to improve the utilization ratio of network. The Digi Mesh network based on 802.15.4 standard provided 10 40 bit/s independent channels on the frequency band of 915 MHz. The nodes were clustered according to the distribution characteristics of the communication node geographical location. No cluster head was chosen to avoid early failure due to excessively long distance of single-hop or excessive retransmission task of the same node. The clustering result of nodes for double-channel communication is shown in Figure 2. The squares in the same color belong to one cluster, and share the same channel.

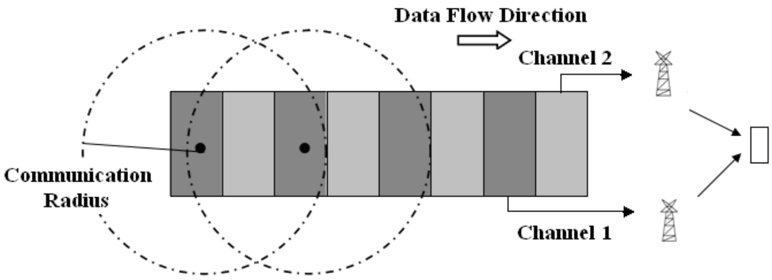

Figure 2. The Clustering Scheme of Communication Nodes

4. Design of Sensor Node

4.1. Overall Design of Sensor Node

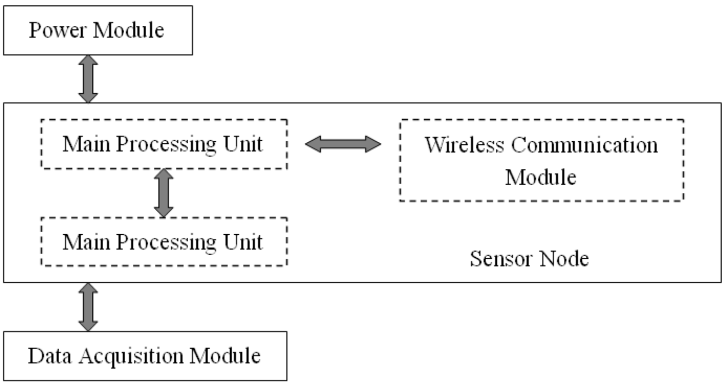

Figure 3. Block Diagram of Sensor Node

A sensor node design scheme is proposed in this article based on the requirement of power line state monitoring on equipment stability and power consumption. The node function is composed of state collection and wireless communication and the structure diagram is shown in Figure3.

The state collection system is composed of the data collector and main processing unit installed on the cable line. Specifically, the 16-bit RISC mixed-signal processor Msp430F169 single chip was used in the main processing unit. It has powerful functions and low power consumption and could be used to receive process, store and transmit data and images. The wireless communication system was composed of 9Xtend wireless radio frequency module (XTend module for short) based on DigiMesh protocol. Under a stable operation condition that the transmitting power of the module was 500 mW, the users were allowed to receive 900 MHz signals at a visual distanced of 20 km. Meanwhile, synchronous sleeping and awakening of different nodes were allowed to greatly reduce the power consumption during communication of the monitoring system. This would meet the requirement of long-time outdoor operation of equipment.

During the operation of the state monitoring system of power cable outer sheath, the data collector transmitted the collected state information data of outer sheath to the main processing unit via RS232/485. Then the information was transmitted to a node close to the monitoring station on the same channel via XTend module after processing and analyzing by the main processing unit.

4.2. Data collection

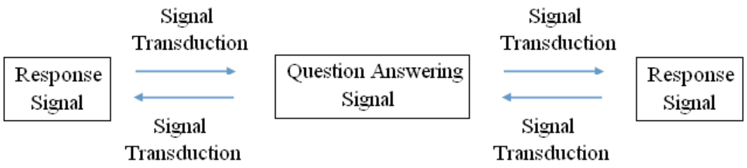

Figure 4. Schematic of Data Acquisition

Data collection is mainly undertaken by the data collector. During normal operation of the cable, line-frequency induced current or induced ring current will be generated in the cable metallic sheath. In such a case, the data collector will measure the line-frequency induced voltage, and line-frequency induced current or induced ring current in the outer sheath. Once short circuit, lightning surge or internal over-voltage is detected on the cable, a very high line-frequency over voltage or impulse over voltage will be generated on the metallic sheath [10]. The data collector transmits pulse signals to nearby data collectors via the cable after installation, and the nearby collectors generate response after receiving the pulse signal. The sender records the information on the circuit based on the answering signal after receiving it, and then transmits the question and answering information and response information to the node via the data transmission unit. The data processing center will analyze and process the information. The state of the cable outer sheath will be assessed according to the processed data.

4.3. XTend Inter-module Communication

The process of wireless transmission and receiving of image information between XTend modules is shown in Figure 5. XTend module A and XTend module B both operated on a frequency band of 900 MHz

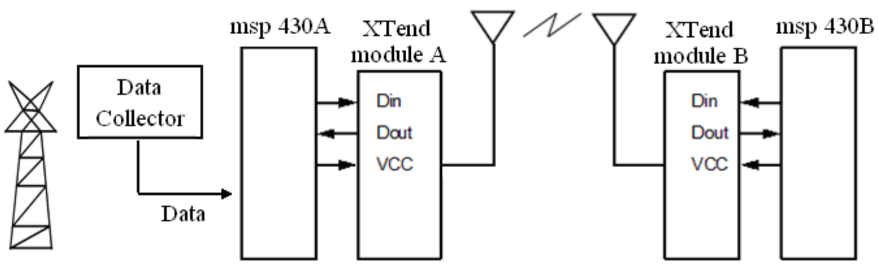

Figure 5. Schematic Diagram of Image Information Transfer

In the receiving process of code stream, the first byte entering into the data receiving buffer of XTend module A will serve as the start of the data series. When the data receiving buffer of XTend module A can no longer receive data, the data in the buffer will be packed and transmitted to XTend module B wirelessly.

The data transmission rate between XTend modules was set at 115,200 bps. Without considering the data delay in the network and time for data packing, the transmission time for a data collection was about 3.6 seconds.

4.4. Equipment Power Supply

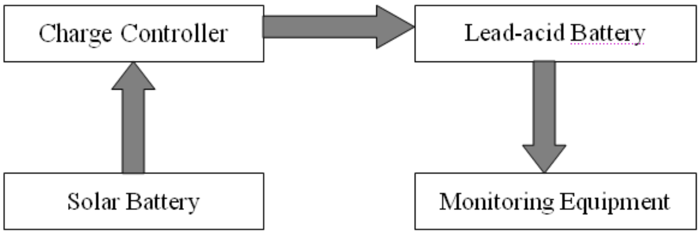

Figure 6. The Scheme of Power Supply

The power supply to the monitoring equipment was from the batteries and solar cell floating charging. The schematic diagram for power supply to the system is shown in Figure 6. The maintenance-free lead-acid battery is generally used. The power of XTend module and camera was 500 mW. The maximum power of main control chip was 30 mW. Most of the works on the up direction (from data collector to the monitoring station) were monitored data collected periodically at an interval of 30 minutes. Take 10-level chain for example. In the cycle that the state monitoring data should be transmitted, the communication equipment could be awakened to transmit the data in a timely and fast manner. The work circle lasted for about 5 minutes. In the cycle that no data should be transmitted, the communication equipment generally could automatically enter a dormant state. The capacity of solar batteries serving as power supply of the equipment was 100 Ah, and the voltage was 5 V. Without considering the voltage drop caused by battery loss and solar battery charging, the working time of the monitoring equipment was about 120 days.

The solar batteries were used as the charging source, which will not be affected by man-made factors and external interference and have a long-term low operation cost and easy maintenance. They could be used to automatically supply power to the testing equipment for a long time. For the sake of safety, no long wire could be hung from the tower. Therefore, the solar power supply system and the monitoring equipment should be installed on the same tower. This means that the volume and weight of the power supply system should be within the designed bearing capacity and wind resistance of the tower. The enclosure was made of antimagnetic metallic materials and it was connected to the earth via the tower. This shielded the electromagnetic interference, and prevents dust, water and lightning stroke, thus ensuring the stability and reliability of the monitoring system.

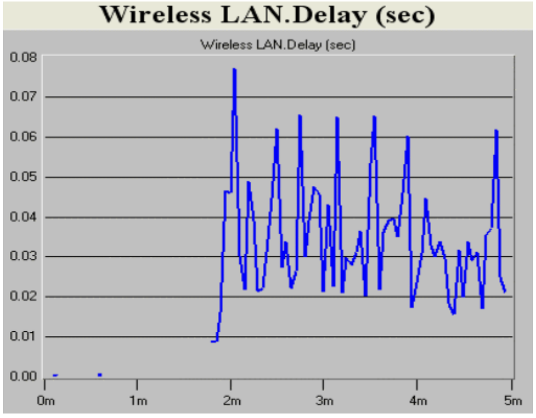

Figure 7. The Network Delay

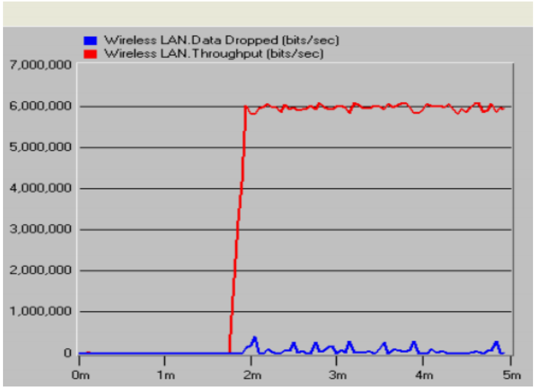

Figure 8. The Network thought and Data Dropped

5. Experiment Result and Analysis

The OPNET Modeler based on 802.15.4 standard was used to simulate the communication system. Within the 500*5,000 m area, 30 normal nodes were placed evenly. There were 2 available channels and two aggregation nodes. The data were collected at each normal node at an interval of 30 minutes. The data transmission rate between nodes was set at 115, 200 bps/s. The collected data include the change of network throughput, data packet dropout and network delay with the time of simulation. The simulation results are shown in Figure7 and Figure8.

As shown in Figure7, in the early stage after system booting, there were only two short non-continuous distribution segments of system delay, and such delay lasted for a short time and had a small value. This indicated that the data transmission quantity in the early stage after system booting was small. The data distributed continuously and fluctuated at about 1.8 m. As shown in the figure, the first peak value is obviously greater than the other peak values. As time went on, the fluctuation amplitude decreased and stabilized within 0.01 to 0.07, i.e., the system time delay was between 10 ms and 70 ms. this indicated that the time delay of the system was subtle and the system was operating stably.

As shown in Figure8, when the system started normal operation (after 2 m), the throughput of system fluctuated slightly near 6,000,000 bits/sec. The packet loss probability was fluctuating with small amplitude. After 4m, the packet loss probability dropped obviously and there was a decrease in fluctuation amplitude. Furthermore, the loss bit number was quite small compared with the system throughput. This indicated that the system was highly reliable after the system reached a stable transmission state.

6. Conclusions

The line monitoring scheme proposed in this article mainly aims at improving the existent insufficiency of the power cable line communication, which has improved the flexibility, timeliness, reliability, and economical efficiency of the communication system, and reducing the blindness. All equipment used in this scheme enjoyed simple configuration, low cost, easy maintenance and high expandability. Through monitoring power transmission line by data collector, more intuitive line information was obtained. Meanwhile, the monitored data on other sensors could be passed back via the communication system, and this improved the utilization ratio of the network. Through OPNET simulation and field test, this scheme was proved to be practical and feasible. In addition, the normal operation of the system enjoys characteristics such as short delay, high stability, low packet loss probability of the system and high reliability. In this article, only three chains were taken as an example to describe the communication method of the monitoring system. The cooperation of multi aggregation nodes may be used to balance the load when the electric transmission line is complicated.

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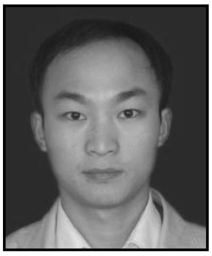

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