Evaluation of Satellite Signal Reception Error by Sky View Factor for QZSS Short Message SS-CDMA Communication System

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Abstract**—** We have proposed Spread Spectrum Code Division Multiple Access (SS-CDMA) short message communication using Quasi-Zenith Satellite System (QZSS) for safety confirmation system at the time of large disaster. The proposed system controls the transmission timing using highly accurate time and position information obtained from the QZSS. To realize the proposed system, we evaluate the time synchronization accuracy. In this paper, the satellite signal reception error due to sky view factor is evaluated. As a result of evaluating satellite signal reception error, the error amount is 46.0 ns in an environment with a sky view factor of 39.0 %. It is found that the proposed system has sufficient promise to be realized.

Keywords— Satellite Communication, Quasi-Zenith Satellite System (QZSS) , Global Positioning System (GPS), BeiDou Navigation Satellite System, Spread Spectrum (SS), Code-Division Multiple-Access (CDMA), Sky View Factor (SVF)

I. INTRODUCTION

During the Great East Japan Earthquake that occurred in March 2011, the earthquake and tsunami caused damage to cables, destruction of station buildings, and power outages in the affected areas, resulting in a large-scale loss of terrestrial telecommunications infrastructure. The damaged terrestrial communication infrastructure was also rendered unusable due to congestion caused by traffic concentration and power outages. This made it difficult to confirm the safety of the victims, and it took a long time to do so [1]. After the Great East Japan Earthquake, the operation of a location short message communication system using the Quasi-Zenith Satellite System (QZSS) was planned as a safety confirmation system that does not depend on terrestrial communication infrastructure [2],[3]. This system utilizes a geostationary satellite located at 140 degrees east longitude, and enables two-way communication via satellite from a personal wireless terminal, which can be a cell phone or a car navigation system, with location information, terminal identification (ID), and a message of about 140 hours. QZSS is composed of multiple Quasi-Zenith Satellites (QZS) with asymmetric figure-8 orbits that orbit the earth at the same speed as the earth's rotation and can stay at the high elevation angle of the zenith of Japan for about eight hours, which makes it possible to obtain Global Positioning System (GPS) signals in urban areas with many high-rise buildings and in mountainous areas. GPS signals in urban areas with many tall buildings and in mountainous areas where it is difficult to receive GPS signals.

There are two major technical challenges to realize this system. First, it is necessary to realize long-distance communication with a satellite at a distance of about 39,000 km from the ground using a low-gain antenna with a transmission power of about 1 W and near omni-directionality, because a personal wireless terminal such as a cellular phone serves as a transmitting station. Second, it is necessary to realize a system that can accommodate a large number of simultaneous communication requests from many victims and avoid congestion in the event of a large-scale disaster such as the Great East Japan Earthquake. The target capacity of the short message communication function indicated by the Cabinet Office of Japan is more than 3 million messages per hour [4]. The frequency bandwidth that can be used for satellite communications is limited, and a system that can achieve very high frequency utilization efficiency is required. In order to satisfy this requirement, we have developed a synchronized Spread Spectrum Code Division Multiple Access (SS-CDMA) that achieves high spreading gain by using s SS with long-spread codes, and utilizes the long spread codes for users' CDMA, which can accommodate a large number of users. The synchronized SS-CDMA scheme has been proposed to accommodate a large number of users [5]-[13]. In the synchronized SS-CDMA scheme, it is necessary to make the CDMA user multiple connections very dense in order to accommodate a large number of terminals. Therefore, it is necessary to synchronize users precisely in the time and frequency domains and to ensure code orthogonality among users. Here, QZSS, which is a positioning system unique to Japan, can ensure a high elevation angle, and can obtain highly accurate time and position information. The proposed synchronized SS-CDMA scheme is characterized by synchronizing the uplink signals of all users at the time of satellite delivery and ensuring code orthogonality by controlling the timing and frequency of transmission and sending short messages at each terminal using such high-precision positioning information.

We have constructed and evaluated a transmission timing control system. In this paper, we measure and evaluate the reception error of satellite signals at the time of reception from satellites with different sky view factors. Sect. 2 describes the outline of the synchronized SS-CDMA system using satellite positioning signals. In Sect. 3, an overview of the satellite signal reception error, its measurement method, and its variation with the sky view factor are evaluated.

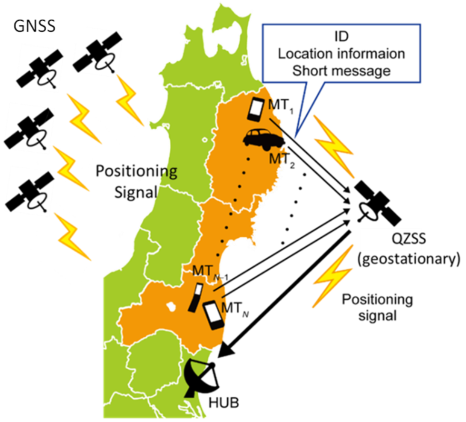


Fig. 1 Location and short message communication system using QZSS

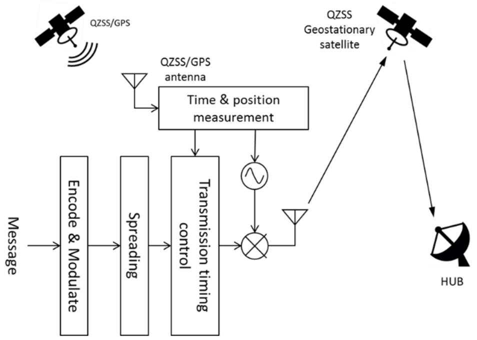


Fig. 2 Block diagram of synchronized SS-CDMA communication

II. SYNCHRONIZED SS-CDMA SYSTEM USING SATELLITEPOSITIONING SIGNALS

In this section, an overview of the synchronized SS-CDMA uplink system using satellite positioning signals is given. An overview of the synchronized SS-CDMA scheme in the uplink system using satellite positioning signals is described, including the terminal function and the method to realize direct communication with a satellite at a distance of about 39,000 km.

A. Overview of Synchronized SS-CDMA Scheme

Fig. 1 shows a schematic diagram of the synchronized SS-CDMA system. Positioning signals are provided by QZS and GPS satellites, and highly accurate time and location information is obtained. The terminal sends an uplink signal to the QZSS geostationary satellite with the terminal identification number assigned to each terminal, accurate location information, and a short message. The uplink signal is returned via the satellite to the unaffected ground hub station, where it is reverse-diffused and demodulated. The demodulated information is stored in the management server and can be viewed by clients with a browser.

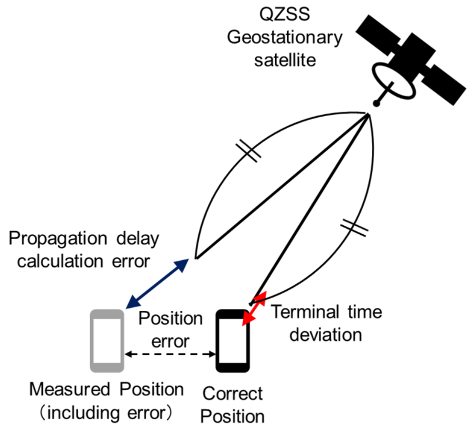


Fig. 3 Factors of satellite arrival timing error

This section describes the mechanism of the precise synchronization control between terminals using the satellite positioning signals. Since the communication target of the proposed system is a satellite at a distance of about 39,000 km, the round trip time is about 0.52 seconds, which is very large, and there are a large number of terminals that wish to communicate with each other. Therefore, it is necessary to realize the system without using feedback control. Terminal functional block of synchronized SS-CDMA system that achieves inter-user orthogonality by feed-forward control. Fig. 2 shows the causes of satellite arrival timing errors. Using the positioning and timing information provided by the reported positioning signals, the system encodes, modulates, and spreads the signals in the same way as a general spread spectrum system, applies transmission timing control and frequency control, and transmits a message to the satellite. The above two controls can be realized without any feedback configuration such as closed-loop control, because the control is based on the reported positioning signals.

Next, this section describes a method to realize direct communication with a satellite at a distance of about 39,000 km using a mobile terminal. The proposed system uses synchronized SS-CDMA for direct communication with satellites with low power consumption, which can be installed in mobile terminals such as cellular phones and car navigation systems, and for accommodating a large number of terminals simultaneously. In the synchronized SS-CDMA system, spread spectrum is used to obtain spread gain to enable low-power communications. Assuming that the transmitting power of the mobile terminal is 1W and that the required signal-to-noise ratio (*S/N*) at the satellite arrival point is 8 dB, a spreading gain of about 40 dB is required to establish a line between the terminal and the satellite. This can be achieved by using a long spreading code with a code length of about 10,000. This long spreading code is also used for code division multiple access. Using a spread code with a code length of 10,000, we target simultaneous communication of several 1,000 to 10,000 terminals (capacity factor: several 10 to 100 %). The capacity factor is defined as the number of multiple access users divided by the spreading code length. The time unit allocated to a group for simultaneous communication is called a slot, and time-division multiple access using multiple slots achieves the capacity of 1 million users per hour.

B. *Satellite arrival timing error required for highly accurate user terminal accommodation*

In this subsection, we explain the details of the timing control in the synchronized SS-CDMA system, and describe the causes of errors in the timing of arrival of radio signals to satellites and the timing errors required for accurate accommodation of user terminals. First, each terminal obtains a highly accurate time-station position and current time by using positioning signals obtained from QZSS. This short message communication system is designed for a wide disaster area such as the Great East Japan Earthquake, and we consider that the terminals that wish to communicate with each other are scattered over a very wide area. Therefore, the time until the uplink signal arrives at the satellite varies depending on the difference of the terminal positions among the terminals on the ground. Therefore, we calculate the propagation distance from each terminal to the geostationary satellite using the acquired time-station position, satellite position and time information, and adjust the transmission timing of radio waves according to the obtained propagation delay time to realize synchronization and code orthogonality of the uplink signals of all terminals when they reach the satellite.

Since the time and location information used for transmission timing control is generated using both positioning signals, errors occur due to differences among individual terminals, differences in the number of visible satellites, and satellite positioning environments such as multi-paths. The error causes an error in the timing of arrival of the radio wave transmitted from the mobile terminal to the satellite. The errors in the timing of arrival at the satellite may affect the code orthogonality of the radio waves transmitted from each terminal at the time of arrival at the satellite, and therefore, it is necessary to evaluate the errors in the timing of arrival at the satellite.

Fig. 3 shows a schematic diagram of the factors causing satellite arrival timing errors in a synchronized SS-CDMA system. The components of the satellite arrival timing error are the transmission timing control error which occurs at the timing of transmission from the terminal to the satellite, and the satellite signal reception error which occurs at the time of reception from the satellite. The transmission timing control error occurs when the transmission timing of each user terminal is controlled and the signal is actually transmitted. Satellite signal reception error is composed of two components: terminal time deviation caused by time information error and propagation delay calculation error caused by position information error. The satellite signal reception error is composed of the following two components. When there is a terminal time deviation, the uplink signals from each user terminal arrive at the satellite at different times, and the transmission characteristics are degraded. When the propagation delay calculation error exists, the transmission characteristics are degraded due to the error in the transmission timing of each user terminal depending on the direction and magnitude of the position error and the difference in the arrival timing of the uplink signal to the satellite.

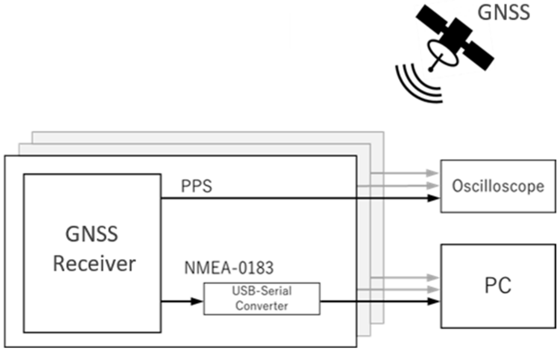


Fig. 4 Satellite signal reception error measurement system

It has been clarified that an accuracy of about 56 ns or less is required for near 100 % user accommodation in the synchronized SS-CDMA system. Furthermore, an evaluation of transmission timing control error using an Field Programmable Gate Array (FPGA) showed that a clock frequency accuracy within 5 ppm is considered to be sufficient to achieve a sufficient transmission timing error accuracy (within ±20 ns) [13]. In the Long Term Evolution (LTE) terminal standard, the accuracy of clock frequency error, which is considered to be a major factor of transmission timing control error, is within 0.1 ppm [14], in which case the maximum clock frequency error is 0.6 ns. Therefore, whether or not the satellite signal reception error is within 56 ns among the satellite arrival timing errors is an indicator for the realization of a transmission timing control system.

III. MEASUREMENT METHOD OF SATELLITE SIGNAL RECEPTION ERROR

This section describes the measurement method of satellite signal reception error and its evaluation application. The satellite signal reception error was measured using GPS and QZSS, but it was found that adding BeiDou Navigation Satellite System (BeiDou), a Chinese satellite, was sufficient, so three types of satellites (GPS, QZSS, and BeiDou) were used. The GPS, QZSS, and BeiDou satellites are used. In order to simulate the actual operating environment, the sky view factor is varied (sky view factor: 95.3 %, 76.5 %, 39.0 %) and measurements are made for each.

A. *Measurement method*

In this subsection, we describe the measurement system for satellite signal reception errors. The block diagram of the satellite signal reception error measurement system is shown in Fig. 4. The satellite signal reception error is measured by inputting position information from a Global Navigation Satellite System (GNSS) receiver to an oscilloscope and position information to a PC. Pulse Per Second (PPS) signals are recorded as time information, and National Marine Electronics Association (NMEA) 0183 format data are recorded as position information. The GNSS receiver used is the GT-902PMGG, and three measurements are made for each evaluation to account for terminal-to-terminal variations. An Agilent DSO9254A oscilloscope with a sampling rate of 10 GS/s is used.

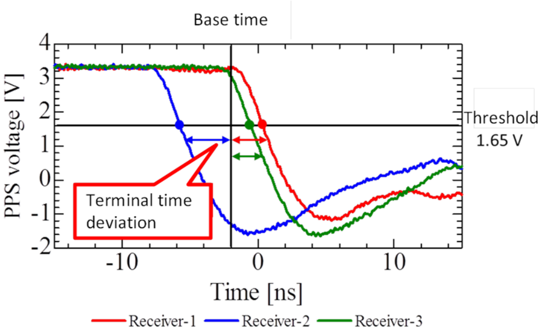
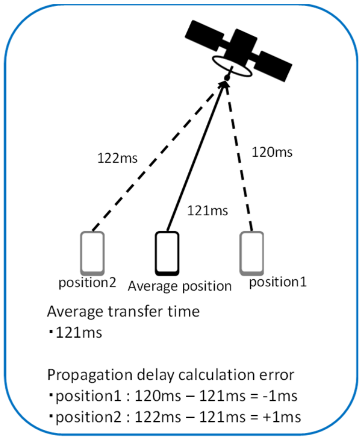


Fig. 5 Example of calculation of terminal time deviation



Average transfer time
・121ms

Propagation delay calculation error
・position1 : 120ms – 121ms = -1ms
・position2 : 122ms – 121ms = +1ms

Fig. 6 Example of calculation of propagation delay calculation error

The terminal time deviation is measured by measuring the PPS signal and obtaining the time at which the 3.3 V signal falls every second in synchronization with Coordinated Universal Time (UTC). In this measurement, the falling time is defined as the time when the PPS signal first falls below the threshold value. The threshold is set at 1.65 V, which is half of the maximum value of the PPS signal.

The measurement of propagation delay calculation error is based on the latitude and longitude The data in NMEA0183 format, which includes position information in degrees, altitude, and geoid height, is recorded using the terminal software Tera Term ver. 4.105.

B. *Evaluation Applications*

In this section, we describe how to calculate the terminal time deviation, propagation delay calculation error, and satellite signal reception error from the PPS signals and NMEA data obtained in the measurements. The calculations are outlined in the form of an evaluation application that we have developed ourselves using Python. Fig. 5 shows an example of the calculation of terminal time deviation. The terminal time deviation is calculated from the average of three time data recorded at the same time and the difference of each terminal's time data.

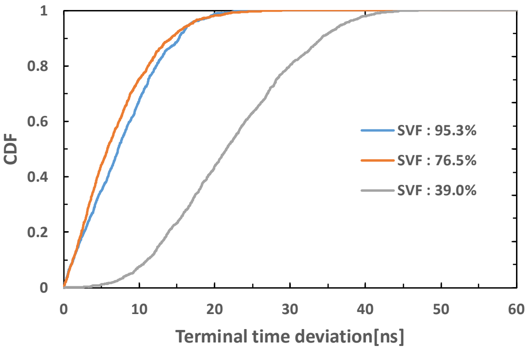


Fig. 7 Terminal time deviation

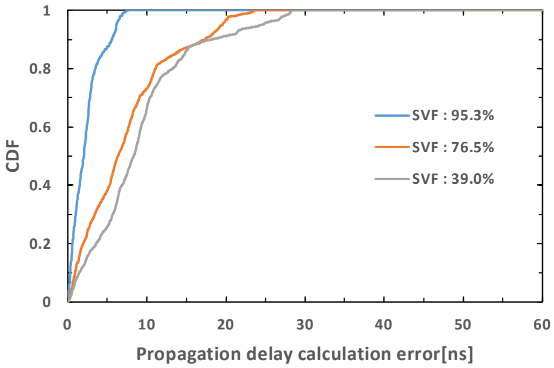


Fig. 8 Propagation delay calculation error

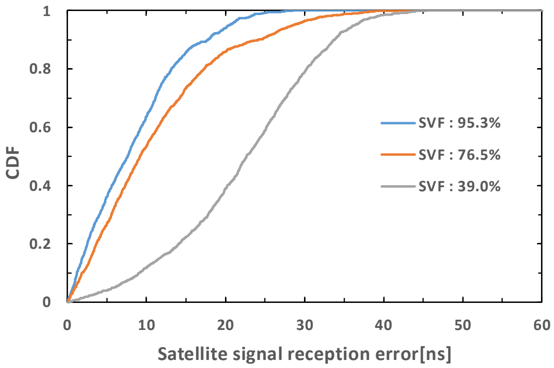


Fig. 9 Satellite signal reception error

Fig. 6 shows an example of the calculation of propagation delay calculation error. The information necessary for the calculation is extracted from the NMEA sentences of the log data output every second using Python sprint. The extracted position information, which can be expressed in terms of latitude, longitude, and geoid height, is transformed into a geocentric Cartesian coordinate system and obtained as the observed position.

Next, the average position is obtained from all the data of the observed positions for each second. The average position is calculated for each receiver. The propagation time between the average position and the geostationary satellites located at 140 degrees east longitude and 35,786 km altitude, which are the communication partners, is calculated. The propagation time between the observed position and the geostationary satellite is calculated in the same way for each second. The difference between the propagation time at the observed position and the propagation time at the average position is the propagation delay calculation error. The terminal time deviation and the propagation delay error are assumed to have a sign of ± because they are obtained by the difference of averages.

Finally, the satellite signal reception error is calculated by the sum of the terminal time deviation and the propagation delay error. The accuracy of the above three types of errors is evaluated by calculating the absolute value of each signed value, and then the Cumulative Distribution Function (CDF) is calculated. The terminal that reaches 1 most slowly from the calculated CDF is evaluated as the value of each error.

C. Satellite signal reception measurement results

In this subsection, we describe the results of measurement and evaluation of satellite signal reception errors. Fig. 7 shows the results of terminal time deviation. The results are 24 ns for 95.3 % sky view factor, 28.9 ns for 76.5 % sky view factor, and 47 ns for 39. 0 % sky view factor. The propagation delay increases by a factor of about two with changes in the sky view factor. Next, Fig. 8 shows the results of propagation delay calculation error. The results are 7.7 ns for a 95.3 % sky view factor, 23.7 ns for a 76.5 % sky view factor, and 28.4 ns for a 39.0 % sky view factor. The propagation delay calculation error increases by a factor of about four with changes in the sky view factor. Fig. 9 shows the results of satellite signal reception error. The results are 30.1 ns for 95.3 % sky view factor, 43.7 ns for 76.5 % sky view factor, and 46.0 ns for 39.0 % view factor. The satellite signal reception error increased by a factor of 1.5 with changes in the sky view factor, but even at the worst sky view factor of 39.0 %, the error is within 56 ns, which was the required condition.

IV. CONCLUSION

In this paper, satellite signal reception errors for short message Spread Spectrum Code Division Multiple Access (SS-CDMA) communications using the Quasi-Zenith Satellite System (QZSS) are measured and evaluated in terms of sky view factor (95.3 %, 76.5 %, 39.0 %). In summer (from late May to early June), even in an environment with the lowest sky view factor (39.0 %), which is most affected by multipath, the value was 46.0 ns, which is lower than the required condition of 56ns. From these results, it can be concluded that the accuracy of the satellite arrival timing error is sufficient to realize the proposed system in the summer season.

ACHKNOWLEDGMENT

A part of this work was obtained from the commissioned research (No. 06701) by National Institute of Information and Communications Technology (NICT), Japan, JSPS KAKENHI Grant Number JP 21H01319, and the Cooperative Research Project Program of the Research Institute of Electrical Communication (RIEC), Tohoku University.

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