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Performance Analysis of Packet Transport Network Communication for Integrated Wide-Area Protection

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Abstract

As a new protection, wide-area protection enables protective relaying, and automatic control based on electric power system network communications and comprehensive judgment of multi-point information, which plays an increasingly important role in the secure and stable operation of electric power system. Interaction of wide-area information relies on communication network featuring high reliability and low time delay. On the other hand, most service of power transformation station is gradually towards IP and data oriented, along with the development of smart grid. This paper aims to introduce the wide-area protection technology supported by Packet Transport Network (PTN) communication technology, with analyzing the QoS (Quality of Service) network assurance architecture of PTN network, which establishes three planes, including transport plane, management plane, and control plane, based on ASON (Automatically Switched Optical Network) technology. After demonstrating the QoS assurance system of PTN from traffic control and transmission route, this paper introduces PTN networking test. Based on detailed parameters in the test results, the transmission performance of PTN on time delay, protection, and time synchronization of various electric power communication services are analyzed, with showing that PTN can fully meet the requirements of electric power communication.

***Keywords**: Integrated Protection, Packet Transport Network, Quality of Service. PTN communication performance*

1. Introduction

Electric power communication network bears a variety of specific services of electric power system, which makes it the infrastructure support facility for the stable operation of the electric power system. Currently, electric power communication network bears the following six types of services: power automation, secure protection, voice, video conferencing, corporate management, and video surveillance. The information needed to be transmitted by the six types of services requires a variety of communication services, including low-speed data, real-time data, data files, voice, video graphics, and video streaming, among which, each service has different requirements [1]. Among the six services, secure protection service mainly adopts TDM transmission mode due to strict requirements on real-time and reliability (particularity for electric power application). Beside this, the other services will adopt IP packets for transmission mode in the future. Furthermore, for secure protection service, wide-area protection will be the inevitable trend of the future smart grid. As a new protection, wide-area protection enables protective relaying and automatic control based on electric power system network communications and comprehensive judgment of multi-point information, which plays an increasingly important role in the secure and stable operation of electric power system. However, wide-area protection requires high reliability and strict time delay characteristics for communication network. Therefore, the future smart grid should meet

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the communication requirements of wide-area protection, and supports other IP packet services (data services) at the same time. In other words, a new communication technology that enables real-time and reliable transmission of TDM services and efficient transmission of IP packet services (data services) is in need. Under this circumstance, PTN technology answers the call [11].

2. The Generation of PTN Technology

Currently, electric power communication network mainly adopts SDH network technology, which is a stable and mature network features high efficiency, low time delay, and high reliability of TDM service, with end-to-end management capability [13]. But under the new development trend of smart grid services, the SDH/MSTP technology based on circuit switching gradually shows its limitations, including low bear efficiency and poor flexibility for data services. In this case, PTN technology emerged to compensate for the limitations of SDH/MSTP for data services. Based on packet switching, PTN technology overcomes the weakness of SDH rigid bandwidth and achieves statistical multiplexing and efficient transmission in packet services [2]. In the meantime, PTN technology features service level, operation, management, maintenance, clock, and protection, which contribute to a connection-oriented multi-service unified transmission technology. However, wide-area protection requires high reliability and strict delay characteristics for communication network. So will PTN technology meet the communication requirements of wide-area protection? The following part will discuss the issue.

3. Features of PTN Technology

3.1 QOS Network Assurance Architecture

Due to the wide-area protection requirements, a large number of service state information and control commands are required to have high reliability and strict time delay characteristics [12]. Therefore, to be applied in electric power system, PTN technology must be able to provide reliable transmission system similar to SDH, namely, end-to-end QoS service assurance that meets the requirements. To this end, based on ASON technology, PTN established QoS network architecture that includes transmission plane, management plane, and control plane [9].

Transmission plane: achieves functions including: PTN interface service adaptation, operation administration maintenance (OAM) packet forwarding and processing, service packet label forwarding and switching, network protection, Quality of Service (QoS) handling, processing and transmission of synchronization information and line adaptation of NNI interface. It contains modules including: traffic classification and marking, queuing and scheduling, traffic policing, congestion management, congestion avoidance, traffic shaping, and connecting operation [10].

Control plane: completes the path to processing traffic, including resource discovery, announcements, reservation, scheduling, route selection, monitoring, with modules like route, signaling, and resource control.

Management plane: achieves functions including: channel routing, fault management, network element and subnet level topology management and status monitoring, access routing, configuration management, performance management, and security management.

Function modules of QoS network assurance architecture can be managed to the level of network node, such as traffic classification and queuing; or to the level of network segment, such as QoS route. For the latter, signaling must be exist between network nodes, no matter the segment is end-to-end, end-to-side, side-to-side, or network-to-network.

In this architecture, service traffic control and service routing control are adopted by QoS service assurance technology to manage and control network traffic to avoid blockage, improve transport reliability of service data traffic, service quality, and effective utilization of network resources in the network [3].

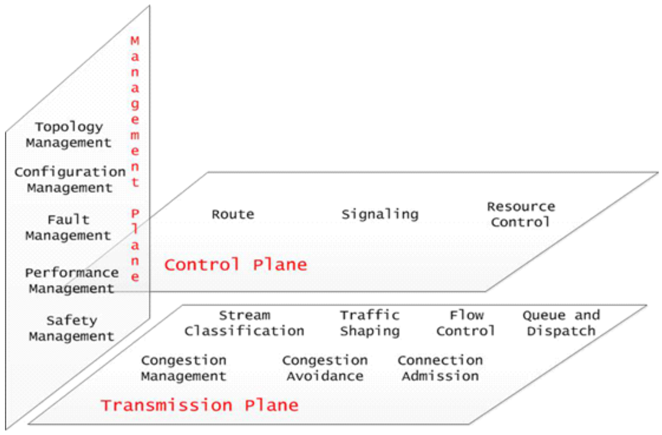

Figure 1. The QoS Network Assurance Architecture

3.2 PTN Traffic Control Technology

Service quality of PTN network refers to different service quality assurances based on different service requirements in the network, with controlling traffic in the PTN network as its main method. Refer to Figure 2 for the function model.

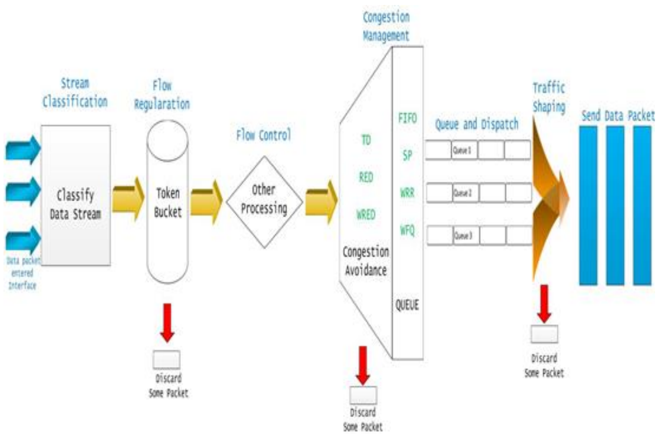

Figure 2. The Model of Traffic Control

Traffic control function aims to provide different service quality assurance, including packet loss rate, time delay, jitter, and wideband for various services in the network, to achieve the comprehensive system that bears data, voice, and video services at the same time. Its function model includes traffic classification, traffic marking, traffic policing, queue scheduling, congestion management, congestion avoidance, traffic shaping, and connection permission, which can be divided into UNI (User Network Interface) side function and NNI (Network Node Interface) side function [4].

3.2.1 Traffic Classification: Traffic classification performs packet marking to packets in PTN network [6]. After being marked based on service levels, different packets can be received in the form of single packet in the network. Generally, packet marking is located at the entrance and divided into different classifications based on port or protocol. A value is set in a certain domain based on the protocol (such as the ToS domain at the IP entrance, or EXP, PW, MAC, VLANID domain at the MPL entrance or the combination). Then the packet is classified and determined to belong which ensemble and service level protocol, by resolving various domains at the packet entrance.

Traffic classification algorithm is meant to build a set of ranges, among which, each domain is mapped by a rule type, with forming a data structure that contains multiple rules. Traffic classification is characterized by a number of data items. Data classification means that the data packet that contains multiple data matches to each domain for the best match.

3.2.2Traffic Policing: Traffic policing is implemented by limiting the speed of service traffic [6]. In order to protect the resources, a certain traffic that accesses the network is monitored to stay in a reasonable range or to be punished for the excess traffic. In traffic policing, excessive traffic of certain connection can be handled by dropping packets or resetting the packet priority. Refer to Figure 3 for traffic policing process.

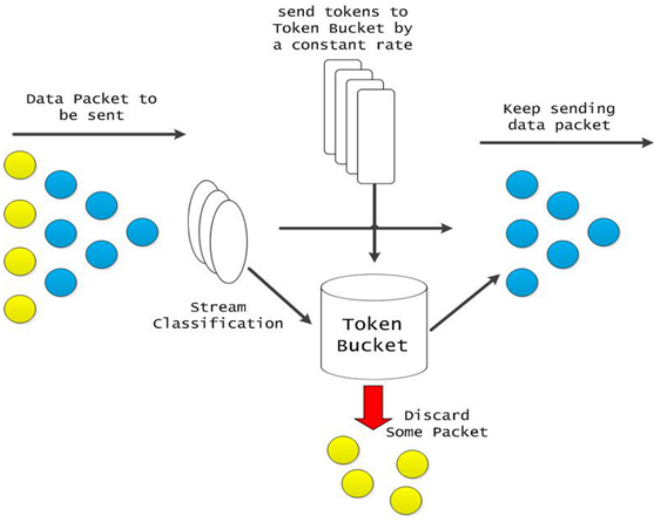

Figure 3. The Process of Traffic Policing

Suppose the maximum size of the token bucket is MBS, and SIR is the token generation rate by the token bucket. At time 0, the token bucket is full, *i.e.*, the number of tokens Tc (0) = MBS. At time t, when the B byte sized packet PK is reached: if Tc (t) is not smaller than B, which indicates the assessment result is coincident, the PK packets can be sent to adjust the number of tokens Tc (t), Tc (t) = Tc (t) -B; If Tc (t) is less than B, which indicates the result is failed, then the PK packets cannot be sent and PK packets should be dropped.

To provide service priority function, the marks of the packets with positive assessment result can be marked to other priorities before forwarding.

3.2.3 Traffic Shaping: Traffic shaping is a measure commonly used to adjust the traffic output rate and reduce downstream NE loss due to uniform packet sending. Different from traffic policing, traffic shaping place the packets need to be dropped to the buffer or queue. (Refer to Figure 4)

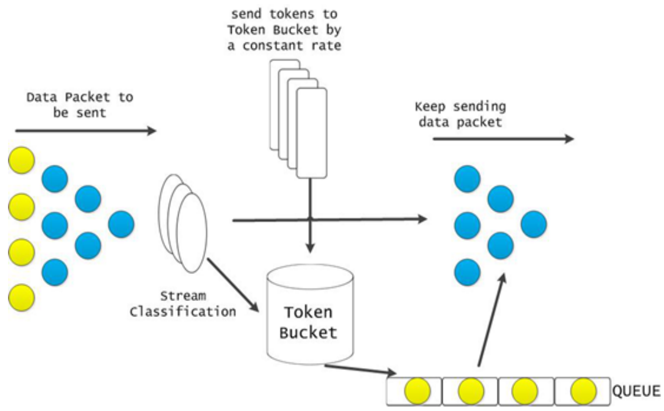

Figure 4. The Process of Traffic Shaping

3.2.4 Congestion Management: Congestion management mainly adopts queuing technology to monitor network load, anticipate and avoid congestion. The traffic is classified by a queuing algorithm, and sent out by certain priority algorithm. Each queue algorithms would seriously impact the allocation, time delay, and jitter of the broadband resources, to solve specific network traffic problems.

3.2.5 Congestion Avoidance: Congestion occurs when the link bandwidth and buffer space is insufficient, namely, exceeds the load capacity of the network. Severe traffic congestion is mainly caused by packet loss, which is because router queue is always full. Congestion avoidance is mainly achieved through packet loss.

A typical congestion avoidance mechanism is, when traffic accessing the network is reduced in the condition of congestion, the packet loss or lifetime expiration will be considered to be signs of network congestion, except there is a clear indication. This enables higher priority traffic to get continued normal service. When congestion is weakened, the sender can increase appropriate amount of traffic.

Congestion can be tested by detecting the average length of the queue at the line output end. If congestion occurs, to avoid overall synchronization and release network congestion, packet loss should be implemented to inform the source to reduce the congestion window and reduce the data transmission rate. For packet loss, tail drop (dropping newly arrived packets) and head drop (dropping first arrived packets) can be used, without dropping packets in a fixed manner, rather than distinguishing packet dropping level. In power applications, in order to ensure QoS of different services, high and low thresholds and drop probability can be set, by sensing the packet dropping priorities, for the packets based on different priorities to provide different dropping characteristics for packets with different priorities.

3.2.6 Queue Scheduling: Queue scheduling aims to handle packets with different priorities in classification, which means that packets with higher priorities will be sent first. In this way, different service QoS assurances are provided. General methods of queue scheduling include first in first out (FIFO) queue, Strict-Priority (SP) queue, Weighted Round Robin (WRR) queue, and Weighted Fair (WFQ) queue [15].

The defaulted FIFO queue scheduling treat all service in a united way, without distinguished services, in low QoS service quality.

SP queue scheduling classifies packets at the out end based on service level. In queue scheduling, packets are sent in strict accordance with the priority order from highest to lowest, which means that packets with higher priority will always be sent before packets with lower priority.

For the multiple queues contained in the WRR queue, users can customize the weight of each queue weight, percentage or byte count, and WRR will implement scheduling based on the parameters set by the user. In the meantime, SP algorithm can be integrated by setting priorities to WRR priority level queues. In queue scheduling, WRR will be implemented in the first priority level queue. When there is no packets to be sent in the first priority level queue, WRR will be further implemented in the second priority level queue. In this way, priority level and sending weights are both taken in consideration at the same time.

WFQ scheduling enables fair chance in each queue, namely, priority is considered on the basis of WRR scheduling. Statistically, WFQ allows more chances for high priority packets than low priority packets. WFQ can implement automatic traffic classification based on "session" information (including protocol type, source and destination TCP or UDP port number, source and destination IP address, and priority in ToS domain), and provide as many queues, to place each traffic evenly into different queues, and balance the time delay of each traffic in general. In the dequeue, WFQ can assign the bandwidth of each traffic based on the priority. The smaller the priority value, the less the resulting bandwidth, and vice versa[5].

3.3 PTN Transmission Route Technology

Traffic control ensures that data with higher priority is sent first among all the data with different quality of service requirements. But from end-to-end perspective, to solve the impacts of packet transmission, including burst traffic, dynamic routing, changing time delay, and jitter, PTN introduces connection-oriented route control T-MPLS technology, which enhances packet services scalability, end to end QoS, and efficient traffic scheduling mechanism [8].

As a subset of MPLS, data in the data forwarding plane of the T-MPLS is forwarded based on T-MPLS label [14]. Label forwarding network consists of entrance label edge router (LER) internal label switch router (LSR). When data traffic enters into the label switched network, the entrance label edge router (LER) will map the data traffic to a forward equal class (FEC), namely the collection of packets forwarded along the same path, and add short labels with fixed length for each packet. After that, the data is transmitted along the LSP constituted by a series of LSR, which forwards packets based on the label they carries in switched manner. PTN network routing control technology maintains LSP and forwards data based on network state, including information dissemination, path selection, LSP establishment, and data forwarding, as shown in Figure 5.

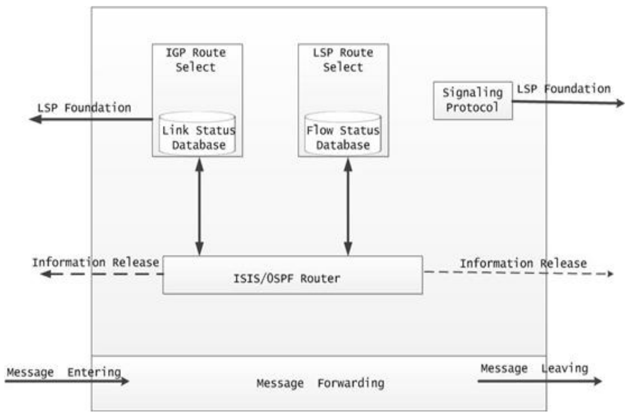

Figure 5. The Frame of Transmission Route

4. System Analysis of Ceramic Design System

4.1 The Related Concepts of Transmission Delay

Time delay refers to the time interval between the first bit in the data packet entering the first node device and the last bit leaving the last node device.

For PTN transmission network, the time delay formula is as follows: Time delay = packet delay + service delay + QoS delay + fiber transmission delay, where the parameters are described below [7].

Packet delay: the time delay that TDM services / data traffic is encapsulated as a pseudo wire (PW) packet.

Business processing delay: time for packet processing by the device, including packet validity check, packet filtering, checksum calculation, packet encapsulation and forwarding, which is related to the process capability of the device.

QoS delay: For packet switching equipment (PTN switches / routers), distinguished services are provided. The priorities of service data packets are classified, to ensure services with higher priorities are forwarded first through queue scheduling, and ensure the QoS characteristics of services with different priorities. Services with higher business priorities will be allocated with sufficient bandwidth and forwarded first, while services with lower priorities will be in the queue and delayed forwarding, resulting in time delay, which plays a significant role in the scenarios where there is a large amount of services and network congestion.

In fact, TDM service or important data services will be set to the highest priority and ensured by setting promised information bandwidth. However, in most cases, electric power communication network is lightly loaded, so the time delay caused by QoS is not prominent.

Optical fiber transmission delay: As an electromagnetic wave signal, optical signal owns a propagation speed of 2 * 105 km/s in the optical fiber, with transfer delay of 5 s per kilometer. This factor is in linear relationship with fiber distance, with nothing to do with communications technology.

In addition, PTN service adopts static configuration, which means, service connection channel has been established before the service transmission. Therefore, service connection does not generate time delay in the whole time delay.4.2 Based on Parts of Ceramic Product Design Process Model Material

4.2 Analysis Time Delay of Data Services Based on PTN Technology

Among various data services in electric power network, video services that requires lower transmission time delay, requires information collection and control services with high real-time requirements. For example, for intelligent power transformation station, the total transmission time of GOOSE messages shall be less than or equal to 3ms.

Analysis referring to time delay formula: For data services, the delay of packet processing is minor; and in light loaded network, the delay caused by QoS is also minor. Therefore, the service time delay of PTN is mainly related to the processing capabilities of PTN device itself. With the improvement of PTN device processing capabilities (including CPU, port speed, and packet switching chip), PTN shows higher performance, with national standard requirements as follows: the single station time delay of 64 B shall be less than 100 s.

To verify the actual results, an IPTS8300 PTN device is tested by spirent SPT2000 network tester. The test environment is shown in Figure 6.

For the single time delay of GE service of 1000 Mbps from A to C station, the GE service traffic is 100%, while the fiber transmission delay can be ignored for the short distance. The delay test result of data traffic is shown in Table 1:

As is shown in the table, for data traffic delay, PTN equipment can reach higher requirements. Test data of 3 stations shows that: The longer the packet, the greater the time delay. But for all kinds of frame length, the delay does not exceed the maximum of 30 s, and each station is not more than the maximum of 10 s (transmission link for 10Gbps).

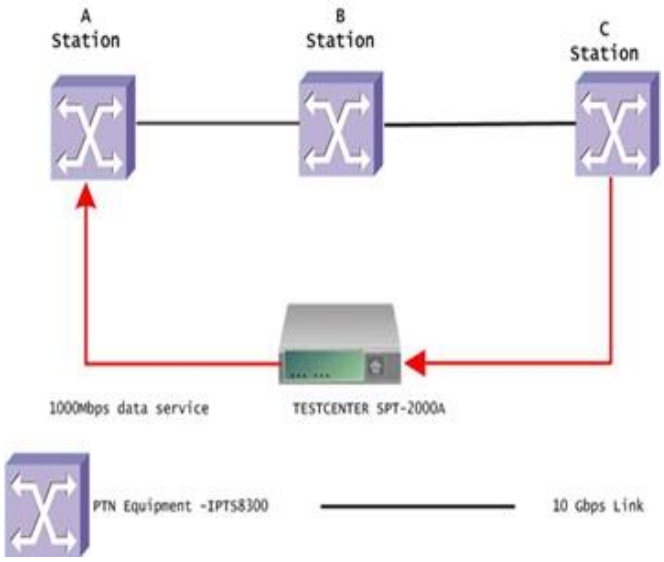

Figure 6. Environment of Delay Testing for Data Service

Table 1. Results of Delay Testing for Data Service

Data Packet Length (B)	Minimum Time Delay (us)	Maximum Time Delay(us)
64	9.72	10.82
128	11.11	12.20
256	12.70	13.61
512	15.69	16.40
1024	21.11	21.93
1518	26.57	27.33

4.3 Analysis on Transmission Delay of TDM Service

PTN adopts an end-to-end pseudo-wire emulation technology (PWE3) to convert the TDM services to packets for further transmission. Because of the service-to-packet conversion, and time delay in PTN network forwarding, the time delay indicators in TDM service is important, especially for key TDM services in relaying in communication network. In order to verify the actual time delay effect of TDM service, an IPTS8300 PTN device is tested by EXPO tester. The test environment is shown in Figure 7.

The service bandwidth is E1 (2 Mbps), with 1000Mbps of low priority background traffic added.

It should be noted that, after packet cutting and pseudo-wire to TDM service traffic, PTN device use constant rate to transmission the data package, in which payload of data package can be set (such as 64, 128 and 256 B). Clearly, the greater the data package payload, the greater the packet delay, *i.e*. the time to capsulate the data package is longer.

For example, for E1 services, the speed is 8000 fps (or 125 s per frame), and the size of 1 frame is 32 B. In packages encapsulation, if the payload size of the data package is set to 128 B, then 1 package can hold four frames TDM services. In order to encapsulate the four frames services, you need to wait for 125 s * 4 = 500 s, in other words, the minimum of 500 s of time delay is in need. Similarly, if the payload size of the encapsulated packet is 64B, then 125 s * 2 = 250 s time delay is in need.

In the experimental environment, different package payload sizes are used for comparison convenience, with time delay results from A to D station as shown in Table 2.

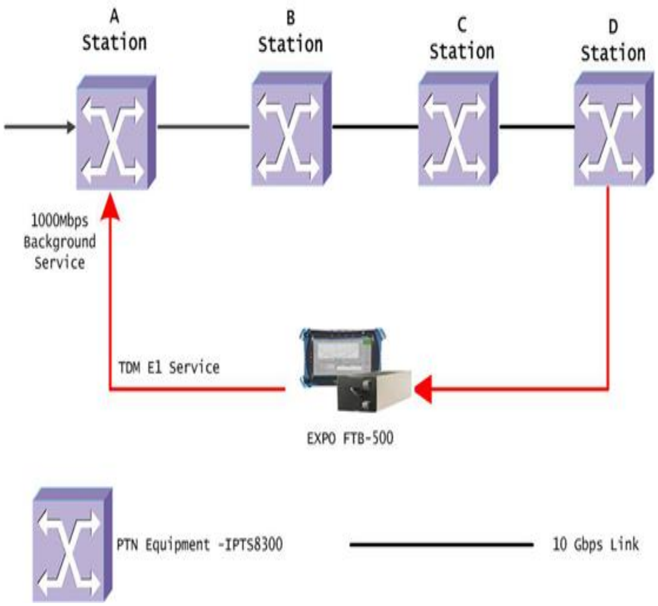

Figure 7. Environment of Delay Testing for TDM Service

Table 2. Results of Delay Testing for TDM E1 Service

Packet payload length of TDM services (B)	E1 Minimum Time Delay (us)	E1 Maximum Time Delay (us)
64	570	1150
128	1570	1940
256	3570	3980
512	7030	7490

As shown in the test results: The smaller the payload of encapsulated packet, the smaller the time delay; Delay is mainly caused by the first and last nodes encapsulation delay, and the intermediate B and C stations are was packets pass-through As described in 2.1, time delay of pass-through station is basically delay is less than 10 s, that is to say, even in circumstances of complex networks and many hops in the transmission path, the time delay caused by pass-through does not account for too much (time delay caused by passing through 10 stations is only about 10 * 10 s = 100 s).

The delay jitter (delay change) here is caused by low-priority background traffic, but its impact on the overall high-priority TDM traffic is small (as shown in Table 2, the difference between the maximum and minimum delay, namely jitter is only about 500 s).

In short, by setting small package payload (such as 64B), the time delay of TDM services in PTN network can reach 1 to 2 ms, even in poor transmission path (namely many hops in between). Provided that the requirement of protective relaying is 5 ms, there are 3 ms left to be used for transmission distance. Based on the transmission delay of 5 s/km, the time delay requirements of protective relaying can be met in the optical transmission network of 600 km.

Under the 100% background traffic, TDM E1 service delay is smaller than 12 ms, which is related to the encapsulation package payload length. Despite the reduction on transmission efficiency by using shorter length of package byte, its impact on light loaded power communication network is small, but the time delay performance is better.

4. Conclusion

This paper analyzes the application of PTN communication technology in electric power communication network, especially the feasibility of PTN technology in wide-area protection. As is seen from the above analysis, through traffic control and route control technology, PTN inherits the high availability, reliability, and high service scheduling mechanism from SDH, and achieve differentiated service in electric power network, which significantly improves data traffic characteristics, raises cache utilization, reduces time delay, and ensures QoS indicators, including service bandwidth and performance. Further, the paper analyzes and evaluates time delay performance indicators of PTN technology for electric power communication services. For Ethernet services, time delay characteristics of PTN is stronger than that of SDH network; while for TDM services, time delay characteristics of PTN is weaker than that of SDH network, but it still can fully meet the transmission performance requirements of protection services. Actually, the integrated performance indicators (including time delay, reliability, network protection, and synchronization) of PTN technology are better than those of SDH technology. Due to limited space, other performance indicators will be evaluated and analyzed in detail in subsequent papers.

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