

Random Access Control Scheme with Reservation Channel for Capacity Expansion of QZSS Safety Confirmation System***

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SUMMARY For capacity expansion of the Quasi-Zenith Satellite System (QZSS) safety confirmation system, frame slotted ALOHA with flag method has previously been proposed as an access control scheme. While it is always able to communicate in an optimum state, its maximum channel efficiency is only 36.8%. In this paper, we propose adding a reservation channel (R-Ch) to the frame slotted ALOHA with flag method to increase the upper limit of the channel efficiency. With an R-Ch, collision due to random channel selection is decreased by selecting channels in multiple steps, and the channel efficiency is improved up to 84.0%. The time required for accommodating 3 million mobile terminals, each sending one message, when using the flag method only and the flag method with an R-Ch are compared. It is shown that the accommodating time can be reduced to less than half by adding an R-Ch to the flag method.

key words: Quasi-Zenith Satellite System (QZSS), Global Positioning System (GPS), access control, frame slotted ALOHA, flag method, 1-bit flag, synchronized spread spectrum code division multiple access (synchronized SS-CDMA)

1. Introduction

During the Great East Japan Earthquake in 2011, much of the terrestrial communication infrastructure was destroyed in the earthquake and the tsunami. Furthermore, the infrastructure that was not damaged by the earthquake or the tsunami became unusable due to a power failure and congestion caused by a lot of requests. As a result, a lot of time was required to confirm someone's location and circumstances, thus rescue and support service could not be provided immediately. Therefore, a safety confirmation system that can be performed without a terrestrial mobile network is necessary.

After the earthquake in 2011, it has been discussed that the 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]. In the safety confirmation system, it is assumed that personal wireless terminal such as mobile phones and car navigation systems are used. For these mobile terminals (MTs), a transmission power of 1 W is necessary to realize communication

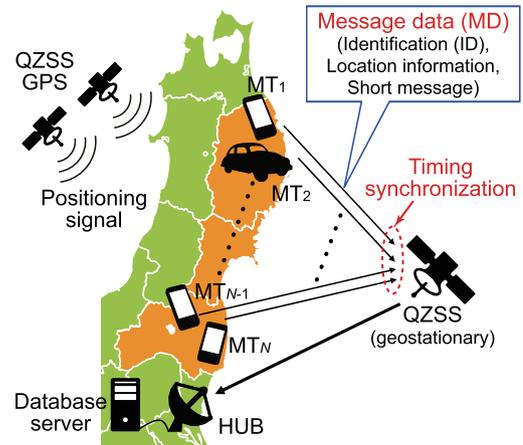


Fig. 1 Overall structure of QZSS safety confirmation system with synchronized SS-CDMA.

with the satellites, located at a distance of approximately 36,000 km away, when the MTs use low-gain non-directional antennas.

To realize this system, we have previously proposed synchronized spread spectrum code division multiple access (synchronized SS-CDMA) [2]–[10]. In the synchronized SS-CDMA, long spreading codes are used for SS to ultra wideband in order to get high spreading gain and to realize direct communication between the MT and the satellite. Furthermore, it is possible to accommodate messages from many MTs at high density by utilizing orthogonal code for CDMA in the uplink. Generally, the CDMA scheme demands precise transmit power control to suppress inter-code interference. Because it needs a fast feedback control channel, satellite communication systems with a large number of terminals has difficulty with adopting the CDMA scheme, as satellite communication suffers from long round trip delays. SS-CDMA mitigates this issue by means of the orthogonal code as a spreading code and achieves high-density uplink transmission.

Figure 1 shows an overall structure of the QZSS safety confirmation system using synchronized SS-CDMA. MTs send message data (MD) to a database server via satellite and a hub station (HUB). The satellite operates as a relay between the MT and the HUB. The MD includes unique identification data (ID), location information, and a short message of the individual's circumstances. In order to realize quick safety confirmation, it is necessary to accommodate MD sent from

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a large number of MTs (3 million or more [1]) within a limited time. Since most of the uplink (from MT to satellite) and downlink (from satellite to MT) bandwidth is used as a data channel, low bandwidth is assigned as a control channel. Moreover, there is a long round-trip time (RTT) condition of approximately 0.48 s due to the distance between the satellite and MT (or HUB) of approximately 36,000 km.

It is well-known that the ALOHA-based random access method performs well for satellite communication systems, radio frequency identifier (RFID) systems, and initial link establishment of the mobile communication system. Especially, CDMA slotted ALOHA [11]–[13] has been proposed and evaluated for satellite packet communication and other tasks. In order to optimize the communication capacity of the ALOHA-based system, it is important to estimate the number of MTs that wish to communicate. However, it is difficult to realize optimized random access by using the conventional method since it is assumed that a massive number of terminals request access at the same time during big disasters.

Therefore, we have previously proposed a large-capacity QZSS safety confirmation system using frame slotted ALOHA with flag method [2], [3]. By applying the flag method, it can always communicate in an optimum state that yields maximum channel efficiency. However, the maximum channel efficiency is 36.8%, which means that more than half of all MTs must retransmit their MD. Although reservation ALOHA (R-ALOHA) [14]–[16] has been proposed for improving the upper limit of the channel efficiency, it has difficulties to improve the throughput of R-ALOHA because of the long RTT and the massive number of MTs.

In this paper, we propose an access control scheme with a reservation channel (R-Ch) to improve the upper limit of the channel efficiency for the QZSS safety confirmation system using synchronized SS-CDMA. The R-Ch is a control channel that uses bandwidth from the data channel spectrum. By computer simulation, we evaluated the time to accommodate 3 million MTs, when each MT sends one piece of MD. We obtain that the proposed scheme improves the channel efficiency.

This paper is organized as follows. In Sect. 2, the conventional access control scheme with flag method is explained. In Sect. 3, the proposed access control scheme with R-Ch is explained. In Sect. 4, the time required to accommodate MTs for the frame slotted ALOHA with flag method is evaluated. Finally, the conclusions are given in Sect. 5.

2. Access Control Scheme for QZSS Safety Confirmation System

2.1 QZSS Safety Confirmation System

Table 1 shows an assumed condition of the QZSS safety confirmation system with synchronized SS-CDMA. In this paper, the satellite's altitude is 35,786 km because the satellite is assumed to be in a geostationary earth orbital satellite. The system uses the S band between MTs and the satellite and

Table 1 Condition of the QZSS safety confirmation system with synchronized SS-CDMA.

	Altitude	35,786 km
Use band	MT \leftrightarrow satellite	S band, FDD
	satellite \leftrightarrow HUB	Ku band, FDD
	Transmit power of MT	1 W (30 dBm)
	Length of spread code	10,000
	Packet length of MD	300 bits
	Chip rate	1 Mchip/s
	Bit rate	100 bit/s
	The target capacity per hour	3 million or more MT

the Ku band between the satellite and the HUB. Frequency division duplex (FDD) is used between MTs and the satellite, and is also used between the satellite and the HUB. The transmission power of each MT is 1 W. The packet length of the MD is 300 bits. The MD packet includes ID, location information, and a short message. Location information consists of latitude, longitude and height. The number of bits for latitude, longitude and height is 33, 34 and 22 bits, respectively. This gives a high position resolution of better than 2 m in the horizontal and vertical direction. ID is 28 bits. The short message is 160 bits. Remaining 23 bits are check digits. The length of the spread code is 10,000 and the chip rate is 1 Mchip/s; therefore, the bit rate is 100 bit/s. The target capacity per hour is 3 million MD or more.

In addition, the proposed system assumes that the MT and satellite timing is synchronized by using synchronized SS-CDMA [4], [5], [7]–[10]. The MTs have synchronized clocks with a precision of order 50 ns by using highly accurate QZSS and the Global Positioning System (GPS) positioning signals [7]–[10]. Since the MTs can estimate the distance to the satellite by receiving QZSS and GPS positioning signals, MTs can send their signals to the satellite with timing lag taken into consideration. Therefore, the received signal of the satellite is synchronized with less than 50 ns order precision.

Highly accurate timing and frequency synchronization among all MTs is the most important issue for the synchronized SS-CDMA to provide high-density multiple access using long spreading codes in the uplink. We have previously evaluated the synchronization accuracy necessary to achieve nearly 100% of the accommodation rate in the synchronized SS-CDMA by computer simulation. As a result, the timing accuracy required to achieve a 1% packet error rate was nearly equal to 56 ns [5].

2.2 Access Control Scheme Using Frame Slotted ALOHA with Flag Method

Figure 2 shows a frame slotted ALOHA with CDMA using time synchronization. Figure 2(a) shows a time structure of the frame slotted ALOHA. A frame structure of the frame slotted ALOHA with CDMA using time synchronization is shown in Fig. 2(b). The frame is constructed from the L time slots and S CDMA channels that are identified with a spreading code. The number of CDMA channels S is constant for a system, whereas the time slots L is variable

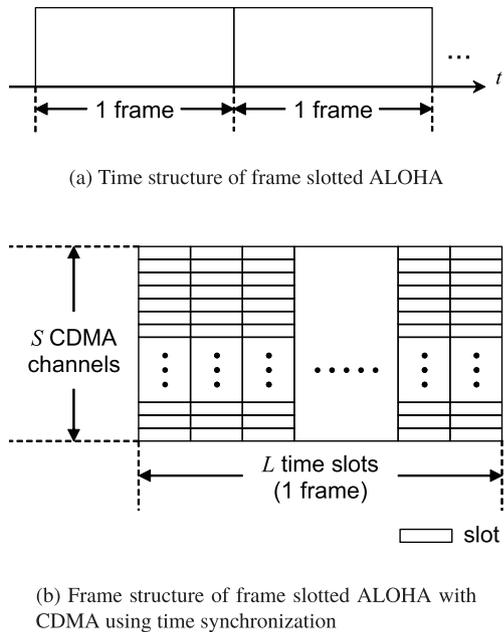


Fig. 2 Frame slotted ALOHA with CDMA using time synchronization.

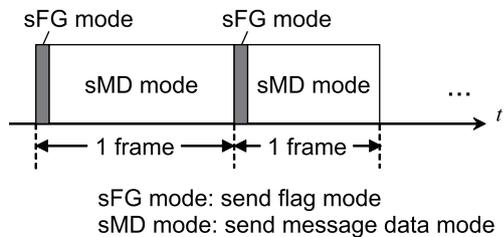


Fig. 3 Frame slotted ALOHA with flag method.

depending on how many of the MTs that are active. Each MT selects a channel and a time slot randomly, and then transmits the MD. Each MT will transmit their MD only once per frame. Under this condition, the channel efficiency of frame slotted ALOHA is maximized when it satisfies Eq. (1),

$$SL = N, \tag{1}$$

where N is the number of MTs that wish to communicate in a frame. Worth to note is that the time required for each MT to have their data sent, the completion time, is expected to be longer than the time elapsed during L time slots. The reason is that it is difficult to satisfy Eq. (1) because the HUB can not know the number of MTs that request to send MD.

We have previously proposed flag method to provide a control channel in order to estimate the number of MTs that desire to send the MD [2], [3]. Figure 3 shows a frame slotted ALOHA with flag method [17]–[19]. The flag method has two modes, send flag mode (sFG mode), where time is allocated to send control data, and send message data mode (sMD mode), where time is allocated to sending MD.

Figure 4 shows an exchange of signals in sFG mode. In sFG mode, the HUB sends a control signal (sFG) to estimate

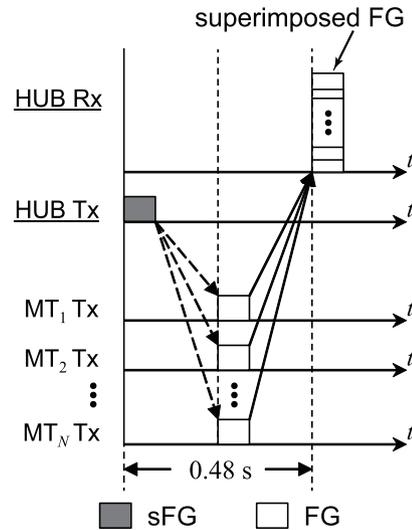


Fig. 4 Exchange of signals in sFG mode.

the number of MTs. MTs send a 1-bit flag signal (FG). The HUB receives the superimposed FG from MTs and estimates the number of MTs by measuring the received total power of FGs.

In sMD mode, the HUB optimizes the number of slots per frame L by the estimated number of MTs. Since the ID numbers are evenly distributed among MTs, and since it is a random process as to which MTs that will want to send data, each time slot will on average have an equal number of MTs. Therefore, the HUB can communicate in a state of optimum throughput by controlling the timing that each MT sends their MD.

3. Proposed Access Control Scheme with Reservation Channel (R-Ch)

3.1 Procedure of Access Control with R-Ch

Although the HUB can communicate in an optimum state by using flag method, more than half of the MTs must retransmit their MD due to the low channel efficiency of 36.8%, which is the optimum channel efficiency with slotted ALOHA [20]. This low channel efficiency results from the collision among users with random channel selection. To address this issue, it is necessary to suppress the duplication in channel selection to improve the channel efficiency. We propose an access control scheme using an R-Ch. Figure 5 shows a frame slotted ALOHA using flag method with an R-Ch. The R-Ch uses a part of the sMD mode and serves as a control channel for slot reservation.

The access scheme using an R-Ch is divided into two steps, the reservation phase and transmission phase, in sMD mode. In the reservation phase, each MT reserves a channel to send their MD. In the transmission phase, each MT sends their MD using their reserved channel.

Figure 6 shows a behavior of the reservation phase. Firstly, a multiple access group of MTs is divided into some

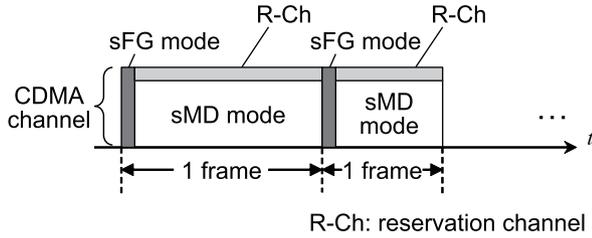


Fig. 5 Frame slotted ALOHA using flag method with an R-Ch.

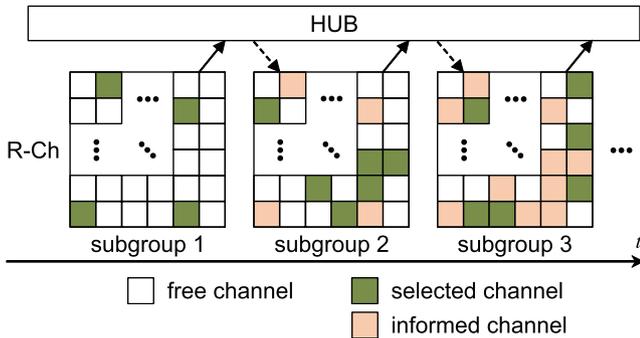


Fig. 6 Behavior of reservation phase.

subgroups. Secondly, channel reservation is performed in a subgroup, and the result sent to the HUB. Thirdly, MTs in the next subgroup select a channel based on the vacant channel information from HUB. The purpose of dividing the access group is to reduce the collision probability of R-Ch. In the reservation of subgroup 1 in Fig. 6, sufficiently many channels are prepared for a small number of MTs. Hence, the collision probability decreases significantly compared with the case where they are not divided. In the reservation of subgroup 2, the MTs receive information of the vacant channels after the reservation of the subgroup 1, so there is no collision between the subgroups 1 and 2. Moreover, even in the reservation of subgroup 2, the collision probability between MTs of subgroup 2 is low since sufficiently many channels are prepared for a small number of MTs. By repeating this, it is possible to suppress the collision due to random channel selection. Therefore, channel efficiency will be improved. In this scheme, the HUB does not have to identify the ID of each MT, and only has to know the reserved channels. Therefore, it can be realized by a very simple control.

Figure 7 shows a flowchart of the control algorithm employed by the HUB. At first, the HUB estimates the number of MTs by using the flag method. The HUB then updates the number of time slots L . After this, the HUB executes the reservation phase and the transmission phase of sMD mode. The following shows the flow from the start to the end of the communication. The numbers n) in the following description correspond to those in Fig. 7.

- 1) The HUB broadcasts the control signal of sending FG.
- 2) MTs that want to send their MD reply with the FG signal.
- 3) The HUB estimates the number of MTs from the total power of received FGs.

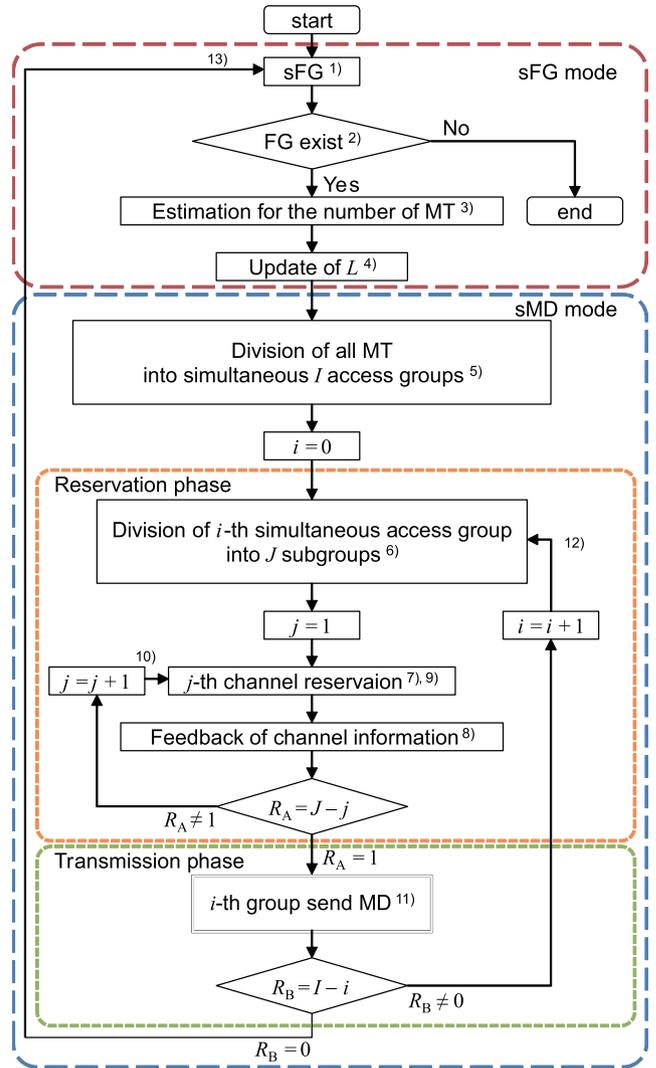


Fig. 7 Flowchart of the control algorithm employed by the HUB. This flowchart shows procedure from the start to the end of the communication.

- 4) The HUB updates L using the estimated number of MTs.
- 5) The HUB divides MTs into I multiple access groups.
- 6) The HUB divides each multiple access group into J subgroups.
- 7) For each subgroup, the MTs reserve a channel in order from the first subgroup.
- 8) The HUB aggregates the reservation state, and then broadcasts the information of vacant channels for next subgroup.
- 9) MTs in the next subgroup select and reserve channels based on the vacant channel information from the HUB.
- 10) 8) and 9) are repeated until $(J - 1)$ subgroups complete the reservation.
- 11) MTs that complete the reservation send their MD using the reserved channel. MTs in the J -th subgroup send their MD over the remaining vacant channels directly, without channel reservation.
- 12) 6)-11) are repeated until all MTs in the multiple ac-

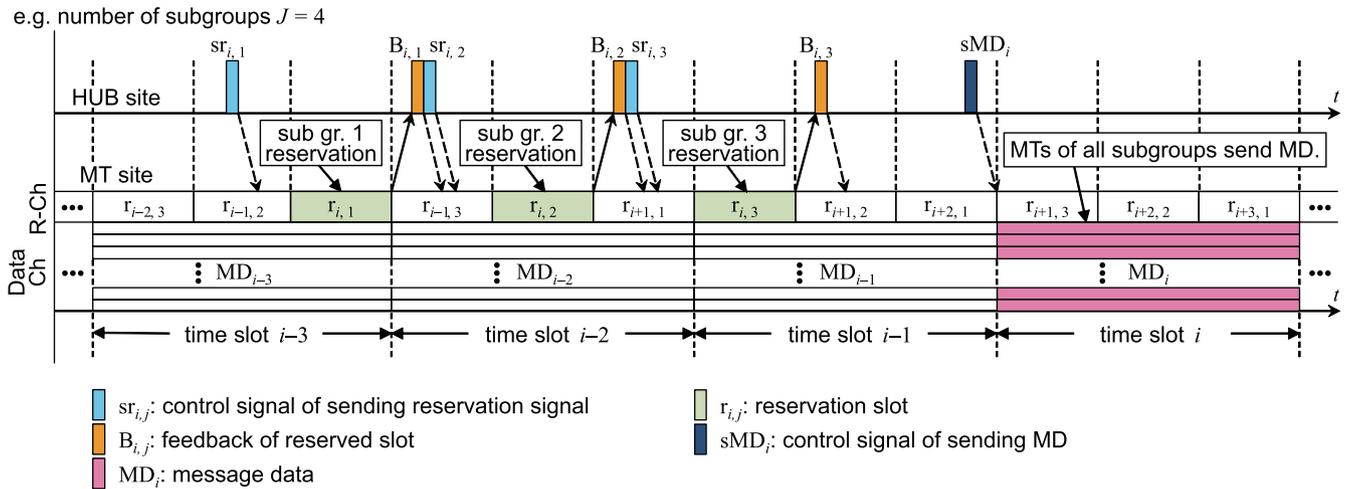


Fig. 8 Flow from the reservation phase to the transmission phase. This flow shows the case of the number of subgroups $J = 4$.

command type: sr	multiple access group #: i	subgroup #: j	reception start time on the satellite: t
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(a) Control signal of sending reservation signal ($sr_{i,j}$)

command type: sMD	multiple access group #: i	reception start time on the satellite: t
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(b) Control signal of sending MD (sMD_i)

Fig. 9 Structures of the control signals.

cess group complete sending their MD.

- 13) Returning to 1), and the above steps are repeated until the response to the control signal of sending their MD disappears.

The selected channel information aggregated into the HUB is used only to provide the vacant slot information to MTs of next subgroups. Since no MTs use the feedback of the last (J -th) subgroup, MTs in the last subgroup only perform the transmission phase. The MTs that failed to receive the a flag of acknowledgement (ACK) are retried with the next SFG mode.

Figure 8 shows a flow from the reservation phase to the transmission phase in the case of the number of subgroups $J = 4$. Since the RTT affects the feedback of the vacant channels, it is necessary to consider its influence. In this case, three subgroups per one time slot reserve the channel. Figure 9(a) shows a structure of sending a reservation signal $sr_{i,j}$. The signal $sr_{i,j}$ includes the multiple access group number i , subgroup number j , and reception start time information of the satellite. Note to MD_i in the time slot i of Fig. 8, the first subgroup reserves channels in $r_{i,1}$. Using the feedback, the second subgroup reserves channels in $r_{i,2}$. Similarly, the third subgroup reserves channels in $r_{i,3}$. In time slot i subgroup 1-3 send their MD using the reserved channel. The fourth subgroup selects channels from the va-

cant channels, and then sends their MD. Thus, duplication in the channel selection can be reduced.

The MTs control the transmission timing of MD so that the MD reaches the satellite synchronized at the notified timing from HUB. The transmission timing of MD is controlled based on two type signals: (1) a control signal for slot time informing from HUB, and (2) highly accurate timing and positioning information obtained from QZSS and GPS. The control signal of MD_i from HUB is written as sMD_i in Fig. 8. Figure 9(b) shows a structure of sending MD. The signal sMD_i includes the multiple access group number i permitted to transmit MD and reception start time information of the satellite. By using highly accurate timing and positioning information obtained from QZSS and GPS, the stricter transmission timing of MD is controlled as in the following steps [2]–[10]. Firstly, the clock of MT is synchronized with highly accurate timing information obtained from the QZSS and GPS signal. Secondly, the MT calculates the distance between the MT and the satellite using highly accurate position information obtained from the QZSS and GPS signal. Finally, the MD is transmitted at the time considering the latency due to the distance from the MT to the satellite. As a result, the MDs of the multiple access group arrive at the satellite in synchronization with the reception start time of the satellite.

3.2 The Number of Required R-Ch

As shown in Fig. 5, a part of the data channel is allocated to the R-Ch. Figure 10 shows a percentage of R-Ch to the data (CDMA) channel in the case where $(J - 1)$ subgroups perform reservation per time slot. In Fig. 10, the number of data channels including R-Ch is 10,000, the length of the MD packet is 300 bits, and the data rate is 100 bit/s. Therefore, one time slot is 3 s. The 1-bit flag signal is used for channel reservation, and is spread by using a spread code in the R-Ch. Since $(J - 1)$ subgroups reserve channels per time slot, the time to be allocated to each subgroup is

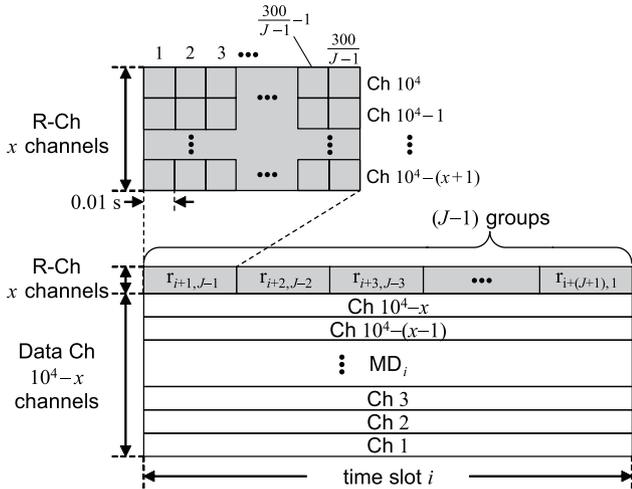


Fig. 10 Percentage of R-Ch to the data channel.

$300/(J-1)$. The number of reservation channels that are available per time slot is $300x/(J-1)$, where x is the number of CDMA channels for the R-Ch. Since the reservation channel equals to the number of channels which are used for data transmission, it is necessary to satisfy the following,

$$\frac{300x}{J-1} = 10000 - x. \quad (2)$$

From Eq. (2), x is as follows,

$$x = \left\lceil \frac{10000(J-1)}{300+J-1} \right\rceil, \quad (3)$$

where $\lceil a \rceil$ is defined as the smallest integer that is greater or equal to a . When each multiple access group is divided into 4 ($= J$) subgroups, that is when 3 ($= J-1$) subgroups reserve channels, $x = 100$. Thus the number of channels for the R-Ch depends on the number of subgroups. However, since the number of subgroups is assumed to be 32 at most, the occupancy of R-Ch is less than 10% (See Fig. 11 in detail).

3.3 Theoretical Value of Channel Efficiency

In this subsection, we find the theoretical value of channel efficiency per time slot in each number of subgroups. Since MTs in the same subgroup select a channel randomly in vacant channels in $r_{i,j}$ shown in Fig. 10, the protocol is the same as slotted ALOHA. The percentage of T_j to c_j can be considered as the throughput T , where T_j is the number of MTs that could select a channel without duplication in the j -th subgroup and c_j is the number of vacant channels. The theoretical formula of the throughput T of slotted ALOHA is used to a calculation of the theoretical value [20]:

$$T = \frac{T_j}{c_j} = G_j e^{-G_j} \quad (4)$$

From Eq. (4), T_j is as follows,

$$T_j = G_j e^{-G_j} c_j, \quad (5)$$

where G_j is the traffic in the j -th subgroup that is determined by Eq. (6),

$$G_j = \frac{N_j}{c_j}, \quad (6)$$

where N_j is the number of MTs of j -th subgroup. Average of N_j is equal to N/IJ . In order to calculate the number of duplicate channels easily, three or more MTs are decided not to select the same channel. Therefore, the number of duplicate channels in the j -th subgroup F_j is as follows,

$$F_j = \left\lceil \frac{N_j - T_j}{2} \right\rceil. \quad (7)$$

The number of channels used in the j -th subgroup is the sum of the number of channels without duplication (same as the number of MTs that could select a channel without duplication) and the number of duplicate channels. Therefore, the number of channels used in the j -th subgroup is $T_j + F_j$. The information of the channel used is fed back to next subgroup, and then c_j is updated:

$$c_j = c_{j-1} - (T_{j-1} + F_{j-1}) \quad (8)$$

The number of channels that the first subgroup can reserve is the total number of channels S minus the number of channels used for the R-Ch, $c_1 = S - x$. The channel efficiency in the i -th time slot C is the percentage of the number of MTs that succeed in transmitting divided by the total number of channels S . This is obtained by the Eq. (9),

$$C = \frac{1}{S} \sum_{j=1}^J T_j = \frac{1}{S} \sum_{j=1}^J G_j e^{-G_j} c_j. \quad (9)$$

When calculating the theoretical value, the number of MTs in the multiple access group was decided to be equal to the number of channels for data channel c_1 . The number of subgroups J were decided to be 2, 4, 8, 16, 32, and 64, since dividing MTs into subgroups of the power of 2 can be easily realized by classifying it with specific bits of ID (28 bit). For example, in the case of $J = 4$, the MTs are divided into 4 subgroups of "00", "01", "10" and "11" by the specific two bits of each ID. Assuming that these bits are allocated evenly, the four subgroups are expected to contain an equal number of terminals.

Figure 11 shows a theoretical value of channel efficiency in each subgroup that is obtained by using Eqs. (4)–(9). When the number of subgroups increase, the channel efficiency will be improved. This is because the duplication between subgroups is suppressed. However, the channel efficiency degrades after the peak of 83.2% calculated at $J = 32$. This is because for more subgroups to be set, the data channel has to allocate more slots for the reservation channel and end up with fewer slots for data transmission. Accordingly, the best channel efficiency is obtained at $J = 32$.

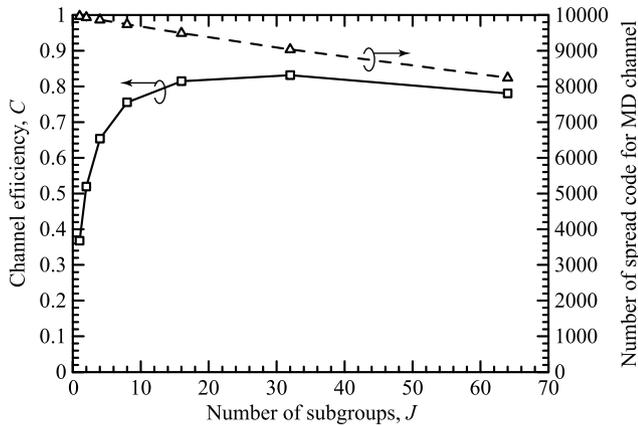


Fig. 11 Theoretical channel efficiency and number of spread code for MD channel.

Table 2 Simulation condition.

Total number of MT (N)*	300,000
Number of CDMA channel (S)*	1,000
Bit rate	100 bit/s
Bit per MD packet	300
Number of subgroup (J)	2, 4, 8, 16, 32
Round-trip time (RTT)	0.48 s

* They are scaled to 1/10 to shorten the calculation time.

4. Evaluation of Proposed Access Control Scheme with R-Ch

4.1 Simulation Condition

Table 2 shows a simulation condition. Originally, the number of MTs was 3 million and the length of the spread code was 10,000, but in order to shorten the calculation time, they were scaled to 1/10 (* in Table 2). Each MT is decided to send one MD. MTs that succeed with data transmission receive ACK, and thereafter stops generating traffic. MTs that receive no ACK will try to retransmit their MD in the next frame. In this simulation, the time to accommodate all MTs that desire to send MD is evaluated. The channel efficiency of each time slot is also evaluated. The number of time slots was decided to be 2, 4, 8, 16, 32, and 64. If the number of time slots of the frame I becomes smaller than the number of subgroups J , resources required for reservation will be insufficient. Hence, in this simulation, when I becomes smaller than J , the HUB stops using the R-Ch and operates only by the flag method. All signals sent from MTs are decided to be received without error.

4.2 Channel Efficiency and Accommodating Time

Figure 12 shows simulation results of channel efficiency when only flag method was used and when flag method with an R-Ch was used. The vertical axis indicates the channel efficiency, and the horizontal axis indicates the lapse time from the start. The triangles represent the average accommodating time. Those results are the average of simulations

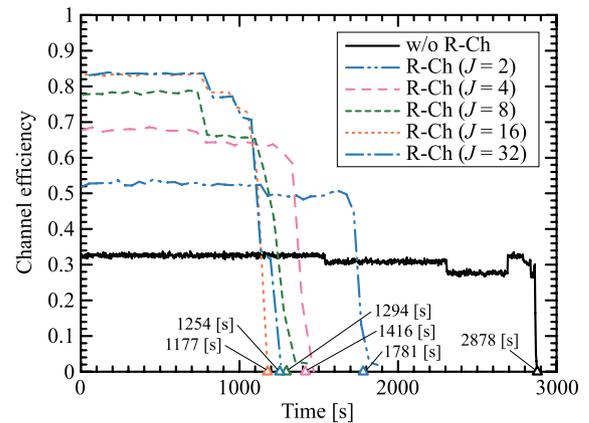


Fig. 12 Channel efficiency and average accommodating time by computer simulation.

performed 30 times. There are some stepwise variations observed in Fig. 12 despite having performed the simulation 30 times. The reason is that the initial number of MTs is fixed at 300,000. By fixing the number of MTs, there is a fixed bias in the number of subgroups and the number of slots in each trial. The channel efficiency improves as the number of subgroups is increased, and tend to be same as the theoretical value shown in Fig. 11. As the channel efficiency improves the accommodating time is shortened. Since the channel efficiency is 83.9% at $J = 16$ and 84.0% at $J = 32$, $J = 32$ is the best. In contrast, since the accommodating time is 1,177 s (19 minutes 37 seconds) at $J = 16$ and 1,254 s (20 minutes 54 seconds), $J = 16$ is the shortest. This is because if the number of time slots of the frame I becomes smaller than J , the flag method is the only method to be performed. Assuming that I is the same, the suspension timing of R-Ch is faster when J is large than when J is small. Hence, in the case of large J , there are many MTs that wish to communicate even after the use of R-Ch has stopped. Compared with the case of using R-Ch, the throughput when using only the flag method deteriorates (the maximum channel efficiency of 36.8%), so the accommodation time will increase after the suspension timing of R-Ch. In the condition of Fig. 12, it is seen that the influence of throughput degradation by using only the flag method is significant for $J = 32$ or more. From the above results, the accommodating time is seen to be the shortest in the case of $J = 16$. Comparing to the case with no reservation channel it is seen that the accommodating time can be reduced to less than half.

4.3 Accommodating Time Considering Packet Error Rate (PER)

In the condition of PER 1% [5], there are some MTs that do not succeed in packet transmission due to packet error. The MTs that failed to receive the ACK are retried with the next sFG mode. The increase in the accommodation time because of this retransmission is calculated as 1.4% in the case of $J = 16$ of Fig. 12. The details are as follows.

In the case of $J = 16$ of Fig. 12, since the channel effi-

ciency is 81.9% in the first frame, the rate of communication failure due to random access is 18.1%. Considering PER, the rate of communication failure increases by 0.8% to 18.9%.

In the second frame, the number of MTs requesting communication increases by 4.4% by considering PER. In the third and subsequent frames, same as in the second frame, it is also assumed that the accommodation time increases by 4.4%. This increment of the number of MTs simply influences the increase of the accommodating time. From Fig. 12, the accommodating time required for the second and subsequent frames without considering PER is 407 s, that is excluding the time of first frame 770 s from the total accommodating time 1177 s. Considering PER, the accommodating time required for the second and subsequent frames increases by 18 s (4.4% of 407 s). Since the increment accommodating time of 18 s is 1.4% for the whole accommodating time, the influence of increase in accommodation time considering PER is negligibly small.

5. Conclusion

In this paper, we have proposed an access control scheme with a reservation channel (R-Ch) for the Quasi-Zenith Satellite System (QZSS) safety confirmation system. The channel efficiency and the accommodating time using the flag method with an R-Ch has been evaluated. By selecting channels in multiple steps, packet collisions among subgroups are suppressed, and it is possible to improve the channel efficiency significantly. By computer simulation, a channel efficiency of 84.0%, a value that matches the theoretical value, has been confirmed. With the proposed method the accommodating time is reduced to less than half. This makes it possible to accommodate 3 million MTs within approximately 20 minutes, when the number of subgroups is 16.

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References

- [1] Cabinet Office, Government of Japan, Performance Standard (PS-QZSS) and Interface Specification (IS-QZSS), <http://qzss.go.jp/en/technical/ps-is-qzss/ps-is-qzss.html>, accessed April 13th, 2018.
- [2] T. Takahashi, Y. Miyake, F. Yamagata, H. Oguma, S. Kameda, N. Suematsu, T. Takagi, and K. Tsubouchi, "Large-capacity QZSS location and short message system using frame slotted ALOHA with flag method," 24th Annual IEEE Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2013), pp.3280–3285, Sept. 2013. DOI: 10.1109/PIMRC.2013.6666713
- [3] T. Takahashi, Y. Miyake, S. Kameda, A. Taira, F. Yamagata, H. Oguma, N. Suematsu, T. Takagi, and K. Tsubouchi, "QZSS short message SS-CDMA communication system: High efficient access control scheme using flag signal," IEICE Trans. Commun. (Japanese Edition), vol.J97-B, no.11, pp.1096–1105, Nov. 2014.
- [4] A. Taira, Y. Miyake, S. Kameda, N. Suematsu, T. Takagi, and K. Tsubouchi, "System stability of SS-CDMA location and short message communication using QZSS," Asia-Pacific Microwave Conference 2014 (APMC 2014), pp.947–949, Nov. 2014.
- [5] Y. Miyake, A. Taira, S. Kameda, H. Oguma, N. Suematsu, T. Takagi, and K. Tsubouchi, "Transmit performance with timing and frequency error of QZSS SS-CDMA short message communication system," IEICE Trans. Commun. (Japanese Edition), vol.J98-B, no.4, pp.397–405, April 2015.
- [6] K. Ohya, T. Takahashi, S. Kameda, H. Oguma, A. Taira, N. Suematsu, T. Takagi, and K. Tsubouchi, "Efficient random access control scheme with reservation channel for QZSS short message SS-CDMA communication," IEEE Wireless Communications and Networking Conference 2016 (WCNC 2016), pp.2611–2616, April 2016. DOI: 10.1109/WCNC.2016.7565147
- [7] K. Ohya, S. Kameda, H. Oguma, A. Taira, N. Suematsu, T. Takagi, and K. Tsubouchi, "Experimental evaluation of timing synchronization accuracy for QZSS short message synchronized SS-CDMA communication," IEEE 27th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2016), pp.493–498, Sept. 2016. DOI: 10.1109/PIMRC.2016.7794636
- [8] K. Ohya, S. Kameda, H. Oguma, and N. Suematsu, "Experimental evaluation of transmission timing control method for QZSS short message synchronized SS-CDMA communication," 2017 9th International Conference on Ubiquitous and Future Networks (ICUFN 2017), pp.361–366, July 2017. DOI: 10.1109/ICUFN.2017.7993809
- [9] S. Kameda, K. Ohya, H. Oguma, and N. Suematsu, "QZSS short message synchronized SS-CDMA communication," 2017 International Conference on Solid State Devices and Materials (SSDM 2017), pp.341–342, Sept. 2017 (invited).
- [10] R. Kawai, H. Oguma, S. Kameda, and N. Suematsu, "Construction of transmission timing control system using FPGA for QZSS short message synchronized SS-CDMA communication," 8th International Conference on ICT Convergence 2017 (ICTC 2017), pp.218–223, Oct. 2017. DOI: 10.1109/ICTC.2017.8190972
- [11] R.K. Morrow, Jr. and J.S. Lehnert, "Packet throughput in slotted ALOHA DS/SSMA radio systems with random signature sequences," IEEE Trans. Commun., vol.40, no.7, pp.1223–1230, July 1992. DOI: 10.1109/26.153367
- [12] D. Makrakis and K.M.S. Murthy, "Spread slotted ALOHA techniques for mobile and personal satellite communication systems," IEEE J. Sel. Areas Commun., vol.10, no.6, pp.985–1002, Aug. 1992. DOI: 10.1109/49.144885
- [13] M. Saito, H. Okada, T. Sato, T. Yamazato, M. Katayama, and A. Ogawa, "Throughput improvement of CDMA slotted ALOHA systems," IEICE Trans. Commun., vol.E80-B, no.1, pp.74–80, Jan. 1997.
- [14] W. Crowther, R. Rettberg, D. Walden, S. Ornstein, and F. Heart, "A system for broadcast communication: Reservation-ALOHA," Proc. 6th Hawaii International Conference on System Sciences (HICSS), Jan. 1973.
- [15] S.S. Lam, "Packet broadcast networks — A performance analysis of the R-ALOHA protocol," IEEE Trans. Comput., vol.COM-29, no.7, pp.596–603, July 1980. DOI: 10.1109/TC.1980.1675630
- [16] S. Tasaka, "Stability and performance of the R-ALOHA packet broadcast system," IEEE Trans. Comput., vol.COM-32, no.8, pp.717–726, Aug. 1983. DOI: 10.1109/TC.1983.1676309
- [17] S. Kameda, A. Yamaguchi, S. Fukuyo, H. Oguma, H. Nakase, T. Takagi, and K. Tsubouchi, "High-speed and large-capacity RFID inventory method using 1-bit flag," 3rd International Symposium on Wireless Communication Systems (ISWCS2006), Sept. 2006. DOI: 10.1109/ISWCS.2006.4362363
- [18] S. Kameda, A. Yamaguchi, S. Fukuyo, H. Nakase, T. Takagi, and K. Tsubouchi, "High-speed RFID inventory method using 1-bit flag," IEICE Trans. Fundamentals (Japanese Edition), vol.J89-A, no.12, pp.1057–1067, Dec. 2006.
- [19] S. Kameda, S. Fukuyo, A. Yamaguchi, H. Oguma, H. Nakase, T. Takagi, and K. Tsubouchi, "Evaluation of high-speed and large-capacity RFID inventory method using 1-bit flag," 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC2007), Sept. 2007. DOI:

10.1109/PIMRC.2007.4394251

- [20] L.G. Roberts, "ALOHA packet system with and without slots and capture," *ACM SIGCOMM Comput. Commun. Rev.*, vol.5, no.2, pp.28–42, April 1975. DOI: 10.1145/1024916.1024920



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