Experimental evaluation of synchronization accuracy considering sky view factor for QZSS short message synchronized SS-CDMA*

Suguru Kameda1a), Kei Ohya1, Ren Shinozaki2, Hiroshi Oguma2, and Noriharu Suematsu1
1 Research Institute of Electrical Communication, Tohoku University, 2–1–1 Katahira, Aoba-ku, Sendai 980–8577, Japan
2 National Institute of Technology, Toyama College, 1–2 Ebie-Neruya, Imizu, Toyama 933–0293, Japan
a) kameda@riec.tohoku.ac.jp

Abstract: We have previously proposed synchronized spread spectrum code division multiple access (SS-CDMA) as a method for short message communication using the Quasi-Zenith Satellite System (QZSS). In this paper, we have evaluated the time synchronization accuracy due to the sky view factor experimentally. The absolute time error to achieve a 100% cumulative probability density function (CDF) was evaluated to 26.5 ns when using an elevation mask of 30°. This means that it is possible to achieve 98% of the accommodation rate in the proposed synchronized SS-CDMA under the condition of a sky view factor of over 44%. The main cause of absolute time error is considered to be deterioration of the position dilution of precision (PDOP).

Keywords: timing synchronization, GPS, sky view factor, elevation mask, number of visible satellites, PDOP

Classification: Satellite Communications

References


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1 Introduction

During the Great East Japan Earthquake in March 2011, much of the terrestrial communication infrastructure was destroyed in the earthquake and the tsunami. After that, it has been discussed that Quasi-Zenith Satellite System (QZSS) should have a safety confirmation system for individual’s location information and short messages as one of the functions [1].

Fig. 1(a) shows the overall construction of QZSS safety confirmation system. The location and short message system will be realized using personal wireless terminals such as a mobile phone and a car navigation system. It is necessary to establish a line of sight for about 35,800 km between each mobile terminal (MT) and a satellite. The MTs have to transmit with the transmission power of less than 1 W using an omnidirectional antenna. In addition, the system needs to accommodate more than 3 million users per hour without congestion, because many users try to communicate with others in times of big disaster [1].

To realize this system, we have previously proposed the synchronized spread spectrum code division multiple access (synchronized SS-CDMA) [2, 3, 4, 5]. The synchronized SS-CDMA uses long orthogonal spreading code (length of 10,000) to get high spreading gain and to accommodate many users.

Fig. 1(b) shows the block diagram of the MT in the synchronized SS-CDMA. Each MT can calculate its own location and time precisely, and synchronize its own clock and frequency using the highly accurate QZSS and Global Positioning System (GPS) signals. Since each MT controls the transmission timing, each uplink signal arriving at the satellite is synchronized with each other. The synthesized uplink signal is then folded back to the HUB station that is on ground unaffected by
the disaster. The HUB station despreads and demodulates the signal. The demodulated data is received in the management server, and the client can confirm it.

Highly accurate timing synchronization among all MTs is the most important issue because the synchronized SS-CDMA provides high-density multiple access using long spreading codes in the uplink. In the case of a high-density environment with 98% accommodation rate for MTs, the required timing accuracy is 56 ns or less for the system to achieve a 1% packet error rate within an $E_b/N_0$ penalty of 0.5 dB [4]. Here, the accommodation rate is defined as the number of multiplexing MTs over the spreading code length.

In this paper, we have evaluated the time synchronization accuracy in the synchronized SS-CDMA experimentally. The sky view factor, a measure of satellite visibility, is reduced due to shielding by buildings. In this study, we have evaluated the difference in absolute time that is obtained from GPS positioning signals for various sky view factors by controlling the elevation mask.

2 Experimental evaluation of absolute time error in MT

Figs. 2(a) and 2(b) show a block diagram and a photograph of the measurement system, respectively. Using two commercially available GPS oscillators, the relative error of pulse per second (PPS) signals between oscillators is measured and evaluated. The GPS disciplined temperature compensated crystal oscillator (TCXO) GF-180TC [6] manufactured by FURUNO ELECTRIC CO., LTD. was used. It synchronizes with the Coordinated Universal Time (UTC), that is the time information to be broadcast from GPS, and generates PPS signal that rise once per second. Assuming that all MTs have this GPS oscillator in use, the time synchronization between MTs is evaluated. As shown in Fig. 2(a), the PPS signal output from the two GPS oscillators were input to an oscilloscope to measure the relative time difference between two pulses. The GPS antenna AU-117 [7] manufactured by FURUNO ELECTRIC CO., LTD. was used. The cable length between each GPS antenna and GPS oscillator was 5 m. The phase difference between the two cables

![Overall construction](image)

![Block diagram of MT](image)

Fig. 1. QZSS safety confirmation system with synchronized SS-CDMA.
was adjusted within 2 ps. Therefore, the timing difference generated between the GPS oscillator and the oscilloscope is sufficiently smaller than the difference generated between the GPS oscillators.

Fig. 2(c) shows an example of the measured time pulse. The two leading edges of the pulse were observed and the difference was calculated. It assumes that there is a correct absolute time between the two timing pulse measurements. Therefore, the time deviation of the MT is a half of the difference between two timing pulses, which is the maximum time error.

The measurement location was the rooftop of South Wing, Building #1, the Research Institute of Electrical Communication (RIEC), Tohoku University. It is an environment that can ensure a sufficiently open sky and a low influence from multipath. There are no large buildings in the vicinity.

In this experiment, the measurement was carried out by controlling the elevation mask. With the function of the elevation mask, it is possible to avoid
using the positioning signals from the GPS satellites located below a certain elevation angle. The positioning signals from the GPS satellites located at low elevation angle tend to cause a positioning error due to the influence of multipath. On the other hand, if the elevation mask is large, the positioning accuracy deteriorates under the influence of the small number of visible satellites. In this experiment, we set the elevation mask to 0°, 20° and 30°. When the elevation mask is 0°, 20° and 30°, the sky view factor is nearly equal to 100%, 60% and 44%, respectively. In this experiment, the increase in the relative time difference of the time pulses by increasing the elevation mask of one of GPS oscillator shown in Fig. 2(a).

Fig. 2(d) shows the cumulative probability density function (CDF) of the observed relative error of the time pulses. This experiment was conducted for 12 hours. Measurement start times (UTC) were 20th Nov. 2014 at 00:00 in the case of elevation mask of 0°, and 20th March 2015 at 00:00 in the case of elevation mask of 20° and 30°, respectively. When the elevation mask is 0°, the performance differences between GPS oscillators can be measured, since the satellite visibility of the two GPS oscillators is equal. When the number of visible satellites is reduced by setting a large elevation mask, it can be seen that the relative time difference is large. When the elevation mask was 0°, 20° and 30°, the absolute time error to achieve a 100% CDF was 10.0 ns, 19.0 ns and 26.5 ns, respectively. Therefore, it is possible to achieve 98% of the accommodation rate in the proposed synchronized SS-CDMA under the condition of a having sky view factor of over 44%.

3 Experimental evaluation of number of visible satellites and PDOP

In order to clarify the influence of satellite visibility, we have evaluated the number of visible satellites and the position dilution of precision (PDOP) for various degrees of satellite visibility by controlling the elevation mask. Here, the PDOP describes three-dimensional position error caused by the relative position of the GPS satellites [8].

In this experiment, the SCR-u2C [9] manufactured by Sensorcomm was used. The global navigation satellite system (GNSS) module of SCR-u2C is the NEO-M8T [10] manufactured by u-blox. Although the NEO-M8T can receive multiple GNSS signals, only the GPS signal was used for this evaluation in order to match the measurement conditions of Sect. 2. This experiment was conducted for 5 hours 50 minutes. Measurement start time (UTC) was 7th March 2018 at 0:35. The measurement location was on a rooftop on Imizu Campus, National Institute of Technology, Toyama College. It is an environment that can ensure a sufficiently open sky and a low influence from multipath. There are no large buildings in the vicinity.

Fig. 3(a) shows the CDF in relation to the number of visible satellites. It was found that the proposed system could work well if the number of visible satellites located above the elevation mask of 30° is more than 4.

Fig. 3(b) shows the CDF in relation to PDOP. When the elevation mask was 0°, 20° and 30°, the PDOP to achieve a 100% CDF was 3.2, 6.9, and 12.1, respectively. We can see that the PDOP of less than 12.1 will correspond to the
In the case of the 0° elevation mask in Fig. 2(d), it seems that the influence of multipath on positioning accuracy is small despite the existence of positioning signals from GPS satellites located at low elevation angles. From Fig. 3, we can deduce that this result is because of good PDOP conditions with a large number of visible satellites during the measurement.

4 Conclusion

In this paper, we have evaluated the time synchronization accuracy of the synchronized spread spectrum code division multiple access (SS-CDMA) experimentally for a safety confirmation system with the Quasi-Zenith Satellite System (QZSS). The absolute time error due to the sky view factor has been measured by controlling the elevation mask. The reception timing error at the satellite was evaluated to 26.5 ns when using an elevation mask of 30°. This means that it is possible to achieve 98% of the accommodation rate in the proposed synchronized SS-CDMA under the condition of having sky view factor of over 44%. The main cause of absolute time error is considered to be deterioration of the position dilution of precision (PDOP).

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