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KASS Message Scheduler Design

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ABSTRACT

The Korea Augmentation Satellite System (KASS), which is under development in Korea as a Satellite Based Augmentation System (SBAS) is expected to broadcast SBAS messages to air space in Korea according to the international standards defined by the International Civil Aviation Organization (ICAO) and the Radio Technical Commission for Aeronautics (RTCA). Around 13 SBAS messages are broadcast in every second to transmit augmentation information which can be applicable to a wide area in common. Each of the messages requires a different update interval and time-out according to the characteristics, purpose, and importance of transmitted information, and users should receive and combine multiple SBAS messages to calculate SBAS augmented information. Thus, a time to take acquiring first SBAS position by users differs depending on broadcasting various SBAS messages with which order and intervals. The present paper analyzes the considerations on message scheduling for broadcasting of KASS augmentation information and proposes a design of KASS message scheduler using the considerations. Compared to existing SBAS systems, which have a wide range of service area, a service area of the KASS is limited to Korea only. Thus, the numbers of ionosphere grid points and satellites to be augmented are expected to be smaller than those of existing SBAS. By reflecting this characteristic to the proposed design, shortening of broadcast interval of KASS message is verified compared to existing SBAS and a measure to increase a speed of acquisition of user navigation solution is proposed utilizing remaining message slots. The simulation result according to the proposed measure showed that the maximum broadcast interval can be reduced by up to 20% compared to that of existing SBAS, and users can acquire KASS position solution faster than existing SBAS.

Keywords: KASS, SBAS message, scheduler, time to first fix

1. INTRODUCTION

A Satellite Based Augmentation System (SBAS) is an augmentation system that broadcasts information needed to ensure integrity to correct errors of measurements from arbitrary receivers located over a large range of areas. In contrast with the Ground Based Augmentation System (GBAS) in which correction can be done with a single message, the SBAS should broadcast a total of 13 messages in every second alternately to transmit information applicable to a large area in common (RTCA 2006). SBAS messages include satellite orbital error, satellite clock error, and correction and integrity information with regard to ionospheric error, and SBAS messages are broadcast at a different update interval according to the characteristics related to each information as well as having a different time-out. Thus, since SBAS users should combine different formats of messages collected in every second to calculate correction and integrity information that can be applied to measurements, SBAS-based position solution can be determined only after collection of SBAS messages at a specific period of time. Thus, a time to first fix (TTFF) to determine the first SBAS position solution differs according to when a user starts collection of SBAS messages, and for general SBAS users in contrast with airplane users, a

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specific SBAS message may be failed to be received if an environment of SBAS signal reception is poor, resulting in possible unavailability of SBAS position solution for a certain period of time. Furthermore, accuracy of navigation solution can be degraded as a result of using outdated correction information until the up-to-date messages are received as well as a protection level in consideration of this inaccuracy is increased, which is why message scheduling affects accuracy, availability, and continuity of navigation solution (Lawrence et al. 1996). Thus, it is necessary to consider a message scheduling technique that can maximize navigation performance and minimize a TTFF considering the characteristics of SBAS messages (Han et al. 2011).

The Korea Augmentation Satellite System (KASS) is an SBAS system, which is under development and construction in Korea. It complies with the SBAS message format of international standards and will be planned to broadcast SBAS signals to Korea and surrounding regions after 2020 (Park et al. 2016). The KASS aims to provide SBAS services not only for aviation users primarily but also for other general users. An SBAS reception environment of general users may be poorer than that of aviation users and navigation performance of general users can be degraded due to the loss of SBAS messages accordingly. Therefore, it is necessary to design a message scheduler considering the above problem.

Furthermore, reference stations of the KASS that will collect measured data of the Global Positioning System (GPS) are planned to be installed in Korean territory so that augmentation information that is applied to GPS measurements received around the Korean Peninsula is included in the KASS message and broadcast (Yun 2015). The numbers of ionosphere grid points (IGP) and satellites to be corrected at a certain period of time in the KASS are expected to be less than those of other SBASs that provide services in a large area. As a result, the required number of SBAS messages is expected to be decreased accordingly. Thus, it is possible to develop message scheduling that can shorten a TTFF compared to existing SBASs.

The present paper analyzed characteristics of message scheduling of the SBASs, which are currently operating, and requirements for SBAS message generation, and designed an SBAS scheduler. The design approaches of the KASS message scheduler were derived by taking inherent characteristics of the KASS into consideration, and designs that can improve navigation performance of KASS users were derived by comparing results using each of the design approaches. In Section 2, contents related to the scheduler design among the message requirements defined in the SBAS standards are described. In Section 3, real messages that are broadcast from existing SBAS are analyzed and the result of the scheduler design based on the analysis is presented. In Section 4, considerations on the scheduler design of KASS messages are derived as well as design approaches. In Section 5, conclusions are presented.

2. REQUIREMENTS OF SBAS MESSAGES

Table 1 presents a message type (MT), contents, maximum update interval, and time-out in the SBAS message (RTCA 2006). Users cannot employ each message individually but should combine contents of specific messages. In the present paper, messages related to major causes of errors are divided into two: satellite orbital and clock error, and ionospheric delay error, for which the SBAS provide augmentation information, and requirements of each message are summarized.

Table 1. SBAS message definition, update interval and time-out (RTCA 2006).

MT	Content	Maximum update interval (s)	Time-out (s) for LPV, LP, LNAV/VNAV	Time-out (s) for en route, terminal, LNAV
0	Don't use for safety applications	6	N/A	N/A
1	PRN mask	120	600	600
2~6, 24	UDREI	6	12	18
2~5, 24	Fast corrections	6~60	12~120	18~180
24, 25	Long term corrections	120	240	360
7	Fast correction degradation	120	240	360
9	GEO navigation data	120	240	360
10	Degradation parameters	120	240	360
12	UTC timing data	300	86,400	86,400
17	Almanac data	300	-	-
18	Ionospheric grid mask	300	1,200	1,200
26	Ionospheric corrections	300	600	600
27	Service level	300	86,400	86,400
28	Clock-ephemeris covariance	120	240	360
62/63	Internal test/null message	-	-	-

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2.1 Satellite orbital and clock error-related message

The augmentation information with regard to satellite orbital and clock errors of users is calculated using MTs 1, 2~7, 10, 24, 25 and 27 or 28. Among them, MT 1 that provides a pseudo random noise (PRN) mask specifies the PRN number of target satellite of augmentation information supply, MTs 2 to 5 and 24 provide fast corrections, MT 7 provides fast correction performance degradation factor, MTs 24 and 25 provide long-term correction, and MT 28 provides covariance matrix with which users can calculate δUDRE (Yun 2015) that represents a level of residual error after correction with regard to orbit and clock errors that are increased further as users are farther from the reference station network. Thus, they should have the same issue of data PRN mask (IODP). IOD is a serial number that is increased whenever new augmentation information is created, which is used to distinguish messages that should be combined. Since MT 6 broadcasts user differential range error indicators (UDREI), which are integrity information with regard to fast corrections provided by MTs 2 to 5 and 24, they should have the same IOD fast corrections (IODF) to be combined for the use. Note that the UDREIs are included in MTs 2 to 5. Thus, if MTs 2 to 5 are broadcast in every six second, MT 6 message may not be needed.

MT 10 broadcasts performance degradation factor with regard to multiple corrections, and MT 27 broadcasts δUDRE with regard to orbit and clock errors according to user's location and the same values are broadcast for all satellites. Thus, they do not include IODP or IODF.

MTs 2 to 5 and 24 that broadcast rapidly changing fast corrections whose maximum update interval is at least 6 seconds should be broadcast most frequently while slowly changing long-term corrections (MT 25) and performance degradation factor (MTs 7 and 9) can be broadcast at an interval of 120 seconds.

2.2 Ionospheric error-related message

The augmentation information with regard to ionospheric delay error is calculated using information provided by MTs 10, 18, and 26. MT 18 message that provides Ionosphere Grid Point (IGP) Mask designates locations of IGPs and MT 26 provides ionospheric augmentation information at each of the IGPs. Thus, MTs 18 and 26 can be employed only if they have the same issues of data IGP mask (IODI).

Since the maximum update interval for ionosphere-related messages is 300 seconds, the same augmentation information should be used for 10 minutes if a message was lost due to long update interval although the share out of all messages is small. Since a time-out is 600 seconds, if messages were lost twice, ionospheric error correction could not be done until new message is received thereby degrading accuracy and availability.

Table 2. Major message type share of WAAS, MSAS and EGNOS messages on August 15, 2016.

System	Message type share (%)								
	2	3	4	25	26	27 or 28	62/63	etc.	empty
WAAS	16.7	16.7	16.7	12.9	8.0	9.8	11.5	7.73	0
MSAS	16.7	16.7	16.7	10.1	3.8	6.3	2.4	8.7	18.6
EGNOS	24.8	24.8	24.8	5.1	11.2	0.5	-	9.3	0

2.3 Other messages

MTs 9 and 17 broadcast navigation and almanac messages including location information of Geostationary Earth Orbit (GEO) satellites. MT 12 broadcasts parameters that are used to calculate a time difference between SBAS network time and coordinated universal time (UTC), which may not be broadcast if not required by the service provider. MT 62 is an internal message that can be used for internal test purpose and MT 63 is a null message without any information, which broadcasts useless data from user's viewpoints.

3. DESIGN OF THE SBAS MESSAGE SCHEDULER

The characteristics of scheduling of messages that are broadcast by the Wide Area Augmentation System (WAAS), the MTSAT Satellite Augmentation System (MSAS), and the European Geostationary Navigation Overlay Service (EGNOS), which were developed in the past and now under operation, are analyzed to design a scheduler that satisfies the SBAS message requirements analyzed in Section 2. To do this, an SBAS message scheduler that reflects each of the above characteristics is designed, with which the authors created virtual messages and compared the scheduling result with those of real messages to verify the design results.

3.1 Analysis on existing SBAS message scheduling

Daily data of the WAAS, the MSAS, and the EGNOS collected at August 15 in 2016 (CNES 2016) were analyzed. Table 2 and Fig. 1 present a major message type share, and Table 3 presents a mean time interval for each major message. The analysis result on each message is as follows:

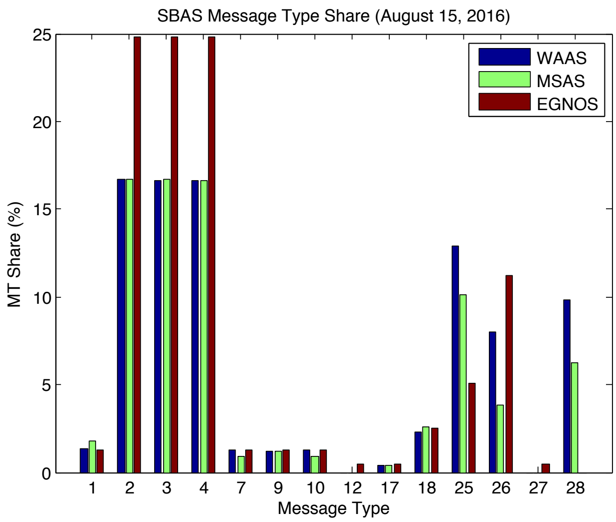

Fig. 1. Message type share of WAAS, MSAS and EGNOS messages on August 15, 2016.

Table 3. Mean time interval between major messages of WAAS, MSAS and EGNOS on August 15, 2016.

System	Time interval (s)					
	2	3	4	25	26	27 or 28
WAAS	6	6	6	85	288	103
MSAS	6	6	6	85	288	89
EGNOS	4	4	4	93	196	196

3.1.1 Satellite orbital and clock error-related messages

The analysis result on MT 1 message shows that the WAAS provides augmentation information for 32 GPS satellites and three geostationary satellites, and the MSAS and the EGNOS provide augmentation information for 31 GPS satellites and two geostationary satellites. Each of MTs 2 to 5 should broadcast augmentation information for 13 satellites defined in the PRN masks. If MT 4 is used, 39 satellites can corrected. Thus, it is obvious that all existing systems are not needed to broadcast MT 5 messages. However, since MTs 2 to 4 should be broadcast within every six second, they accounted for 50% or more of total messages. In the EGNOS, a ratio of MTs 2 to 4 was higher than that of other SBASs, which was because the WAAS and the MSAS broadcast messages in every six second while EGNOS broadcasts messages in every four second.

MT 25 broadcasts long-term correction for two or four satellites. If a change rate of correction is included in a message, velocity code is set to 1, in which correction for two satellites in a single message should be broadcast. If velocity code is set to 0, correction for four satellites in a message should be broadcast. In the WAAS and the MSAS, velocity code is set to 1 while that in the EGNOS is set to 0. The numbers of satellites that to be corrected at a specific period of time in the WAAS, MSAS, and EGNOS are 15~21, 9~21, and 16~22 satellites, respectively. Thus, in the WAAS, MSAS, and EGNOS, 8~11, 5~11, and 4~6 of MT 25 messages should be broadcast, respectively. As this characteristic is reflected in a message share, message shares of MT 25 in the WAAS and MSAS were twice that in the EGNOS.

Table 4. IGP band and the number of blocks in each block defined in WAAS, MSAS and EGNOS messages on August 15, 2016.

System	WAAS					MSAS			EGNOS				
IGP band	0	1	2	3	9	0	7	8	3	4	5	6	9
Number of IGP blocks	3	5	5	3	7	1	5	5	4	6	5	1	6
Total number of IGP blocks to be broadcast	23					11			22				

Each of the SBASs broadcasts one of MT 27 or 28 message for δUDRE broadcast. The WAAS and the MSAS broadcast MT 28 while the EGNOS broadcasts MT 27. Since MT 28 broadcasts covariance for two satellites in a single message, it had much higher share than that of MT 27. If δUDREs for multiple regions are broadcast in MT 27, a number of messages should be broadcast. However, since the EGNOS divides a region into the following individual regions (latitude N20°~N70°, longitude W40°~ E40°) and sets their δUDRE to 1 while setting other regions to 100. As a result, only a single message is broadcast continuously thereby having a very low share.

Since MTs 2 to 5 are broadcast within six seconds of interval, MT 6 was not broadcast and MTs 7, 10, and 17 that were broadcast have a similar share in all systems regardless of the number of satellites. MT 24 is employed when the number of satellites set in the PRN mask is 1~6, 14~19, 27~32, or 40~45. Since existing SBASs do not have such number, no system employs the MT24 now.

3.1.2 Ionospheric error-related message

The analysis result of MTs 18 and 26, which are related to the ionospheric error correction shows that the WAAS broadcasts ionospheric corrections for a total of 23 blocks in five bands and the MSAS broadcasts them for a total of 11 blocks in three bands, and the EGNOS broadcasts them for 22 blocks in five bands as presented in Table 4. As presented in Table 3, since the WAAS and the MSAS broadcast MT 26 at an interval of 288 seconds, and the EGNOS broadcasts it at an interval of 196 seconds, which is why EGNOS has a high message share of MT 26 as shown in Fig. 1.

3.1.3 Other message

Since MTs 9 and 17 are not related to an amount of augmentation information, a similar share is revealed in all systems. Since the WAAS and MSAS do not generate

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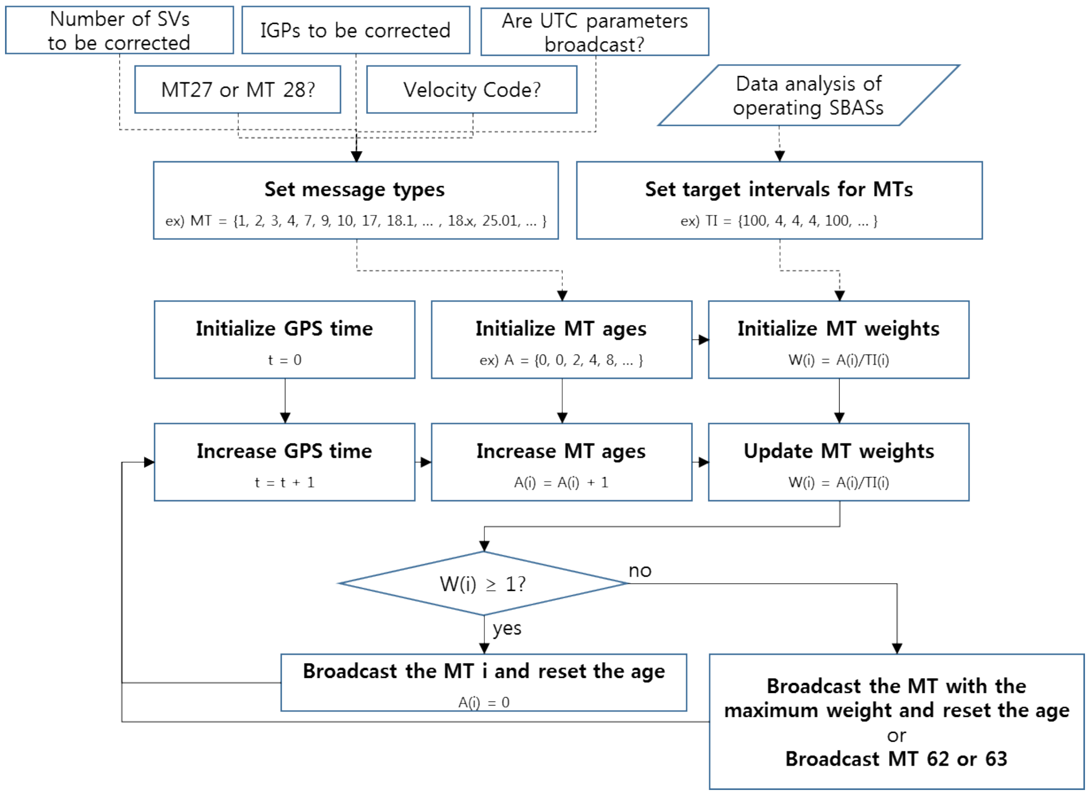

Fig. 2. SBAS message scheduler flow.

UTC parameters, MT 12 is not broadcast. The WAAS and the MSAS broadcast MTs 62 or 63 messages whereas the EGNOS does not broadcast them at all.

3.1.4 Analysis result on existing SBAS message scheduling

The summary of Tables 1 and 3 indicates that the WAAS and the MSAS broadcast each message at nearly the maximum update interval and internal or null message is broadcast at the rest of the time whereas the EGNOS broadcasts messages at 2/3 of the maximum update interval and useless messages are not broadcast. As such, since the message update interval in the EGNOS is shorter than those of other systems, TTFF and navigation performance of EGNOS users are expected to be better than others in terms of viewpoints on message scheduling only.

3.2 Design of the SBAS message scheduler

3.2.1 Flow chart of the scheduler

An SBAS message scheduler was designed considering the characteristics of analyzed existing SBAS message, and the flow chart is shown in Fig. 2. Considering the following conditions: the number of target satellites to be corrected at the SBAS, number and location of valid IGPs, whether UTC parameter is broadcast or not, a measure of broadcast of δUDRE out of MTs 27 and 28, and velocity code of MT 25, a message type to be broadcast is determined, and a target interval (TI) with regard to each message is set based on the analysis result on existing SBAS messages. An age of each message is initialized and then age is divided by TI thereby setting a weight. While the GPS time is increasing, an age of every message is incremented by one. Accordingly, a weight is updated and if a message whose weight is one or larger is found, the message is broadcast and an age is reset to 0. If there is no message whose weight is one or larger found, a message whose weight is the largest is broadcast or MT 62 or 63 is broadcast.

3.2.2 Result of scheduler implementation

A scheduler to which each of the characteristics of the WAAS, MSAS, and EGNOS is inputted was implemented based on the result in Section 3.1. Fig. 3 shows the result using the scheduler. A message type share of each system indicated in Fig. 3a showed that it was similar to a real share distribution in Figs. 1 and 3b verifies that the maximum broadcast interval satisfied the requirements of the maximum update interval demanded by the RTCA (2006).

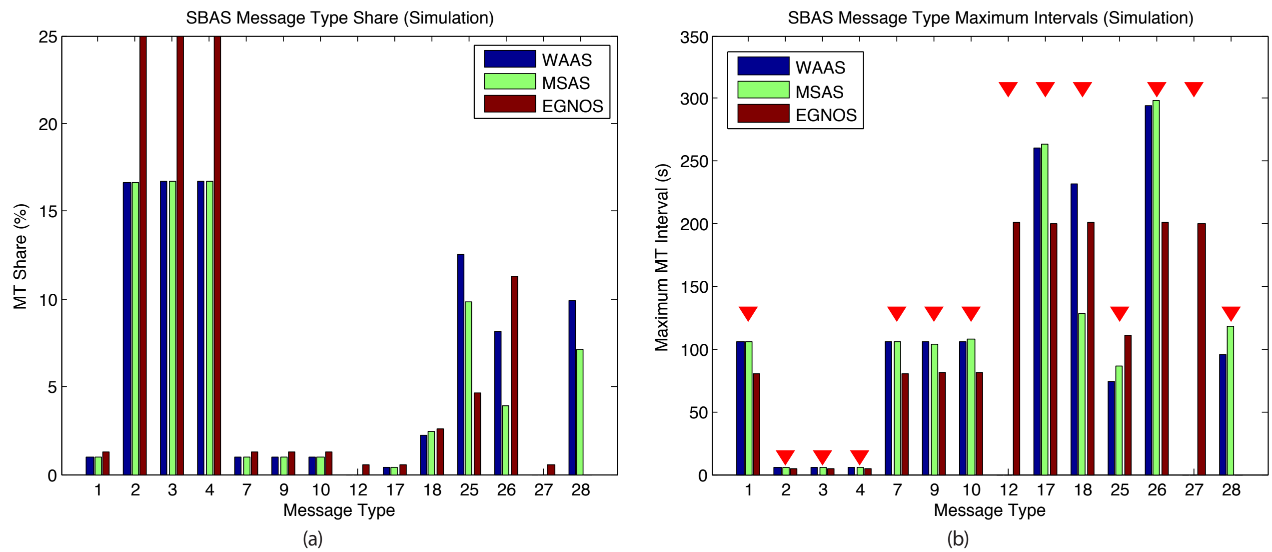

Fig. 3. Message type share (a) and maximum intervals (b) of each simulated message types in cases of WAAS, MSAS and EGNOS. Red triangles mean the maximum update interval required by RTCA (2006).

4. DESIGN OF THE KASS MESSAGE SCHEDULER

In the present section, inherent characteristics of the KASS that are needed to be considered during the design of the KASS message scheduler is analyzed and applied to the SBAS scheduler proposed in Section 3 thereby deriving a design measure of the KASS message scheduler. The present section proposes a measure that maximizes KASS user navigation performance using simulation results about the derived measure.

4.1 Inherent characteristics of the KASS and considerations on the scheduler design

The reference stations in the KASS are planned to be installed only in Korea and the number of visible GPS satellites is expected up to 13~14. Thus, when augmentation messages with regard to GPS satellite orbit and clock errors including geostationary satellites such as existing SBASs are constructed, only 15 to 16 spaces out of 39 spaces assigned to MTs 2 to 4 messages have a valid value so that around 60% of total space is expected to have invalid values. According to RTCA (2006), since the PRN mask is rarely changed except a new satellite is added to a satellite group, all of MTs 2 to 4 should be broadcast even if the number of satellites that are augmented at a certain period of time in the KASS is small. However, if the PRN mask is designed to be changed frequently in accordance with a visible satellite at that time, using only MTs 2 and 3 enables broadcasting of augmentation information with regard to 26 satellites so that 15% or higher share of MT 4 message can be used for other messages.

Since long-term correction (MTs 25 and 28) broadcasts augmentation information only for visible satellites within the service area, a share is reduced according to a ratio of the number of visible satellites in each system. Assuming that the number of visible satellites in the KASS is up to 16, eight MT 25 messages are needed to be broadcast when velocity code is one, and four messages are needed to be broadcast when velocity code is 0, which indicates that 67% to 73% of the share needed in existing SBASs presented in Section 3.1.1 is required.

Ionosphere pierce points (IPP) calculated via the measurement from visible satellites are expected to be located at from E105 to E150 degrees longitude and from N15 to N55 degrees latitude approximately according to Yun et al. (2011). Thus, IGPs where ionosphere augmentation information is needed to be provided are expected to be defined as 90 grid points approximately located at from N15 to N55 degrees latitude out of grid points located at from E105 to E135 degrees longitude in Band 7 and grid points located at from E140 to E150 degrees longitude in Band 8. Accordingly, MT 26 generates augmentation information for a total of seven blocks: five blocks in Band 7 and two blocks in Band 8. Since a message type share of MT 26 where ionosphere augmentation information is included is proportional to the number of target blocks, only 30% of messages compared to that of WAAS or EGNOS, and 64% of messages compared to that of MSAS are expected to be needed approximately.

As mentioned in the above, since the numbers of visible

Table 5. KASS message scheduler configurations.

Configuration	Cases		
	W: WAAS type E: EGNOS type	F: Use 2 fast correction messages only(w/o MT4)	L: Reduce TI for MTs with long update interval
KASS-W	W	No	No
KASS-WF	W	Yes	No
KASS-WL	W	No	Yes
KASS-WFL	W	Yes	Yes
KASS-E	E	No	No
KASS-EF	E	Yes	No
KASS-EL	E	No	Yes
KASS-EFL	E	Yes	Yes

satellites and IGPs where KASS augmentation information should be provided are smaller than those in existing SBASs, ratios of related messages are expected to be decreased. Compared to a message type share in the WAAS, around 16% due to no use of MT 4 message, around 5% in MTs 25 and 28 due to the reduction in the number of visible satellites, around 6% in MT 26 due to the reduction in the IGPs, and around 10% in MT 62, which is a unnecessary message, are expected to be decreased, resulting in around 37% message slot vacancy. Compared to a message type share in the EGNOS, around 25% in MT 4 message and around 8% in MT 26 message are expected to be decreased, resulting in a total of 33% empty space (Yun et al. 2016). If a scheduling algorithm is designed considering a method that reduces a message update interval by taking advantage of the vacant slots, there is a room to improve user navigation performance.

4.2 Design of the KASS message scheduler

As analyzed in Section 3.1.4, there was a clear distinction of scheduling algorithm among WAAS, MSAS, and EGNOS. Thus, two characteristics were taken into consideration, and eight design approaches in consideration of three elements using the inherent characteristics of the KASS analyzed in Section 4.1 were derived, which are presented in Table 5. In the table, 'W' and 'E' refer to WAAS type and EGNOS type. Since the MSAS was developed based on the same algorithm by the WAAS developer, it is not marked separately. 'F' refers to the use of only two fast correction messages excluding MT 4 message instead of using all three fast correction messages in existing SBASs. 'L' refers to a set up where TI was reduced compared to existing setup in order to utilize empty message slots in the KASS as much as possible. It is set to broadcast messages with long update intervals, which affect the TTFF significantly, more frequently than existing interval by shortening a TI except for MTs 2 to 4.

Table 6. Simulated major message type share for KASS (%).

Cases	Message type share (%)								Max interval (s)
	2	3	4	25	26	27 or 28	62/63	etc.	
KASS-W	16.7	16.7	16.7	9.9	2.5	7.2	24.5	5.8	292
KASS-WF	16.7	16.7	-	9.9	2.5	7.2	41.1	5.9	285
KASS-WL	16.7	16.7	16.7	15.6	10.9	12.5	0	10.9	66
KASS-WFL	16.7	16.7	-	20.8	14.6	16.7	0	14.5	54
KASS-E	27.0	27.0	27.0	4.7	4.6	0.7	-	9.0	167
KASS-EF	35.9	35.9	-	6.9	6.8	1.0	-	13.5	117
KASS-EL	16.7	16.7	16.7	9.5	16.7	2.4	-	21.3	44
KASS-EFL	17.2	17.2	-	12.5	21.9	3.1	-	28.1	34

5. RESULT OF KASS MESSAGE GENERATION

The simulation results where eight design approaches described in Section 4 were applied are presented in Table 6 and Figs. 4 and 5 in which message type share and broadcast interval are provided.

For KASS-W, as MTs 25, 26, and 28 messages were reduced compared to those in the WAAS, MTs 62 and 63 were increased thereby generating useless messages at about 24.5% rate. When MT 4 was not employed (KASS-WF), a useless message rate was increased to 41%. When an update interval of messages except for fast corrections was appropriately shortened in order to prevent vacant slots from occurring (KASS-WL, KASS-WFL), the shares of MTs 25, 26, and 28 increased significantly. Accordingly, while broadcast intervals of all messages were maintained within the requirement, broadcast intervals of messages other than MTs 2 to 4 were reduced overall simultaneously as shown in Fig. 5a thereby reducing the maximum broadcast interval, which was 292 seconds in KASS-W decreased to 54 seconds in KASS-WFL, resulting in a message share reduced within 20%.

For KASS-E, as a share of MT 26 including ionosphere augmentation information was reduced more than that of the EGNOS, shares of MTs 2 to 4 were raised. If MT 4 message is removed in the KASS-EF, shares of MTs 2 and 3 and other messages were increased thereby decreasing broadcast intervals of all messages overall, resulting in reduction in the maximum broadcast interval to 117 seconds. If 'L' is additionally set, shares of messages types whose broadcast interval is long were raised overall, resulting in significant reduction in the maximum broadcast interval to 34 seconds.

Since velocity code in MT 25 is 1 in the WAAS type, MT 25 messages should be broadcast more frequently than EGNOS type whose velocity code is 0, and since 8 to 11 MT 28 messages should be broadcast, their shares were higher than that of EGNOS type that broadcast only one MT 27 message. Thus, a broadcasting interval of EGNOS type was

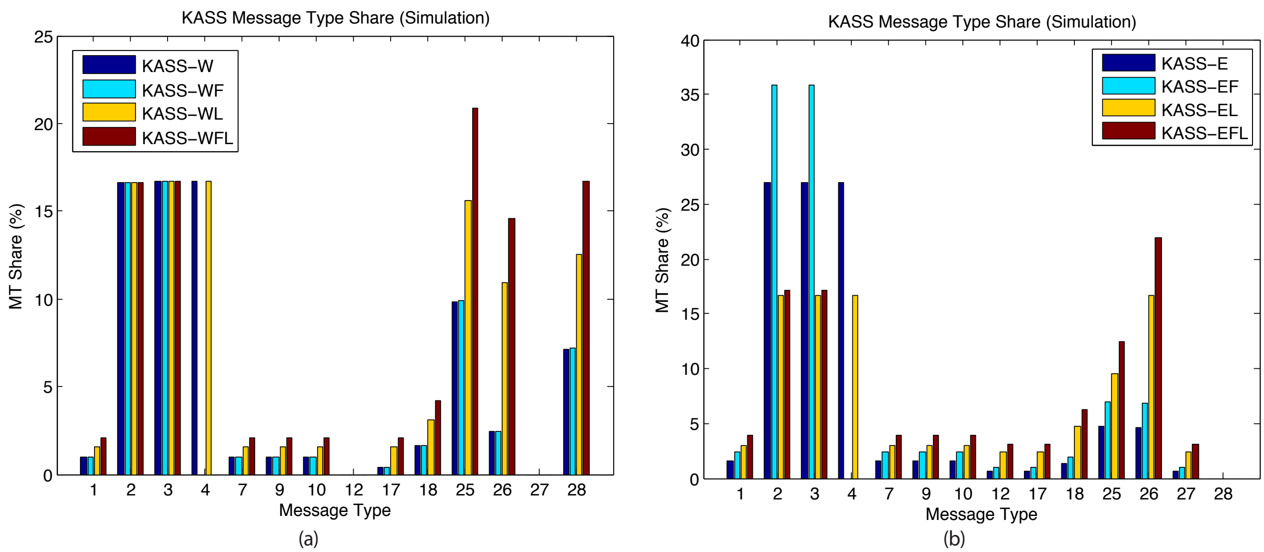

Fig. 4. Message type share of the simulated KASS message types in different scheduling cases.

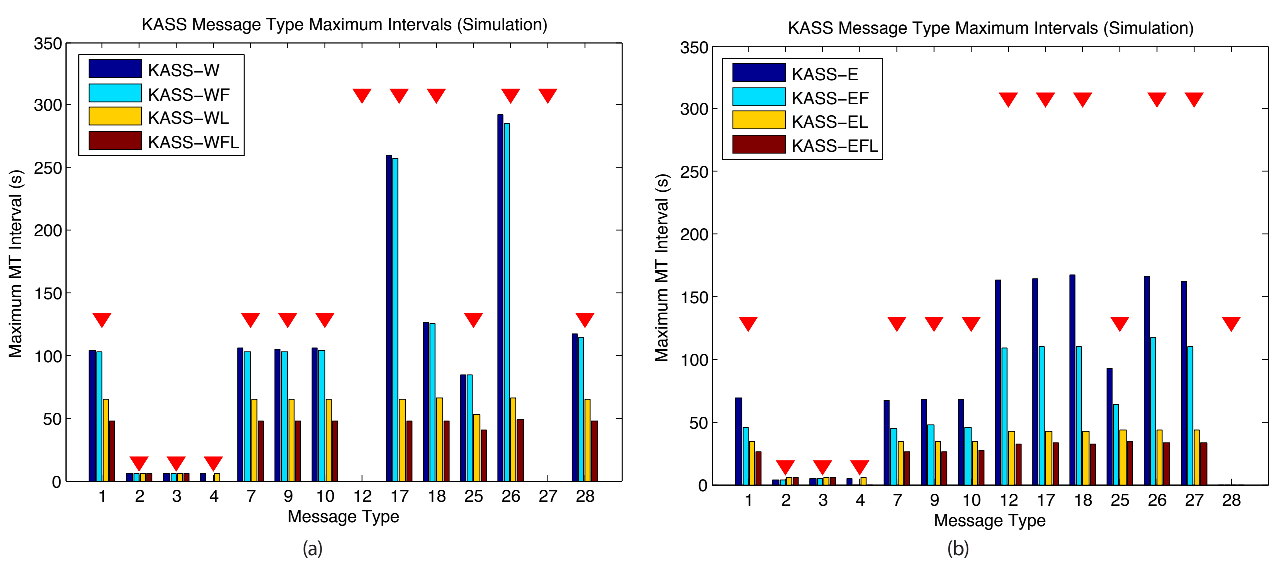

Fig. 5. Maximum intervals of each simulated KASS message types in different scheduling cases.

shorter overall and an interval was minimized as ‘F’ and ‘L’ were additionally set.

Fig. 6 shows maximum intervals of all the simulated KASS message types in different scheduling cases. These values are assumed to be equivalent to the maximum TTFF that can determine the initial SBAS position solution by applying all augmentation information by users. Accordingly, if messages are broadcast with similar setups in existing SBASs, TTFF of four minutes or longer (KASS-W) or three minutes (KASS-E) are expected to be needed. However, if improvements in consideration of inherent characteristics of KASS are reflected, TTFF can be reduced to one minute or shorter (KASS-WFL) or 30 seconds (KASS-EFL), resulting in shortening by 80%, which will be expected to improve availability of SBAS position solution of users.

6. CONCLUSION

The present paper summarized requirements of SBAS messages and analyzed message update interval and message type share in existing SBASs. It also derived considerations on the design of the KASS message scheduling algorithm taking the inherent characteristics of the KASS. Based on the analysis result, a message scheduler that exhibited similar features to existing SBASs was designed and simulations were implemented as well as presenting design measures that reflected the

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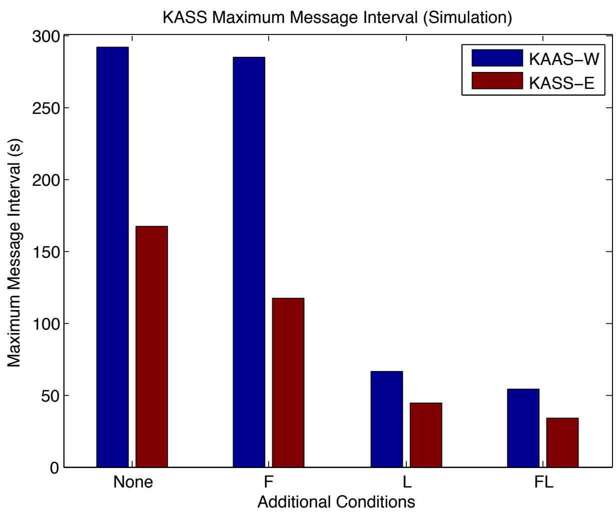

Fig. 6. Maximum intervals of all the simulated KASS message types in different scheduling cases.

KASS characteristics. In the simulation of the proposed measures, the number of augmentation-needed satellites and regions of IGPs were reduced due to the arrangement of KASS reference stations distributed over a narrow region compared to other SBASs thereby increasing the number of vacant message slots. With additional design element considered, an update interval was also verified to be reduced by 20%. This result indicates that TTFF performance of users can be improved and not only aviation users but also general ground users whose signal reception environment of geostationary satellites is poor can acquire improved KASS position solution than using existing method if the proposed measures are applied to the currently developing KASS, improving navigation availability of KASS users and expanding service areas of the KASS.

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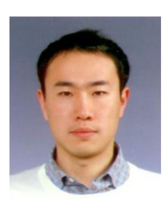

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