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Road and Rail Infrastructure V

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PERFORMANCE EVALUATION OF A PRECISE TIME SYNCHRONIZATION TECHNOLOGY FOR TRAINS

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Abstract

The next-generation railway network based on IEC 61375-3-4 Ethernet Consist Network (ECN) can use RFC 1305 network time protocol (NTP) for time synchronization. In an ideal case of no congestion in the local network, the time synchronization error of NTP is up to 1 ms; however, when the network experiences congestion, an error of more than 100 ms occurs. For a high-speed control of vehicles, a more precise time synchronization technology that can reduce the time synchronization error to a few microseconds is desired. In this study, we implement a precise time protocol for multiple trains connected by multi-stage ECN switches. We also evaluate its performance.

1 Introduction

With the advancement of railway technology, the speed of the railway vehicle is rapidly increasing. For high-speed operation, most of the parts of the vehicle are interconnected through networking and high-capacity data are exchanged at a high speed. Currently, railway vehicles are developed on the X-by-wire technology. However, the wire cannot achieve a speed of even 1 Mb/s. In Korea, the communication interface for railway cars uses RS-485, which can achieve a speed of several tens of kb/s. However, since a point-to-point connection structure is used, there is a disadvantage that the cable connection expands exponentially as the number of parts to be connected increases. To overcome these problems, 100 Mb/s Ethernet technology has been established as the next-generation communication interface for railway vehicles. Although the Ethernet Consist Network (ECN) was established in 2014 according to the IEC 61375-3-4 standard, the research and development in this technology is still in progress in Korea. In the application of ECN to railway cars, Ethernet quality of service (QoS) is an important issue to be considered. Fortunately, IEC 61375-3-5 defines a method for evaluating QoS. However, the problem of time synchronization between devices dispersed in a vehicle is yet to be considered. In this study, we implemented a time synchronization system that considers a multi-stage network environment in which several vehicles are connected and we measured its performance.

2 Time synchronization

A railway vehicle consists of several vehicles. The data communication network for the vehicles is called a consist network, which has terminals of each vehicle connected. The entire network of the vehicle is connected to the backbone. Figure 1 shows an example of a switch-based network. Here, the physical configuration of the network can have a ring-shaped or a ladder-shaped structure to provide redundancy. In addition, to prevent a broadcast storm, a logical spanning tree protocol is used.

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The IEC 61375-3-4 ECN standard specifies the conditional use of the network time protocol (NTP) for time synchronization. The NTP has a visual error of several milliseconds even in a congested state; when network congestion occurs, its synchronization performance can reduce to 100 ms. This is not suitable for use for inter-terminal time synchronization in a system that needs to process high-speed control. A better technique than the NTP is required for all terminals in the vehicle to synchronize within a more precise time. The IEEE 1588 precise time protocol (PTP) is suitable for this purpose because it can provide a high visual synchronization performance with a visual error of only several microseconds. The IEEE 1588 PTP is also used as a core protocol in audio/video bridging (AVB) for automotive as well as general IT. Figure 2 below shows the time synchronization method using the IEEE 1588 PTP. The time information of each terminal is exchanged; the time difference (offset) is calculated by considering the propagation delay time and the time is readjusted.
Because the railway car structure consists of a long connection of nodes, there is a large difference between the frame transmission delay between two adjacent vehicles and that between adjacent vehicles that are farther from the source. Figure 3 illustrates this concept.

![Figure 3 Accumulation of frame transmission delays.](image)

If the frame is delivered by the store-and-forward method, the transmission delay between adjacent vehicles is 6.4 µs, including the preamble and the inter-frame space. In the case of a 64-byte frame, the delay is 57.6 µs because store-and-forward needs to be performed nine times. Assuming the worst case of a nonlinear Ethernet, i.e., where 1522 bytes of frames arriving first in all vehicles are to be transmitted, the maximum delay at both end terminals is 1.17 ms. Therefore, even in the worst case, the terminals of all vehicles can ideally receive the message within 1.17 ms.

However, this system is not suitable for high-speed vehicle control systems if all vehicles receive data within a few milliseconds and the time synchronization between terminals differs by several milliseconds. For a transmission delay of several milliseconds, the synchronization time difference between the terminals should be smaller than this. In other words, a visual difference of several microseconds is desired. For this purpose, the IEEE 1588 precision time synchronization protocol is required. For high-speed time synchronization, the system configuration should be developed by considering a small delay. While the time synchronization protocol message is implemented in the software layer as shown in the illustration on the left side of Figure 4, the PHY module should be updated immediately before frame transmission.

3 Implementation

Figure 4 shows the board developed for the measurement of the time synchronization performance of a multi-stage structure. The board consists of STM32F407 as a main processor and LAN9355 as a switching fabric. The PTP software module runs on the main processor. The switching fabric carries the PTP packets and updates the timestamp field of PTP packets whenever a packet arrives at it.

In consideration of the railway vehicle environment, six boards are connected as shown in Figure 5. To realize multi-stage time synchronization, it is necessary to relay the time synchronization function in the middle. The device should be capable of serving both master and slave roles, which is called the boundary clock (BC). The BC operates as a slave for the upper master clock and as a master for the lower slave, as shown in Figure 6. In a railway car, the TCMS head unit becomes the grand master clock and the ECN switches become BCs to process the time synchronization packets. Therefore, all devices can function at the same time and the car can be controlled more precisely.
Figure 4  Hardware module of the developed high-speed time synchronization system.

Figure 5  Experimental environment with six devices connected.
4 Results

Figure 7 shows the time synchronization results between the two devices. The pulse-per-second (PPS) between the two systems is compared using a two-channel oscilloscope. It can be seen that the PPS of the slave clock is within 100 ns, on the basis of the PPS of the master clock. In a multi-stage network, the PPS of the slave clock is within 20 µs, on the basis of the PPS of the master clock.
5 Conclusion

In Korea, since the ECN technology is not yet applied to railway vehicles, discussion on precise time synchronization technology is premature. However, because ECN is a very important platform for data transmission between parts of railway vehicles, before its implementation in railway vehicles, proper structure and function definitions must be established to avoid the compatibility and standardization difficulties that are currently experienced in railway vehicles. In this paper, we introduced a precise time synchronization technology, proposed the necessary configuration to implement it, and demonstrated the results.

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