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A Synchronization Method for Timing the Network Using Single-TimeSync Frame*

Sunghwan Kang[1], Jungwon Lee[1], Minjun Kim[1],
Sangryul Ryu[2], and Sungho Kim[1]

[1]Department of Computer Engineering, Kyungpook National University
Buk-gu, Daegu, 702-701, Korea
{shkang,jwlee,mjkim}@mmlab.knu.ac.kr, shkim@knu.ac.kr
[2]Department of Computer Science, Chungwoon University
Hongseong-gun, Chungchungnam-do, 350-701, Korea
rsr@chungwoon.ac.kr
http://mmlab.knu.ac.kr

Abstract. Network synchronization is important to time-sensitive applications. Legacy NTP provides the base time to other network devices. Time accuracy gets lower as the stratum goes down, due to jitter/wander. To solve this problem, IEEE 1588 PTP and IEEE 802.1AS were developed. These technologies, however, have problems with too many messages being generated. Therefore, this paper proposes a synchronization method timing the LANs using Single-TimeSync frame. This method is able to reduce network overload caused by too many messages and the processing complexity of the network devices. This methid also has the advantage that does not affect the time accuracy but provides a simple process in each network device. We provide some experimental results on the performance of this method using OPNET.

Key words: Timing and Synchronization, NTP, IEEE 1588 PTP, IEEE 802.1AS, Time-Sensitive Applications

1 Introduction

As multimedia services increase through a network, more service satisfaction can be provided for users. We can already experience Voice Over Internet Protocol (VoIP) and Internet Protocol Television (IPTV), which are various technologies of multimedia services [1][2]. However, current Internet technology has reached its uppermost limits in intercontinental and national services. The Institute of Electrical and Electronics Engineers (IEEE) 802.1 Audio/Video Bridging (AVB) Task Group (TG) has been assembled to overcome these limits [3]. IEEE 802.1 AVB provides new quality of service (QoS) guaranteed networks and supports consumer electronics, Digital Versatile (Video) Disk (DVD), High-Definition Television (HDTV), and High Fidelity (HiFi) Audio, in residential

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areas. Fig. 1 represents the communication between time-sensitive consumer electronics applications in a home network.

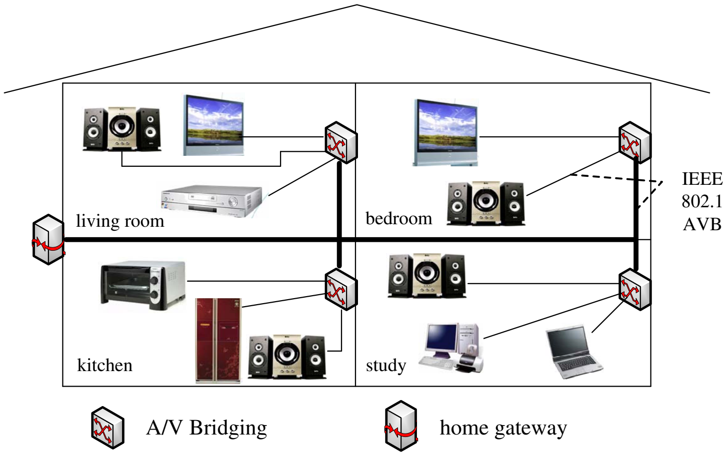

Fig. 1. Communication between time-sensitive consumer electronics applications in home network and the range of IEEE 802.1AVB

Network devices operate the service based on each local clock. Because a local clock of any device is different from another local clock, each time-sensitive application is not synthesize another one. Therefore, every local clock is synchronized with typical local clock (i.e., master clock) in bridged LANs. There are several approaches to network synchronization. Network Time Protocol (NTP) relies on sophisticated mechanisms to access national time, organize time-synchronization subnets, and adjust the local clock in each participating peer [4][5]. IEEE 1588 Precision Time Protocol (PTP) is based on one node transmitting a time synchronization message, followed by another time-synchronization message containing the precise time of the previous time message [6][7].

IEEE 802.1AS enables stations attached to bridged LANs to meet the respective jitter, wander, and time synchronization requirements for time-sensitive applications [8]. IEEE 1588 PTP and IEEE 802.1AS, however, have problems with a lot of unnecessary messages. Therefore, this paper proposes a method of time synchronization for time-sensitive applications using Single-TimeSync frame in bridged LANs. This method is able to reduce network overload by unnecessary messages and processing complexity of the network devices. It also has an advantage in that it does not affect the time accuracy but just provides the required simple process in each network device.

The rest of this paper is organized as follows. In section 2, we deal with a problem caused by the existing methods, NTP, IEEE 1588 PTP, and IEEE 802.1AS. Section 3 presents the proposed method of time synchronization using Single-TimeSync frame. In Section 4, we simulate the performance of the proposed method and compare it with IEEE 1588 PTP and IEEE 802.1AS. Conclusions and future work are described in Section 5.

2 Legacy synchronization methods

In this section, current methods of time synchronization are described. NTP is a legacy time synchronization method which provides hierarchical time accuracy. IEEE 1588 PTP is used for industrial automation systems, and IEEE 802.1AS is used for researching time-sensitive applications in bridged local area networks.

IEEE 802.3 Ethernet sets the synchronization of devices by extracting information about the frame preamble, but with no consideration of jitter/wander [9][10]. Fig. 2 represents an example of transmission delays caused by jitter.

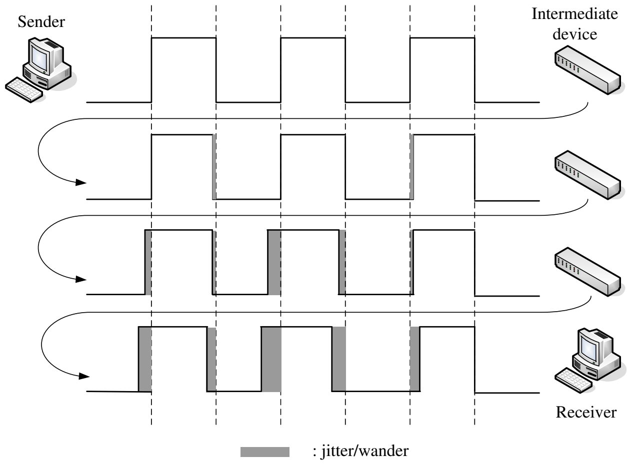

Fig. 2. Small variations in the clock jitter can add up as the clock is retransmitted from one device to the next, resulting in jitter accumulation

The jitter/wander is defined by the Maximum Time Interval Error (MTIE), which is a peak-to-peak phase variation for an observation interval, expressed as a function of the interval length. The peak-to-peak is taken over all possible observation intervals of a given length in the measurement sample [11]. The following Eq. (1) can be used to estimate MTIE from measured or simulated data.

$$MTIE(n\tau_0) = \max_{1 \le k \le N-n} \left(\max_{k \le i \le k+n} x(i) - \min_{k \le i \le k+n} x(i) \right), n = 1, 2, ..., N-1 \quad (1)$$

Here, $x(i)$ is the i^{th} phase offset sample (out of N total samples), τ_0 is the sampling time, $n\tau_0$ is the observation interval. For example, multiple audio tracks from the same program can be transported to speakers in different locations (required synchronization: $\pm 10\mu s$), and voice and corresponding video streams from the same program can be played simultaneously (required synchronization:$\pm 80ms$).

The NTP server provides the base time for other NTP clients. The time client requests the time information from the NTP server and the NTP server responds with its own time information to its time client. The time synchronization equation can therefore be written as Eq. (2).

$$T_2 - t_1 = at_1 + B + \rho(t_1) \tag{2}$$

Here, Let T denote the time measured at the time server clock, and let t denote the time measured at the time client clock. The time client clock frequency offset a is the deviation between the time client crystal oscillator output and the time server reference oscillator, and B is the absolute time offset. $\rho(t)$ is a random delay function. It is an important factor in end-to-end jitter/wander adjustment. IEEE 1588 PTP and IEEE 802.1AS are methods for reducing the $\rho(t)$.

IEEE 1588 PTP defines a protocol enabling precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing and distributed objects. The protocol is applicable to systems communicating via packet networks, and it supports system-wide synchronization accuracy in the sub-microsecond range with minimal network and local clock computing resources. The default behavior of the protocol allows simple systems to be installed and operated without requiring the administrative attention of users [12].

A PTP network has a single Ordinary Clock (OC) Grand Master (GM) with each other OC being a slave of the GM. Another example of these concepts, illustrated in Fig. 3, is a wireless network that is synchronized by a wired network, i.e., one of the wired network nodes contains a wireless Access Point(AP) and a Boundary Clock (BC) and collocated Peer-to-Peer Transparent Clock (P2P TC). The GM is in the wired network[6]. In this example, each wired network node (other than the GM) is a slave of the GM. Each wireless endpoint is a slave of the BC, which is a slave of the GM.

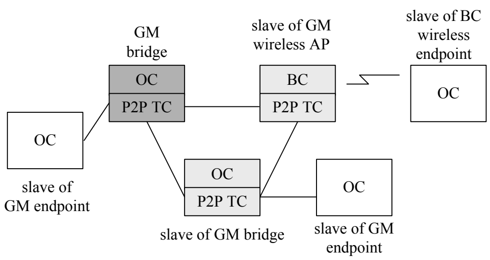

Fig. 3. Illustration of master/slave hierarchy in IEEE 1588 PTP/IEEE 802.1AS network that has both wired and wireless portions

3 Timing and Synchronization Using Sinlg-TimeSync Frame

In the previous section, current methods of timing and synchronization were surveyed. These technologies provide precise time accuracy and effective time adjustment. IEEE 1588 PTP and IEEE 802.1AS, however, have problems where there are a lot of unnecessary messages being generated. Therefore, we propose a method of time synchronization for time-sensitive applications using Single-TimeSync frame in bridged LANs.

This method is able to reduce network overload caused by too many messages and processing complexity of the network devices. This also has an advantage in that it does not affect the time accuracy but just provides the required simple process in each network device. In the method described in this paper, all functions are encapsulated in a Single-TimeSync frame, using the minimal Ethernet frame size. Each device emits these frames at their link-dependent interval as illustrated in Fig. 4.

Within IEEE 802.1AS, a variety of function/direction specific frames are transmitted. IEEE 1588 PTP and IEEE 802.1AS involve seven separate frame transmissions (as opposed to two). For this illustration, we can assume that both master and slave devices desire to calibrate link delays, to minimize topology-change transients.

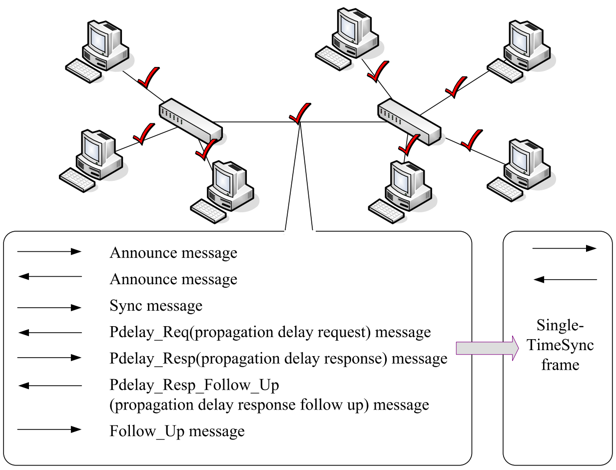

Fig. 4. Within this paper, all functional are encapsulated into a Single-TimeSync frame

In a full-duplex Ethernet model, the Single-TimeSync frame facilitates synchronization of neighboring clock-slave stations. The frame, which is normally sent at 10ms or 100ms intervals, includes time stamp information and the identity of the networkś clock master, as illustrated in Fig. 5. The Single-TimeSync frame consists of four parts, VLAN, distinguishing AVB frames and Single-TimeSync frame from others, grandmaster selection, and timing and synchronization.

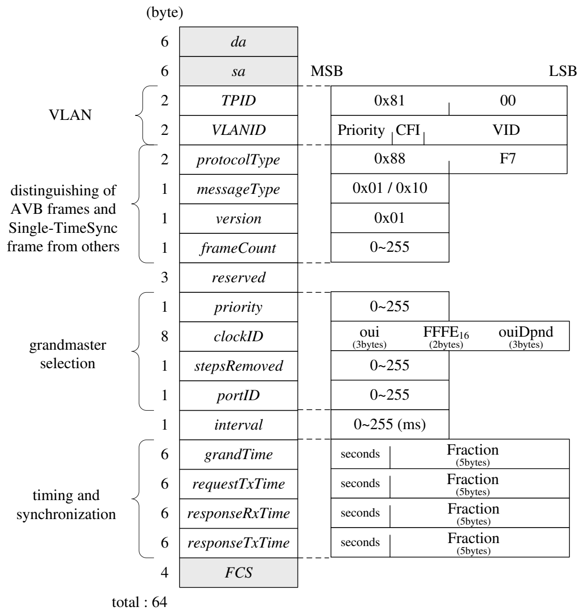

Fig. 5. The proposed frame, Single-TimeSync frame, format is used in Full-duplex Ethernet model

3.1 Single-TimeSync Frame Format

IEEE 802.1AS is considered to have a VLAN topology. Therefore the Single-TimeSync frame has the *TPID*, *VLANID*. *TPID* is a constant parameter, 0x8100. *VLANID* consists of *Priority* (7), *CFI* (0) and *VID* (variable). For distinguishing AVB frames and the Single-TimeSync frame from others, *protocolType* (0x88F7), *messageType* (0x01 or 0x10), *version* (0x01), and *frameCount* (0∼255) fields are used. The constant *protocolType* is introduced because it was raised in the July, 2007 AVB TG meeting. This *protocolType* is used for all AVB messages. The *messageType*, 0x01, is used for grandmaster selection and the *messgeType*, 0x10, is used for time adjustment or link delay measurement. The version field that identifies the version number is associated with the fields that follow it. The *frameCount* field is incremented on a one-by-one basis between successive Single-TimeSync frame transmissions.

For grandmaster selection, *priority* (0∼255), *clockID* (oui, FFFE16, ouiDependent), *stepsRemoved*, *portID* fields are used. The *priority* field can be configured by the user. The *clockID* field, a globally-unique field, ensures a unique precedence value for each potential grandmaster, should the priority field have the same value. The *oui* (organizationally unique identifier) field of the *clockID* field is supplied by the IEEE/RAC for the purpose of identifying the organization supplying the 24-bit *ouiDependent* field, which is supplied by the oui-specified organization. The concatenation of the *oui* and dependentID provides a unique identifier. The *stepsRemoved* field represents the number of hops from the grandmaster. This eliminates an ambiguous path from the grandmaster to intermediate bridge ports. The *portID* field is the unique value in bridge. It is used for the port state decision.

For timing and synchronization, *grandTime*, *requestTxTime*, *responseRxTime*, and *responseTxTime* fields are used. The *grandTime* field specifies grandmaster synchronized time. The *requestTxTime* field specifies the local free-running time within the source station, when the previous Single-TimeSync frame has been transmitted on the opposing link. The *responseRxTime* specifies the local free-running time within the target station, when the previous Single-TimeSync frame was received on the opposing link. The *responseTxTime* specifies the local free-running time within the neighbor station, when the previous Single-TimeSync frame has been transmitted on the incoming link.

3.2 Grandmaster Selection Algorithm

The grandmaster selection algorithm compares fields describing two clocks, contained in respective Single-TimeSync frames sent by those clocks, to determine which node has priority. This algorithm is used to determine which of the clocks is the best clock. It is also used to determine whether a newly discovered clock, referred to as a foreign master, is better than the local clock itself. Each port of an ordinary clock maintains a separate copy of the port state (MASTER or SLAVE state).

The timing information of the Single-TimeSync frame is exchanged with the *priority*, *clockID*, *stepsRemoved*, and *portID*. The grandmaster selection algorithm uses these for grandmaster selection. The grandmaster selection algorithm is presented in Fig. 6. When an AVB network is set up, all AVB devices transmit the Single-TimeSync frame. Each device compares itself to these fields. If the *priority* field value of the sender is smaller than the priority of the receiver, and the *clockID* field value of the sender greater than the *clockID* of the receiver, the port state of the receiver is decided to be the MASTER state. Otherwise, the port state of the receiver is decided to be the SLAVE state. While in the SLAVE state, when this endpoint does not receive the event from the Single-TimeSync frame three times, all AVB devices transmit the Single-TimeSync frame. When a new device is added, this device transmits the Single-TimeSync frame and checks the grandmaster selection conditions.

In the case of the device being a bridge containing multiple ports, the grandmaster selection algorithm makes comparisons with additional conditions. The *stepsRemoved* field is incremented by each bridge and thus represents the distance from the grandmaster. When the bridge works SLAVE, this bridge has one SLAVE port and a lot of MASTER ports. Therefore, a port is necessary decided

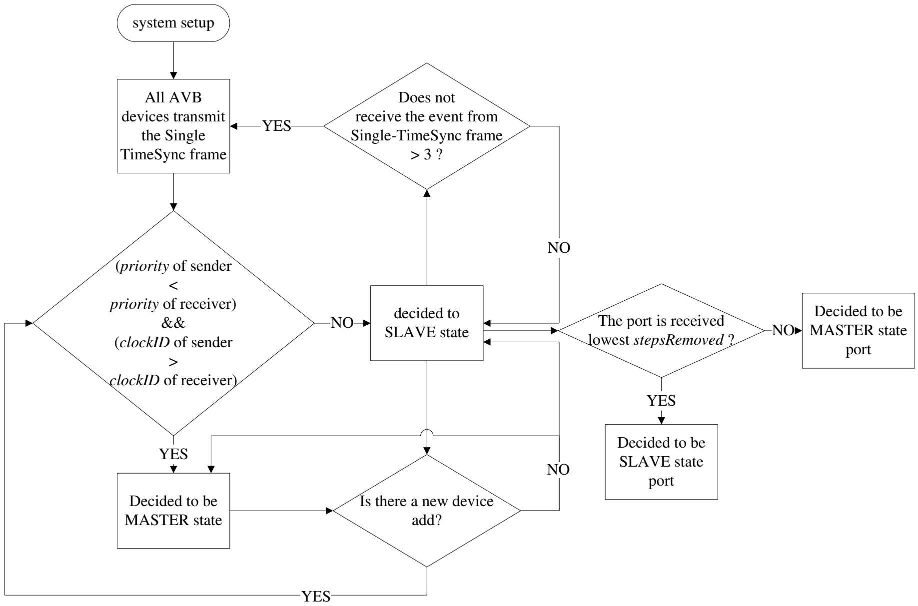

Fig. 6. Flow chart of the grandmaster selection algorithm in the case where the end-point contains a single port

port state for each other works. When the port is received lowest *stepsRemoved* from grandmaster, this port is decided to SLAVE state port. Otherwise other ports are decided to MASTER state port.

3.3 Synchronizing The Clocks

The 802.1AS provides mechanisms for conveying time stamps generated at the sources of Single-TimeSync fames along with any corrections needed to ensure that the recipient of the Single-TimeSync frames receives the most accurate time stamp possible. The actual distribution of the time information between the *grandTime* or baseTime and time stamp fields is implementation-dependent, provided the distribution is such that a receiving device performs the computations on time stamp fields and obtains the most accurate time stamp possible.

Synchronization accuracy is affected by transmission delays, and the receive port is responsible for compensating grandTime, baseTime affiliations by frame-transmission delay. The clock-slave entity uses the computed cable-delay measurement and is therefore responsible for initiating such measurement. Cable-delay measurements begin with the transmission of frame F1 between the clock-slave and clock-master nodes and conclude with the clock-master response, a transmission of frame F2 between the clock-master to clock-slave nodes, as illustrated in Fig. 7. Based on the preceding listed values, Eq. (3) defines the computations for computing mean_propagation_delay. Although not explicitly

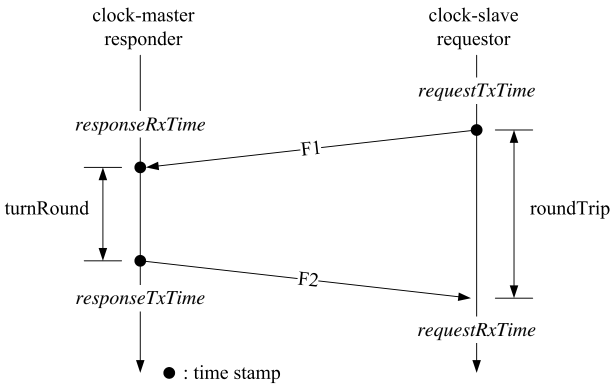

Fig. 7. Link-delay compensation between clock-master and clock-slave

stated, the best accuracy can be achieved by performing this computation every cycle.

$$mean\_propagation\_delay = (roundTrip - turnRound)/2 \quad (3)$$

Where, *roundTrip* = *requestRxTime* - *requestTxTime* and *turnRound* = *responseTxTime* - *responseRxTime.*

4 Experimental Results

We experimented with comparison simulations between NTP, IEEE 1588 PTP, IEEE 802.1AS, and Sing-TimeSync using OPNET simulator. A simulation project model is illustrated in Fig. 8. OPNET can create a network environment very similar to that of the real network. A network scale used in simulation is an 'office network (100mX100m)' that provided by OPNET default scenario model. That can assume that a scale of home network in a real network environment. A node model which includes the TimeSync module is an OPNET standard model, ethernet_station_adv. An ethernet_station_adv-compatible bridge model is used which is compatible with the standard MAC. The AVB network is able to have 100Mbps or greater speed links. We have to satisfy the synchronization accuracy in 1ms over 7 hops and accumulate simulation results every 100 values and choose the maximum value. A delay is applied to distance based [13].

In our simulation the numbers of control frames were reduced when using the Single-TimeSync frame. The numbers of control frames are 47% decreased using the Single-TimeSync frame when compared to IEEE 802.1AS. The message count vs. simulation time is represented in Fig. 9. According to this graph, the proposed method uses only a few control messages in comparison to IEEE 802.1AS. Therefore, it has the advantage of decreasing messages while not affecting time accuracy.

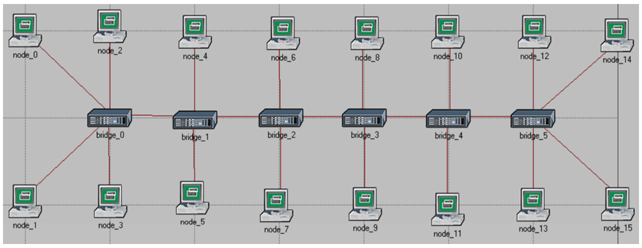

Fig. 8. A baseline scenario of a simulation project model

We tested the end-to-end delay vs. hop count when GM is selected (Fig. 10) and time is synchronized (Fig. 11). In comparison to GM selection, because three methods are using only one message for GM selection, the end-to-end delays do not have any effect In comparison to time synchronization, because the existing methods are using too many messages, the end-to-end delay differences are sufficiently observable. The proposed method, however, has lower end-to-end delay because of using just one frame. The proposed method also has advantages in processing complexity, due to a simple processing mechanism in every device (endpoints and intermediate bridges).

We simulated time variation in the farthest node from the grandmaster if the end nodes keep time accuracy in it. The time variation of the node, which has the maximum hop count, is represented in Fig. 12. The NTP has a wide range of fluctuation because it does not calculate link delay. IEEE 802.1AS and the Single-TimeSync frame, however, have a narrow range of fluctuation because of the peer-to-peer link delay measurement mechanism. We can also observe that the Single-TimeSync frame has a lower fluctuation than IEEE 802.1AS. Therefore, the proposed method has the advantage of decreasing processing time in each node while not effecting the time variation.

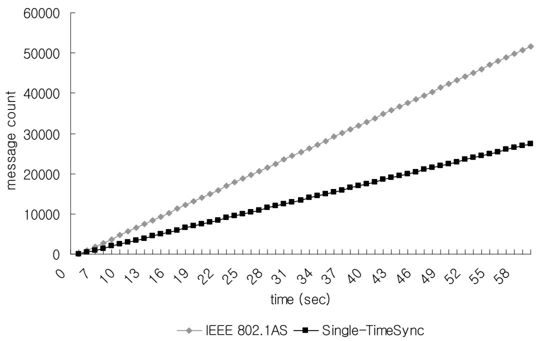

Fig. 9. The number of control frame of IEEE 802.1AS and proposed method

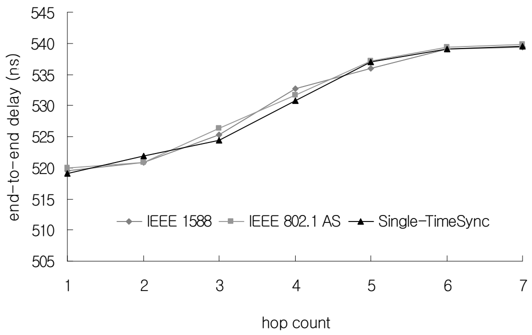

Fig. 10. A comparison of three methods when GM is selected

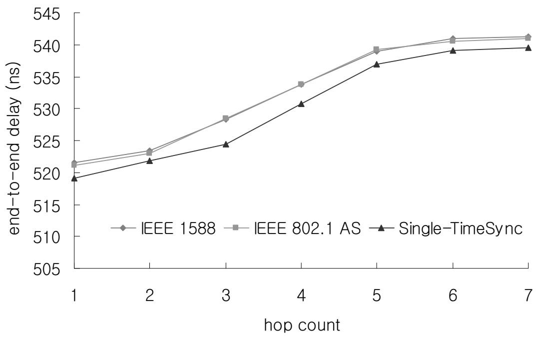

Fig. 11. A comparison of three methods when time is synchronized

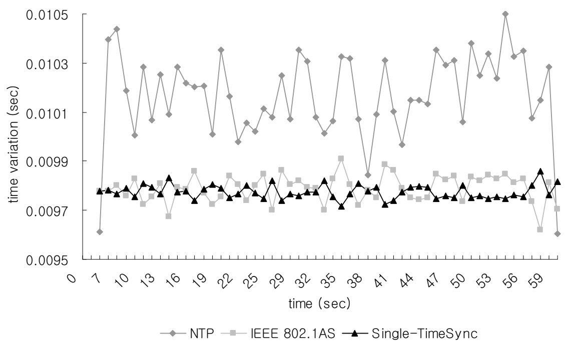

Fig. 12. Time variation of NTP, IEEE 802.1AS and Single-TimeSync

5 Conclusions

Time and frequency alignment is critical for ensuring QoS for applications such as voice, real-time video, wireless hand-off, and data over a converged access medium. NTP does not support precise synchronization in real-time devices due to considerations of jitter/wander. IEEE 1588 PTP and IEEE 802.1AS support real-time applications but have too many messages and high processing complexity of network devices in bridged LANs. Therefore, we have proposed a method of time synchronization for time-sensitive applications using a Single-TimeSync frame in bridged LANs. This method is able to reduce network overload from too many messages and processing complexity of network devices. It also has an advantage in that it does affect time accuracy but just provides a simple process in each network device. The proposed method is restricted to LANs. More research, however, is needed for time synchronization over the core network. We are researching with ITU-T G.8261/Y.1361 (G.pactiming) technology for the whole network environment.

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