Research on Routing Protocol of Real-time Monitoring Nodes in Transformer Substation

De-meng BAI¹*, Cheng-qi LI¹, Jia-feng QIN¹ and Guo-cheng WANG²

¹State Grid Shandong Electric Power Research Institute, Jinan
²Shandong Zhong Shi Yi Tong Group, Jinan

*Corresponding author

Keywords: Routing protocol, Real-time monitoring nodes, Energy efficiency.

Abstract. The safety, stability and reliability of electrical equipment are directly related to the operation of the electrical system. Discovering various electrical equipment problems and effective treatment of the problem without delay will minimize the probability of electrical equipment failure. In electrical equipment monitoring and maintenance, Application of real-time monitoring is one of the most important elements. Real-time monitoring node can detect equipment failure promptly which will avoid the expansion of accident caused by the long test period or manual inspection. Working time of online monitoring nodes is limited by power consumption of node itself. Application of routing protocol can optimize energy consumption and extend working time of nodes.

Introduction

At present, there is a widespread application of WSNs (wireless sensor network) such as monitoring and surveillance in the military, civil industries and traffic control fields. The development of online monitoring devices benefit from the improvement of wireless sensor node technology[1]. In the power industry online monitoring technology is mainly used for real-time monitoring of electrical equipment status.

Because of the special environment of the transformer substation, the monitoring node is usually a wireless sensor node (wsn) [2]. This is due to the following two aspects, on the one hand, wireless sensor nodes are easy to be deployed, on the other hand this can reduce security incidents caused by the deployment of power wires. However, the power of the wsn needs to be replaced after working for a period of time, improving the energy efficiency of wsn to extend their lifetime is important for power equipment maintenance.

Current Situation

Monitoring nodes in transformer substation usually communicate with the base station which is operated by telecom operators, each monitoring node is configured with a SIM card chip with which the node access to the Internet [3], the monitoring information on the web access into the power intranet after security conversion.

The situation of each monitoring node contains a SIM card to transmit information will waste resources, and increase operation and maintenance costs. On the other hand, the distance between transformer substation and base station is usually long, the long transmission distance also has a greater pressure on the node battery. Recent research shows that routing protocol plays a significant role in balancing energy consumption and improving performance of network stability.

In the transformer substation, each monitoring node can be regarded as one node of wireless sensor network. The main role of routing protocols is to make regulations on how to transmit information between nodes.

Energy efficient routing protocol is challenging for that it should be simple, energy efficient and robust to cope with a large number of nodes with limited energy and changes of network topology.
Moreover, the applied routing strategy should ensure minimizing energy consumption and extending network lifetime.

In recent years, many energy efficient routing protocols are proposed which can be classified into four main schemes: network structure, communication model, reliable routing and topology based [7-9]. The most commonly used routing protocol is network structure based which can be further classified as flat or hierarchical.

In routing hierarchy theory, the traditional approach of each monitoring node with a SIM card in transformer substation is a flat structure. Monitoring nodes in flat structure consume more energy when transmitting information, battery of the node will decay faster.

In this paper, two improvements are proposed based on hierarchical routing protocols. One is that the residual energy level of node is introduced in CH election phase; the other is that an improved relay node selection mode based on energy aware and data merge strategy is taken during multi hop routing. The main design features of proposed method are: energy efficiency, multi hop routing considering the trade off relationship between the relay nodes’ residual energy and the distance from nodes to BS. The proposed routing scheme is divided into two phases: the first phase is that election of cluster head and cluster formation, and the second phase is multi hop routing based on energy aware strategy.

The rest of this paper is organized as follows. Section 3 introduces energy model. Section 4 presents energy aware multi hop routing protocol. In Section 5, the simulation testing on stability of monitoring nodes is conducted and results are illustrated. Finally, our conclusions are presented in Section 6.

Energy Models

We consider a sensor network which contains n homogeneous nodes that are deployed randomly over a terrain to monitor the targeted environment. The set of nodes can be expressed as S=\{S1,S2,...Sn\} where n is the total number of nodes and each node has a unique ID.

Energy model from transmitter to receiver of the monitoring node can be illustrated as Fig 1. According to free space propagation model, transmitting a l-bits message at a distance d using the simple radio model the radio expends is:

\[ E_{tx}(l,d) = E_{elec} \times l + \varepsilon_{mp} \times l \times d^4 \]

where \( \varepsilon_{fs} \) represents short distance attenuation coefficient while \( \varepsilon_{mp} \) represents long distance attenuation coefficient. \( E_{elec} \) is the energy consumption for transmitting or receiving one bit message. And \( d_0 \) is decided by:

\[ d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \]

The consumption of receiving l bits is:
The consumption of aggregating data from n nodes is:
\[ E_{\text{elec}}(l) = E_{\text{elec}} \times l \times n \]

Where EDA is the energy consumed by aggregating one bit.

Hierarchical Routing Protocol of Real-time Monitoring Nodes

Based on traditional hierarchical routing protocol, this routing protocol proposes two improvements. First, the residual energy level of node is introduced in CH election phase; second, an improved relay node selection mode based on energy aware and data merge strategy is taken during routing. Compared with normal approaches, the improvements are vital to energy efficiency and network stability.

Forming Clusters and CH Election

In this phase, the node itself determines whether to be a CH by using a stochastic algorithm related with residual energy in each round. CH aggregate, compress and forward the data to BS. The member node will choose the nearest CH as the receiving node. CH receives data from all other nodes, gathers and aggregates data, and then selects relay CH nodes for creating a route to BS.

In order to improve the network lifetime, the energy consumption of node should be well balanced. In this proposed method, the following parameter is taken in CH election.

Node residual energy: the residual energy of selected nodes which will participate in CH election is higher than member nodes. It is denoted as \( E_{\text{res}}(j) \) in this paper and the initial energy of the node is \( E_0 \).

The nodes calculate average energy \( E_{\text{res}} \) with the received broadcast messages from neighbors. Then the nodes participate in CH election as normal approaches if \( E_{\text{res}}(j) > E_{\text{res}} \).

Cluster Maintenance phase: the structure of cluster will not change until the energy of CH is less than the residual energy of the cluster members. Therefore, the cluster changes when this condition happens:
\[ E_{\text{res}}(\text{CH}) < \overline{E_{\text{res}}} \]

 Relay Node Selection and Route Creating

If \( d(\text{CH}, \text{BS}) < d_0 \) which means energy consumption is related with \( d_2 \), the CH sends data to BS directly.

Relay node selection and route creating will start when \( d(\text{CH}, \text{BS}) > d_0 \). Initially, CH broadcasts a REQ_RELAY message to all nodes within transmitting range. Each relay CH candidate that receives this message calculates its residual energy and their position, puts the results into an ACK_RELAY message and sends back to requesting CH. Requesting CH calculates the distance from this node to CH and BS with receiving ACK_RELAY from all possible candidates. Then maximum relay node function:

\[ F_{\text{rn}}(j) = E_{\text{res}}(j) \frac{d(CH,j)}{d(j,BS)} \cos \phi \quad \forall j \in n \]  

Figure 2. Relay node selection view.
Where \( n \) represents the number of node within the transmission range of CH, \( d(CH, j) \) is the distance from CH to node \( j \) and \( d(j, BS) \) is the distance from node \( j \) to BS.

As we can see, the relay node with large amount of \( E_{res}(j) \) residual energy takes more responsibility in routing phase. In this case, it will lead to a load balance of energy consumption. Here helps to find out the smallest distance to BS in theory in order to save energy on the whole.

\[
\cos\phi = \frac{d(CH, BS) + d(CH, n_j) - d(n_j, BS)}{2 + d(CH, BS) + d(CH, n_j)}
\]

(2)

As we can see, choosing a node with \( \cos\phi < 0 \) or \( \phi > 90^\circ \) will prolong transmission distance. According to expression (1), we choose the node with max FRN\((j)\) as the relay node. In the next hop, the relay node acts as CH and choose relay node again.

Figure 3. Data merge view.

As Figure 3 illustrated, nodes will merge the same message sent by different nodes in order to reduce energy consumption. If the message is sent recently, CH will abandon the message in case bringing about information flood.

**Performance Evaluation**

Network lifetime and network stable period:

![Figure 4. Number of dead nodes with rounds.](image)

![Figure 5. Network stable period.](image)

First, we evaluate the improved protocol by comparing network lifetime with normal approaches. Fig 6 shows percent of dead nodes with rounds, as can be seen dead node appears 400 rounds later than normal approaches, which is 20% of normal approaches stable period. The end of network using normal approaches ends when the first dead node appears in the improved network. So energy efficiency is improved in the network that uses improved protocol. With more nodes alive in the network, the sensing area can be monitored accurately and QoS of network will be improved relatively.
Fig 6 shows comparison of stable period. According to test sequence, the average stable period of improved protocol is 2435 rounds while normal approaches is 1867 rounds. Stable period of improved protocol is beyond thirty percents than normal approaches.

**Performance Evaluation**

In this paper, we propose an improved routing protocol for real-time monitoring nodes in transformer substation that is based on normal hierarchical protocol but employs a new multi hop routing strategy. The improved protocol contributes to network stability and optimizes energy consumption. This can benefit application of WSNs and improve performance of stability. One disadvantage of this new protocol is that the nodes die rapidly at the end of simulation. In the future work, we will concentrate on developing an improved routing protocol that uses load balance strategy to get a better promotion.

**References**

[1] Pantazis N, Nikolidakis S, Vergados D. Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey[J]. Communications Surveys & Tutorials, 2013, vol(15):551-591.

[2] Al-Karaki J N, Kamal A E. Routing techniques in wireless sensor networks: a survey[J]. IEEE Wireless Communications, vol(11):6-28

[3] Sabarish B A, SashiRekha K. Clustering based energy efficient congestion aware protocol for Wireless Sensor Networks[M]. Nagercoil, India: Emerging Trends in Electrical and Computer Technology.

[4] Chen T Y, Wei H W, Lee C R, et al. EEGRA: Energy Efficient Geographic Routing Algorithms for Wireless Sensor Network[J]. Journal of Interconnection Networks, vol(14):104-113

[5] Gautam N, Pyun J Y. Distance aware intelligent clustering protocol for wireless sensor networks[J]. Communications and Networks, vol(12): 122-129.

[6] Heinzelman W R, Chandrakasan A, Balakrishnan H. Energy-efficient communication protocol for wireless microsensor networks[J]. System Sciences, vol(2): 1-10.

[7] Farooq M.O, Dogar A.B, Shah G.A. MR-LEACH: Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy[M]. Venice, Italy: Sensor Technologies and Applications (SENSORCOMM).

[8] Heinzelman W B, Chandrakasan A P, Balakrishnan H. An application-specific protocol architecture for wireless microsensor networks[J]. Wireless Communications, vol(1): 660-670.

[9] Bhattacharya S, Bandyapadhyay S. A dynamic energy efficient multi hop routing technique using energy aware clustering in wireless sensor network[M]. Kanyakumari: Electronics Computer Technology