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Improvement of Reachability and Promptness of an Augmentation-Signal-Based Early Warning System Using Multiple Satellites of the QZSS Constellation

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Abstract: *During an environmental disaster it is likely that essential information will not delivered because of damage to the communicated infrastructure. Satellites, which will be unaffected by environmental damage, may provide a way to communicate essential information during a disaster. We aimed to determine if using multiple satellites of the Quasi-Zenith Satellite System (QZSS) to deliver disaster information can improve communication during a disaster. The ability to receive an emergency message from multiple satellites was analyzed, using the only QZSS satellite. Predictions of reception were also made for the three proposed QZSS satellites by overlaying sky images with the satellite constellation. The results from this study suggest that delivering emergency messages via multiple satellites in areas where satellites have high elevation will improve communication. Additionally, delivering messages via the geostationary satellite and quasi-zenith satellites will likely be effective in areas where satellites have low elevation.*

Keywords: *Global navigation satellite system, Quasi-Zenith Satellite, Early warning system, Augmentation Signal, Disaster Information*

1. Introduction

At the time of a large-scale disaster such as an earthquake or tsunami, it is possible for there to be a period in which victims and relief and rescue workers find it difficult to obtain required information owing to the destruction or interruption of the information infrastructure. Therefore, instruments that transmit disaster information via communication satellites, which would be unaffected by the information infrastructure on the ground, have gained attention as a means to fill the information blackout period; e.g., satellite cellular phones, although they are not widely used by individuals compared with cellular phones. Studies are underway on a method to distribute disaster information by superimposing the information on the augmentation signal of positioning satellites [1][2][3]. In this approach, information can be distributed to receivers of a global navigation satellite system (GNSS) such as the widely used Global Positioning System (GPS), GLONASS and other positioning satellites such as the Quasi-Zenith Satellite (QZS). The authors previously conducted an evaluation experiment in which information was actually distributed by the QZS, and confirmed that the information can be displayed on a cellular phone via a GNSS receiver [4]. On the other hand, Europe has been working on emergency message services using GNSS since 2005 with the introduction of the ALIVE (Alert interface via EGNOS) Concept[1]. The concept showed the possibility to use SBAS message broadcast capability as a means for disaster announcements. It was followed up by the project MAGES (Mature Applications of Galileo for Emergency Scenarios) involving 20 EU organizations and companies co-funded by European GNSS Agency (GSA) [5]. MAGES contributed to the introduction of the European Galileo and EGNOS for emergency management applications and investigated technical and non-technical benefits and advantages of Galileo in comparison to existing solutions. It especially investigated the role of GNSS for disaster alerting, including the analysis and prototyping of the ALIVE concept.

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Given that disaster information is transmitted by positioning satellites using the augmentation signal of the satellites, challenges that need to be overcome are the reception loss and limited transmission capacity of information. Employing satellites, information can be distributed to a wide area simultaneously, and also to specific areas where device users are located using location information. In this case, as the granularity of an area becomes finer, the amount of information that can be sent to the area reduces and the time required to distribute information to all areas increases. In view of this, the authors performed experiments on message formats and distribution schedules used in transmitting disaster information via positioning satellites, and designed a distribution schedule with consideration of the reception loss as well as the number of repetitions and the priority levels of important information when using the QZS in Japan. The results confirmed that the approach provides the high standard of deliverability and immediacy required to distribute high-priority information [6].

Although the QZS system (QZSS) currently comprises a single satellite located in a quasi-zenith orbit (QZO), it is planned that the system will comprise four satellites in total, one in a geostationary orbit (GEO) and three in QZOs, by the late 2010s. There will always be one or more satellites positioned over Japan owing to the presence of the satellite in QZO. In Asia and Oceania, it will be possible to receive signals from the QZSS and there will be regions that have several satellites in the sky simultaneously depending on their orbits. It is thus considered possible to improve promptness and reachability when sending emergency messages using multiple satellites of the QZSS. However, as the arrangement of QZSs varies depending on the ground position, it is necessary to consider a method of operating multiple satellites, especially when distributing disaster information to a wide area. The present study suggests methodology of using multiple satellites to improve reachability and promptness when sending an emergency message via the QZSS. It further evaluates availability in terms of reception for a proposed method of using multiple satellites. The results of the study will assist in constructing an early warning system that distributes disaster information using multiple QZSs.

2. Early Warning System Using a QZSS Augmentation Signal

2.1. System overview

The system for the evacuation support of many users provides disaster information to users' devices with GNSS receivers using L1-SAIF signals of the QZSS during a disaster. In particular, we assume the use of a mobile phone with GNSS function capability to receive evacuation guidance information (e.g., maps and directions and distances to refuges (Fig. 1) in a disaster.

Because the user simultaneously acquires the emergency message and position information from a satellite, we consider providing disaster information corresponding to the position of the user and the type of disaster. The system thus has two receiving modes. One is a wide-area broadcast mode, which can send an emergency message simultaneously over a large area of Japan; e.g., we can send an early warning of an earthquake. The other is an area-selected broadcast mode. This mode can send messages to a specified area, such as when sending a tsunami warning to a coastal area.

2.2. System structure

Fig. 1 shows that the system consists of three parts: transmission, receiving and satellite segments. The transmission segment transmits emergency messages to the satellite segment in the following sequence. First, the Disaster Management Center gathers disaster information released by Disaster Prevention Agencies. Examples of the gathered information are information on weather, earthquakes and tsunamis. Second, the Disaster Management Center converts the disaster information to an emergency message for transmission by a QZS in accordance with the message format. The Disaster Management Center decides the distribution schedule according to the priority and redundancy of information and transmits the emergency message to the Master Control Station. Third, the Master Control Station collects the Monitor Station results and generates a navigation message. The Master Control Station uplinks both the navigation message and emergency message to the QZS via the Tracking Control Station. The satellite segment consists of both the QZS and GNSS. The L1-SAIF (submeter-class augmentation with integrity function) signal with the navigation message and superimposed emergency message is then generated and transmitted by the QZS to the Receiving Segment. The receiving segment is based on devices equipped with GNSS receivers capable of receiving the L1-SAIF signal. The receiving segment receives the L1-SAIF signal and position information from the QZS and also receives position information from other GNSSs. The L1-SAIF signal contains the emergency message that is decoded by the receiving segment so that the user obtains the disaster information. Thus, receiving segments provide users only information for the user's area in the case that disaster information is transmitted in accordance with the area.

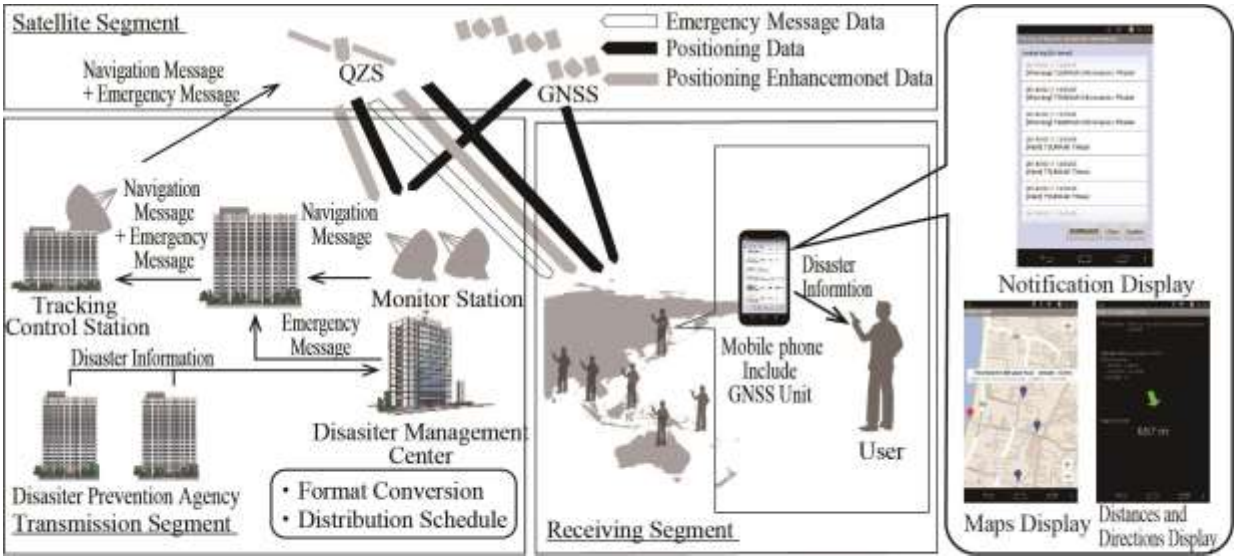

Fig. 1: Schematic of the system used to transmit disaster information.

2.3. QZSS

As discussed above, the QZSS will comprise four satellites by the late 2010s—three satellites in QZOs and one satellite in GEO. With only one QZO satellite, we can see the one QZO satellite above us in Japan area for about 8 hours per day. With three QZOs satellite, the QZSS can cover for 24 hours as shown in Fig. 2 [7]. However, the elevation angle of QZO satellites will change according to time and location.

A QZS can transmit a message to the user using the L1-SAIF signal and LEX signal as a GPS augmentation service. In this study, we consider that an emergency message is sent to the user using the L1-SAIF signals of the QZSS. These signals are defined as having full compatibility with the SBAS L1 signals. The signal frequency is the same as that for the GPS/SBAS L1 signal (1575.42 MHz). The L1-SAIF signal is made up of 250 bits and has the format shown in Fig. 3. The data rate is 250 bps, so one message is transmitted every second [7]. In this study, we use a 212-bit data field within a 250-bit. In addition, the augmentation message is assigned a message type depending on the content of information, and the maximum delivery interval is determined by the information. The L1-SAIF signals are used mainly for the distribution of a navigation message to augment information of submeter-class accuracy using the QZSS. Furthermore, we should select the transmission interval of the navigation and the emergency message so as not to degrade the positioning accuracy. In a relevant study, Sakai et al. [8] reported that positioning accuracy was not degraded by inserting a dummy message of up to 50% of the entire message. Therefore, in this study, we set the transmitting interval as one message every 2 seconds.

2.4. Message format and distribution schedule

The disaster information is encoded according to the message format to deliver the emergency message within the limited data capacity of the L1-SAIF signal. The emergency message is then transmitted by the QZS in accordance with a distribution schedule that considers priority and redundancy.

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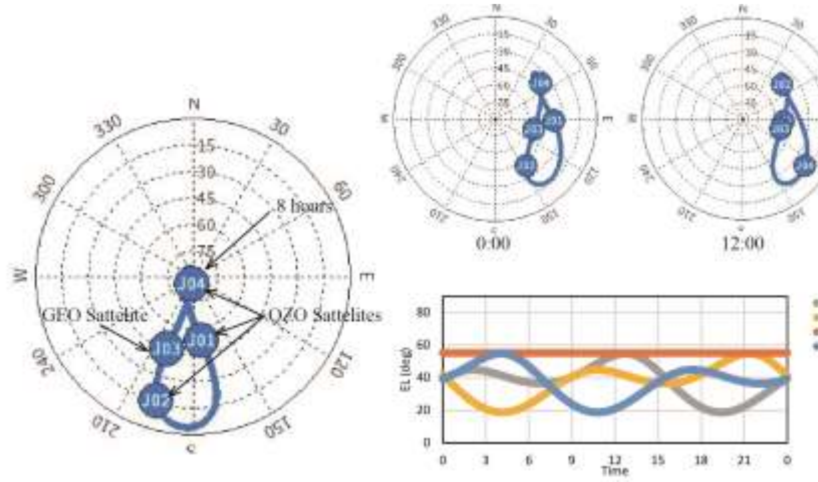
The system delivers disaster information in a wide-area broadcast mode and an area-selected broadcast mode depending on the selected type of disaster. Therefore, we designed the three emergency message formats shown in Fig. 4.



a) Example of a satellite constellation of the QZSS (Yokohama, Epoch: September 1, 2025, 00:00:00 UTC)

b) Variation in the positioning and elevation angle of the QZSS constellation (Phuket, Epoch: September 1, 2025, 00:00:00 UTC)

Fig. 2: The satellite constellation.

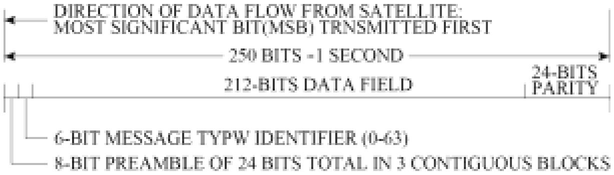


Fig. 3: Message block format [7].

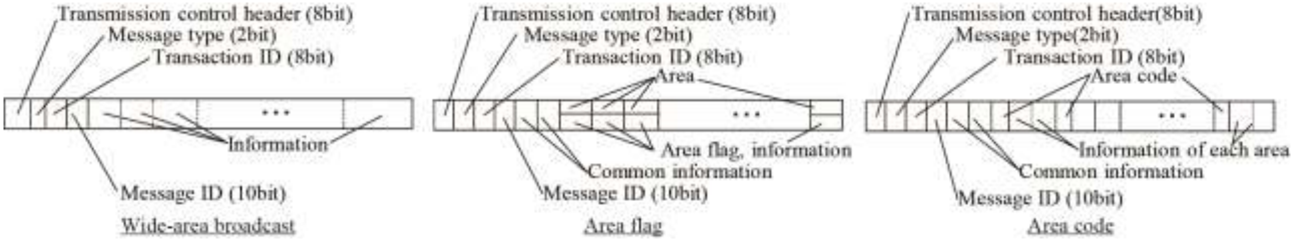


Fig. 4: Message formats.

The wide-area broadcast mode using the wide-area broadcast format provides the same disaster information to the distribution area. In contrast, the area-selected broadcast mode using the area flag format and area code format provides disaster information corresponding to the area in which there are users. A single emergency message distributed in area flag format or area code format includes disaster information for multiple areas. A user's device receives the emergency message and extracts disaster information for the user's area. The area flag format sets the area region. We input the disaster information depending on the area. For example, in the case of a tsunami warning, we input the alert level determined for each area. The area code format decides the area code and uses both the disaster information and area code of the area to transmit the information. In addition, the area flag format and area code format both include common information that is provided to all users in the entire region to which information is to be transmitted. A piece of disaster information will occupy a certain number of bits in a message. Therefore, some disaster information is transmitted to all areas in one message, and some disaster information is transmitted to all areas in several messages. For example, in Japan, earthquake seismic intensity is divided into 188 areas, yet we can only transmit information relating to 47 areas in one message. We thus need to transmit four messages. From the user's point of view, only one of the four emergency messages provides disaster information for the user's area, and the remaining three messages provide disaster information for areas that the user is not in.

We designed the following delivery schedule to deliver disaster information using the emergency message format.

1. The latest information released from the disaster prevention agency is delivered five times.
2. If information is in conflict with other information, the disaster information with the higher priority is delivered.
3. If the priority of the information is the same, the latest information is delivered.
4. If there are two or more instances of latest information with the same priority, the disaster information is delivered in turn.
5. High-priority information is redistributed.
6. If the latest information is announced during redistribution, the latest information is delivered.

In this system, an emergency message can be lost as a short-term random loss or a long-term burst loss. To prevent the effect of random losses, we deliver the latest information repeatedly. The probability that an emergency message is received at least once is given by formula (1). The number of repetitions of the emergency message was set to five because this was the number of repetitions for which we calculated there is a probability of 95% or higher that at least one message would be received under the assumption of a loss rate of reception of 50%.

$$P=\sum_{n=0}^{n} {}_{n}C_{r}\left(1-\alpha\right)^{r}\alpha^{n-r} \qquad (1)$$

P: reception probability n: number of repetitions of the emergency message

α: loss rate of reception r: number of messages (r =1)

To prevent the effect of burst losses, we redistribute high-priority information when not delivering other information.

3. Design of Methods of Using Multiple Satellites

It will be possible to see multiple QZSs from locations in Asia and Oceania. The use of multiple QZSs will improve the transmission of information from the point of view of reachability and promptness. In the transmission of disaster information by a QZS, buildings or objects blocking the line of sight to the satellite can cause burst loss, resulting in the user being unable to receive signals from the satellite. There is little concern about signal loss if the elevation angle of the satellite is high, even when the user is surrounded by buildings. Fig. 5 shows an example of a sky image from the user's point of view and the satellite constellation. However, the exact number of satellites blocked will depend on the user's surrounds. On the one hand, information can be more securely delivered using multiple satellites to disseminate the same information, reducing the risk of burst loss from blocking objects. On the other hand, because the amount of information that can be sent from a single QZS is only 212 bits per second, if different information is disseminated by multiple satellites users can receive more information with greater immediacy. In wide-ranging disasters, information must be sent to a large area, and the latter approach would allow users to receive information for their specific area more quickly.

The use of multiple satellites can thus improve the transmission of information from the point of view of reachability and promptness, but methods to achieve these objectives differ. For example, if the same information is disseminated from four satellites, then delivery of the information is more likely to be guaranteed, but the amount of information is no greater than if the information had been sent from a single satellite, and the delivery is no faster. This method is useful when disseminating information within a limited area, and when immediacy is not of prime importance. However, it is not effective when the disaster area is large, such as in a tsunami disaster, and the information needs to be delivered as quickly as possible. If four satellites each disseminate different information, then the promptness of the information will improve, but the possibility of signals being blocked by surrounding buildings and other objects will increase, and thus, information is not as securely delivered. This paper considers the performance of different methods of using multiple satellites of the QZSS constellations calculated by simulation.

Fig. 5: Example of a sky image and the QZSS constellation.
（Phuket, Epoch: September 1, 2025, 00:00:00 UTC, calculated using Rtklib[8]）

3.1. Simulation of the QZSS constellation

We investigated methods of using multiple satellites of the QZSS to send emergency messages from the viewpoint of improving reachability and promptness. Since the arrangement of the QZSS constellation changes according to time and the ground location, when evaluating methods of using multiple satellites, it is necessary to consider the arrangement and elevation angles of the QZSS satellite constellation at different ground locations.

We investigated the arrangement of satellites of the QZSS as seen from the five locations shown in Fig. 6 a) in evaluating methods of using multiple satellites. The five locations are Yokohama in central Japan; Bali in Indonesia, which is located on the equator; Melbourne in Australia, which is located in the Southern Hemisphere; Phuket in Thailand, which is located near the equator east of Japan; and Guam, which is located near the equator west of Japan. We calculated changes in the arrangement and elevation of the satellite constellation with time for the five locations.

We simulated the arrangement of the satellite constellation using the orbital parameters of the QZSS given in TABLE I and TABLE II [9][10] and RTKLIB software[11].

TABLE I: Quasi-zenith orbit parameters

Orbit parameter	Nominal allocation
Semimajor axis	42614 km
Eccentricity	0.075
Inclination	40 degrees
Argument of perigee	270 degrees
Right ascension of the ascending node	Block 1-Q: 117degrees Block 2-Q: 117±130 degrees
Central longitude	136 degrees

Epoch: September 1, 2025, 00:00:00 UTC

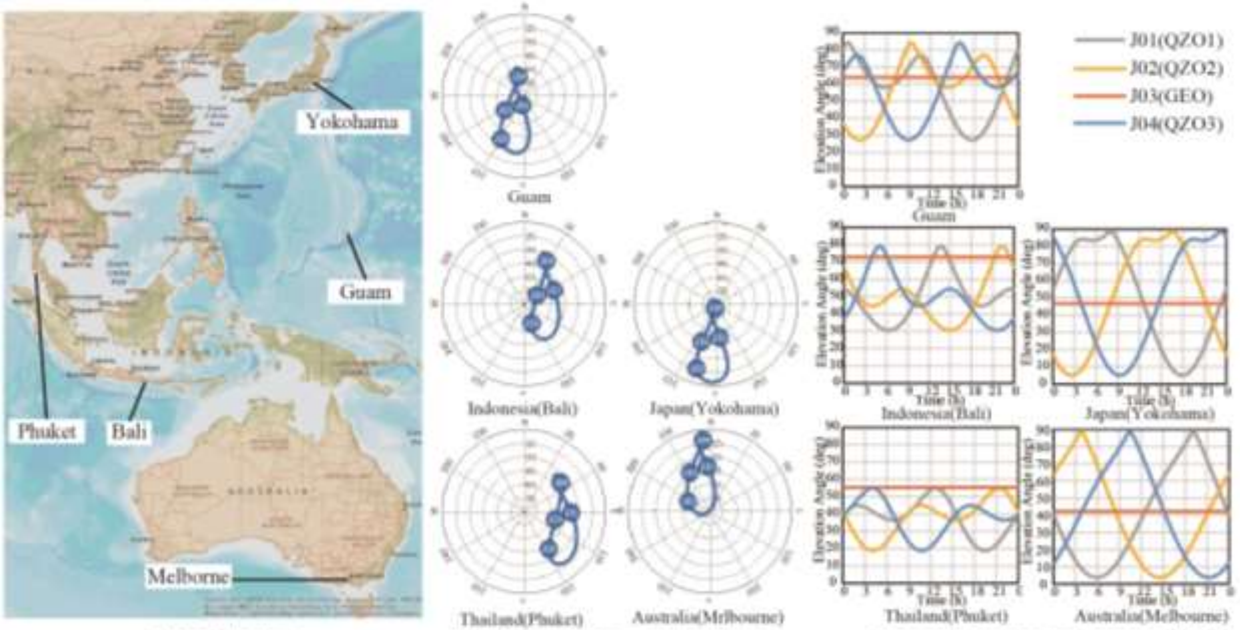
TABLE II: Geosynchronous orbit parameters

Orbit parameter	Nominal allocation
Longitude	E 127 degrees
Latitude	0 degrees

Epoch: September 1, 2025, 00:00:00 UTC

3.2. Simulation results of the QZSS constellation

Fig. 6 shows simulation results of the arrangement of the QZSS constellation as seen from each ground location and the change in elevations of the satellites over 24 hours at each location. Fig. 7 shows the changes in elevations of the highest and second-highest QZO satellites and GEO satellite with time.



a)Target locations.

b)QZSS constellations as viewed from different ground locations (Epoch: September 1, 2025, 00:00:00 UTC).

c)Temporal variations in elevations of QZSs at different ground locations (Epoch: September 1, 2025, 00:00:00 UTC).

Fig. 6: QZSS constellation and temporal variations in the elevations of highest QZSs at different ground locations. (Epoch: September 1, 2025, 00:00:00 UTC)

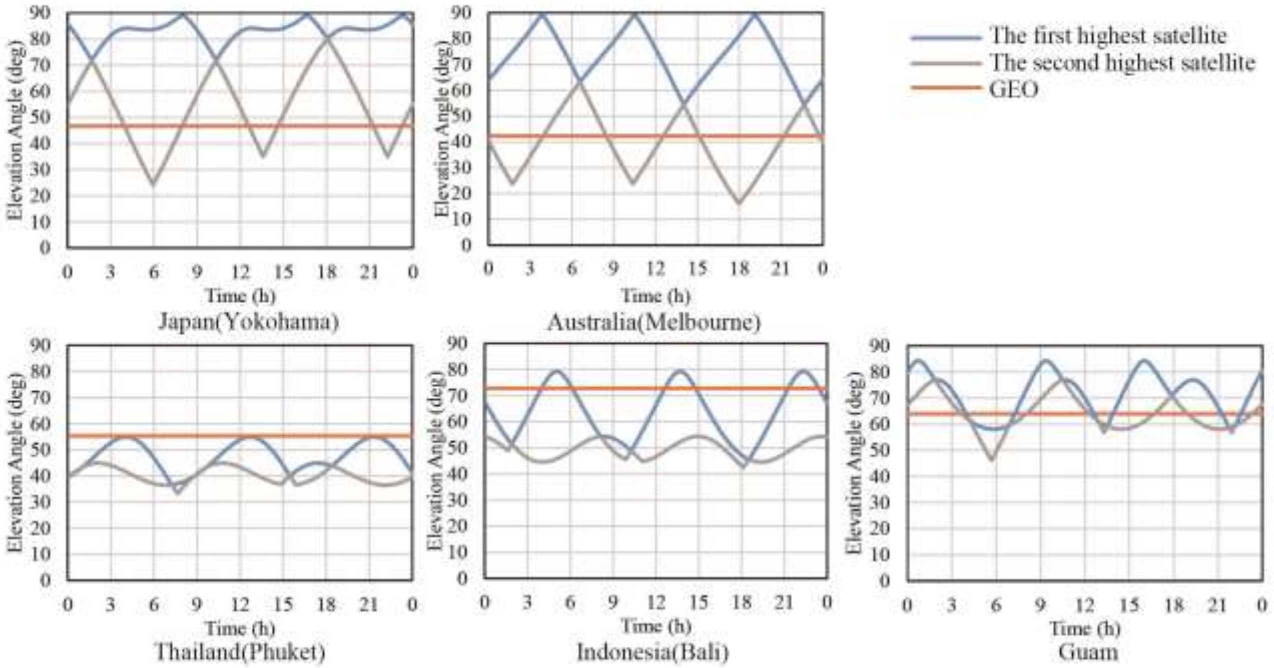


Fig. 7: Temporal variations in the elevations of highest QZSs at different locations (Epoch: September 1, 2025, 00:00:00 UTC)

3.3. Evaluation of methods of using multiple satellites

The results obtained for the QZSS constellation show that the highest QZS elevation angle is more than 70 degrees most of time in Yokohama and Melbourne. The emergency message can thus be received because of the low possibility of buildings or objects blocking the line of sight to the satellite. We previously conducted an experiment in which we received an emergency message from a high elevation angle of 81–88 degrees in Yokohama and confirmed that the emergency message is generally receivable except in a few spots such as at the side of a building in partial areas where there is an urban canyon [12]. Therefore, it would be unnecessary to ensure reachability using other satellites in time zone and areas where the satellite has a high elevation angle. At certain times, there are two satellites at elevation angles over 70 degrees in the sky above Yokohama. At those times, to advance the promptness of the delivery of information, we can focus on increasing the distribution speed of the emergency message. More specifically, we replace the distribution method used for a single satellite with a method for multiple (two) satellites each at an elevation angle higher than a set provisional angle. Which of the two satellites to employ is selected as follows. First, the satellite that has the lower waiting time in the delivery schedule is chosen. Second, if waiting times are equal, a satellite is chosen randomly. The provisional elevation angle is set as 70 degrees because one of the satellites of the QZSS is always positioned above 70 degrees in Japan. However, prescribing an elevation angle of 70 degrees strongly limits the time in which two satellites will be used in this manner. Thus, to improve the promptness of delivery, it is necessary to reduce the provisional elevation angle. However, the user may also be located in areas with high-rise buildings, which are common in Japan. Fig. 8 shows an example of overlaying the QZSS constellation and a sky image for Yokohama where high buildings are concentrated. Depending on the reception point, high buildings can block elevation angles greater than 60 degrees. At the same time, our previous experiments revealed that there are locations that cannot receive messages from a satellite having an elevation angle of 81–88 degrees [12]. Therefore, the provisional elevation angle should be set carefully by considering the situation of reception in each region.

In the case that the satellites are positioned at a lower elevation angle, there is a high possibility that signals would be blocked by buildings. However, as shown Fig. 6, each satellite is located at a different position; therefore, even though some satellites are blocked, others possibly are not. Thus, users can receive information if they can communicate with one satellite and all satellites send the same information so as to ensure the reachability of information.

Proposed method of using multiple satellites thus need to consider the following points. Using the elevation angle as a criterion, in areas where satellites are above the provisional elevation, the aim is to improve promptness by delivering different information via those multiple satellites, whereas in areas where all satellites are below the provisional elevation, the aim is to improve reachability by delivering the same information from multiple satellites simultaneously. Besides, in the case of one satellite being above the provisional elevation, the only satellite sends the information. Thus, it is not possible to improve promptness. Consequently, improve promptness is affected by the number of areas where two satellites are above the provisional elevation.

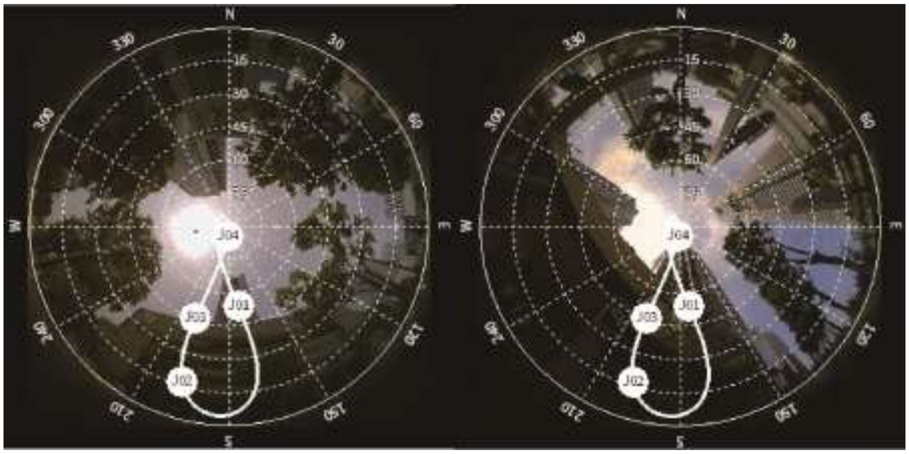


Fig. 8: Overlay of a sky image and the QZSS constellation
(Yokohama, Epoch: September 1, 2025, 00:00:00 UTC)

Hence, as a method to improve promptness, our proposal is to send different information from GEO and QZO satellites. We consider applying our method to the distribution of emergency information in response to a tsunami disaster over a wide area, such as in the event of a tsunami in the Indian Ocean. In Asia, the disaster area would be in equatorial regions. In addition, GEO satellites are positioned above the equator and thus located at high elevation angles in equatorial regions. We can improve the promptness of the delivery of information through the division of information between GEO and QZO satellites, while at the same time improving the reachability of information by delivering the same information using the three satellites in QZO, which are the components of the satellite constellation that vary over time. The number of repetitions in the distribution schedule proposed in the present research is assigned with regard to information division. In the standard case, for example, information is sent four times, twice by GEO satellites and twice by QZO satellites. The messages are sent in random order. Different emergency messages are sent by GEO and QZO satellites at the same time.

4. Evaluation of Methods of Using Multiple Satellites According to the Reception of an Emergency Message

This study proposes methods of using multiple satellites of the QZSS constellation to transmit an emergency message, where reachability and promptness are improved by distributing the same information or different information using multiple satellites. Therefore, the user receives an emergency message from multiple satellites. We need to evaluate the methods in terms of the reception of an emergency message. However, since the QZSS currently operates only one satellite, we cannot actually receive signals from multiple satellites. We thus overlaid sky images with the satellite constellation to predict the reception status. In addition, we confirmed the reception status of the emergency message under the condition that a satellite can be seen. Because the reception of an emergency message in an area where a satellite is at a high elevation angle has previously been reported [12] and a combination of four satellites of the QZSS is planned to allow communication in areas where satellites are at low elevation angles, we evaluated the proposed methods for an area in which satellites are at a low elevation, namely Phuket.

4.1. Estimate of the reception status of an emergency message and experiment on reception

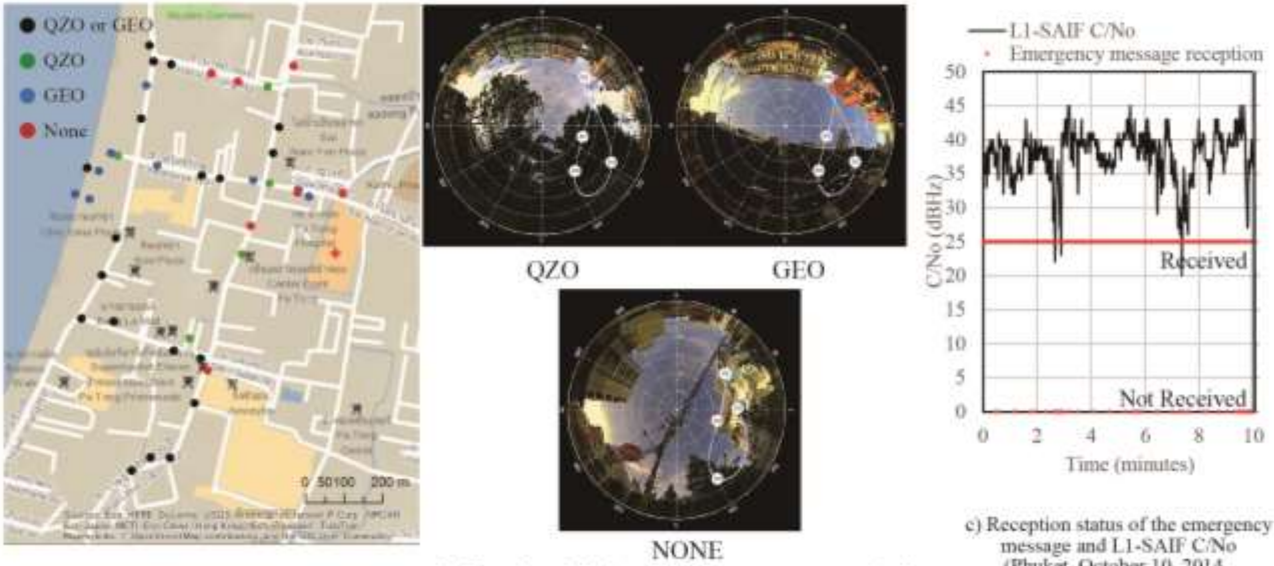
Given that the QZSS presently operates only one satellite, we cannot actually receive signals from multiple satellites. We thus took a sky image at different ground locations using a fish-eye camera (Opt, NM33-N). The sky image is overlaid with the arrangement of the satellite constellation determined using RTKLIB software [11]. We therefore evaluated the blocking of a satellite signal by buildings to estimate whether an emergency message is received by a user. We decided that is possible to receive an emergency message in the case that the line of sight to the satellite is not blocked by buildings. In the case of the QZO satellites, because the satellite constellation changes with time, we decided that a message can be received when one or more QZO satellites are not blocked by buildings at any time within a 24-hour period. The target area in this study is Phuket because the QZSs have a low elevation angle in this area.

To confirm that an emergency message can be received when a satellite can be seen, we conducted a reception experiment for an emergency message sent by the currently operational QZS and measured the loss rate of reception. The experiment was conducted in Phuket on 10 October 2014. We received the emergency message over a period of 10 minutes in an area where communication with the satellite was not blocked. During that time, the elevation angle of the QZS was 43 degrees in the test area. The interval of transmission of the emergency message was once every 2 seconds. In this experiment, we used a GNSS receiver (SONY, QZPOD) and smartphone (Google, Nexus5, OS: Android 4.4). L1 and L1-SAIF signals were received by the GNSS receiver and the emergency message was acquired from the L1-SAIF signal and the position information of the user from the L1 signal. The smartphone recorded these data.

4.2. Estimate of the reception status of the emergency message and result of the reception experiment

Fig. 9 a) shows the status of signal acquisition from the QZS expected from sky images taken in Phuket. A sky image was taken at each point in the figure, and the color of the point indicates the status of signal acquisition from the QZS. A blue plot indicates that the emergency message is received from the GEO satellite, a green point indicates that the emergency message is received from one or more QZO satellites over a period of 24 hours, a black point indicates that the emergency message is received from the GEO satellite and one or more QZO satellites at the same time, and a red point indicates the emergency message cannot be received over 24 hours. In addition, Fig. 9 b) shows an example of a sky image when messages could be received from a QZO satellite and from the GEO satellite and when a message could not be received.

Fig. 9 c) shows the reception status of the emergency message and L1-SAIF Carrier to Noise Ratio (C/No) in Phuket. The black line indicates L1-SAIF C/No and the red points indicate the reception status of the emergency message, where the receiving state is denoted “Received” and the non-receiving state “Not received”.



a) Status of signal acquisition from the QZSS in Phuket.

b) Examples of sky images when messages are received from a QZO satellite, received from the GSO satellite and not received.

c) Reception status of the emergency message and L1-SAIF C/No (Phuket, October 10, 2014, 12:00–12:10 UTC, QZS elevation of 43 degrees)

Fig. 9: Status of signal acquisition from the QZSS, example of sky images and reception status of the emergency message.

4.3. Evaluation of methods of using multiple satellites according to the reception of an emergency message

Fig. 9 c) shows that we can receive an emergency message stably from the existing QZS at an elevation of 43 degrees and that the loss rate reception is 16%. Hence, when there is line of sight to a satellite, we expect to receive emergency messages.

Fig. 9 a) shows that one or more of the four QZSs will be visible in many areas of Phuket, and it is expected that emergency messages can be received from one or more satellites in those areas. Therefore, the method proposed to improve the reachability of delivery using four satellites can be used in many places. However, there are some places where emergency messages cannot be received from any of the satellites. In those places, although the situation can be regarded as a temporary reception loss of signals if there are nearby areas where a signal can be received when users are on the move, there is the possibility that emergency messages cannot be delivered at all when signals are not received in a wide area. Therefore, in such areas, it is considered necessary to supplement the provision of disaster information to users by, for example, reemitting signals to terminal devices via antennas erected at locations where the signals can be received consistently or using a speaker with a GNSS receiver in elevated areas.

Given that the GEO satellite and one of the three QZO satellites are visible in many areas as shown in Fig. 9 a), employing the methodology proposed to improve the promptness and reachability of delivery using GEO and QZO satellites, it is expected that emergency messages can be received in those areas. However, there are areas where a signal can only be received from only the QZO satellite or GEO satellite, and these areas thus have lower reception probability. Therefore, the appropriate method should focus mainly on promptness while allowing for a decrease in reception probability in certain areas. Additionally, in areas that cannot receive signals when this method is employed, it is necessary to use supplementary techniques such as the use of speakers and reemitting signals.

As described above, the study found that although the proposed methodology of using multiple satellites in areas where satellites are at low elevation angles may require supplementary techniques in some places where signals cannot be received, from the view point of the receivability of emergency messages, using four satellites to improve the reachability of delivery is an applicable method. It also revealed that a method of using GEO and QZO satellites to improve the promptness and reachability of delivery can be used when it focuses on promptness and allows for a decrease in reception probability in areas where signals cannot be received from both types of satellites.

5. Conclusions

We examined methods of using multiple satellites to improve reachability and promptness when receiving an emergency message from the QZSS according to the arrangement and elevation angle of the QZSS constellation.

We consequently proposed a methodology of using multiple satellites to improve reachability. The methodology delivers different emergency messages via multiple satellites in areas where satellites are at high elevation to improve promptness and delivers different emergency messages via the GEO satellite and QZO satellites in areas where satellites are at low elevation. Furthermore, to examine the availability of reception when using the proposed method for multiple satellites in areas where the satellites are at low elevation, we evaluated the possible use of the proposed methodology in a reception experiment and the status of signal acquisition from the QZSS that is expected from sky images.

The study found that although the proposed method of using multiple satellites in areas where satellites are at low elevation may require supplementary techniques in some places where signals cannot be received, from the view point of the receivability of emergency messages, using four satellites to improve the reachability of delivery is an applicable method. The study also revealed that the method of using GEO and QZO satellites to improve the promptness and reachability of delivery can be employed when it focuses on promptness and allows for a decrease in reception probability in certain areas where signals cannot be received from both types of satellites.

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