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Research Article

A Wireless Routing Protocol for Pumps Monitoring in Large Industrial Plant

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Abstract: According to the demands of pump monitoring in large industrial plant, a new routing protocol combined with proactive routing and on-demand routing named Command Substitution and Sequential Cache(CSSC) is designed in this paper. We fuse and modify traditional routing protocols and on-demand routing protocols to meet two main data acquisition ways in pump monitoring of large industrial plant: spot inspection and alarm. Experiments show that, this protocol can effectively reduce the controlling overhead and transmission delay.

Keywords: Control overhead, equipment alarm, pumps monitoring, spot inspection, transmission delay, wireless routing

INTRODUCTION

Pump equipment is the most widely used in the construction of petrochemical production machinery and equipment (Ray, 2012). Currently, the monitoring for vast majority of pump equipment in the chemical plant still depends on the regular offline monitoring. And a widespread problem for this monitoring is that there is not enough monitoring density. In recent years, with the development of sensor and communication technology, the wireless monitoring system by constructing pump group can effectively improve the monitoring quality and reduce the operation maintenance costs of the system (Gollagi and Rajpurohit, 2011).

The range of large chemical plant tends to be very large. And the location of the pump equipment containing in the plant is dispersed (Anonymous, 2011). The data source node generally need to use the relay multi-hop communication with on-site monitoring center, which makes the entire wireless monitoring network have the characteristics of Ad Hoc network. However, Ad Hoc network faces terminal little memory, low CPU processing power, lower network bandwidth. Therefore, the Ad Hoc network is relied on to meet all the needs of wireless monitoring. The design of routing protocols is critical (Arvind and Sugumaran, 2011; Samia and Shreen, 2011).

Routing protocol is conventions and norms, which guides business data from the source node to the destination node for the communication network (Zhi *et al*., 2010). Routing protocol in the OSI architecture for Ad Hoc Networks usual is mainly achieved by the network layer. Network layer defines communication protocol of the network operating system, confirms address for the information, and translates logical address and the name into physical address. It also determines the route selection along the network from the source node to the target node, and processes business flow problems, such as the exchange of routing and congestion control of data packets (Saker, 2011; Bao-Qiang and Jian-Huan, 2012).

A good routing protocol must respect the reality (Rida and Khoukhi, 2012). Compared to traditional Ad Hoc network, industrial wireless monitoring network has its own characteristics. This problem would be discussed mainly from the functional requirements and network environment in the following text.

The so-called point inspection is a process for conducting preventive careful for the equipment provisions parts (points) about abnormal or normal. The demanding for inspection to routing protocol should have the following two characteristics:

- Point test executed regularly constitute the main source of data for the wireless monitoring system. Therefore, the overhead of routing protocols become the key for affecting the monitoring efficiency of the whole network. The efficiency of a routing protocol used in point inspection should be as high as possible.
- Inspection is executed for a fixed-point and a given person. In other words, the monitoring person need traversal all pump equipment for the device. The traversal will cause large interval for the data acquisition. Therefore, monitoring system has less demanding about real-time for data transmission.

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Alarm process is generally that certain sensitive parameters are firstly set alarm limits. The engineering and technical personnel should timely access the information when vibration exceeds the alarm value while the pump is running. The following requirements for network routing are needed when alarms are analyzed and diagnosed:

- Alarm transmission is sensitive for detention. Engineering and technical personnel need timely diagnose with alarm information.
- Pump equipment alarm is a low probability event. And its routing overhead is relatively small for the entire network.
- There has the following characteristics compared to the traditional Ad hoc networks, pump group monitoring network of large-scale chemical plant for the application environment.
- Due to the fixed position of the measured pump and on-site center, the network topology is generally considered to be static.
- Communication range for the distance between tested pump and on-site center greater than the node, typically need to be connected through a multi-hop.
- With monitoring Centre. The transfer of all kinds of information in the network has an obvious orientation. It is not peer-to-peer network.
- Industrial wireless monitoring network can make the topology and routing information burning entry wireless node in the form of the header file. Thereby the topology of the network can be controlled. Therefore, this belongs to the "semi-self-organization" network.
- There are large metal objects in industrial installations. Therefore, external interference is greater. And wireless media transmission reliability is even worse.

Therefore, node discovery and routing can be omitted directly and done to the header file of the different nodes. So loops and distributed routing algorithm is not considered to be the focus. The network layer protocol is mainly responsible for the function of routing choice. This also makes the routing overhead have further compression. Then, the fluctuations of the channel for the industrial environment are more intense. Therefore, the entire routing protocols need to respond to the rapidly changing wireless environment. Especially the alarm data needs to be sent to the monitoring center as short delay as possible.

MATHEMATICAL MODELING

- Monitoring system network structure of the pump group for a large chemical plant can be represented by an undirected graph G (V, E). Wherein, the peak of the graph indicates the network node. And the edges of the graph indicate the network link. V is a collection of nodes in the network structure. And $V = \{n_i\}$. E is the collection of the link containing two nodes. And $E = \{l(n_i, n_j) : n_i, n_j \in V\}$. The connection path L between pump node and site monitoring center for the entire network is composed of a group of link $\{l_1, l_2, l_3, l_4, ... l_n\}$ and a group of nodes $\{n_1, n_2, n_3, n_4, ... n_k\}$.
- The standardized routing overhead is defined as the ratio of the total flow of the control packet to the total flow of the data packet reached the destination node successfully. For multi-hop control packets, each hop transmission is counted as one. Standardized routing overhead is shown as formula (1).

$$\text{Routing overhead} = \frac{\text{the total packet number has been sent and forwarded}}{\text{the number of the packet has been received}} \quad (1)$$

During the update process of network for proactive routing protocol, periodically broadcast routing for each node in the network to other nodes renewed packet. And then the routing information update is completed. The reason for using this routing updates is that any two nodes in the network may be required communication. For industrial wireless monitoring network, data are only exchanged between the data source node and site monitoring center. All available relay path can be established when the deployment is completed. Therefore, under the guidance of the on-site monitoring center, through appropriate routing choice the update of the entire wireless network can be fully executed with the traversal form along with point inspection process. And control routing overhead can also be largely reduced.

- For the network calculus, transmission delay is defined as: it is assumed that the data stream that flows into and flows out a radio path can be used $R(t)$ and $R^*(t)$, respectively. And for a no loss system, at the time of t its propagation delay can be shown as equation two.

$$d(t) = \inf\{\tau \geq 0 : R(t) \leq R^*(t+\tau)\} \quad (2)$$

It can be seen from the formula (2) that the transmission delay is essentially horizontal distance between $R(t)$ and $R_1^*(t)$. It is shown as Fig. 1.

For network calculus, transmission backlog is defined as: For a no loss system, at the time of t, data backlog of its system is shown as formula (3):

$$Q(t) = R(t) - R^*(t) \quad (3)$$

By the formula (3), for wireless relay transmission system demanding routing protocol, in order not to cause loss for the data backlog, the slope of output cumulative function must be greater than that of the

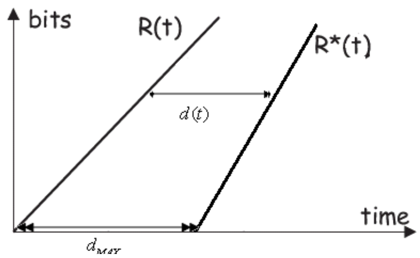

Fig. 1: Data represents of the transmission delay

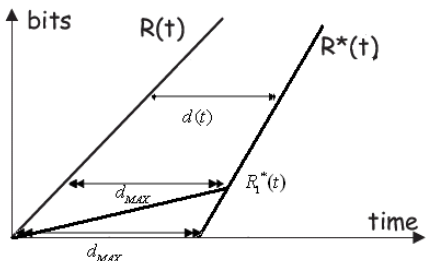

Fig. 2: The affection of accumulation function on delay

input cumulative function. Therefore, the maximum data delay occurs at the time of the completion of the routing establishment. It is shown in Fig. 1. So, intuitive analysis result is that the accumulation of certain data will be produced using the characteristics of industrial wireless monitoring system when certain data will be transmit at the time of discovery and establishing for the route. And a new accumulation function $R_1^*(t)$ will be formed. Therefore, the purpose of reducing delays can be achieved as shown in Fig. 2.

The Methods: According to the demanding characteristics of the pump monitoring large-scale chemical plant, a new routing protocol is designed combined initiative routing with on-demand routing. This protocol is called Command Substitution and Sequential Cache (CSSC). The routing protocol is based on two main data acquisition mode for point inspection command of the pump monitoring and equipment alarm in a large chemical plant. During executing the command of the point inspection, based on the form of on-demand routing protocol, but at the same time the whole network update needs to be completed periodically. During the update of the whole network, the form of nodes broadcast flooding for the original table routing is modified. And the routing update process is integrated among point inspection process. Through the appropriate path selection, the path information is combined with point inspection data packets. Eventually the traverse form is employed to complete the whole network routing update. And thus the purpose of control minimized routing overhead is achieved. In the execution of apparatus alarm, the form of on-demand routing protocol is still based on. But the characteristics of topology fixed for industrial wireless monitoring network are also taken advantage. With routing table formed during routing update phase, the control routing overhead can be reduced with the multicast form instead of broadcast form. And with the initiative route characteristics, alarm data packets containing numbered are to replace the RREQ command for route discovery. This makes the on-demand routing produce a certain output data accumulated during path setup process. And the purpose of reducing data transmission delay can be achieved.

The initialization of the network The entire network topology for SINK end is known for the wireless architecture in this paper. Therefore, it is called the network as a “semi-self-organizing network”. The network meets the following model:

- The topology of the network known for SINK end is referred to herein as "architect nodes".
- All the relay for gradient of one can communicate directly with SINK end. It is called to herein as “the guidance node”.
- Other nodes is called a "slave nodes".
- The entire network initialization process is initiated by the architect node. The guidance node is to lead the establishment of the single path and collect path information. And then it is sent to the architect node.
- Other nodes are only to have the ability of learn and forward packets. And they wait passively control packets from other nodes.

According to the target needed to be done for initialization and the analysis for the characteristics of the network model, the following initialization process based on the depth traversal thinking is designed:

- The SINK node broadcasts contains beacon of instructor node address. The instructor node joins the network after receiving the beacon.
- The SINK node collects node information of mentors. If there is a dead pixel it immediately reported to the monitoring center. And all containing the path are set to invalid path.
- The SINK node end traverses all available paths with a depth-first form. The node sends path update command to the corresponding guidance for each traversal of a path.
- Mentors node forwards path update command to the corresponding slave node. And the update command of the path contains allocation information of slot bandwidth assigned by SINK node for the node. Slave node sends request to join to become the children of the node after receiving the command. At the same time, the slave node receives slot allocation of guidance node. And with delay interrupt way, a transmission time and a reception time are adjusted to slot period assigned by the guidance. The instructor node has been forwarded paths update command to the pump

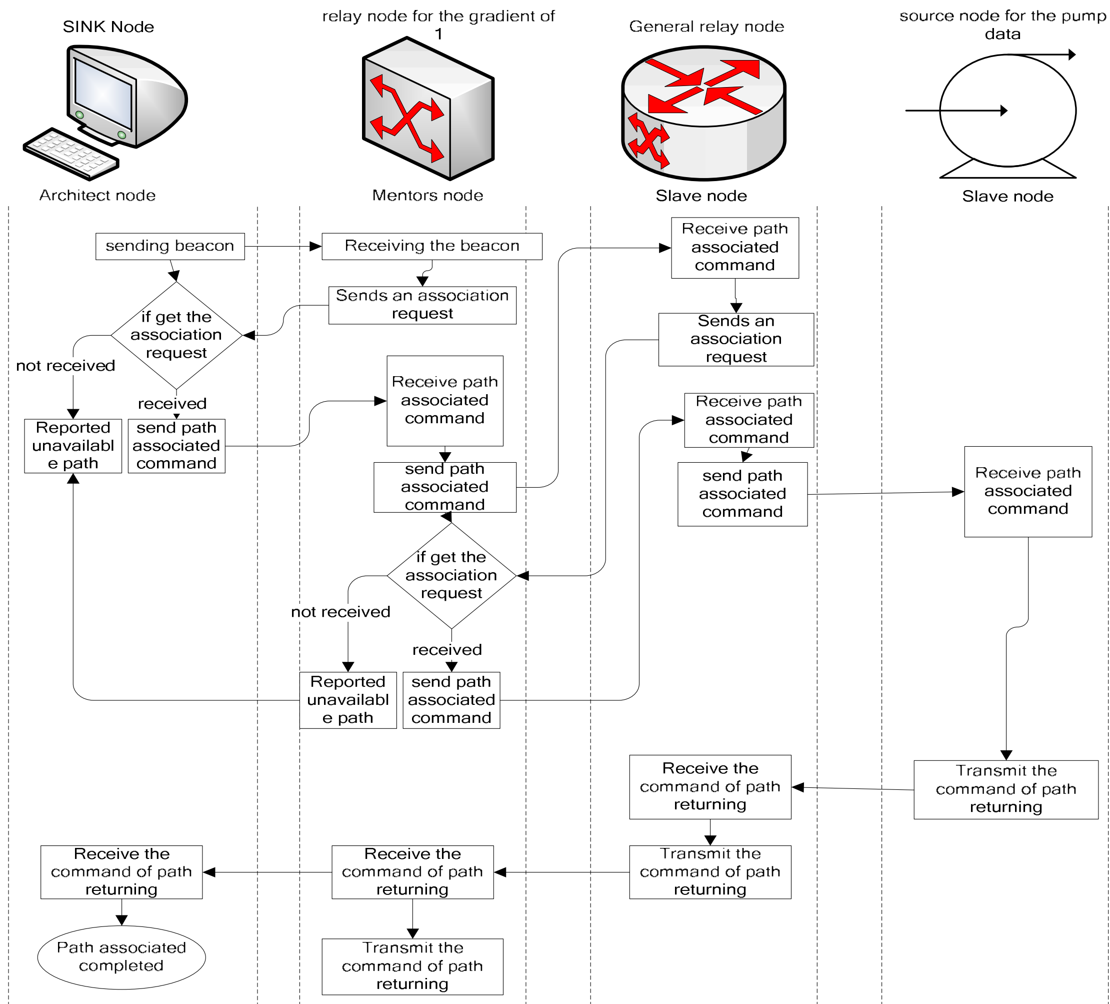

Fig. 3: Initialization flowchart of the whole network

node. The pump node according to the original path returns path information.

If slave node on certain path is found to be bad point during this time, the hop slave node returns fault information. Mentors node collects and forwards to the SINK node. SINK node is immediately reported to the monitoring center, and all containing the path is set to an invalid path.

- If the path information is normal, guidance nodes collect path information and forward to the SINK node. SINK node updates the local routing table, traverses the next available path, and goes to step 3.

Taking a path initialize as the example, the entire process is shown in Fig. 3.

The execution flow of point inspection command The path selection problem is divided into routing updates and route choice during the execution process of point inspection command. Route selection of network layer is determined by the communication primitives of APP layer. When network layer is notified to adopt path selection of routing update, it marks a new network updated start. The network layer will mark Position 1 for traversal of each link structure in all the routing tables. The sum of the flag for all traverse is the values of update flag in the routing table. Inspecting for the corresponding pump equipment, the network layer is firstly based on routing table statistics and draws all paths to reach the pump. And then the path is sorted according to descending order of update flag. Then the largest path of update flag is selected as point inspection path. And its corresponding structural body is encapsulated into inspection command frame of the network layer. After completed the package, it is further encapsulated by the MAC layer. After receiving point inspection data, the network layer will mark Position 0 for traversal of each link structure in all the routing. And the value of the update flag is automatically updated in the routing table. When wireless network routing update is completed, the point seized command without path updating can make the network layer base on multiple criteria to select the optimal route. This

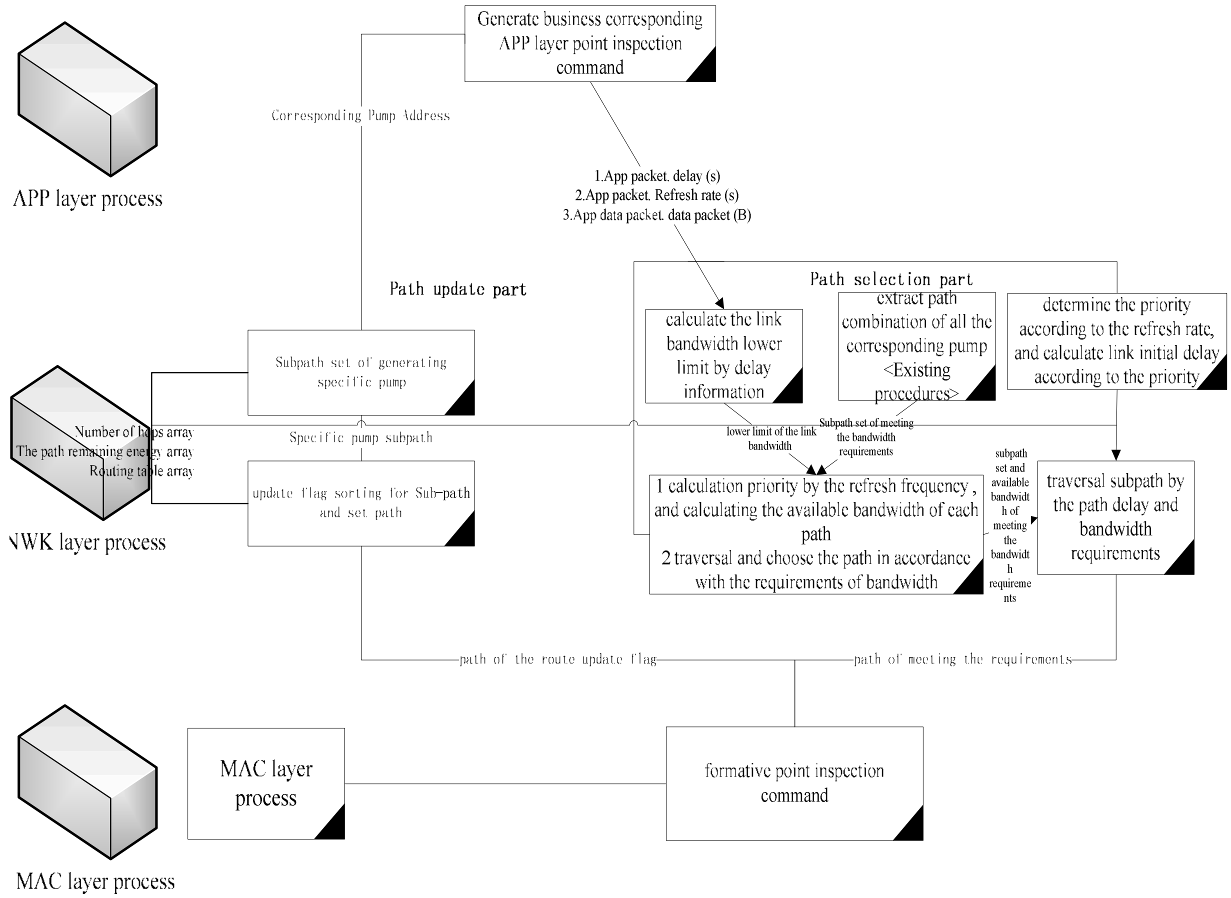

Fig. 4: Flowchart of the path selection process

article employs the Qos indicators. It means transmission delay of total route and available bandwidth. Selection criteria of optimal link are to select minimal delay path in the case of the available bandwidth to meet the requirements. The flow chart of selection process for entire path is shown in Fig. 4:

The establishment process of alarm routing: Firstly, the data source nodes connected the pump broadcast the first frame of data packet to all hop nodes. This is as routing requests. When the relay nodes receive the data grouping, they respond the routing information of this link to the source nodes. As source nodes receive routing information again, in accordance with the merits of the relay node they sort and select the best relay nodes as temporary relay node. Specific selection criteria are the smallest node meeting the requirements of the available bandwidth link gradient. If the node gradient is consistent, then it selects a link of the shortest transmission time. Then it transmits the second frame of the data packet to the provisional relay node as an acknowledgment frame. When relay node received the second frame data, it is about to down continue forwarding for the received first frame of data. The nodes without being selected as temporary relay still keep the first frame packet. If temporary relay node does not have any of the next hop relay in line with the requirements, then it issues invalid path to the source node frame. And all existing packet will be discard. The source node chooses the second best relay as temporary relaying and transmits a second data frame. This is as the cycle until the SINK node is reached. It is shown in Fig. 5.

Simulation experiments: The purpose of the experiment and the overall design This experiment chooses Chapter Four. It is based on 1.4 million tons reforming system to build a wireless monitoring for Liaoyang Petrochemical of China Petrol system. Routing protocols designed in this chapter are in the form of a program to burn to each node model. Data are collected by running the simulation program. The purpose of this simulation is to verify the routing protocol superiority:

- In the case of the point inspection route, the route has higher efficiency than the other table routing.

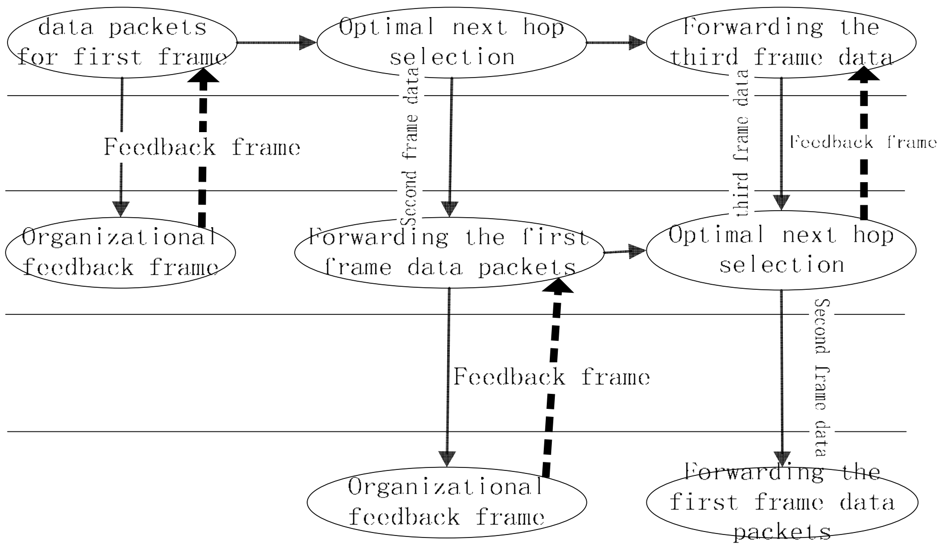

Fig. 5: Establishment process an alarm routing

Table 1: Parameter settings of the simulation scenarios

Parameter	Value
Wireless transmission distance	<55m
Wireless channel bandwidth	127Kb/s
Node distribution area	200m× 200m
Node deployment	GrASP
The number of nodes	35
Simulation time	5 hours
Packet size	1926 bytes
MAC protocol	802.15.4
Routing Protocol	DSDV, CSSC, AODV

- In the case of the alarm routing, the real-time nature of the route is better than that of the other on-demand routing.

Factory scene of OPNET simulation model is chosen. Plane range of the entire plant is square meters of 200 * 200. And the 10 * 10 m is meshed. The locations of site monitoring center, wireless relay nodes and the pump data source wireless node are taken from the conclusions of Chapter IV. The entire OPNET network model is shown in Fig. 6. As in the monitoring process of the entire pump equipment through different wireless relay node, control command radiates to each the pump node from the SINK node while data information continually converges to SINK node from pumps node. To simulate this channel condition, the network model of the tree has been established. Among them, node stands for SINK node, node ... is on behalf of the relay nodes, and nodes ... stand for pumps nodes.

The parameter settings of the simulation scenarios are shown in Table 1.

In this paper, analysis of the above parameter settings is to compare the performance of three protocols AODV, DSDV and CSSC.

Comparison of routing overhead state for point inspection The average routing overhead for every half hour in three different protocols in five hours of uninterrupted cycle point inspection process is shown in Fig. 7.

It can be seen from Fig. 7 that routing overhead of AODV routing protocol is lager. The routing overhead produced by data transmission is even increased more than the routing overhead of network initialization. The larger routing overhead is still triggered by route discovery and reverse route to build needed before each data packet transmission. Industrial radio channel instability will generate a large number of retransmissions in the process of establishing routing. This will also increase the number of control packets sent in the process of routing establishment. Thereby the routing overhead of AODV will increase. For DSDV routing protocol, since the data packet is forwarded in accordance with the routing table, thus the routing establishment process is eliminated during the AODV process. And then routing overhead is less than AODV protocol. However, routing maintenance of DSDV protocol requires to conduct a full network routing table updates every certain time. The entire update process requires that each wireless node broadcasts routing update packet. The CSSC agreement proposed in this paper during the device point inspection process, a specific path can be selected to complete the update of the whole network diameter. Therefore, after completing initialization, the CSSC routing overhead quickly decreased. And it is significantly lower than DSDV protocol.

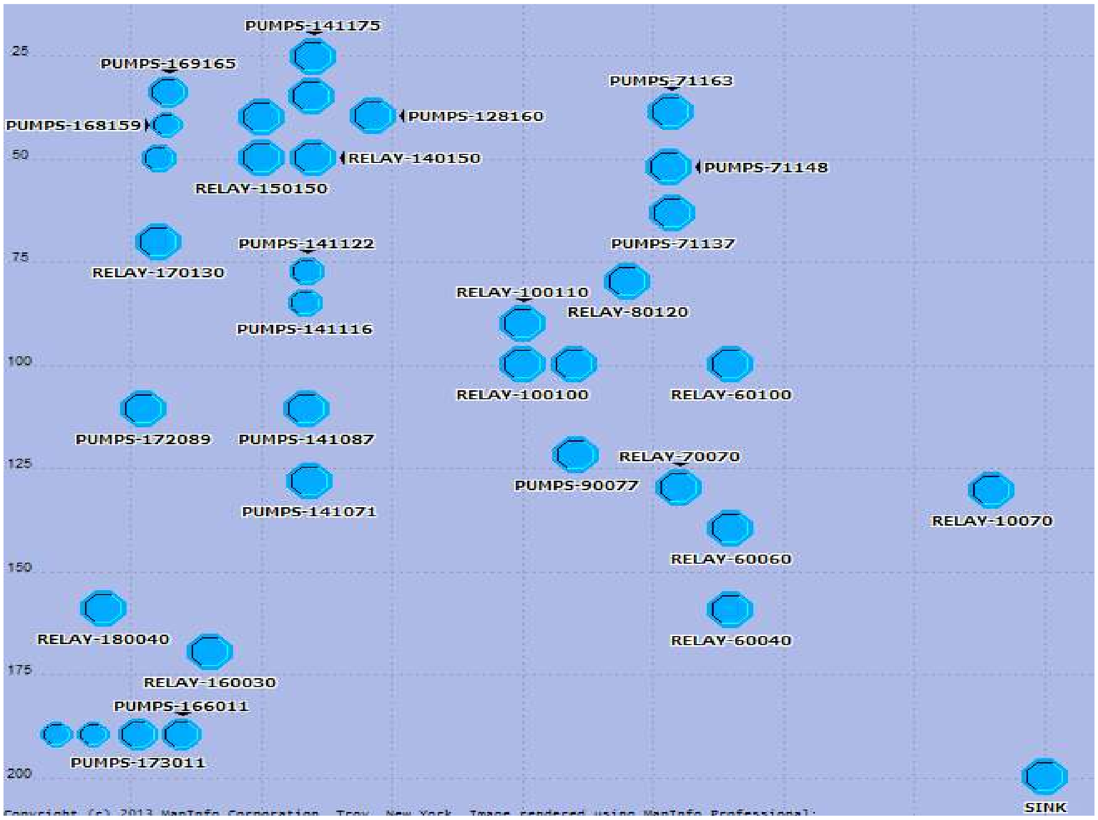

Fig. 6: OPNET network model of the factory scene

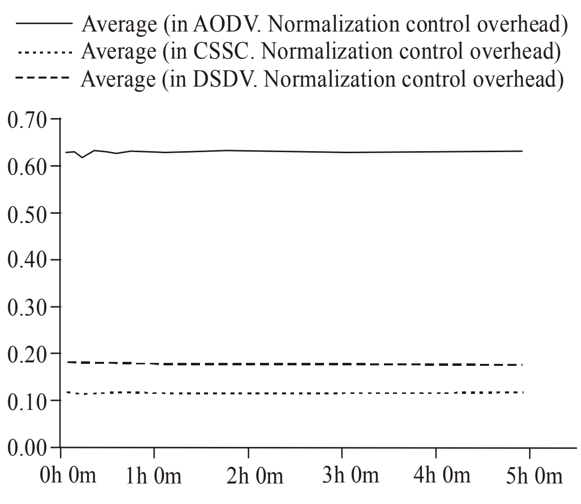

Fig. 7: Average routing overhead of three protocols

Delay comparing of device alarm: The average packet delays generated by alarm process within the 5 hours for three different protocols are shown in Fig. 8.

As can be seen from Fig. 8, the delay generated by the DSDV routing protocols is larger. And it is choppy. Such a large delay is caused by frequent data retransmissions and route switching generated by the fluctuation of the radio channel during transmission process of each alarm data packet. The analysis in

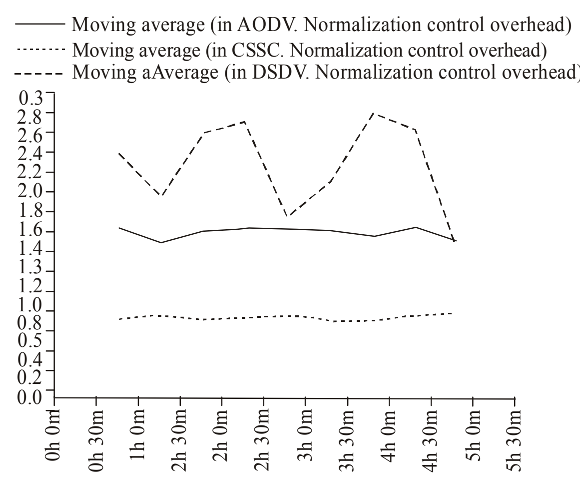

Fig. 8: the average delay of three different protocols

Chapter IV shows that industrial wireless channel is choppy. In such a channel, if a radio path about larger interference and smaller bandwidth is selected, frequent data retransmission and routing switch will be caused during the relaying process. And this will lead to reduced transmission of real-time and reliability. Thus the monitoring and diagnostic will be affected. While for DSDV routing protocol, the data packet is forwarded according to the routing table, therefore the need for building routing process of the AODV process is eliminated. Therefore, a data packet transmission delay is relatively low. The CSSC protocol proposed in this paper during equipment inspection process adopts table routing protocol to group and forward, the data transmission delay is almost unanimous with DSDV routing. However, as part of the data needs to be forwarded in accordance with updating the path of the routing table, the delay path is not necessarily to be least. CSSC protocol transmission delay is slightly larger than DSDV protocol. But there can be seen from certain figure this difference can be almost ignored.

CONCLUSION

This chapter first analyzes the functional requirements of pump group wireless monitoring system of large chemical plant for routing protocols. And it proposed that routing protocol applied to the system should make the point inspection command and the device alarm separately design so as to reduce the routing control overhead as much as possible in the process of the Periodic Inspection and improve the protocol efficiency. Transmission delay should be as short as possible in order to improve the real-time monitoring and diagnosis when the equipment alarms. Based on the above analysis, we design a new routing protocol command alternative and step by step cache protocol with a combination of active route and on-demand routing suitable for wireless monitoring of pump group. And the various data structures used in the agreement and the implementation process of the five major operating are described: bandwidth allocation, network initialization, time synchronization, point inspection and equipment alarm. Finally, OPNET simulation platform verified the superiority of the agreement.

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