An Adaptive Routing Algorithm Over Packet Switching Networks for Operation Monitoring of Power Transmission Systems

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Abstract—This paper reports on the development and subsequent use of a packet switching communication model for monitoring of power transmission line systems. Modern fault detection and fault location techniques for EHV/UHV transmission networks usually work based on the data measured by a phasor measurement unit (PMU). Digital cameras have also been widely utilized to monitor the physical status of power transmission lines on electricity pylons. PMU measures voltage and current phasors with synchronized time stamps, and then transmits the measured data to a monitoring center for analysis. The transmission of these data is required to be very stable. For the sake of operation speed and system security, the development of an enhanced communication infrastructure that guarantees the quality of service (QoS) for the essential measured data is a crucial issue. We have developed an adaptive routing algorithm for packet switching networks to guarantee the QoS of important power system communications and have conducted computer simulations to demonstrate the effectiveness of the proposed algorithm. The proposed algorithm can minimize transmission delay and reduce the number of redundant transmissions caused by loss of packets. Hence, the simulation results show the feasibility of packet switching networks on monitoring power systems.

Index Terms—Adaptive routing algorithm, network fault tolerance, packet switching network, power transmission system, QoS.

I. INTRODUCTION

In POWER systems, the importance of fault detection and location systems for power transmission lines has increased dramatically in recent decades. EHV and UHV transmission lines play essential roles in delivering electrical power from power plants to local transformer substations [1]–[3]. Occurrences of faults on the transmission line system may influence a large region of end-users and result in millions of dollars of economic losses. Hence, power companies have the responsibility to ensure the quality and reliability of their electrical power transmission networks. If a fault is happening on one of the power transmission lines, power companies have to isolate the faulty region from the entire power transmission network in order to protect the power systems from systematic collapse. Any delay within the fault detection and localization system [4], [5] to react may increase the chance of a major blackout. There are two primary reasons that may cause the entire or a part of a power system to collapse, which are: 1) logical errors in the protection algorithm and 2) delays of packets within the communication system. Accurate detection of the fault type and the fault location is crucial to inspection, maintenance, and repair of transmission systems. Since these algorithms depend heavily on speed and reliability of communication systems [6], this study focuses on improving the second reason mentioned above.

In order to monitor the status of the power system, power companies usually install a certain number of measurement units in the power transmission network [4]. We can obtain two types of information from the power system: 1) transmission line parameters, such as receiving end/sending end voltage and current phasors measured by PMU and 2) video surveillance of the transmission lines on electricity pylons recorded by camera. The measurement units capture these data and then transmit them to a monitoring center for analysis.

Power companies prefer to use unified and simplified communication network structures in order to integrate the telecommunication network with power system controls. The easiest and safest way is to use special-purpose communication lines, such as optical Ethernet, to connect directly all measurement units with a central network hub in the monitoring center. In this way, the architecture of the communication network would be a star-topology, and the power companies can minimize the risk of the entire network failing. However, the maintenance cost of such a centralized network topology is high. In addition, the Digital Object Identifier 10.1109/TPWRD.2008.2008494

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link has no tolerance for any single link network failure; thus, essential data might be permanently lost on such an occurrence.

In this study, we present a packet switching network model with an adaptive routing algorithm and priority scheme that can transmit transmission line parameters and video surveillance streams with guaranteed quality of service (QoS) and priority control. Packet switching techniques are used to achieve the maximal utility of the link capacity available in a telecommunications network. It has proved very successful in wide-area network cores. By taking advantage of packet switching technology, we propose a new adaptive routing algorithm to enhance system fault tolerance and priority control, and to reduce system delay. The algorithm provides redundant links adjoined to the communication network without increasing the complexity of the network topology. With the proposed routing algorithm, the network can transmit essential and general information about the condition of power transmission lines with higher QoS. Finally, we conducted a computer simulation based on the architecture of the Taipower EHV/UHV transmission system.

This paper is organized into six sections, the first of which is the introduction. In the Section II, we introduce the traffic model incorporated with PMU, Global Positioning System (GPS), and digital video cameras. Section III presents the packet-switching based communication model and the proposed adaptive routing algorithm. In the Section IV, we introduce the Taipower 345 kV power transmission network for performance evaluation. Section V presents the test results of the proposed communication model and routing algorithm. Finally, we give conclusions and a short discussion in the last section.

II. NETWORK TRAFFIC MODELS

A. Transmission Line Parameters at Power Transformer Substations

In recent years, many previous studies have proved the effectiveness of PMU in power protection systems [7]–[13]. The distinct feature of PMU is that it is able to provide phasor measurement of voltages and currents from widely dispersed locations in a power transmission network. PMU measures the three-phase voltages and currents, simultaneously. To avoid the effect of delay in communication links, PMU requires an external sampling synchronization device to become fully functional [9]. There are two approaches to synchronize the time on each PMU, GPS, and Synchronous Optical Networking (SONET). The GPS uses a constellation of Medium Earth Orbit synchronous satellites that transmit microwave signals to allow GPS receivers to determine their time. SONET uses two closely related multiplexing protocols that transfer multiple digital bit streams using laser diodes over the same optical fiber. GPS receiver is a portable device so it can be easily moved or reoriented. The accuracy of GPS time is ±340 nanoseconds relative to Coordinated Universal Time (UTC) on a single time. SONET requires Ethernet links to operate. It is suitable for power protection system if it starts with a highly accurate Primary Reference Source (PRS) clock of Stratum-1 quality. However, installing a Stratum-1 PRS to the system is highly expansive and unsuitable for this study. In this study, since the pulse per second (PPS) signal in GPS has an accuracy ranging from a few nanoseconds to a few microseconds, we integrate a commercial GPS receiver with PMU to provide for the sampling synchronization. Previous studies have verified the validity and performance of sampling synchronization of GPS-PMU configuration via field tests in substations of Taipower 161-kV power transmission networks [8], [9]. Fig. 1 depicts a one-line two-side simulated power transmission system that was equipped with GPS-PMU devices.

To measure the three phase voltages and three phase currents with higher phase angle precision in a power system that has a fundamental frequency of 60 Hz, we suppose that the sampling rate of GPS-PMU is $60 \times 32 = 1,920$ samples per second. We use MATLAB/Simulink to simulate the power system, and then take the simulated voltage and current waveforms as the synchronized sampled data (three phase voltages and currents) from power transformer substations. GPS-PMU organizes the measured transmission line parameters into a single packet. The arrangement of the payload of the packet is as follows: 1) sequence number (SEQ, 2 bytes); 2) time stamp (TSM, 7 bytes); 3) GPS time (GPST, 8 bytes); 4) GPS status (GPSS, 1 byte); and 5) measured transmission line parameters (TLP, 48 bytes). Since the total size of measured data is 66 bytes per sample, according to the specification of packet-switching techniques [14], we need to split each packet into two smaller cells. The packets have a 53-byte fixed-size format (including 5 bytes of header information). Thus, the network traffic generated by each GPS-PMU is $1,920 \times 53 \times 2 = 203,520$ bytes (106 cells) per second. Fig. 2 shows the format of cells generated by GPS-PMU.

B. Weather Monitoring and Video Surveillance on Pylons

In recent years, wireless sensor networks have become an active topic in the fields of wireless communication and measurement instrumentation. A network of compact surveillance sensors is now available on the commercial market. Each sensor module is equipped with a tri-axial accelerometer, temperature sensor, and humidity sensor. We can integrate a digital camera and a wind speed meter with the sensor module to make wireless video surveillance and wind speed monitoring possible.

In the simulation part of this study, we suppose that every electricity pylon has a sensor module attached to it. The sensor modules can spot potential threats such as bad weather or earthquake. Digital cameras on the sensor modules provide
visual observation of the status of power transmission lines. The sensor modules feed information on what is happening around the pylon back to the monitoring center for further analysis.

Since the average distance between two pylons is about 300 m, the wireless sensor module needs an external high-gain antenna for connectivity. The sensor module constantly measures the environmental conditions around the pylon, and then organizes these data into packets. The arrangement of the payload of the packet is as follows: 1) sequence number (NC represents “no content”), and cell (b) carries the transmission line parameters measured by GPS-PMU.

Fig. 2. Format of cells generated by GPS-PMU, where cell (a) carries timestamp information (NC represents “no content”), and cell (b) carries the transmission line parameters measured by GPS-PMU.

will disassemble the video streams into smaller packets and generate 313 packets per second. Thus, the network traffic generated by a sensor module is $313 \times 30 = 9,390$ bytes per second.

The destination of the video stream packet is the nearest transformer substation, and then the packet assembler at the substation will reassemble the payload of the video stream packet into the format of a cell used in packet-switching networks. Thus, the substation sends the environmental data and video stream back to the monitoring center by generating one cell per minute and 196 cells per second to the packet-switching network, which are equivalent to 53 bytes per minute and 10,388 bytes per second, respectively.

III. COMMUNICATION MODEL AND ADAPTIVE ROUTING ALGORITHM

A. Communication Model

The packet generated by GPS-PMU is crucial for power system protection. Thus, it requires stringent traffic QoS. The environmental conditions measured around pylons provide data only for long-term analysis and have no immediate causal effect on the security of power transmission lines. The monitoring center activates the video surveillance function of the wireless sensor modules only when something of interest has happened. Thus, the packets that carry video surveillance streams have higher traffic QoS than those for environmental conditions.

In this study, we assume that all switches in the substations are shared memory type asynchronous transfer mode (ATM) [14] switches with priority control. According to a previously proposed study, shared buffer ATM switches provide the best performance compared to other types of switches. When an ATM switch receives a cell, the switch stores the cell at a logical output port queue. The priority control immediately puts the memory address of the cell into the address management first-in first-out (FIFO) queue of corresponding priority class [15]. Next, based on its destination the priority control selects cells to be output by referring to the memory addresses in the address management FIFO queues. Fig. 4 depicts the architecture of the shared buffer ATM switches. In the simulation, we assume that a time slot for a packet switching cell is equal to 2.83 $\mu$s at 155 Mbps link speed, the size of address management FIFO is 5000 cells, and the total size of the logical output port queue is 50,000 cells. We denote a set of priority classes by A, B, and C, which correspond, respectively, to measured transmission line parameters: A) sequence number, B) three-axis accelerations, C) temperature, D) humidity, and E) wind speed.

Fig. 3. Format of packets generated by wireless sensor modules.

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parameters, video surveillance streams, and environmental conditions around pylons. Among these priority classes, class A has the highest priority.

B. Adaptive Routing Algorithm for Packet-Switching Communication Network

Although the priority control is able to guarantee QoS for essential information, the network’s ability to maintain an unobstructed data flow is another important issue. Fault-tolerance means that the network can operate properly in the event of the failure of some links. This goal can be attained by constructing redundant links. Load balancing is another crucial technique to distribute the network traffic evenly across the communication network. Thus, no hot spot (i.e., the switch that works with maximal capacity) is created. In order to attain these functions, network administrators need to constantly update the routing table on every switch. In this section, we present an adaptive routing algorithm that enables the switches to automatically update its routing table to attain an optimal path for packets. The routing algorithm is a standalone algorithm that allows the switches to work independently without any assistance from network administrators or control computers in the monitoring center.

We suppose that we constructed a packet-switching communication network \( \mathcal{N}(\Gamma, \Lambda) \), where \( \Gamma \) is a set of ATM switches, and \( \Lambda \) is a set of links. Let \( s \) be a power transformer substation, and let \( d \) be the monitoring center. The communication network \( \mathcal{N} \) in fact is a graphic model as depicted in Fig. 5. The substation \( s \) is equipped with a GPS-PMU. The GPS-PMU puts the values of transmission line parameters in a packet and sends the packet to the monitoring center via the packet-switching network. In addition, the substation also relays packets received from other substations (e.g., \( x_1, x_2 \), etc.) and wireless sensor modules (e.g., \( w_1, w_2 \), etc.) to the monitoring center. We classify connections into two categories, constant bit rate (CBR) connections and unspecified bit rate (UBR) connections.

The proposed routing algorithm consists of two stages, an exploration stage, and an evolutionary stage. First, we connect all switches in \( \Gamma \) according to the predetermined links in \( \Lambda \). The first task for the switch at substation \( s \) is to identify its neighboring switches (for example, at \( w_1, w_2, \) etc.) and construct a private connection matrix \( T_s \) to register all possible outgoing links. It also initializes a goodness of links matrix \( G_s \) to register the goodness of outgoing links for forwarding a cell to the destination \( d \). Then, the switch enters the first stage of the routing algorithm.

In this study, the mission of the packet-switching communication network is to monitor and transfer the operation status of the
power transmission system. Thus, the final destination of all information is the computers in the monitoring center. Under this assumption, Fig. 6 shows the flow diagram of the first stage (exploration stage) in the proposed routing algorithm. The switch that connected to the network sends out a number of set-up request cells to the switch in the monitoring center. When the switch receives these cells, it sends back ACK cells to the switch. Finally, the lower delay times of the cells. The switch uses the average transmission delay on each outgoing link to calculate goodness of links matrix $G_s$ by

$$G_s(x_i) = \frac{1}{\sum_j 1/\bar{h}(x_j)}$$

where $G_s(x_i)$ is the goodness of sending a cell to the monitoring center by forwarding the cell to the next switch $x_i$. After all switches have completed the first stage, the switch $s$ sends a setup request cell to the monitoring center $d$ via the outgoing link with highest $G_s(x_j)$ to construct a priority class-A CBR connection. This connection is for transmitting cells generated by GPS-PMU. The remaining outgoing links $x_j$ with smaller $G_s(x_j)$ becomes redundant links and serve as backup links in case of network failure of outgoing link $x_i$. The constructed connection has the highest QoS, and is always valid at all times. The routing algorithm resets the connection channel when the QoS of the channel has degraded and becomes unable to satisfy the communication demands of the power transmission system.

In the second stage (evolutionary stage), we construct connections for transmitting data generated by wireless sensor modules to the monitoring center. Fig. 7 shows the configuration of the hybrid network that combines packet switching network and the wireless sensor networks. We take the switch in the substation $s$ as an example. It receives packets from wireless sensor modules, extracts the payload, and reassembles the payload into cells that are compatible with the packet switching networks. When the switch receives a packet that contains environmental conditions or the starting packet of the video surveillance stream from the wireless sensor networks, the switch sends a setup request cell to the monitoring center $d$. We initialize a proportion matrix $P_s$, and set the values in $P_s$ to $G_s$. We define a function to calculate the weights of outgoing links chosen to relay the information by

$$[P_s(x_i)]^C_1 \cdot \left[1 - B_s(x_i)\right]^C_2$$

where $P_s(x_i)$ is the proportion of the cell relayed to $x_i$, $B_s(x_i)$ is bandwidth utility ratio of the outgoing link to $x_i$, and $C_1$ and $C_2$ are weighting factors that regulate the importance of $P_s(x_i)$ and $B_s(x_i)$ during the calculation. The probability of choosing $x_i$ as the next switch to relay the cell is

$$\sigma(x_i) = \frac{[P_s(x_i)]^C_1 \cdot \left[1 - B_s(x_i)\right]^C_2}{\sum_j [P_s(x_j)]^C_1 \cdot \left[1 - B_s(x_j)\right]^C_2}.$$  

In (3), the proposed routing algorithm is able to achieve the function of load balancing because the higher $B_s(x_i)$, the lower the chance that $x_i$ has been chosen to be the next switch to relay the cell. Therefore, the proposed routing algorithm is capable of preventing the sending of more cells to busy switches. When the packet reaches the monitoring center, the monitoring center sends back the transmission delay time, denoted by $\Phi$, by an ACK cell. $P_s(x_i)$ is updated by

$$\Delta P_s(x_i) = \frac{C}{\Phi} \cdot P_s(x_i) + \Delta P_s(x_i).$$

In order to keep the proportion matrix $P_s$ normalized, every time after it is updated, it must be normalized by

$$P_s(x_i) = \frac{P_s(x_i)}{\sum_j P_s(x_j)}.$$  

The value of $P_s(x_i)$ is updated once the switch $s$ receives an ACK cell of a setup request cell.

IV. TESTING SAMPLES OF POWER TRANSMISSION SYSTEMS

Fig. 8 depicts a real 345-kV power transmission network system encountered in Taiwan. In this study, we apply the proposed communication model and adaptive routing algorithm to the power system in Fig. 8 using MATLAB/Simulink.
Fig. 8. Topology of a real 345-kV power transmission network system encountered in Taiwan.

The power transmission system consists of three power plants, thirty-nine lines, and twenty-four buses. We take account of the parameters of the transmission lines during the simulation. Table I summarizes the profile of the tested power transmission system.

The monitoring system consists of four primary parts, GPS-PMU, the monitoring center, the packet switching network, and the SQL database. In the simulation, we assume that each bus in the power transmission system is equipped with a GPS-PMU regardless of the installation cost. Thus, the power system has 24 GPS-PMUs attached to it. Fig. 9 shows the topology of the simulated communication network. We can see that each switch has at least two outgoing links to enhance the reliability of the communication system in case of network failures. Furthermore, the total length of the power transmission lines is 939.61 km. We suppose that the average distance between two pylons is 300 m, and thus, 4705 pylons are required to hold the transmission lines up in the air. According to this configuration, each pylon has a wireless sensor module attached to it, and we integrate the wireless sensor networks to the packet switching network as branches connected to ATM switches.

To verify the performance of the proposed adaptive routing algorithm over the packet switching network, we have conducted extensive simulation studies for various network failures and network traffic conditions. We discuss the simulation scenarios in the next section.

V. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed routing algorithm based on the traffic model and packet switching network model described in previous sections. The transmission traffic consists of three types of data, transmission line parameters, environmental conditions, and video surveillance streams. The GPS-PMU installed at each substation measure the three-phase voltages and currents on the bus, and sends the measurement results to the monitoring center via a packet switching network. This type of data is essential for the protection system of power transmission network and requires the highest priority traffic without excessive delay time. The goal of this study is to test the robustness of the proposed routing algorithm when the network traffic encompasses packets from different kinds of networks.

To set up the simulation conditions, we refer to the specifications of the 'Cisco Catalyst 8540' ATM switch. We assume that the ATM switch is equipped with one route processor and two switch processors, and the bandwidth of the shared memory is 40 Gbps. The function of the two deployed switch processors is to enhance the throughput. The maximum throughput of the ATM switch is 24 million cells per second.

In order to reduce the cost of constructing the telecommunication network, we build 22 short distance ATM transmission links between 17 power transformer substations in the tested sample network. Each substation has no more than three transmission links connected with other substations. Thus, the

<table>
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<th>#</th>
<th>Source Substation</th>
<th>Destination Substation</th>
<th>Length (km)</th>
<th># of Lines</th>
<th># of Pylons</th>
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network topology is simply a mesh network. The transmission delay time for transmitting a cell depends heavily on the speed of the ATM fabric and is calculated by

\[
\text{Total Maximum Delay Time} = \text{Maximum Delay Time on ATM Fabric} + \text{Routing Delay} + \text{Queueing Delay Time} + \text{Miscellaneous Delay Time}
\]  

(7)

where the maximum delay time on the ATM fabric is 41.6 ns (switching 24,000,000 cells per second). The routing delay depends on the operating frequency of the route processor. In this simulation, we assume that the routing delay is 10 ns. For a shared memory switch with 155 Mbps transmission speed, the queueing delay is 2.83 \(\mu s\) times the number of cells in the queue of the output port controller. The miscellaneous delay time is extra delay time caused by other factors, e.g., speed of electric signals (speed of light). The channel release time is set to 1 min. Each switch can maintain a maximum of 65,535 channels.

First, we evaluate the performance of the priority control. All substations transmission channels to the seventh substations (Panchiao substation and monitoring center). In the exploration stage, each node sends 250 set-up request cells in order to find the possible paths to the Panchiao substation. The transmission rate of each channel is set to 2 Mbps. The discovery result of the exploration stage is

**Path of connection** | **Avg. delay time**
--- | ---
1 → 2 → 4 → 7 | 9.94152 \(\mu s\)
2 → 4 → 7 | 6.19544 \(\mu s\)
3 → 5 → 4 → 7 | 9.07704 \(\mu s\)
4 → 7 | 2.95364 \(\mu s\)
5 → 4 → 7 | 5.89575 \(\mu s\)
6 → 8 → 7 | 7.20400 \(\mu s\)
7 | 1.00856 \(\mu s\)
8 → 7 | 4.12068 \(\mu s\)
9 → 8 → 7 | 6.80057 \(\mu s\)
10 → 7 | 3.10924 \(\mu s\)
11 → 12 → 9 → 6 → 8 → 7 | 19.0185 \(\mu s\)
12 → 9 → 6 → 8 → 7 | 13.9469 \(\mu s\)
13 → 10 → 7 | 6.33952 \(\mu s\)
14 → 15 → 13 → 8 → 7 | 13.7164 \(\mu s\)
15 → 13 → 8 → 7 | 9.85507 \(\mu s\)

The average delay times listed above are most likely the same all the time since they carry essential information that requires highest priority traffic. Traffic of priority classes B and C are not able to influence the QoS of priority class A cells. Thus, the average delay times listed above are the delay times of the priority class A cells. The average delay times may change when the connection path is released due to network failure, QoS degradation, or other factors. We will discuss this issue later.

The goodness of links matrix constructed in the exploration stage then becomes the proportion matrix in the evolutionary stage. The proportion matrix is the fundamental guideline to transmit priority classes B and C cells. The priority classes B and C cells are mainly from wireless sensor networks. Since these networks are based on wireless communication, the transmission rate of communication links between two wireless sensor modules is relatively limited if we compare it with the packet switching network. The delay time for transmitting a packet is about 30 microseconds with 1 Mbps transmission speed.

The video surveillance streams recorded by cameras fitted with wireless sensor modules are transmitted by priority class B cells in the packet switching network. Since the bit rate of the video surveillance stream is 10,388 × 8 = 83,104 bps, the nearest connected ATM switch needs to create a connection channel to the monitoring center with a transmission rate of 96 kbps. In this part of the simulation, we randomly activate cameras installed on the pylons. Most of transmission delay is caused by the wireless sensor network because of the long distances between the activated cameras and their nearest substations. Since all wireless sensor modules need to report environmental conditions around the pylons in a fixed interval of time, each wireless sensor module generates a 30-byte priority class C packet, and transmits the packet to the nearest substation. The transmission delay time of the priority class C packet increases if administrators have activated a large number of cameras. However, once these wireless packets reach a substation, the packet switching network is capable of transmitting them to

![Figure 9](image-url)
the monitoring center with minimal delay time. The path of connections created for transmitting priority classes B and C cells may be different depending on the traffic condition in the packet switching network. Fig. 10 shows the box-plot of average delay time versus the number of activated cameras obtained in 1000 repeats of simulations. An inspection of the figure clearly shows that the transmission time delay of the proposed communication model for transmitting video surveillance streams might be up to around 70 s when the number of activated cameras is around 200. This is because the bandwidth of the WSN node is very small. So, once we activate too many cameras, it will cause a large transmission delay. However, once these WSN packets reach the nearest substation, the ATM network will transmit the packets to the monitoring center within microseconds.

Another problem is network failure. The network instruments utilized for power protection systems need to be very stable and reliable. However, in the case of network failure, we need extra backup links to provide fault tolerance. Thus, each substation has two or three communication links connected with other substations. In Fig. 9, the 8th substation obviously is a hot spot in the communication network.

We suppose that all communication links connected with the 8th substation are entirely failed during the simulation. The substations that depend on the 8th substation to relay network traffic (6th, 9th, 11th, 12th, 14th, and 15th substations) send out 250 setup request cells to find out an alternative path to transmit cells to monitoring center. The experimental results are

<table>
<thead>
<tr>
<th>Path of connection</th>
<th>Avg. delay time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 → 2 → 4 → 7</td>
<td>10.9356 μs</td>
</tr>
<tr>
<td>2 → 4 → 7</td>
<td>6.7323 μs</td>
</tr>
<tr>
<td>3 → 5 → 4 → 7</td>
<td>9.82341 μs</td>
</tr>
<tr>
<td>4 → 7</td>
<td>3.22652 μs</td>
</tr>
<tr>
<td>5 → 4 → 7</td>
<td>6.68733 μs</td>
</tr>
<tr>
<td>6 → 1 → 2 → 4 → 7*</td>
<td>13.2148 μs</td>
</tr>
<tr>
<td>7</td>
<td>1.05345 μs</td>
</tr>
<tr>
<td>8 → 7</td>
<td>n/a</td>
</tr>
<tr>
<td>9 → 6 → 1 → 2 → 4 → 7*</td>
<td>17.1455 μs</td>
</tr>
<tr>
<td>10 → 7</td>
<td>3.43064 μs</td>
</tr>
<tr>
<td>11 → 12 → 14 → 15 → 13 → 10 → 7*</td>
<td>20.7475 μs</td>
</tr>
<tr>
<td>12 → 14 → 15 → 13 → 10 → 7*</td>
<td>17.4319 μs</td>
</tr>
<tr>
<td>13 → 10 → 7</td>
<td>7.12563 μs</td>
</tr>
<tr>
<td>14 → 15 → 13 → 10 → 7*</td>
<td>13.9316 μs</td>
</tr>
<tr>
<td>15 → 13 → 10 → 7*</td>
<td>9.94085 μs</td>
</tr>
</tbody>
</table>

where “*” represents a modification of the connection path. We can see that the network failure occurring at the 8th substation slightly affected the QoS of other communication channels. However, the time needed for the network to recover stability is lesser than 2 ms. Fig. 11 shows the delay time variances of each communication channel before and after the 8th substation failed.

VI. CONCLUSIONS

In this study, we proposed a communication model for a power transmission protection system and an adaptive routing algorithm for packet switching networks. By cooperating with ATM switches, the communication model encompasses a complete monitoring configuration for power transmission switching networks and wireless sensor networks to form a system. In order to produce precise simulation results, the
detailed traffic model and network architectures are given to define the entire system.

A real Taipower 345-kV transmission network was modeled for the simulation. The simulation results have shown that the proposed algorithm is able to automatically discover the best path to transmit data to the desired destination, to collect data from different platforms, and is robust against network failure. Also, the priority control helps the ATM switches guarantee the QoS of essential transmission line parameters. Finally, the proposed algorithm and communication model have shown their effectiveness for adaptive and priority controls.

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REFERENCES


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