High-Precision Time Synchronization Network Switch

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Abstract

In power generation and industrial systems, high-precision time synchronization is carried out through a network so that various equipment and units can be synchronized. If an ordinary network switch is applied to the transmission path, however, a rear-end collision delay of a packet may be caused and this delay can greatly affect time synchronization precision. Such a delay is caused by a difference in packet transfer time due to the difference in packet size.

Our industrial gigabit Layer 2 network switch, MEISWAY SW600F, has applied the IEEE 1588v2 (PTP※1) technology. Without affecting the variation in transfer time of the network switch, high-precision time synchronization can be assured. In addition, there is a function to stabilize the network management even in a system where the network data load is relatively high.

1 Preface

Protective relays are required to measure current waveforms simultaneously among multiple substations. When timing control is used on a typical Ethernet line, the timing shifts due to the store-and-forward※2 effect of the switching hub. For this reason, a conventional protective relay system adopts dedicated equipment and a dedicated line by using a cut-through※3 method.

In a protective relay system where a general Ethernet line is applied, a method of bandwidth control may be adopted in order to relieve the effect of Store-and-Forward.

In order to eliminate the effect of Store-and-Forward, it is adequate to adopt the high-precision time synchronization conforming to IEEE 1588v2 (“Precision Time Protocol (PTP)” hereafter). Since the waveform data of protective relays is transmitted in a large volume and in a short period of time, the transmission environment tends to be rigorous compared with an ordinary monitor control system.

To resolve these issues, we developed MEISWAY SW600F (“SW600F” hereafter) as a gigabit Ethernet network switch for protective relays. This paper introduces the major features of SW600F applied to protective relays.

2 Necessity for PTP

2.1 Network Transmission Delay

When the reference clock※4 delivers the time, a machine on receiving side receives the time slightly in the past due to a delay. For this reason, it is necessary for the receiving side to adjust the time by compensating the transmission delay. If the time of transmission delay is unclear, half of the time for both-way transmission of a packet is defined as the transmission delay. Transmit and receive transmission times must be the same for transmission paths other than network switches. If there is a difference, timing may shift as a result of the wrong compensation and will affect the protective relay operation.

The transmission delay time contains a communication line delay and a transfer processing delay by a network switch. In the case of an optical fiber line, the delay is approximately 70% of the light velocity for both sending and receiving, and there is no remarkable difference in the same routing. The transfer time of a network switch differs according to the packet size, but there is no difference for both sending and receiving if the same packet size is used. Fig. 1 shows the comparison of delays due to the packet size. The larger the packet size, the slower the transfer time.

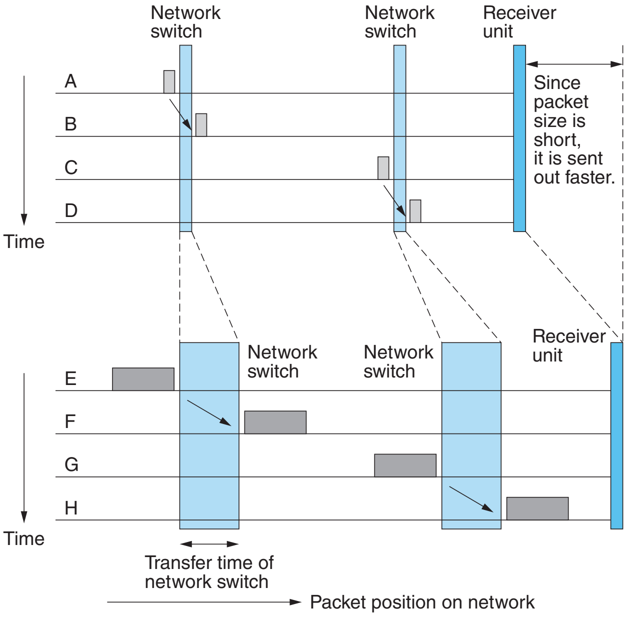

Fig. 1 Comparison of Delays Due to Packet Size

A process is shown when a small packet and a large packet pass through two network switches and are then received. Since the network switch sends out a packet, after it has been received, a larger packet requires a longer transfer time and a delay is caused.

2.2 Effect of Store-and-Forward

The reason the transfer time of a network switch is changed by the packet size results from the effect of Store-and-Forward. When the network switch begins to receive a packet, this packet is stored in the inner memory and the transmission is started after all of the packet is received. Accordingly, a larger packet size requires a longer time for retention in the inner memory, thus extending the transfer time.

When a large-sized packet is received, the network switch begins to transfer the packet from another port. When another small-sized packet is received thereafter, packet transfer is suspended because the larger packet is in the middle of transmission. Since a smaller packet needs a shorter processing time, there can be a phenomenon of rear-end collision while a larger packet is processed. Fig. 2 shows rear-end collision and delay by a small packet.

Such a time difference caused by rear-end collision is substantial. For example, when a 1518 byte※5 packet is sent at a transmission rate of 1 Gbps and another packet of 64 byte is transmitted in succession, a packet-to-packet distance becomes shorter by approximately 12 μs each time a packet passes through a network switch. There is a delay of 12 μs after the occurrence of rear-end collision accordingly.

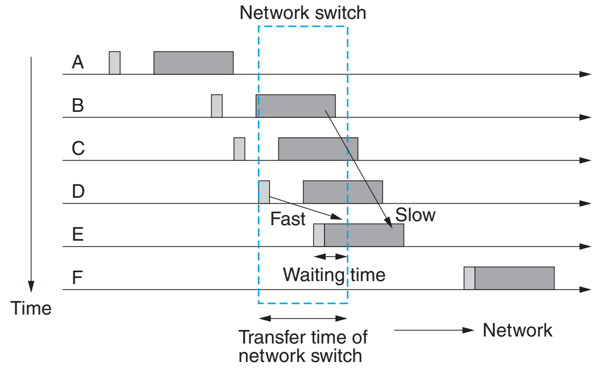

Fig. 2 Rear-End Collision and Delay by a Small Packet

Since the transfer rate of a large packet is low in the network switch, a small packet comes in rear-end collision with the large packet. After, a small packet waits for the completion of large packet transmission every time, and delay time is extended.

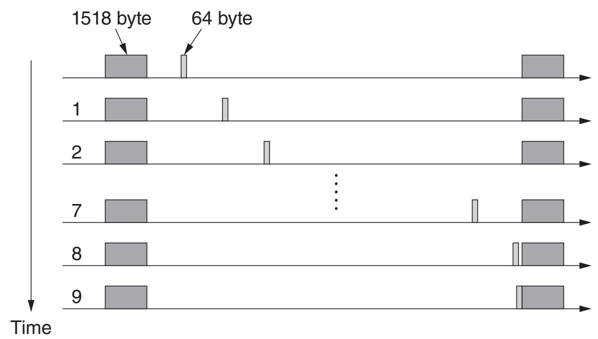

Fig. 3 Delay Caused by Transmission Load and Number of Network Switches

If there is a transfer load, a packet with a small time synchronization comes in rear-end collision with a large one, and an error is generated in the time synchronization. In the case of transmission timing in Fig. 3, a rear-end collision occurs at the 9th packet and a delay is caused at the 10th packet.

Fig. 3 shows a delay caused by a transmission load and the number of network switches. In Fig. 3, a rear-end collision and delay is shown caused when a packet of 64 byte is transmitted under the condition of a 10% load at 1518 byte and 1 Gbps respectively. The distance between packets is long and there is ample allowance in the transmission load. Under such a condition, however, there can be a rear-end collision and delay even though transmission is forwarded at a timing of 64 byte packet. In this case, the delay time amounts to 6 to 121 μs and the time difference is half that at 3 to 61 μs.

In order to reduce such an effect of Store-and-Forward, it is necessary to regulate the packet size, transmission load, and number of network switches.

3 Basic Specifications and Features of SW600F

Table 1 shows the basic specifications of SW600F. **Table 2** shows the environmental conditions. **Table 3** shows the board configuration.

Table 1 Basic Specifications of SW600F

Time synchronization conforms to IEEE 1588v2, and functions of bandwidth control and access list are provided.

Item			Specifications
Switching mode			Store-and-Forward
Switch capacity			13.7 Gbps 2.66 Gbps (For full duplex/ all-port 100 Mbps)
Transmission system			Full duplex/half duplex
Port con-struction (18 ports Max.)	10/100/ 1000BASE-T		16 ports (4 ports are used for combo-board with optical ports)
	Optical ports (4 ports Max.)	1000BASE-LX	Connector used: LC Applicable to Single Mode Fiber (SMF) Applicable to 10 km and long distance (40 km)
Error output terminal			1 contact point
Media Access Control (MAC) address capacity			8000 pcs.
Flow control			IEEE 802.3x (full duplex)・Back pressure (half duplex)
Spanning tree protocol	Support protocol		Improved spanning tree protocol (RTP)
	Network configuration		Loop configuration by optical port
	Processing time for spanning tree protocol		RTP: within 0.5 s for 32 nodes)
VLAN (Virtual Local Area Network)			Tag and port base VLAN conforming to IEEE 802.1Q
Time synchronization			IEEE 1588v2 conformance (EtoE transparency※6) External pulse output, signal output in correct synchronization
Priority control, bandwidth control, and access list			Classification of packets according to IP and port numbers Priority transmission of specified packets, bandwidth control, and destruction are enabled.
Error packet filtering function			Short packet, long packet, Frame Check Sequence (FCS), error packet, symbol error packet
Network control			SNMPv1 (conforming to RFC1157)・MIB II
Network management			telnet・http・ICMP (Internet Control Message Protocol)・IP
Storm control			Broadcast, multicast, and address unlearned packet discarding are enabled.
Serial console			By round connector conforming to EIA/TIA-232-E
Setup save, writing, firmware updating			Via Web (http) or serial port

3.1 Time Synchronization by SW600F

3.1.1 PTP

When the PTP is applied, the transfer time in a network switch is measured and adjusted. Because of this adjustment, time synchronization is never influenced even though a transmission delay should be caused by a packet rear-end collision.

For time synchronization, there are two methods of adjustment: a Point-to-Point (PtoP) adjustment only for two neighboring sections, and an End-to-End (EtoE) adjustment performed by an apparatus installed in the center of the reference clock and terminal unit. In SW600F, a method of EtoE

Table 2 Environmental Conditions

The environmental conditions conform to the Standard of Power Electric Utilities (on Relay) B-402.

Item		Specifications
Type		UT227/＊＊＊A (＊defined by type)
Power source connector		3P terminal board (DC)
Power source voltage range		DC80 V～143 V
Power consumption (in operation)		25 W or below
Operating temperature range (in operation)		−20～55℃
Withstand voltage	Power source primary – FG or SG	AC2000 V for 1 min
Insulation resistance	Power source primary – FG or SG	DC500 V 5 MΩ or above
Power source noise durability		Rectangular impulse noise 2 kV, 50 ns/1 μs
Mass		Approx. 4 kg
External dimensions		W255 × H88 × D250 mm (excluding embossed parts)
Applicable standard		Standard of Power Electric Utilities (on Relay) B-402 (Except for inrush currents)

Table 3 Board Configuration

16 ports of 10/100/1000BASE-T and 2 or 4 optical ports (1000BASE-LX) are installed.

Type	Port configuration classified by type	
	10/100/1000 BASE-T	Optical port (1000BASE-LX)
TYPE 10	16	2 (single mode 10 km) LC connectors, 1 Gbps
TYPE 11	16※1	4 (single mode 10 km) LC connectors, 1 Gbps
TYPE 12	16	2 (single mode 40 km) LC connectors, 1 Gbps
TYPE 13	16※1	4 (single mode 40 km) LC connectors, 1 Gbps

Note. ※1. Since 2 ports out of 16 ports are used as a combo-board with optical ports, they cannot be used at the same time.

adjustment is adopted. Assuming that a 1518 byte packet is a 100% transmission load, the resultant time difference is not more than 1 μs when passage is attempted through ten SW600F units.

3.1.2 External Output of Synchronization Timing

SW600F has a function of outputting a synchronized clock signal at a frequency set at 1 Hz, 50 Hz, 60 Hz, or more. Although SW600F is designed on the assumption that it will be applied to protective relay systems, it can also be synchronized remotely if its external clock signals are connected to any other measuring apparatus or various devices.

3.1.3 Reference Clock

Each remote unit (SW600F) can make time synchronization in relation to the reference clock. This reference clock is an expensive machine generally operated on absolute time of the Coordinated Universal Time (CTU) or Japan Standard Time (JST). In the case of the protective relay systems, it is unnecessary to be synchronized with such a standard time, provided that synchronization of unit to unit timing is secured. The SW600F itself can work as a simplified reference clock. Even when the reference clock is lost because of a failure, other SW600F units can work as a reference clock to succeed in the function.

4 Priority Control, Bandwidth Control, and Access List

For a network of a general monitoring control system, it is necessary to assuredly transmit all information to the destination. Therefore, the application transmits slowly to prevent the packets from being discarded due to lack of internal memory in the hub because of instantaneous transmission load. Alternatively, a software delivery confirmation and retransmission protocol needs to be used.

Waveform data, however, of protective relays are transmitted in a short period and in a large volume and the transmission load is, therefore, high when compared with general monitoring control systems. Transmission check and resending by software are difficult to accomplish in terms of time. Consequently, there is a substantial hindrance in protective functions if a packet entered exceeds the capacity of memory processing in the network switch. Depletion of inner memory will be caused in the network switch for the following reasons:

(1) Difference in I/O transmission rate

For a transfer from a 1 Gbps port to a 100 Mbps port, the inner memory is used for 10 times the capability.

(2) No. of I/O ports

When inputs are entered simultaneously from multiple ports and they are transferred convergently to a single port, the inner memory retention time becomes a total of the respective packet sizes.

(3) Transmission queues due to half duplex and flow control

For the setting of transmission conditions, half-duplex communication or flow control is carried out. When this setting is made, transmission queues are caused. During this period, a received packet is retained in the inner memory.

For protective relays, problems can arise due to the number of ports. Since the inner memory has a small capacity compared with the transmission rate, a depletion of the inner memory may be caused by a momentary high burden. The transfer load is expressed by the amount of data transmitted per second, but the depletion of the inner memory must be addressed for a very short time. Since the waveform data of a protective relay is transmitted periodically, the transfer load is kept constant. In time synchronization, however, transmission timing may be concentrated. For other types of packets, it is also necessary to consider preventing a momentary concentration of loads.

SW600F is provided with three functions described below. By virtue of these functions, the system can be stabilized without disturbing the function of each protective relay.

4.1 Priority Control

The packets to be transmitted are classified into a maximum of eight types. This function is intended to transmit a package that has the highest priority. When time-synchronized packets, waveform data, or such significant packets are preset to have a higher priority, loss and delay of important data can be prevented.

4.2 Bandwidth Control

This function is used to make bandwidth allocation for transmission lines according to the type of a packet. Any packet exceeding the specified bandwidth will be destroyed. Even normal packets like waveform data are also destroyed if they are transmitted in a large volume due to any malfunction.

Since transmission in conjunction with Address Resolution Protocol (ARP) is also limited, the ARP load can be reduced for other equipment and devices.

4.3 Access List

This function is used to transfer only the packets that meet the conditions set in the access list. Unexpected or false communication can be restricted.

5 Postscript

According to the PTP, SW600F can make high precision time synchronization by removing the effect of delay due to Store-and Forward. By virtue of the functions of priority control, bandwidth control, and access list, the network stability can be maintained without disturbing the functions of protective relays.

For ordinary monitoring and control systems, the functions of priority control, bandwidth control, and access list are also available when sending a large volume of data relating to videos, audios, Internet of Things (IoT), and Artificial Intelligence (AI). In addition, the PTP can be extended to other systems where timing control is carried out.

In the future, we will improve its performances of redundancy, stability, and maintainability to better develop our products.

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Notes

※1. Precision Time Protocol (PTP): A communication protocol for high precision time synchronization.
※2. Store-and-Forward: A method of communication after a packet has been captured in an inner memory. The delay time is variable and a broken packet can be discarded.
※3. Cur-through: A method of transmission in a “bit” unit. The delay time is fixed (several bits) and a broken packet cannot be discarded.
※4. Reference clock: A clock to distribute a correct time. In IEEE1588, it is called Grandmaster clock.
※5. 1518 byte: Maximum packet size for the Ethernet (Generally, it is 1518 byte, but it can be modified by various types of setting.)
※6. EtoE transparency: A function to make time synchronization between the last devices. (PtoP transparency is a function to make time synchronization between the neighboring devices.)