Time Synchronization of Plural Roadside Units in 700 MHz Band Intelligent Transport Systems

Masaya YAMADA*, Hideaki SHIRANAGA, Hirofumi URAYAMA and Fumiya SAITO

The intelligent transport system (ITS) using the 700 MHz band accommodates both road-to-vehicle communications (RVC) and inter-vehicle communications (IVC) with a single channel by assigning different transmission time periods for each roadside unit (RSU) and on-board equipment (OBE). As each RSU sends its transmission timestamps and related data (RSU slots) to OBE nearby, each RSU needs to maintain accurate time synchronization for efficient and stable time division control. This paper investigates the causes and effects of the degradation of RSU synchronization and presents a potential solution in simulation and field tests.

Keywords: 700 MHz band intelligent transport system, roadside-to-vehicle communication, time synchronization technology

1. Introduction

In an effort to create a safe road traffic society, a driving safety support system is currently being studied. This system enables the transport infrastructure and vehicles to exchange information through roadside-to-vehicle communication, thereby supporting driving safety for vehicles based on the above information. Communication systems using the 700 MHz band were institutionalized in December 2011 as "the 700 MHz Band Intelligent Transport System (ITS)," and the installation of these systems at an early date is expected. A 700 MHz radio wave is suitable as a roadside-to-vehicle communication medium since this wave is relatively insusceptible to road traffic signs and other shields.

This paper discusses inter-base-station synchronization technology. This technology controls the transmission timing of roadside units (RSUs) with high accuracy and is indispensable for putting 700 MHz ITS into practice.

2. Method for Communication by 700 MHz ITS Communication System

A 700 MHz ITS communication system enables both roadside-to-vehicle communication and inter-vehicle communication on a single-frequency channel. Each RSU is preliminarily allocated with a specific transmission period (RSU*1 slot) so that nearby RSUs will not interfere with each other. Each on-board equipment (OBE) uses the remaining time for transmission (packet transmission) according to the Carrier Sense Multiple Access (CSMA)*2 protocol. A maximum of 16 RSU slots can be set within the transmission period of 100 ms. Each RSU transmits transmission period information (slot start/end and other time information) together with data to surrounding OBEs, while each OBE knows the transmittable period based on the transmission period from the RSU. Each RSU needs to transmit at the most correct timing possible within the allotted RSU slot. To this purpose, the RSU generally uses the reference signal (local clock) of a built-in crystal oscillator or other appropriate device to create the internal time information necessary for determining the transmission timing of the RSU itself. For example, a counter circuit can measure 1 second when it counts 1 MHz local clock one million times. The count value obtained from the counter circuit makes it possible to count the timing at a resolution of 1 μs. However, in this case, the transmission timing of the RSU depends on the frequency accuracy of the local clock inside the unit.

Let's assume that two or more RSUs, namely, RSUs 1 and 2, are located close to each other and the transmission period information from these RSUs has a large time error as shown in **Fig. 1**. In this example, OBE 1 calculates its transmittable time from the transmission period information of RSU 1 and transmits its packet. However, this packet transmission may make a temporal collision and interfere with the RSU slot of RSU 2, which is slightly time-shifted from the RSU slot of RSU 1. On a crowded road in an urban area, in particular, more OBEs will transmit packets and cause frequent packet interferences with the RSU slots.

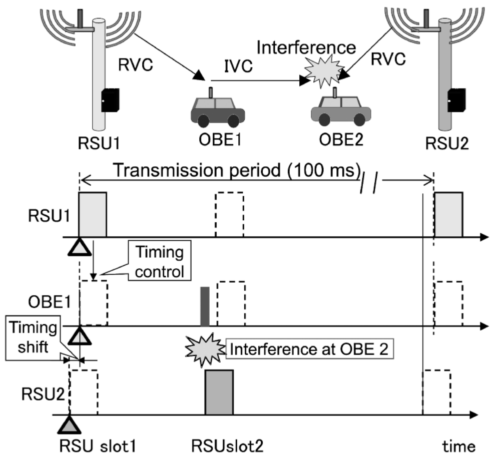


Fig. 1. Example in which the transmission period information of each RSU has a large error

The Association of Radio Industries and Businesses has established a standard[1] to prevent such interferences by requiring each RSU to maintain a time-synchronization accuracy of 16 μs (microseconds) or less. To meet the above requirement, it is essential to develop a high accuracy time synchronization technology that can minimize the time error of the transmission period information between RSUs.

There are two typical types of generally known time synchronization systems: GPS synchronization and over-the-air synchronization. As shown in **Fig. 2**, the GPS synchronization system conducts time synchronization using signals that can be received from a GPS receiver at one-second intervals (1PPS), while the over-the-air synchronization system corrects the synchronization time information of an RSU using the transmission period information from a nearby RSU.

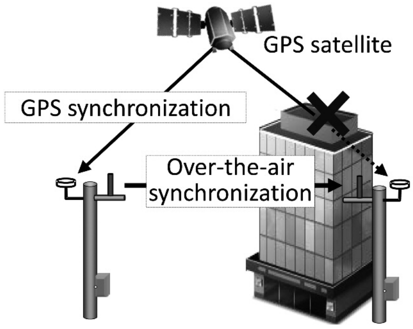


Fig. 2. Time-synchronization methods

3. GPS Synchronization and Associated Problems

An example of an internal operation for GPS synchronization is shown in **Fig. 3**. In this example, two RSUs (RSUs 1 and 2) synchronize with each other after correcting their own counter value by using the rising edge timing of 1pps.

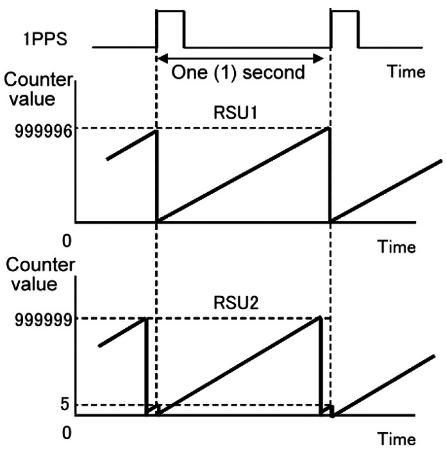


Fig. 3. Example of internal operation for GPS synchronization

In this example, the local clock frequency of RSU 1 is lower by 3 ppm than the reference, while that of RSU 2 is higher by 6 ppm than the reference. As a result, RSU 1 produces the rising edge of 1 PPS immediately after the counter counts 999.996 and sets the counter value to 0. On the other hand, RSU 2 reduces the counter value from 999.999 to 0 and then resets the counter value to 0 at the rising edge of 1 PPS when the value further increases to 5. As described above, the GPS synchronization system can equalize the counter values of RSUs immediately after the rising edge of 1 PPS. However, if the accuracies of local clock frequency of two RSUs are +20 ppm and -20 ppm, a maximum difference of 40 μs may be produced between them immediately before the rising edge of 1 PPS.

3-1 Counter correction mechanism

Use of a high-accuracy oscillator in each RSU to solve the above-discussed problem intrinsic to GPS synchronization increases system cost. As an alternative, we have developed a counter correction mechanism that can minimize the time error even when the local clock accuracy is relatively low. **Figure 4** shows an example of a counter correction mechanism. The correction mechanism of this example uses the difference between the counter value in 1 second and the reference count value obtained from 1 PPS to adjust the counter value of the counter circuit and thus correct the time error.

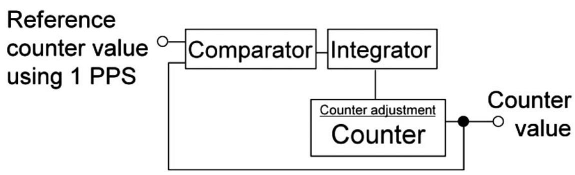


Fig. 4. Counter correction mechanism (example)

An example of the demonstration test results for the performance of the counter correction mechanism is shown in **Fig. 5**. When no counter correction mechanism was used, the time synchronization error between RSUs fluctuated at a period of 1 second. The reason was that the

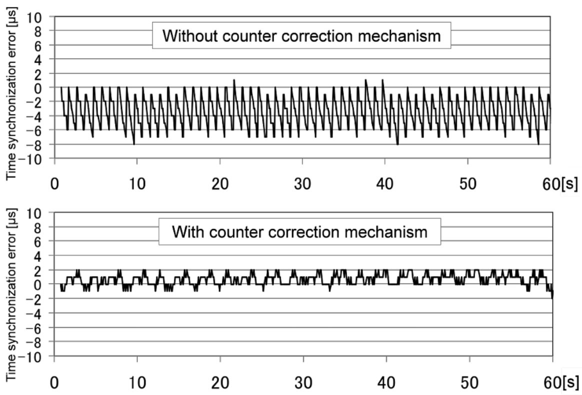


Fig. 5. Effect of counter correction mechanism

error was reset at the rising edge timing of 1 PPS as discussed above, and then the error was accumulated while the counter value of each RSU was counted by the local clock. In contrast to the above, when a counter correction mechanism was used, each RSU was confirmed to suppress the deterioration of the time synchronization error.

3-2 Field testing the effectiveness of counter correction mechanism

To confirm the function of the counter correction mechanism in an outdoor environment, we carried out a field test in Higashi-Ginza, Tokyo by positioning five RSUs as shown in **Fig. 6**.

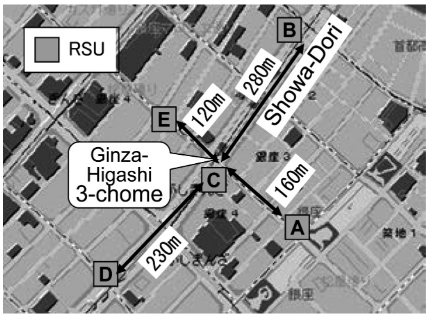


Fig. 6. Location of RSUs for field test in Ginza, Tokyo

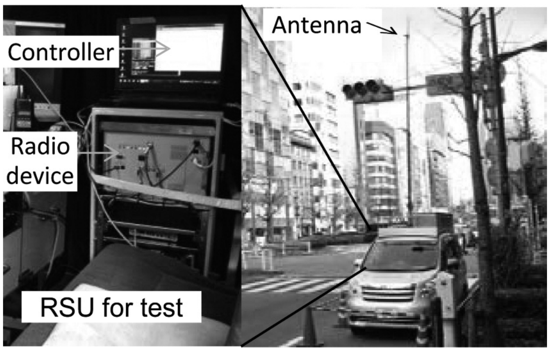


Fig. 7. RSU used for field test and test scene

In the field test, all RSUs were synchronized with GPS. Then the time error between central RSU C and each of the other units A, B, D, and E was measured without using the counter correction mechanism. Following the above, the same time error was measured continuously with the counter correction mechanism of each RSU turned ON. **Figure 8** shows the measurement result for the time error between RSUs B and C, while **Fig. 9** shows the time error density distribution of RSUs A, B, D, and E with respect to RSU C.

As shown in **Fig. 8**, RSU B had a tendency of reducing the time error when the counter correction mechanism was turned ON. **Figure 9** also shows that the other RSUs exhibited the same tendency, confirming that the counter correction mechanism is effective in reducing the time error.

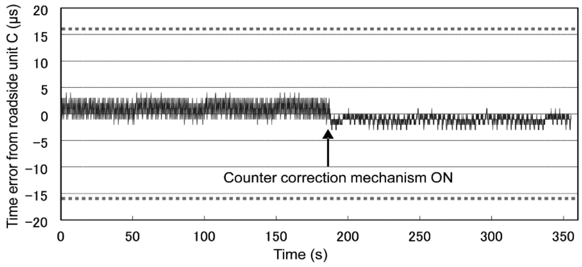


Fig. 8. Time error of RSU B from RSU C

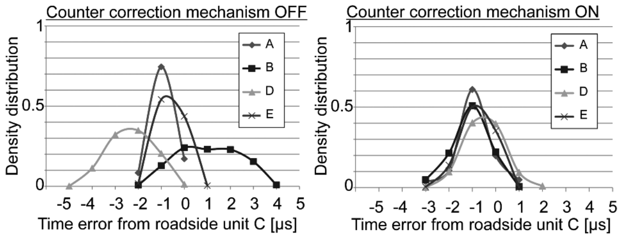


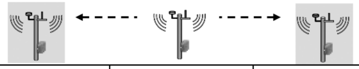
Fig. 9. Distribution of synchronization errors between RSU C and RSUs A, B, D, and E

4. Over-the-Air Synchronization and Associated Problems

Over-the-air synchronization is mainly associated with the following two problems. One is that the communication environment is poor. Such a poor environment causes communication errors and makes it impossible for each RSU to acquire transmission period information from neighboring RSUs when receiving signals from these units. As a result, the time synchronization error increases since each RSU is forced to use only its own local clock for counting. The other is that, due to the order relation of RSU slots that has been set for each RSU, the counter correction of a unit is dependent on the transmission period information it receives from another RSU immediately before transmission. As a result, the time error worsens. In this paper, we propose a method for averaging the time errors of two or more adjacent RSUs as a solution to the above problems, and discuss the simulation results in terms of the effectiveness of this method.

For the simulation, three RSUs were arranged in a row as shown in **Fig. 10**. The type of synchronization, the accuracy of local clock frequency, and the RSU slot number of each RSU were set as shown in this figure. In the simulation, RSU C was assumed to repeat the following operations:

At first, RSU C corrects its own counter by using the information from RSU slot No. 1 of GPS-synchronized RSU A. Secondly, the unit transmits information by RSU slot No. 5. Finally, the unit corrects its counter again on the basis of the information from RSU slot No. 9 of GPS-synchronized RSU B. The results of the above simulation are shown in **Fig. 11**.



RSU	A	C	B
Type of synchronization	GPS synchronization	Over-the-air synchronization	GPS synchronization
Clock accuracy	+20ppm	0ppm	−10ppm
RSU slot number	1	5	9

Fig. 10. Simulation conditions

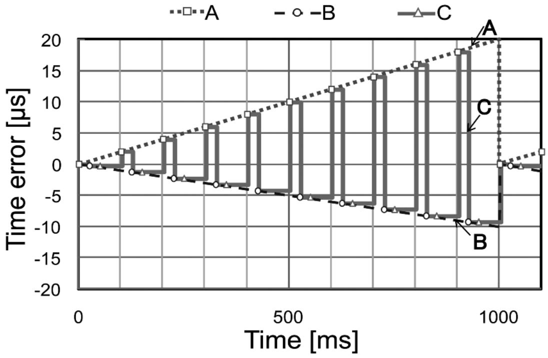


Fig. 11. Simulation results (conventional method)

The above simulation results show that RSUs A and B accumulated time errors depending on the accuracy of their own local clock. In contrast, RSU C corrected its counter every time when it received RSU slots from RSUs A and B, causing the time error to fluctuate remarkably. However, since RSU C's transmission was after roadside A's transmission according to the RSU slot number order, unit C was affected by unit A. In consequence, RSU C had a time error close to that of RSU A.

In this simulation, the time errors of RSUs B and C increased with time and exceeded 16 µs, the acceptable limit specified in the relevant standard. In such a situation, the OBEs entering the zone between these RSUs are estimated to increase the probability of interference with each other because of the collision of transmission packets, as discussed above. Although it might be possible to reduce the time error by rearranging the RSU slots, doing this in response to the change in local clock accuracy would be unrealistic in practice. Therefore, developing a new practical measure was required.

As a solution to this problem, we proposed an "averaged over-the-air synchronization" system. This system averages the time errors from two or more adjacent RSUs that receive information within a given period and uses the averaged time error as a counter correction value. **Figure 12** shows the counter correction value calculation method when this new synchronization system is applied to RSUs A, B, and C used for the above simulation.

The new synchronization system averages the time errors from two or more RSUs and uses the averaged value to correct the counter. According to this scheme, RSU C averages both time errors from RSUs A and B, thereby mitigating the effect of only the time error from a specific RSU. The results of simulation by the new synchronization system are shown in **Fig. 13**.

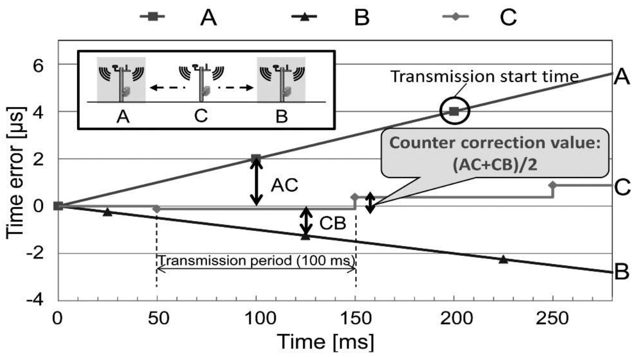


Fig. 12. Simulation results (before implementation of measure)

As **Fig. 13** shows, the averaged over-the-air synchronization system enabled RSU C to correct its counter value by using the average of the time errors from both RSUs A and B, thereby mitigating the deterioration probability of time error from a specific RSU. The averaged over-the-air synchronization system is expected to act as a solution to the problems associated with a poor communication environment. Even in such a poor environment, where an RSU is confronted with many errors in reception from adjacent RSUs and correction of its counter based on the transmission period information is interrupted, use of the new synchronization system will enable the RSU to hold the averaged correction value and use this value to correct the counter. Combined use of the counter correction mechanism, which was discussed in Section 3-1, with the averaged over-the-air synchronization system will enable each RSU to further improve its time synchronization accuracy.

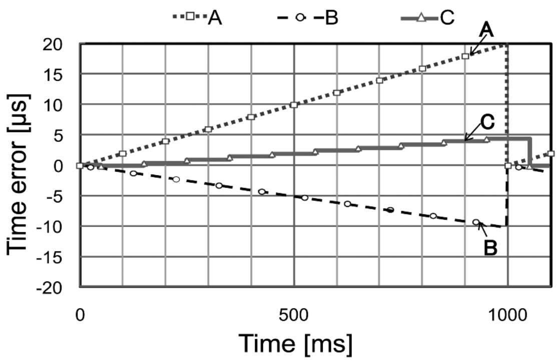


Fig. 13. Simulation results (after application of averaged over-the-air synchronization system)

5. Conclusions

For RSUs that use a 700 MHz ITS communication system, time synchronization between these units is required to accurately maintain the RSU slot transmission timing. GPS synchronization and over-the-air synchronization, which are both generally well known, were chosen as possible time synchronization techniques, the problems associated with the practical use of these techniques were discussed, and practical solutions to these problems were proposed. The effectiveness of these solutions was confirmed by a simulation and field demonstration test.

Road-vehicle cooperative safety driving support systems using a 700 MHz ITS communication system are expected as an effective means of reducing the number of traffic accident fatalities in Japan. The techniques for realizing high accuracy time synchronization between RSUs, which have been discussed in this paper, will enable stable operation of the RSUs used in road-vehicle cooperation systems.

6. Acknowledgements

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Technical Terms

*1 Roadside unit (RSU) is a radio station apparatus installed at the roadside to perform road-vehicle communication with vehicles running nearby the station.

*2 Carrier sense multiple access (CSMA) is a transmission scheme in which a receiver checks whether or not a transmission medium is being used and allows a transmitter to transmit only when the medium is not being used.

Reference

(1) 700MHz BAND INTELLIGENT TRANSPORT SYSTEMS ARIB STD-109 1.1

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