CETRA²⁰¹⁸

5ᵗʰ International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering
Prof. emer. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. emer. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
Assist. Prof. Maja Ahac
Assist. Prof. Saša Ahac
Assist. Prof. Ivo Haladin
Assist. Prof. Josipa Domitrović
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan

Prof. Rudolf Eger
Prof. Kenneth Gavin
Prof. Janusz Madejski
Prof. Nencho Nenov
Prof. Andrei Petriaev
Prof. Otto Plašek
Assist. Prof. Andreas Schoebel
Prof. Adam Szeląg
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics

Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

PERFORMANCE EVALUATION OF A PRECISE TIME SYNCHRONIZATION TECHNOLOGY FOR TRAINS

Pusik Park[1, 2], Jeongdo Lee[1], Jongho Yoon[2]
[1] *Korea Electronics Technology Institute, Republic of Korea*
[2] *Korea Aerospace University, Republic of Korea*

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.
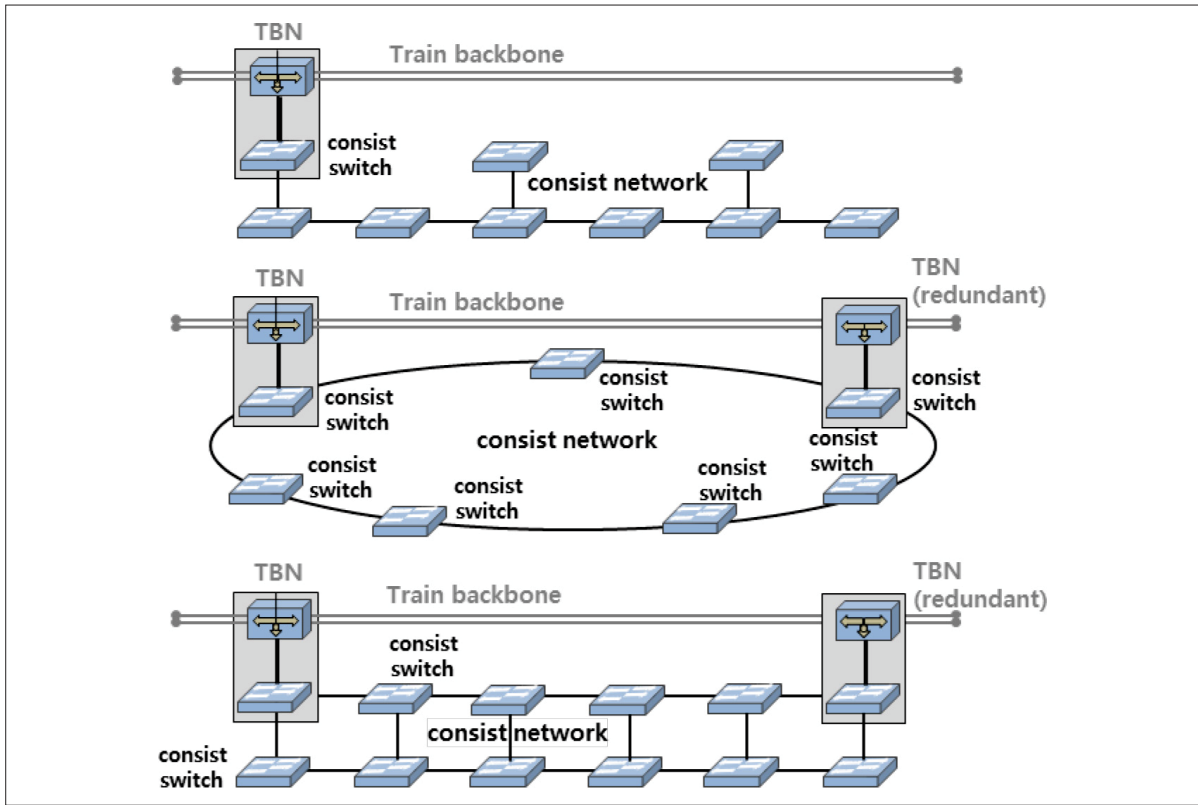
Figure 1   Ethernet consist network.

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.
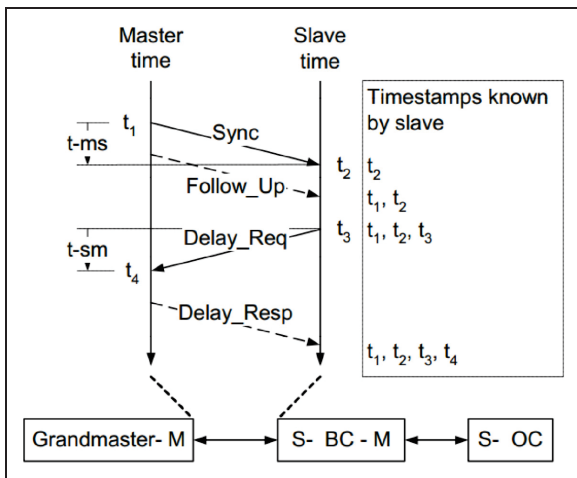

Figure 2   IEEE 1588 PTP time synchronization.

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.
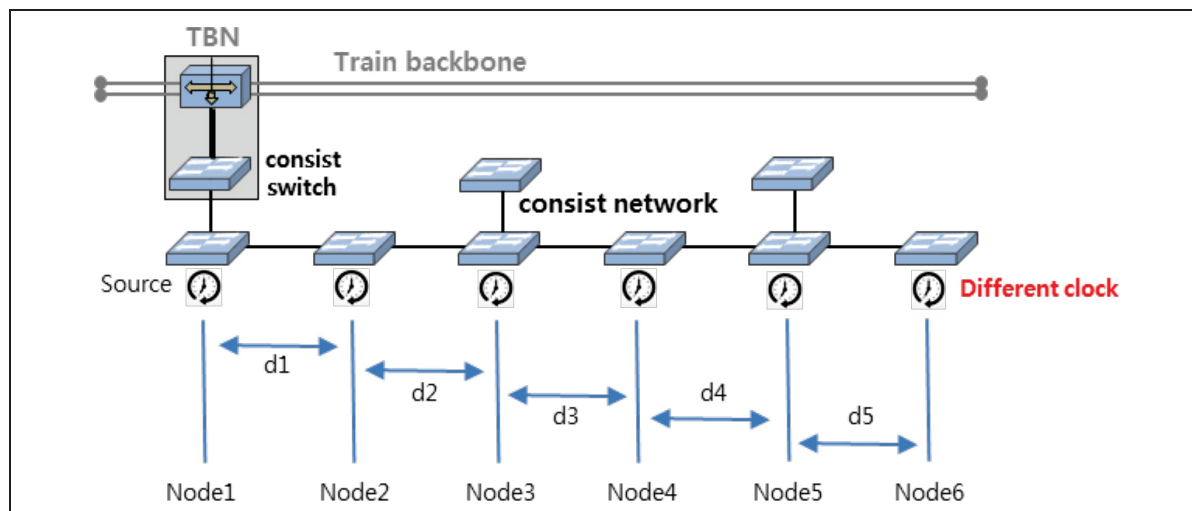

Figure 3   Accumulation of frame transmission delays.

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.
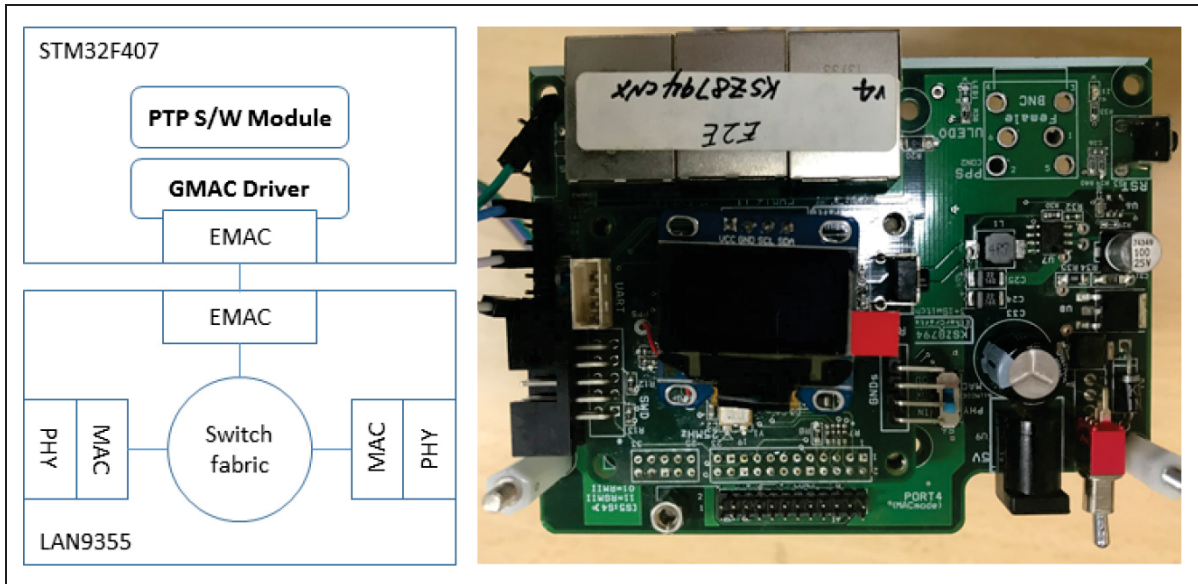
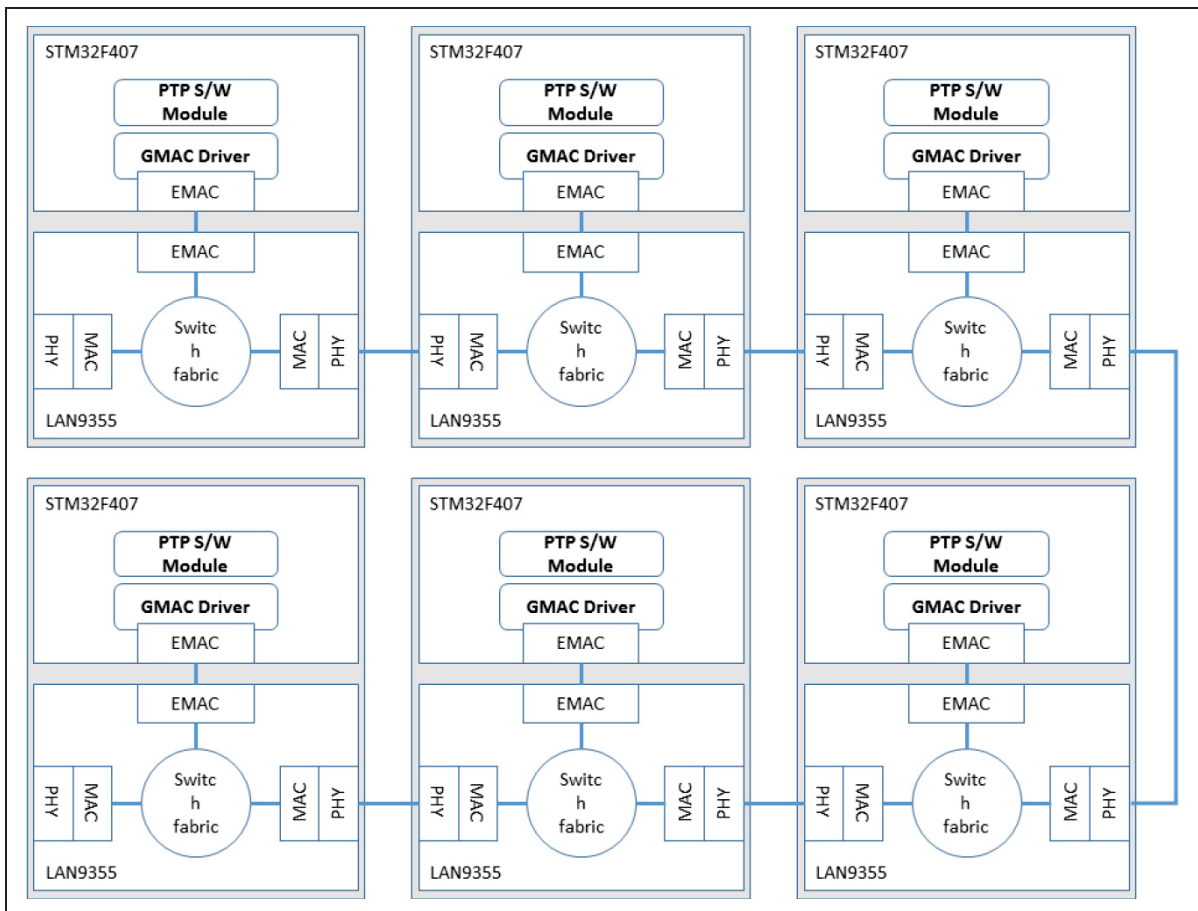**Figure 4** Hardware module of the developed high-speed time synchronization system.

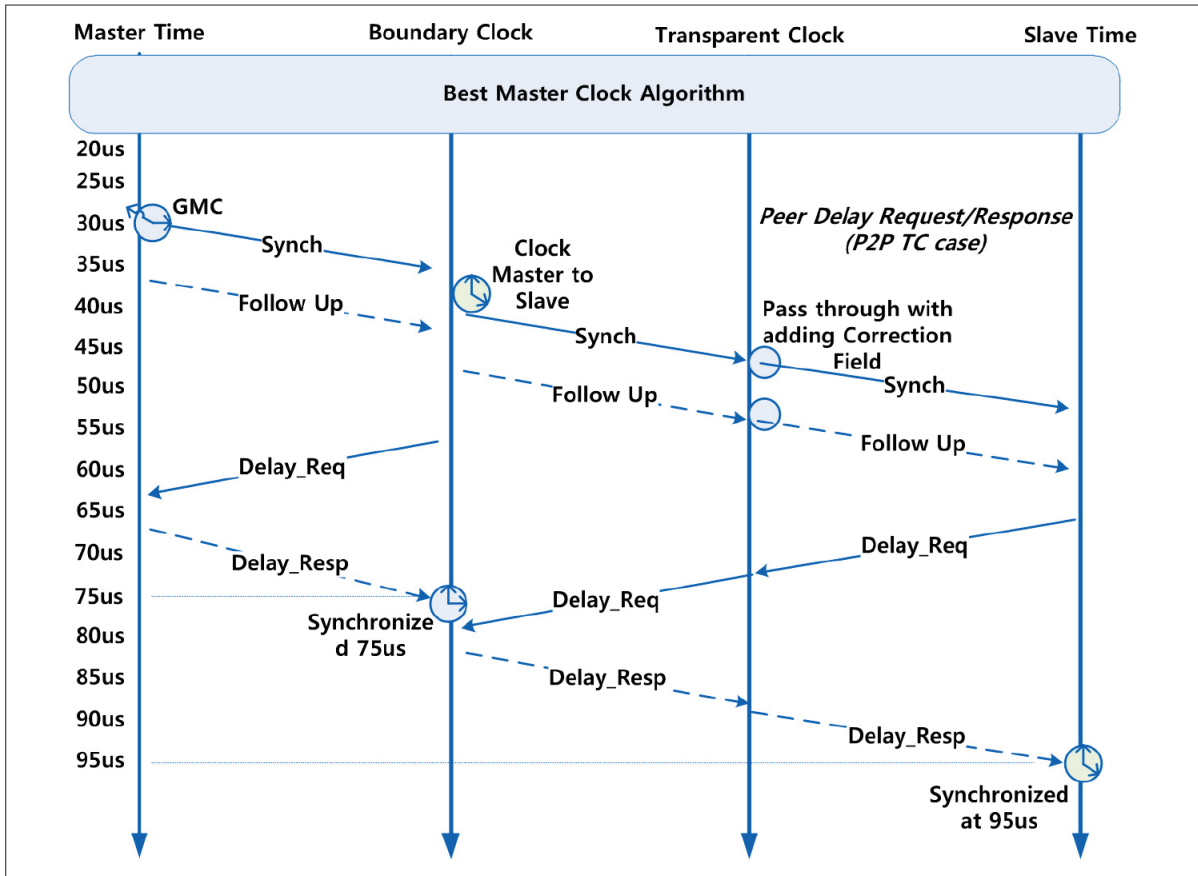**Figure 5** Experimental environment with six devices connected.

Figure 6   Time synchronization on a multi-stage network.

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.
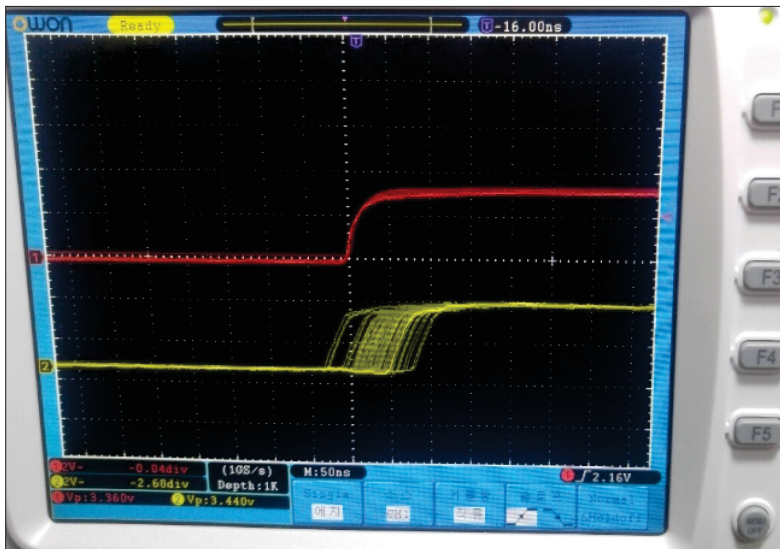

Figure 7   The pulse-per-second of the PTP system measured by an oscilloscope.

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.

Acknowledgement

References

[1] Neil, G.: On board train control and monitoring systems, IET, pp. 1-27, Nov. 2014.

[2] Val, I., Arriola, A., Rodriguez, P. M., Gonzalez-Plaza, A., Alonso, D., Zhang, L., Briso, C., Moreno, J., Sánchez, C. R., Echeverria, E., Goikoetxea, J.: Wireless channel measurements and modeling for TCMS communications in metro environments, 11th European Conference on Antennas and Propagation, pp. 108-112, March 2017.

[3] Yan, L., Fang, X.: Reliable transmission schemes for train control information in high-speed railway, 6th Int. Workshop on Signal Design and Its Applications in Communications, pp. 150-153, Oct. 2013.

[4] Song, Q., Song, Y.: Data-Based Fault-Tolerant Control of High-Speed Trains With Traction/Braking Notch Nonlinearities and Actuator Failures, IEEE Trans. On Neural Networks, 22 (12), pp. 2250-2261, Dec. 2011.

[5] IEC 61375-1 Ed. 3.0, Train communication network – Part 1. General architecture.

[6] IEC 61375-3-4 Ed. 1.0, Train communication network – Part 3-4. Ethernet Consist Network (ECN).

[7] IEEE 1588-2008: Standard for a precision clock synchronization protocol for networked measurement and control systems, Jul. 2008.