Research on Single Frequency BDSBAS Message Scheduler Improvement

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Abstract. With the increasingly high performance requirements of civil aviation for satellite navigation system, Satellite-Based Augmentation System (SBAS) is applied. SBAS can augment Global Navigation Satellite System (GNSS) by broadcasting correction and integrity parameters to users in service area through geostationary satellites (GEOs). Therefore, reasonable schedule and normal broadcast of SBAS messages are important guarantee for SBAS to provide efficient service. By analyzing the single frequency SBAS message scheduler at home and abroad, and combining with the current broadcast messages of the BeiDou Satellite-Based Augmentation System (BDSBAS), this paper proposes a fixed time sequence dynamic message scheduler for BDSBAS. Compared with the fixed sequence message scheduler adopted by BDSBAS at present, the message scheduler proposed in this paper can not only improve the flexibility of message broadcasting, but also achieve the effective message proportion of 100%. On the basis of meeting the message update cycle specified by the International Civil Aviation Organization Standards and Recommended Practices (ICAO SARPs), the update time of all kinds of messages is shortened, and the time required for users to receive all message types for the first time is reduced about 11.7%, which provides more time slot margin support for message alarm and upload failure, and greatly ensures the integrity and continuity of BDSBAS service.

Keywords: Satellite-Based Augmentation System (SBAS) · Fixed sequence message scheduler · Dynamic sequence message scheduler · Fixed time sequence dynamic message scheduler

1 Introduction

With the continuous development of aviation navigation, in order to improve the integrity and continuity requirements of Global Navigation Satellite System (GNSS), the International Civil Aviation Organization (ICAO) proposed the augmentation scheme and related technical indicators of Satellite-Based Augmentation System (SBAS) to augment the accuracy, integrity, continuity and availability of civil aviation users [1]. At present, SBASs that have already provided single frequency service through civil aviation airworthiness certification include Wide Area Augmentation System [2, 3] (WAAS) of the United States, European Geostationary Navigation Overlay Service [4, 5] (EGNOS) of Europe, MTSAT (Multi-functional Transport SATellite) Satellite-based Augmentation

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System [6, 7] (MSAS) of Japan and GPS Aided Geo Augmented Navigation System [8] (GAGAN) of India. BeiDou Satellite-Based Augmentation System [9, 10] (BDSBAS) of China and System for Differential Correction and Monitoring [11] (SDCM) of Russia are in the testing stage, and have not formally provided services to users through civil aviation airworthiness certification.

SBAS broadcasts correction and integrity parameters to augment the users in the service area through Geosynchronous Earth Orbit (GEO) satellites [12]. Due to the variety of single frequency SBAS messages, each SBAS message only contains part of the information of positioning solution and protection level solution. The normal update and broadcast of messages will directly affect the performance of SBAS services. International Civil Aviation Organization Standards and Recommended Practices (ICAO SARPs) [1], Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment (RTCA DO-229E) [13], Minimum Operational Performance Standard for GALILEO/Global Positioning System/Satellite-Based Augmentation System Airborne Equipment (EUROCAE 259A) [14] and other international standards all give detailed description and technical indicators for the basic structure, contents, update cycle and maximum effective time of single frequency SBAS messages. At the same time, SARPs clearly stipulates that in order to further meet the integrity requirements of civil aviation users, SBAS providers need to monitor SBAS in the process of providing services. If there is a Hazardously Misleading Information event during the operation of the system, SBAS shall give warning to the users by massages. To sum up, the reasonable scheduler and normal broadcasting of SBAS messages are the basic requirements and important guarantee for SBAS to provide services to users.

The second section of this paper introduces the basic requirements of single frequency SBAS messages broadcasting, including message contents, message update requirements and message warning constraints. In the third section, we study the domestic and foreign SBAS message schedulers and deduce the BDSBAS message scheduler based on BDSBAS broadcast message at the present stage, and compare the advantages and disadvantages of various message schedulers. In the fourth section, based on the current SBAS message scheduler, combined with the analysis of BDSBAS broadcast message types and contents, a new message scheduler suitable for BDSBAS is proposed. The fifth section uses the design software to verify the correctness and feasibility of the message scheduler proposed in this paper, and compares with the broadcast efficiency of BDSBAS at the present stage. The results show that, compared with the current broadcast strategy, the effective message proportion of SBAS can reach 100%, the broadcast time interval of single frequency integrity messages (MT 2/3/4) can be shortened by 33.3%. The update cycles of other message types have different degrees of improvement. The time for users to receive all types of messages for the first time can be shortened by 11.7%. At the same time, the message scheduler provides more time slot margin for message alarm and upload failure.

2 Research on International Standards of SBAS Messages

The standard of Convention on International Civil Aviation clearly points out that the design, construction and application of SBAS system should follow the standards of

SARPs, and the indicators in the standard are the basic requirements for the standardized construction and use of SBAS under ICAO specifications. This section will take ICAO SARPs as the main research content, combined with the SBAS airborne receiver standards such as RTCA and EUROCAE, to study the international standards of SBAS messages.

Single frequency SBAS messages mainly include SBAS test message, satellite mask message, ephemeris-clock correction message, ionosphere correction message, integrity parameters message, degradation factors message and GEO ephemeris message. There are 64 types of message, but at present, many message types are not defined. The types and main contents of actually used and broadcast messages are shown in Table 1.

Table 1. Single frequency SBAS message types and contents

Message type	Contents
0	"Do Not Use" (SBAS test mode)
1	PRN mask
2–5	Fast corrections
6	Integrity information
7	Fast correction degradation factor
9	GEO ranging function parameters
10	Degradation parameters
12	SBAS network time/UTC offset parameters
17	GEO satellite almanacs
18	Ionospheric grid point masks
24	Mixed fast/long-term satellite error corrections
25	Long-term satellite error corrections
26	Ionospheric delay corrections
27	SBAS service message
28	Clock-ephemeris covariance matrix
62	Reserved
63	Null message

In order to meet the integrity and continuity of user services, SARPs provides specific constraints for the update cycle of SBAS messages, and each SBAS provider should strictly follow the corresponding indicators to update messages when broadcasting SBAS messages. The corresponding requirements of content, update cycle and maximum effective time of messages are shown in Table 2.

Table 2. Message contents update intervals

Data type	Associated message types	Maximum update interval (seconds)	En route, terminal, LNAV time-out (seconds)	LNAV/VNAV, LP, LPV approach time-out (seconds)
Clock-Ephemeris covariance matrix	28	120	360	240
SBAS in test mode	0	6	–	–
PRN mask	1	120	600	600
UDREI	2–6,24	6	18	12
Fast corrections	2–5,24	6	Related to the degradation	Related to the degradation
Long-term corrections	24,25	120	360	240
GEO ranging function data	9	120	360	240
Fast correction degradation	7	120	360	240
Degradation parameters	10	120	360	240
Ionospheric grid mask	18	300	1200	1200
Ionospheric corrections, GIVEI	26	300	600	600
Timing data	12	300	86400	86400
Almanac data	17	300	None	None
Service level	27	300	86400	86400

3 Research on SBAS Message Scheduler At Home and Abroad

The earliest and the longest used SBAS in the world is the WAAS in the United States. Based on the analysis of WAAS messages and related literatures, this paper finds that a fully dynamic scheduler is adopted by WAAS for SBAS message broadcasting. It decides which message is the most important in every second, and then the message is broadcast. The broadcast mode of the messages is more flexible, but due to the update intervals of different types of message are different, the broadcast mode of the messages may lead to the phenomenon that multiple messages broadcast overtime at the same time.

Professor Walter T of Stanford proposed a fixed time sequence message scheduler based on the current message scheduler of WAAS [15] and a rigid message scheduler is adopted. Each message is scheduled to go out at a preset time that repeats over a fixed time interval. In addition, Walter T thinks that a deferred message list should be added to deal with the message timeout caused by WAAS message alarm.

In addition to the methods mentioned above, Korean Yun Y and others referred to WAAS message broadcast mode and proposed a dynamic message scheduler according to the characteristics of KASS [16]. Domestic scholars like Chen Jinping have studied the design of modern GNSS message [17]. Du Juan and other scholars have analyzed SBAS message broadcast characteristics, navigation signal design, satellite-ground transmission information and SBAS service processing, and put forward opinions on SBAS interoperability standard design [18]. However, there are still few researches on BDSBAS message scheduler design in China.

The PRN 130 GEO satellite of BDSBAS began to broadcast messages in July 2019. At the end of July 2020, BDSBAS was officially completed, providing satellite-based augmentation service for China and its surrounding areas. Before the study of this paper, the author conducted a long-term evaluation of BDSBAS broadcast messages. During the evaluation, it was found that BDSBAS messages would appear MT 2/3/4 overtime broadcast, and the timeout interval was mostly 12 s (twice of the maximum update cycle of MT 2/3/4). Combined with this phenomenon and using the received BDSBAS messages to reverse-reasoning message scheduler, it is found that BDSBAS uses fixed time sequence to arrange single frequency SBAS messages, in which every 240 s is a large period of fixed broadcast, every 6 s is a small period of fixed broadcast (broadcast MT 2/3/4), and other messages are inserted into the time slot of every 6 s period with fixed time sequence. If there is no message broadcast in the current time slot, the MT0 will be broadcast, as shown in Fig. 1. The message types broadcast in the first 240 s coincide with the message types broadcast from 241 s to 480 s. Most of the message timeouts are caused by MT0 occupying the broadcast time slot of other message types.

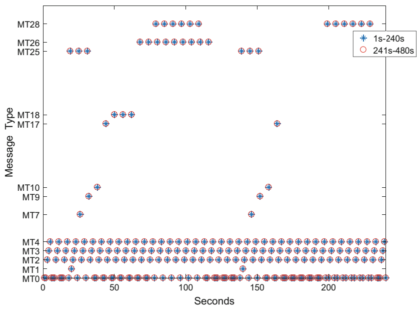

Fig. 1. Single frequency BDSBAS message broadcasting sequence

The advantage of the BDSBAS fixed time sequence message broadcast method is that each message is sent at a preset time and repeated in a fixed time interval. This strict scheduler prevents multiple messages that time out at the same time. However, the time interval of message broadcast is fixed and the reserved time slot margin is too short. Once the SBAS alarm or message upload failure occurs, the message broadcast time may exceed the maximum update cycle, causing user integrity risk. In addition, after BDSBAS formally provides services to civil aviation users through civil aviation test certification, there is no need to continue broadcasting MT0. If the SBAS messages continue being broadcast according to the 240 s cycle, there will be a large number of message slots that are idle, and MT 63 needs to be inserted for broadcast, and the effective message proportion will be greatly reduced.

To sum up, there are mainly two kinds of message schedulers used by SBAS in the world: fixed message scheduler and dynamic message scheduler. The two kinds of schedulers have their own advantages and disadvantages. The advantage of fixed message scheduler is that the message is broadcast accordance with the preset order, which prevents the conflict of multiple messages that time-out at the same time. The disadvantage is that the flexibility is poor, and the proportion of effective messages is low. In the event of message upload failure or message alarm, it will lead to message broadcast timeout; the advantage of dynamic message scheduler is that the message broadcast method is flexible, and the proportion of effective messages is high, but multiple messages may time out at the same time, and it takes longer for SBAS to resume normal message broadcast after long-term system failure.

4 BDSBAS Fixed Time Sequence Dynamic Message Scheduler

This paper holds that although SBAS in different regions need to strictly comply with the relevant standards of ICAO to provide services, SBAS message scheduler should be designed according to the characteristics of different SBAS service regions and message upload method. Therefore, this section first analyzes the message information to be broadcast after BDSBAS formally provides services, and then introduces the fixed time sequence dynamic message scheduler suitable for BDSBAS.

4.1 BDSBAS Broadcast Message Analysis After Officially Providing Service

After officially providing services to civil aviation users, BDSBAS needs to regularly broadcast updated effective messages, including MT1/2/3/4/7/9/10/17/18/25/26/28, based on the single frequency messages broadcast to users by BDSBAS at the present stage. The analysis of update cycle and the number of message required by each type of message is shown in Table 3.

Among them, MT25 and MT28 are related to the number of satellites that BDSBAS can augment at the same time. Each MT25 can broadcast the long-term correction of four satellites at the same time, and each MT28 can broadcast the clock-ephemeris covariance matrix information of two satellites at the same time. After analyzing the broadcast messages in August 2020, it is found that the maximum number of satellites that can be augmented by BDSBAS at the same time is 16. The statistical results of the number of satellites that BDSBAS can augment per second are shown in Fig. 2. The ionospheric corrections and integrity parameters are broadcast by MT18 and MT26, the MT18 broadcast the ionospheric grid point masks information, the MT26 broadcast the ionospheric delay corrections and integrity parameters corresponding to MT18. According to the analysis of the BDSBAS committed service area and ionospheric messages, it is found that the ionospheric mask bands of BDSBAS can be augmented at the same time are 6/7/8 three bands, corresponding to three MT18s. According to the ionospheric

Table 3. Maximum update interval and maximum number of BDSBAS single frequency message

Message type	Maximum update interval (seconds)	Number of messages to be broadcast in a single cycle
1	120 s	1
2–4	6 s	1
7	120 s	1
9	120 s	1
10	120 s	1
17	300 s	1
18	300 s	Up to 3
25	120 s	Up to 4
26	300 s	Up to 9
28	120 s	Up to 8

grid point correspondence analysis of BDSBAS service area, the number of MT26 corresponding to the ionospheric grid point masks of 6/7/8 bands at the same time is 3/5/1 respectively, with a total of up to nine different versions of MT26.

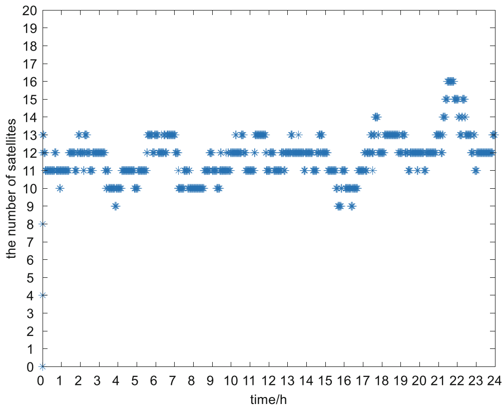

Fig. 2. BDSBAS augmented satellites number per second

4.2 Introduction of Fixed Time Sequence Dynamic Message Scheduler

Compared with the improvement of positioning accuracy, SBAS pays more attention to the integrity of aviation users. Therefore, in addition to meeting the above message update requirements, SBAS message scheduler design should also focus on the following indicators:

1. Message broadcast interval: on the basis of meeting the maximum update cycle of SBAS messages by ICAO SARPs, the actual update cycle of SBAS messages can be effectively reduced, and the impact of correction and integrity parameters delay on service degradation can be reduced.
2. Effective message proportion: after providing services, SBAS needs to broadcast SBAS messages to users through GEO Satellite every second. If there is no message broadcasting at the current time, it will broadcast MT63 to users. Increasing the effective message proportion of SBAS means that users receive more available message information, which can improve the availability of SBAS messages and further improve the integrity requirements of users.
3. Priority broadcast of important messages: ICAO SARPs put forwards two indexes for SBAS messages: the maximum update period and the maximum effective time of messages. The maximum effective time of all kinds of SBAS messages is greater than the maximum update period, which means that even if the SBAS message broadcast time-out, users can still use messages that do not exceed the maximum effective time for augmentation services. Once multiple messages in SBAS system time-out occurs, SBAS message scheduler should have the ability to identify different message priorities, preferentially broadcast messages that exceed the maximum effective time of messages, so as to ensure the continuity of SBAS service as far as possible.
4. Ability to deal with message upload failure and message alarm: in the process of providing services, no matter the message upload failure or message alarm occurs, the current SBAS message scheduler will be affected. The stronger the ability of SBAS message scheduler to deal with the above situation, the stronger the stability of the system.

To sum up, this paper proposes a BDSBAS fixed time sequence dynamic message scheduler based on ICAO SARPs message update requirements and BDSBAS message numbers in each cycle. Fixed time sequence refers to BDSBAS broadcast MT2/3/4 at a fixed time interval of 4 s to improve the redundancy of user integrity parameters and ensure the demand of system integrity; dynamic scheduler refers to that except MT2/3/4, the remaining messages are inserted into the remaining time slots according to the priority of message broadcasting. This method can improve the flexibility of SBAS message broadcasting, improve the proportion of effective messages, and shorten the update cycle of all kinds of SBAS messages.

In addition to the MT2/3/4 of fixed broadcast, the strategy of dynamic schedule of other messages is as follows: the system sets the broadcast weight value for each type of message, the denominator of the weight value is the maximum update period of the message, the numerator is the time interval from the last broadcast, and each dynamic message slot gives priority to the message with the largest weight value, and after the broadcast, the numerator of the weight value of this message type will be updated to 0. If the weight value of multiple messages is the same, the message will be selected for broadcast according to the message priority which is shown in Table 4. The message priority index is related to the maximum effective time of message in precision approach mode. The lower the priority index is, the higher the priority is.

Table 4. Table of priority correspondence of different messages in dynamic schedule stage

Message type	Message priority index
7	1
10	2
25	3
28	4
9	5
26	6
1	7
18	8
17	9

The flowchart of fixed time sequence dynamic message scheduler is shown in Fig. 3. In the initialization phase of the system, the program needs to read all message types to be broadcast by SBAS, the denominator of weight of each type of message, the

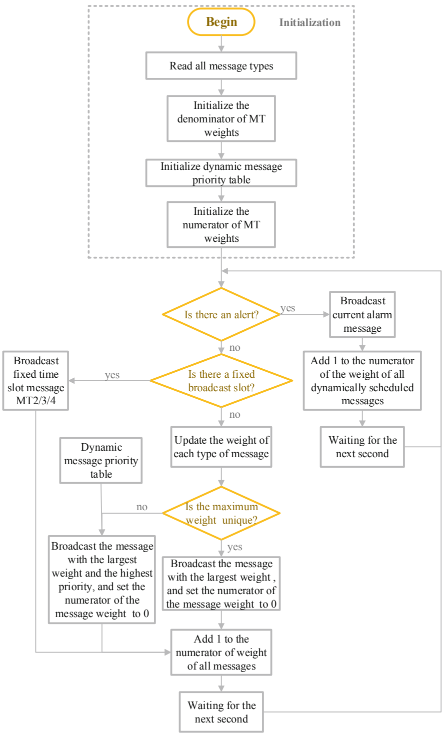

Fig. 3. Flowchart for fixed time sequence dynamic message scheduler

corresponding table of priority of each message type in the process of dynamic message broadcast, and the numerator of weight of all messages to be initially broadcast by the system. The dynamic broadcast message is initialized according to the message priority required by the user's first position. The initialization priority of each message type is shown in Table 5. After the initialization, the program enters into the normal message broadcast stage. In this stage, the program takes into account the message alarm, the same weight of different message types and other abnormal conditions, and gives the flow processing methods in various cases.

Table 5. Priority table of each dynamic broadcast message in system initialization stage

Message type	Message priority index in system initialization phase
1	1
25	3
28	4
7	5
10	6
9	7
18	8
26	9
17	10

5 Feasibility Verification of BDSBAS Message Scheduler

This paper uses the method described in Sect. 4.2, according to the requirements of SBAS 1 Hz update, BDSBAS message simulation broadcast is carried out without considering message alarm and upload failure. SBAS messages are arranged according to the BDSBAS maximum message amount described in Table 3 and all types of messages in seven days are output. The broadcast sequence of the first 1200 s is shown in Fig. 4.

It can be seen from the figure that after the initialization of the program, the update time interval of various types of messages tends to be stable after a period of time. The maximum update period of each message type during simulation is shown in Table 6. It can be seen from the table that there is no message broadcast timeout, which meets the requirements of ICAO for SBAS message broadcast interval.

From the above analysis, it can be seen that in the case of BDSBAS broadcasting the maximum amount of messages, compared with the current BDSBAS fixed sequence message scheduler, the effective message proportion of the fixed time sequence dynamic message scheduler reaches 100%, and the broadcast time interval of single frequency integrity messages (MT2/3/4) is shortened by 33.3%. In the case of no alarm and message upload failure, the update cycle of all types of messages in BDSBAS is improved. The time for users to receive all types of messages for the first time is shortened from 240 s to 212 s, which is about 11.7% shorter. It can greatly improve the integrity of the system.

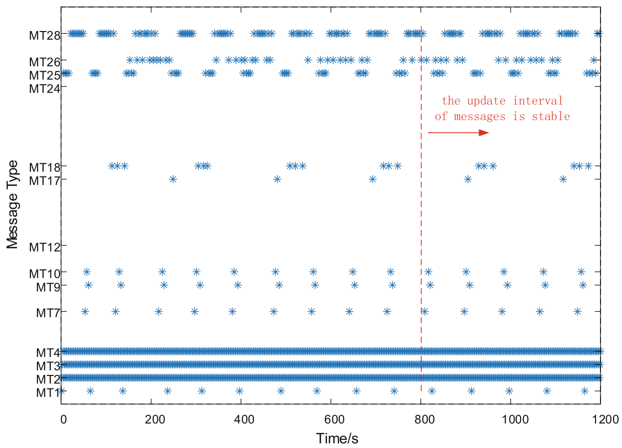

Fig. 4. Sequence diagram of BDSBAS message simulation broadcasting

Table 6. Statistics of the maximum update period of all types of messages broadcast by BDSBAS

Message type	Maximum update interval in the whole time	The maximum update cycle of each message after the message update interval is stable	BDSBAS message update interval at present	The shortening of maximum update period after message update period is stable
1	104 s	88 s	120 s	26.7%
2	4 s	4 s	6 s	33.3%
3	4 s	4 s	6 s	33.3%
4	4 s	4 s	6 s	33.3%
7	96 s	88 s	120 s	26.7%
9	100 s	88 s	120 s	26.7%
10	100 s	88 s	120 s	26.7%
17	104 s	88 s	120 s	26.7%
18	220 s	212 s	300 s	29.3%
25	104 s	88 s	120 s	26.7%
26	232 s	212 s	300 s	29.3%
28	100 s	88 s	120 s	26.7%

In addition, compared with the full dynamic message scheduler, the MT2/3/4 messages do not need to participate in the dynamic selection of the fixed time sequence dynamic message scheduler proposed in this paper, so the probability of multiple messages timeout at the same time is greatly reduced. Once the SBAS has a long-time system failure or system outage, the time required for the proposed method to restore the normal message broadcast it is shorter than the dynamic message scheduler.

In addition to the above analysis, the fixed time sequence dynamic message scheduler proposed in this paper provides more time slot margin support for message alarm and upload failure. Since the maximum update period of MT2/3/4 message is shortened by 2 s, and the maximum update period of other messages is shortened by more than 2 s, at any time, in the case of no more than 2 s continuous message upload failure, there will be no message timeout in delayed broadcast of all message types; in the system initialization stage, in the case of no more than 16 s (the minimum time slot margin of the maximum update period of other messages) continuous message upload failure, except for MT2/3/4 messages, there will be no message timeout in the delayed broadcast of other types of messages. When the message scheduler is stable, except for MT2/3/4 messages, there will be no message timeout when the message upload fails for no more than 32 s (the minimum time slot margin of the maximum update period of other messages). In addition, considering the message alarm, SBAS needs to broadcast one message of MT2/3/4 continuously for 4 s to warn users. In this case, all kinds of messages are delayed and broadcast later. Except for the MT2/3/4, the other messages will not appear the message broadcast timeout, which can greatly guarantee the integrity ability of users.

6 Conclusion

Based on the characteristics of BDSBAS broadcast messages, this paper designs the broadcast sequence of BDSBAS single frequency messages, and proposes a fixed sequence dynamic message scheduler. According to the maximum amount of messages that BDSBAS needs to broadcast after the service is formally provided, this paper uses the method proposed in this paper to simulate BDSBAS message scheduling and broadcasting, and the results show that compared with BDSBAS B1C message, the effective message ratio of the proposed method is 100%, the time for users to receive all types of messages for the first time is shortened by about 11.7%, the update cycle of MT2/3/4 is shortened by 33.3%, and the update cycle of other types of messages is improved to different degrees. At the same time, this scheduler provides more time slot margin support for message alarm and upload failure. To sum up, this method can improve the flexibility of BDSBAS message broadcast, shorten the update cycle of various BDSBAS messages, and better guarantee the integrity and continuity of BDSBAS services.

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