International Civil Aviation Organization

NINETEENTH MEETING OF THE COMMUNICATIONS/NAVIGATION AND SURVEILLANCE SUG-GROUP (CNS SG/19) OF APANPIRG

Bangkok, Thailand, 20 – 24 July 2015

Agenda Item 5: **Navigation**

5.5 Other radio navigation issues

PROGRESS OF THE BDS SYSTEM AND SARPS DEVELOPMENT

(Presented by China)

SUMMARY

This paper presents information of the development of the BeiDou Navigation Satellite System (BDS) and its SARPs. The BDS has officially been providing Open Service (OS) since December 27th, 2012. The BDS will provide global Open Service (OS) after its full deployment in 2020. The development of BDS SARPs was initialized in ICAO in 2011. The approval of BDS SARPs is targeted for 2018 in line with the progress expected on the standardization of the next generation of aviation receivers.

1. INTRODUCTION

1.1 The BeiDou Navigation Satellite System (BDS) has been officially providing continuous and stable Open Service (OS) since December 27th, 2012. The BDS plans to be fully deployed around 2020.

1.2 The development of BDS SARPs baseline is targeted to 2018. The BDS SARPs will be approved when the global service is available.

2. PROGRESS OF BEIDOU SYSTEM DEVELOPMENT

2.1 On December 27th, 2012, the BDS officially began to provide Open Service (OS). BDS currently has 14 satellites (5GEO+5IGSO+4MEO) in orbit and broadcasts B1I and B2I OS signals to civil users.

2.2 On December 27th, 2013, the China Satellite Navigation Office (CNSO) officially released the BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal (ICD Version 2.0) and the BeiDou Navigation Satellite System Open Service Performance Standard (OSPS Version 1.0). The Doc of ICD defines the specification related to open service signal B1I and B2I between the space segment and the user segment of the BDS, and the Doc of OSPS defines functions and performance of BDS open service.

2.3 At the current stage, the BDS regional service capability has been achieved, which can provide continuous OS to the area as shown in Figure 1 & Figure 2, including the most part of the region from 55°S to 55°N, 70°E to150°E.

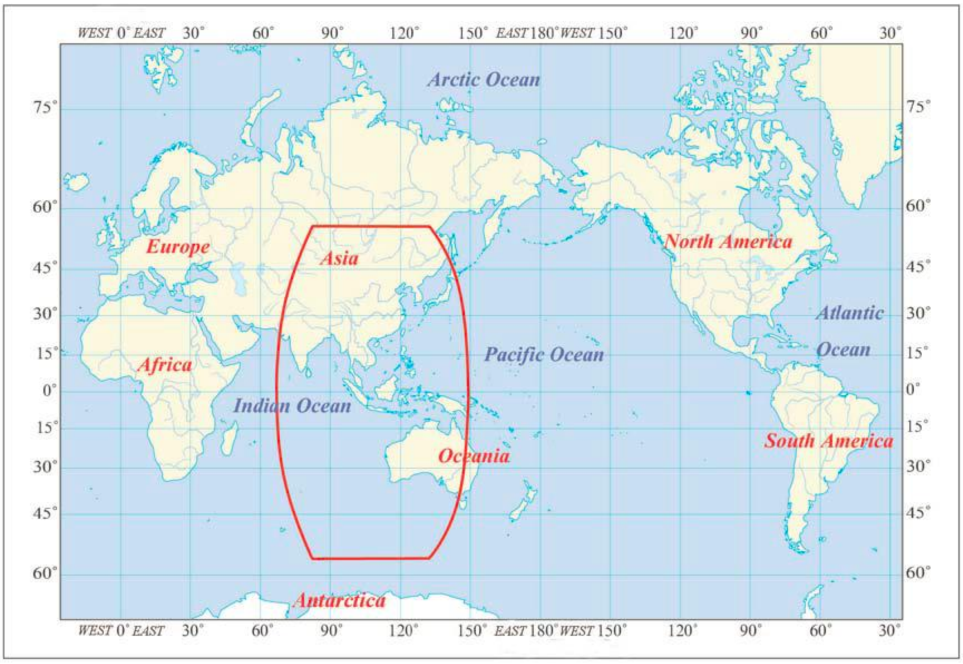

Figure 1 The BDS Service Area

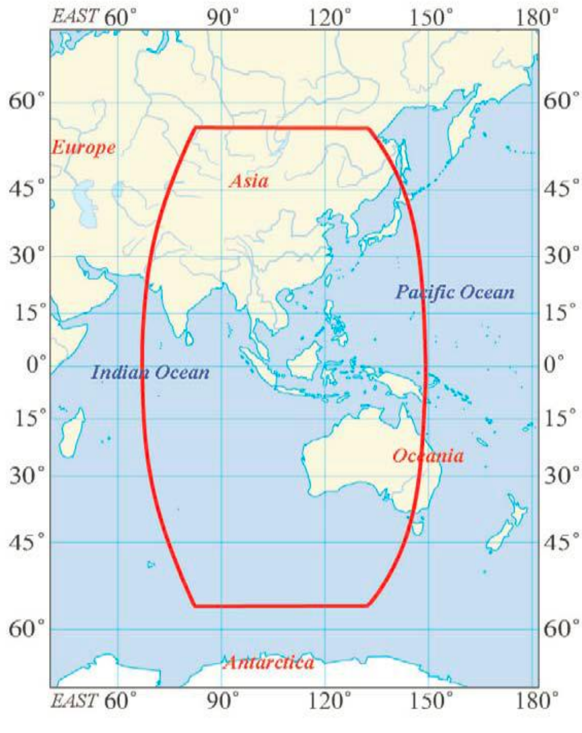

Figure 2 The BDS Service Area(partial enlarged detail)

2.4 BDS plans to launch 2 IGSO and 3 MEO satellites this year, which are all new generation satellites. The test to verify the new type of navigation signal will be carried out on schedule. BDS plans to be of fully deployment around 2020. BDS will be committed to providing stable, reliable and quality satellite navigation services for global users free of charge.

2.5 The B2I signal will be replaced by signal with better performance gradually. The B1I signal will continuously provide global service. Additional OS signals B1C and B2a will be broadcasted. The B1C signal is compatible and inter-operable with GPS L1C and Galileo E1OS signals. The B2a signal is compatible and inter-operable with GPS L5 and Galileo E5a signals. The B1I, B1C and B2a signals of BDS are aeronautical radio navigation signals protected by ITU.

2.6 The functions and performance of BDS global open service are as follows:

- Main functions: positioning, velocity measurement, one-way and two-way timing, short messages;
- Service area: global;
- Position accuracy: better than 10m;
- Velocity accuracy: better than 0.2m/s;
- Time accuracy: 20ns.

2.7 BDS has become one of the 4 core constellations accepted by ICAO. By providing guaranteed satellite navigation service, BDS gives more options to civil aviation users and helps them to enhance the safety of operations. The manufacturers and users are encouraged to push forward their tests, demonstrations and implementations of BDS in various applications.

3. PROGRESS OF BEIDOU SARPs DEVELOPMENT

3.1 An initial draft of BDS SARPs for the signal-in-space is presented to the ICAO NSP during the WGW 12 meeting of NSP in May 2012.

3.2 The GSSG of NSP recommended to baseline the BDS and Galileo SARPs but not seek a formal approval of an Annex 10 amendment before the constellation deployment has progressed further. It was noted that approval of SARPs for all new signals (GPS L5, GLONASS L3, BeiDou and Galileo) should be targeted for 2018 in line with the progress expected on the standardization of the next generation of aviation receivers.

3.3 The BDS will provide global OS free of charge after reach its full constellation and such continuous, stable and reliable service will guarantee and ensure its compatibility with other GNSS constellations under the framework of ICAO SARPs.

4. ACTION BY THE MEETING

4.1 The meeting is invited to:

a) note the information contained in this paper; and

b) discuss any relevant matters as appropriate.

Attachment 1: Report on the Development of BeiDou Navigation Satellite System (Version 2.2)
Attachment 2: BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal (Version 2.0)
Attachment 3: BeiDou Navigation Satellite System Open Service Performance Standard (Version 1.0)

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Report on the Development of BeiDou Navigation Satellite System

(Version 2.2)

China Satellite Navigation Office

December 2013

Contents

Preface

A navigation satellite system can provide all time, all weather and high accuracy positioning, navigation and timing services to users on the earth surface or in the near-earth space. It is an important space infrastructure, which extends people's range of activities and promotes social development. Satellite navigation has been bringing up revolutionary changes to the world politics, economy, military, technology and culture.

With a long history and a splendid culture, China is one of the important cradles of early human civilization. Chinese people used the Big Dipper (*Beidou*) for identifying directions dating back ancient times. They also invented the world's first navigation device, the ancient compass (*Sinan*), which was a great contribution to the development of world civilization. Nowadays, the BeiDou Navigation Satellite System (BDS) will become another contribution of China to the mankind.

In early 1980s, China began to actively study the navigation satellite systems in line with China's conditions. In 2000, the BeiDou Navigation Satellite Demonstration System was established, which made China the third nation in possession of an independent navigation satellite system following the United States and Russia. BDS has formally begun to provide services to the Asia-Pacific region since December 2012, and will provide global services by around 2020.

Many governmental departments in China have been involved in the construction, operation and application management of BDS. As a joint office established by related governmental departments, China Satellite Navigation Office is in charge of management on the construction, application promotion and industrialization of BDS.

Meanwhile, the Expert Committee and the Expert Teams were also established to bring into full play of the expert experiences, as well as to make scientific management and decisions.

BDS will meet the demands of China's national security, economic development, technological advances and social progress, safeguard national interests and enhance the comprehensive national strength. BDS will be committed to providing stable, reliable and quality satellite navigation services for global users. Along with other GNSS providers, BDS will jointly promote the development of the satellite navigation industry, make contributions to human civilization and social development, serve the world and benefit the mankind.

I. System Description

As a global navigation satellite system compatible with other navigation satellite systems worldwide, BDS is independently established and operated by China.

BDS consists of three major components: the space constellation, the ground control segment and the user segment.

The space constellation consists of 5 GEO satellites and 30 non-GEO satellites. The GEO satellites are positioned at 58.75°E, 80°E, 110.5°E, 140°E and 160°E respectively. The non-GEO satellites include 27 MEO satellites and 3 IGSO satellites. The MEO satellites are operating in orbit with an altitude of 21,500 km and an inclination of 55°, which are evenly distributed in 3 orbital planes. The IGSO satellites are operating in orbit with an altitude of 36,000 km and an inclination of 55°, which are evenly distributed in 3 IGSO planes. The tracks of sub-satellite points for those IGSO satellites are coincided while the longitude of the intersection point is 118°E, with a phase difference of 120°.

The ground control segment consists of a Master Control Station (MCS), Time Synchronization/Upload Stations (TS/US) and Monitor Stations (MS). The main tasks of MCS are to collect observing data from each MS, to process data, to generate satellite navigation messages, to upload navigation messages, to monitor satellite payload, to perform mission planning and scheduling, and to conduct system operation and control. The main tasks of TS/US are to upload navigation messages, to exchange data with MCS, to accomplish time synchronization and measurement, under the general coordination of MCS. The main tasks of MS are to continuously track and monitor navigation satellites, to receive navigation signals and provide observing data to the MCS for generating navigation messages.

The user segment encompasses various BeiDou user terminals, including those compatible with other navigation satellite systems, to meet various application requirements from different fields and industries.

The BeiDou Time (BDT) is used as the time reference for BDS. BDT adopts International System of Units (SI) second as the basic unit for continuous accumulations. It does not have leap seconds. The initial epoch of BDT was 00:00:00 on January 1, 2006 Coordinated Universal Time (UTC). BDT is related to UTC through UTC (NTSC), which is maintained by National Time Service Center, Chinese Academy of Sciences. The offset between BDT and UTC is less than 100ns (modulo 1 second). The leap second between BDT and UTC is broadcasted in the navigation message. China Geodetic Coordinate System 2000 (CGCS2000) is used as the coordinate framework of BDS.

Upon the full system completion, BDS can provide positioning, velocity measurement and timing services to users worldwide. It can also provide wide area differential services with the accuracy better than 1m, as well as short messages services with the capacity of 120 Chinese characters per message. The functions and performance specifications are as follows:

- Main functions: positioning, velocity measurement, one-way and two-way timing, short messages;
- Service area: global;
- Position accuracy: better than 10m;
- Velocity accuracy: better than 0.2m/s;
- Time accuracy: 20ns.

II. System Development

i. System Planning

According to the overall requirements of “quality, safety, application and benefits”, adhering to the development principles of “independency, openness, compatibility and gradualness” and following the general guidelines of starting with regional services and then expanding to global services, BDS is steadily accelerating the construction based on a “three-step” development strategy, with details as follows:

Step I: BeiDou Navigation Satellite Demonstration System.

In 1994, China initiated the construction of BeiDou Navigation Satellite Demonstration System. In 2000, the first 2 BeiDou navigation experiment satellites were launched, and the system was established, which made China be the third nation in the world in possession of an independent navigation satellite system. In 2003, the third BeiDou navigation experiment satellite was launched, which further enhanced the system performance.

The BeiDou Navigation Satellite Demonstration System consists of 3 major components: the space constellation, the ground control segment and the user segment. The space constellation includes 3 GEO satellites, positioned at 80°E, 110.5°E and 140°E respectively above the equator. The ground control segment consists of the ground control center and a number of calibration stations. The ground control center is to complete satellite orbit determination, ionospheric correction, user location determination and user short message information exchanging and processing. The calibration stations are mainly to provide the distance measurement and correction parameters to the ground control center. The user segment includes hand-held type, vehicle type, command type and other types of terminals, which are capable of sending positioning requests and receiving location information.

The main functions and performance specifications of the BeiDou Navigation Satellite Demonstration System are as follows:

- Main functions: positioning, one-way and two-way timing, short message communications;
- Service area: China and the surrounding areas;
- Position accuracy: better than 20m;
- Time accuracy: one-way 100 ns, two-way 20 ns;
- Short message communications: 120 Chinese characters per message.

Step II: BDS regional services.

In 2004, China initiated the construction of BeiDou Navigation Satellite System. By the end of 2012, BDS consists of 14 operational satellites in orbit, including 5 GEO satellites, 5 IGSO satellites, and 4 MEO satellites, and possesses Full Operational Capability (FOC) for China and the surrounding areas.

The functions and performance parameters of BDS at this step are as follows:

- Main functions: positioning, velocity measurement, one-way and two-way timing, short message communications;
- Service area: China and the surrounding areas;
- Position accuracy: better than 10m;
- Velocity accuracy: better than 0.2 m/s;
- Time accuracy: 50 ns;
- Short message communications: 120 Chinese characters per message.

Step III: BDS global services.

From 2014, additional satellites will be launched, while regional service performances will be advanced and expanded to the worldwide scope. Approximately 40 BeiDou navigation satellites in total will have been launched by about 2020, and the system with global coverage will be fully established.

ii. Current Status of the System

By October 25th, 2012, 16 BeiDou navigation satellites have been launched to form the constellation and enter into operation by the end of 2012. It possesses FOC and provides continuous passive positioning, navigation and timing services to China and surrounding areas. BDS has brought more navigation satellites resources to the Asia-Pacific region, and can provide more reliable and stable services through joint application with other systems. Currently, BDS is under continuous and stable operation, the system performance meets with designed specifications; while in some areas, the performance is better than the designed specification.

In order to enable users gain a better understanding about BDS and to make BDS serve the users better, China Satellite Navigation Office published the "*BeiDou Navigation Satellite System Signal-In-Space Interface Control Document Open Service Signal (version 1.0)*" on December 27th, 2012, and the "*BeiDou Navigation Satellite System Open Service Performance Standard (version 1.0)*" as well as the "*BeiDou Navigation Satellite System Signal-In-Space Interface Control Document Open Service Signal (version 2.0)*" on December 27th, 2013. Both Chinese and English versions of above documents have been published and are available on BeiDou official website (www.beidou.gov.cn).

The "*BeiDou Navigation Satellite System Open Service Performance Standard (version 1.0)*" provides detailed descriptions for BDS overall structure, SIS characteristics and performance specifications, system open service performance characteristics and specifications, etc. The "*BeiDou Navigation Satellite System Signal-In-Space Interface Control Document Open Service Signal (version 2.0)*" specifies the interface relationship between the satellites and user terminals to use the BDS open service signal B1I and B2I. It identifies the coordinate framework and time reference of BDS, specifies the signal structure, basic characteristics and parameters, and ranging code specifications related to B1I and B2I signals, defines navigation message. With the publication of this document, BDS becomes the first global navigation satellite system which has possessed 2 civil signal frequencies and already provided service capability. Based on these documents, domestic and international enterprises can develop dual-frequency, high-precision BDS receivers, to enable the users enjoy navigation services with higher accuracy.

III. System Applications

Since BDS was officially brought into service, China has achieved remarkable progress in the field of theoretical study, technology R&D, receiver production, application and service development. Along with the construction of BDS and the development of service capabilities, a complete application industry chain has been formed, which consists of fundamental products, user terminals, system applications and operating services. All-round breakthroughs have been made in some key technical areas, such as BDS core chips and modules. The performance of domestic products is comparable to that of international products in the same class. The related products have been gradually used in transportation, marine fisheries, hydrological monitoring, weather forecasting, forest fire prevention, power grid synchronization, timing for telecommunication systems, disaster relief and reduction, national security, and many other fields, which has been resulting in significant social and economic benefits. In particular, BDS played an important role in the South China frozen disaster, earthquake relief in Wenchuan and Lushan, Sichuan Province and Yushu, Qinghai Province, the Beijing Olympic Games, and the Shanghai World Expo.

- In the field of transportation, BDS has been widely used in different areas such as the Demonstration System of Monitoring Management Services in Priority Transportation, the Highway Infrastructure Safety Monitoring System, and the Port Scheduling High-precision Real-time Position Monitoring System.
- In marine fisheries, based on BDS, the marine fisheries integrated information service platform has provided vessel with position monitoring, emergency rescue, information

distribution, fishing boats in and out of port management and other services to the fishery administration departments.

- The hydrological monitoring system was successfully applied at the real-time transmission of hydrological forecast information in mountainous regions, which has improved the accuracy of the disaster forecasting and has helped the planning and scheduling programs for the flood and drought control.

- In the field of weather forecasting, a series of BeiDou terminal equipments have been developed for weather forecast. "Demonstration Application of Monitoring and Warning in Atmospheric, Oceanic and Space" has started, and various practical and feasible system solutions have been worked out to address the automatic data transmission issues among the China meteorological stations.

- In the field of forest fire prevention, BDS has been successfully used, and its positioning and short message communication services have achieved good results in the practical application.

- In the field of time synchronization for telecommunication systems, the successful implementation of BDS two-way timing demonstration program has achieved breakthroughs in some key technical areas such as long distant fiber technology, and an integrated satellite-based timing system has been developed.

- In the field of power distribution, based on BDS, the successful implementation of power system time synchronization demonstration program has created the basis for high precision applications such as the electric accident analysis, the electricity early warning and protection systems.

- In the field of disaster relief and reduction, the navigation, positioning, short message communications and position reporting capabilities of BDS have provided services for the nationwide real-time disaster relief commanding and dispatching, emergency communications, rapid reporting and sharing of disaster information, which has significantly improved the rapid response of the disaster emergency relief and decision-making capability.

China has been drafting a series of policies to enhance satellite navigation application. With satellite navigation being a strategic emerging industry, the BDS application promotion activities have been strongly supported by national ministries, departments and local governments. In August 2013, "*Some Opinions of the State Council on Promoting the Information Consumption to Expand Domestic Demand*" was announced, in which the BDS application industry was identified as one of the national important programs in the information consumption sector. In September 2013, the State Council released the "*National Program for Medium and Long-term Satellite Navigation Industry Development*", which made the overall long-term planning for the satellite navigation industry from the national level.

BDS has brought China navigation satellite and LBS industry into a new era, and will further provide more high-performance positioning, navigation, timing and short-message communication services for civil aviation, shipping, railways, finance, postal, land resources, agriculture, tourism and other industries.

IV. International Exchange and Cooperation

China will carry out active and pragmatic international exchange and cooperation in the field of satellite navigation, in line with China's foreign policies, based on China's primary tasks and strategic objectives for the construction of navigation satellite systems, coordinately utilizing domestic and international markets and resources.

According to the overall development plan of the Chinese navigation satellite system, the international exchange and cooperation activities will be carried out in a phased way with certain focuses. Those activities should be based on the principles of equality, mutual benefit, mutual complementarities, peaceful utilization, mutual development and other generally recognized international principles.

China's international exchange and cooperation in the field of satellite navigation started in 1990s. In recent 20 years, various forms of activities have been carried out with extensive outcome. BDS upholds the principles of openness, cooperation, and resources sharing, adheres to the concept of "BeiDou is of China, and also of the world", has already implemented extensive exchanges and consultation with countries that possess navigation satellite systems, to promote compatibility and interoperability between GNSS. Meanwhile, China also extensively exchanges and cooperates with countries that do not have a navigation satellite system, to share the benefits of navigation satellites with them.

In 1994, under the framework of the International Telecommunication Union (ITU), China started BDS frequency coordination activities. Satellite network information was submitted in accordance with the BDS construction plan and progress. International frequency coordination activities have been conducted in a phased, step by step, focus-centered approach. China has participated bilateral frequency coordination meetings with Europe, the United States and Russia, and has taken part in the World Radio-communication Conference and the meetings of ITU study groups and working groups. In 2012, Chinese delegation participated in the World Radio-communication Conference 2012 of the ITU, and promoted to extend the radio-determination satellite service (space-to-earth) allocations in the S-band, and strive after new adoptable band for navigation satellite systems. Together with delegates from other countries, China successfully pushed forward the S-band (2483.5-2500 MHz) as another band for navigation satellites.

China, as an important member of the International Committee on Global Navigation Satellite Systems (ICG), has participated in each ICG General Assembly Meeting and the ICG Providers Forum. In 2007, BDS became one of the four core providers designated by the organization. During the Sixth Meeting of the ICG, China proposed the initiatives of International GNSS Monitoring & Assessment Service for OS (iGMAS) and BeiDou/GNSS Application Demonstration & Experience Campaign (BADEC), pushed forward the establishment of iGMAS working subgroup and application working subgroup, and became the co-chair of those two subgroups. In November 2012, China hosted the seventh meeting of ICG. More than 200 representatives from 16 counties and areas as well as 18 international organizations joined the meeting. More than 20 proposals were submitted at the meeting, and the "*Joint Statement on Global Navigation Satellite System*" was declared for the first time.

Focusing on compatibility and interoperability, China has carried out the extensive exchange and cooperation with the other navigation satellite systems in the world, strengthened cooperation in sectors of system performance monitoring and assessment, system performance standards, so as to make joint efforts to provide better services for the world.

China has established cooperation mechanisms with some countries in the Asia-Pacific region, and has already carried out extensive cooperation in sectors of precision agriculture, disaster prevention and reduction, transportation and tourism, education and training, system monitoring and assessment. China successfully held the "BeiDou Asia-Pacific Tour" in Pakistan, Korea and other countries. The "BeiDou ASEAN Tour" was one of the activities to celebrate the 10th anniversary of China-ASEAN strategic partnership. In May 2013, the agreement between China and Pakistan for cooperation in the field of satellite navigation was signed under the witness of state leaders from both sides.

China encourages and supports domestic research institutions, industrial enterprises, universities and social organizations, under the guidance of the government policy, to carry out international exchanges, coordination and cooperation activities with other countries and international organizations in the fields of the compatibility and interoperability, satellite navigation standards, coordinates frame, time reference, application development and scientific research. China actively promotes BADEC, iGMAS and other projects, accelerates to push forward BDS to join international organizations, such as the International Civil Aviation Organization (ICAO), International Maritime Organization (IMO), and Third-Generation mobile communication standard Partnership Project (3GPP), develops navigation satellite technology and enhances system service performance.

China actively hosts, organizes and participates in international academic exchanges on satellite navigation. Since 2010, China Satellite Navigation Conference (CSNC) has been held annually, together with many other relative forums and symposium from 2010. CSNC invite major providers of navigation satellite systems, related international organizations and representatives. Those activities make the international community understand and use BDS in a more comprehensive way.

The Chinese government attaches great importance to cultivate talents in navigation satellite area, to keenly promote and develop international GNSS education and training. Under the support of United Nations Office for Outer Space Affairs (UNOOSA), China has established the “Regional Center for Space Science and Technology Education Affiliated to the United Nations”.

Conclusion

The rapid development of BDS is attributed to the growth of China's comprehensive national power and the sustainable development of economy. As always, China will continue to promote the Global Navigation Satellite System construction and industrial development, to encourage use of new satellite navigation technologies, to expand application areas, and to satisfy the ever-growing diversified customer demand. By actively propelling international exchanges and cooperation, China will realize the compatibility and interoperability between BDS and other navigation satellite systems in the world. China will provide global customers with highly reliable positioning, navigation and timing services with excellent performance.

Annex - The BDS Launch Record

- October 31, 2000, launch of 1st BeiDou navigation experiment satellite.
- December 21, 2000, launch of 2nd BeiDou navigation experiment satellite.
- May 25, 2003, launch of the 3rd BeiDou navigation experiment satellite.
- February 3, 2007, launch of the 4th BeiDou navigation experiment satellite.
- April 14, 2007, launch of the 1st BeiDou navigation satellite.
- April 15, 2009, launch of the 2nd Beidou navigation satellite.
- January 17, 2010, launch of the 3rd BeiDou navigation satellite.
- June 2, 2010, launch of the 4th BeiDou navigation satellite.
- August 1, 2010, launch of the 5th BeiDou navigation satellite.

- November 1, 2010, launch of the 6th BeiDou navigation satellite.
- December 18, 2010, launch of the 7th BeiDou navigation satellite.
- April 10, 2011, launch of the 8th BeiDou navigation satellite.
- July 27, 2011, launch of the 9th BeiDou navigation satellite.
- December 2, 2011, launch of the 10th BeiDou navigation satellite.
- February 25, 2012, launch of the 11th BeiDou navigation satellite.
- April 30, 2012, launch of the 12th and 13th BeiDou navigation satellites.
- September 19, 2012, launch of the 14th and 15th BeiDou navigation satellites.
- October 25, 2012, launch of the 16th BeiDou navigation satellites.

BeiDou Navigation Satellite System
Signal In Space
Interface Control Document

Open Service Signal (Version 2.0)

China Satellite Navigation Office

December 2013

Content

1 Statement

BeiDou Navigation Satellite System Signal-In-Space Interface Control Document (hereafter referred to as ICD) is issued by the China Satellite Navigation Office, which reserves the right for final explanation.

2 Scope

This ICD defines the specification related to open service signal B1I and B2I between the space segment and the user segment of the BeiDou Navigation Satellite System. B2I will be gradually replaced by a better signal with the construction of global system.

3 BeiDou System Overview

3.1 Space Constellation

BeiDou Navigation Satellite System is called BeiDou System for short, with the abbreviation as BDS. When fully deployed, the space constellation of BDS consists of five Geostationary Earth Orbit (GEO) satellites, twenty-seven Medium Earth Orbit (MEO) satellites and three Inclined Geosynchronous Satellite Orbit (IGSO) satellites. The GEO satellites are operating in orbit at an altitude of 35,786 kilometers and positioned at 58.75°E, 80°E, 110.5°E, 140°E and 160°E respectively. The MEO satellites are operating in orbit at an altitude of 21,528 kilometers and an inclination of 55° to the equatorial plane. The IGSO satellites are operating in orbit at an altitude of 35,786 kilometers and an inclination of 55° to the equatorial plane.

By the end of 2012, there are five GEO, four MEO and five IGSO BeiDou navigation satellites in orbit.

3.2 Coordinate System

BDS adopts the China Geodetic Coordinate System 2000 (CGCS2000), and the definition is listed below:

The origin is located at the mass center of the Earth;

The Z-axis is in the direction of the IERS (International Earth Rotation and Reference System Service) Reference Pole (IRP);

The X-axis is directed to the intersection of IERS Reference Meridian (IRM) and the plane passing the origin and normal to the Z-axis;

The Y-axis, together with Z-axis and X-axis, constitutes a right handed orthogonal coordinate system.

The origin of the CGCS2000 is also the geometric center of the CGCS2000 ellipsoid, and the Z-axis is the rotation axis of the CGCS2000 ellipsoid. The parameters of the CGCS2000 ellipsoid are as follows:

Semi-major axis: $a = 6378137.0$ m

Geocentric gravitational constant (mass of the earth atmosphere included):

$\mu = 3.986004418 \times 10^{14}$ m^3/s^2

Flattening: $f = 1/298.257222101$

Rate of earth rotation: $\dot{\Omega}_e = 7.2921150 \times 10^{-5}$ rad/s

3.3 Time System

The time reference for the BDS uses the BeiDou navigation satellite system Time (BDT). BDT adopts international system of units (SI) seconds, rather than leap seconds, as the basic unit for continuous accumulation. The start epoch of BDT was 00:00:00 on January 1, 2006 of Coordinated Universal Time (UTC). BDT is counted with week and seconds of week (SOW). BDT is related to the UTC through UTC(NTSC). BDT offset with respect to UTC is controlled within 100 nanoseconds (modulo 1 second). The leap seconds are broadcast in navigation (NAV) message.

4 Signal Specifications

4.1 Signal Structure

The signals on B1 and B2 are the sum of channel I and Q which are in phase quadrature of each other. The ranging code and NAV message are modulated on carrier. The signal is composed of the carrier frequency, ranging code and NAV message.

The signals on B1 and B2 are expressed as follows:

$$S_{B1}^{j}(t) = A_{B1I}C_{B1I}^{j}(t)D_{B1I}^{j}(t)\cos(2\pi f_1 t+\varphi_{B1I}^{j}) + A_{B1Q}C_{B1Q}^{j}(t)D_{B1Q}^{j}(t)\sin(2\pi f_1 t+\varphi_{B1Q}^{j})$$

$$S_{B2}^{j}(t) = A_{B2I}C_{B2I}^{j}(t)D_{B2I}^{j}(t)\cos(2\pi f_2 t+\varphi_{B2I}^{j}) + A_{B2Q}C_{B2Q}^{j}(t)D_{B2Q}^{j}(t)\sin(2\pi f_2 t+\varphi_{B2Q}^{j})$$

Where,

Superscript j: satellite number;

A_{B1I}: amplitude of B1I;

A_{B2I}: amplitude of B2I;

A_{B1Q}: amplitude of B1Q;

A_{B2Q}: amplitude of B2Q;

C_{B1I}: ranging code of B1I;

C_{B2I}: ranging code of B2I;

C_{B1Q}: ranging code of B1Q;

C_{B2Q}: ranging code of B2Q;

D_{B1I}: data modulated on ranging code of B1I;

D_{B2I}: data modulated on ranging code of B2I;

D_{B1Q}: data modulated on ranging code of B1Q;

D_{B2Q}: data modulated on ranging code of B2Q;

f_1: carrier frequency of B1I;

f_2: carrier frequency of B2I;

φ_{B1I}: carrier initial phase of B1I;

φ_{B2I}: carrier initial phase of B2I;

φ_{B1Q}: carrier initial phase of B1Q;

φ_{B2Q}: carrier initial phase of B2Q.

4.2 Signal Characteristics

4.2.1 Carrier Frequency

The carrier frequencies of B1I and B2I shall be coherently derived from a common reference frequency source on board of the satellite. The nominal frequency of B1I signal is 1561.098 MHz， and the nominal frequency of B2I signal is 1207.140 MHz.

4.2.2 Modulation Mode

The transmitted signal is modulated by Quadrature Phase Shift Keying (QPSK).

4.2.3 Polarization Mode

The transmitted signal shall be Right-Handed Circularly Polarized (RHCP). The signal polarization ellipticity is specified in Table 4-1.

Table 4-1 Signal polarization ellipticity

Satellite type	Signal polarization ellipticity
GEO	Ellipticity is no worse than 2.9 dB, angular range: ±10° from boresight.
MEO	Ellipticity is no worse than 2.9 dB, angular range: ±15° from boresight.
IGSO	Ellipticity is no worse than 2.9 dB, angular range: ±10° from boresight.

4.2.4 Carrier Phase Noise

The phase noise spectral density of the unmodulated carrier is as follows:

-60 dBc/Hz @ f_0 ±10 Hz

-75 dBc/Hz @ f_0 ±100 Hz

-80 dBc/Hz @ f_0 ±1 kHz

-85 dBc/Hz @ f_0 ±10 kHz

-95 dBc/Hz @ f_0 ±100 kHz

Where, f_0 is the carrier frequency of B1I or B2I.

4.2.5 User-Received Signal Power Level

The minimum user-received signal power level is specified to be -163dBW for channel I, which is measured at the output of a 0 dB RHCP receiving antenna (located near ground), when the satellite's elevation angle is higher than 5 degree.

4.2.6 Signal Multiplexing Mode

The signal multiplexing mode is Code Division Multiple Access (CDMA).

4.2.7 Satellite Signal Bandwidth and Out-band Suppression

（1）Bandwidth (1dB): 4.092 MHz (centered at carrier frequency of B1I);
20.46MHz (centered at carrier frequency of B2I).
Bandwidth (3dB): 16MHz (centered at carrier frequency of B1I);
36MHz (centered at carrier frequency of B2I).

（2）Out-band suppression: no less than 15 dB on f_0 ±30 MHz, where f_0 is the carrier frequency of B1I or B2I signal.

4.2.8 Spurious

In-band spurious shall be at least 50 dB below the unmodulated carrier over the satellite signal bandwidth (1 dB).

4.2.9 Signal Coherence

（1）The random jitter of the ranging code phase difference (satellite transmitter time delay included) among 4 channels of I and Q on B1, B2 is less than 1ns (1σ).

（2）The random jitter of the initial phase differenal between the ranging code modulated on the carrier and the carrier is less than 3°(1σ) (relative to the carrier) for B1I,B2I.

（3）Carrier phase quadrature difference between channels I and Q:＜5° (1σ).

4.2.10 Equipment Group Delay Differential

Equipment group delay is defined as the delay between the antenna phase center of a satellite and the output of the satellite onboard frequency source. The reference equipment group delay is included in the clock correction parameter a_0 in NAV message with uncertainty less than 0.5ns(1σ).The equipment group delay differential of radiated signals on B1 and B2 with respect to that of reference is given in T_{GD1} and T_{GD2} respectively in NAV message with uncertainty less than 1ns(1σ).

4.3 Ranging Code

The chip rate of the B1I and B2I ranging code is 2.046 Mcps, and the length is 2046 chips.

The B1I and B2I ranging code (hereinafter referred to as C_{B1I} and C_{B2I}) is a balanced Gold code truncated with the last one chip. The Gold code is generated by means of Modulo-2 addition of G1 and G2 sequences which are respectively derived from two 11-bit linear shift registers.

The generator polynomials for G1 and G2 are as follows:

$G1(X)=1+X+X^7+X^8+X^9+X^{10}+X^{11}$

$G2(X)=1+X+X^2+X^3+X^4+X^5+X^8+X^9+X^{11}$

The initial phases of G1 and G2 are:

G1: 01010101010

G2: 01010101010

The generator of C_{B1I} and C_{B2I} is shown in Figure 4-1.

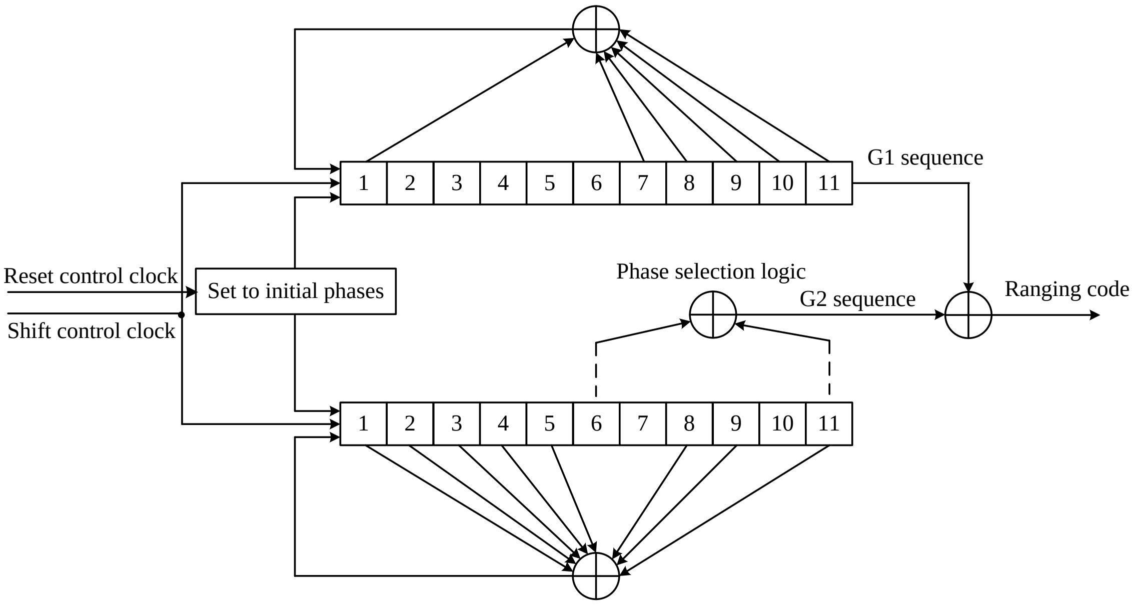


Figure 4-1 The generator of C_{B1I} and C_{B2I}

The different phase shift of G2 sequence is accomplished by respective tapping in the shift register generating G2 sequence. By means of Modulo-2 addition of G2 with different phase shift and G1, a ranging code is generated for each satellite. The phase assignment of G2 sequence is shown in Table 4-2.

Table 4-2 Phase assignment of G2 sequence

No.	Satellite type	Ranging code number	Phase assignment of G2 sequence
1	GEO satellite	1	1 ⊕ 3
2	GEO satellite	2	1 ⊕ 4
3	GEO satellite	3	1 ⊕ 5
4	GEO satellite	4	1 ⊕ 6
5	GEO satellite	5	1 ⊕ 8
6	MEO/IGSO satellite	6	1 ⊕ 9
7	MEO/IGSO satellite	7	1 ⊕ 10
8	MEO/IGSO satellite	8	1 ⊕ 11
9	MEO/IGSO satellite	9	2 ⊕ 7
10	MEO/IGSO satellite	10	3 ⊕ 4
11	MEO/IGSO satellite	11	3 ⊕ 5
12	MEO/IGSO satellite	12	3 ⊕ 6
13	MEO/IGSO satellite	13	3 ⊕ 8
14	MEO/IGSO satellite	14	3 ⊕ 9
15	MEO/IGSO satellite	15	3 ⊕ 10
16	MEO/IGSO satellite	16	3 ⊕ 11
17	MEO/IGSO satellite	17	4 ⊕ 5
18	MEO/IGSO satellite	18	4 ⊕ 6
19	MEO/IGSO satellite	19	4 ⊕ 8
20	MEO/IGSO satellite	20	4 ⊕ 9
21	MEO/IGSO satellite	21	4 ⊕ 10
22	MEO/IGSO satellite	22	4 ⊕ 11
23	MEO/IGSO satellite	23	5 ⊕ 6
24	MEO/IGSO satellite	24	5 ⊕ 8
25	MEO/IGSO satellite	25	5 ⊕ 9
26	MEO/IGSO satellite	26	5 ⊕ 10
27	MEO/IGSO satellite	27	5 ⊕ 11
28	MEO/IGSO satellite	28	6 ⊕ 8
29	MEO/IGSO satellite	29	6 ⊕ 9
30	MEO/IGSO satellite	30	6 ⊕ 10
31	MEO/IGSO satellite	31	6 ⊕ 11

No.	**Satellite type**	**Ranging code number**	**Phase assignment of G2 sequence**
No.	Satellite type	Ranging code number	Phase assignment of G2 sequence
32	MEO/IGSO satellite	32	8 ⊕ 9
33	MEO/IGSO satellite	33	8 ⊕ 10
34	MEO/IGSO satellite	34	8 ⊕ 11
35	MEO/IGSO satellite	35	9 ⊕ 10
36	MEO/IGSO satellite	36	9 ⊕ 11
37	MEO/IGSO satellite	37	10 ⊕ 11

5 NAV Message

5.1 General

5.1.1 NAV Message Classification

NAV messages are formatted in D1 and D2 based on their rate and structure. The rate of D1 NAV message which is modulated with 1 kbps secondary code is 50 bps. D1 NAV message contains basic NAV information (fundamental NAV information of the broadcasting satellites, almanac information for all satellites as well as the time offsets from other systems); while D2 NAV message contains basic NAV and augmentation service information (the BDS integrity, differential and ionospheric grid information) and its rate is 500 bps.

The NAV message broadcast by MEO/IGSO and GEO satellites is D1 and D2 respectively.

5.1.2 NAV Message Information Type and Broadcasting

The NAV message information type and broadcasting are shown in Table 5-1. The detailed structure, bits allocations, contents and algorithms will be described in later chapters.

Table 5-1 NAV message information contents and their broadcasting

<table>
<tr><th colspan="2">Message information content</th><th>No. of Bits</th><th colspan="2">Broadcasting</th></tr>
<tr><td colspan="2">Preamble (Pre)</td><td>11</td><td rowspan="3">Occurring every subframe</td><td rowspan="15">Basic NAV information, broadcast in every satellite</td></tr>
<tr><td colspan="2">Subframe ID (FraID)</td><td>3</td></tr>
<tr><td colspan="2">Seconds of week (SOW)</td><td>20</td></tr>
<tr><td rowspan="9">Fundamental NAV information of the broadcasting satellite</td><td>Week number (WN)</td><td>13</td><td rowspan="9">D1: broadcast in subframes 1, 2 and 3, repeated every 30 seconds.

D2: broadcast in the first five words of pages 1~10 of subframe 1, repeated every 30 seconds.

Updating rate: every 1 hour.</td></tr>
<tr><td>User range accuracy index (URAI)</td><td>4</td></tr>
<tr><td>Autonomous satellite health flag (SatH1)</td><td>1</td></tr>
<tr><td>Equipment group delay differential (T_{GD1},T_{GD2})</td><td>20</td></tr>
<tr><td>Age of data, clock (AODC)</td><td>5</td></tr>
<tr><td>Clock correction parameters (t_{oc}, a_0, a_1, a_2)</td><td>74</td></tr>
<tr><td>Age of data, ephemeris (AODE)</td><td>5</td></tr>
<tr><td>Ephemeris parameters (t_{oe}, $\sqrt{A}$, e, ω, Δn, M_0, Ω_0, $\dot{\Omega}$, i_0, IDOT, C_{uc}, C_{us}, C_{rc}, C_{rs}, C_{ic}, C_{is})</td><td>371</td></tr>
<tr><td>Ionosphere model parameters (α_n, β_n, n=0~3)</td><td>64</td></tr>
<tr><td colspan="2">Page number (Pnum)</td><td>7</td><td>D1: broadcast in subframe 4 and subframe 5.
D2: broadcast in subframe 5.</td></tr>
<tr><td rowspan="3">Almanac</td><td>Alamanac parameters (t_{oa}, $\sqrt{A}$, e, ω, M_0, Ω_0, $\dot{\Omega}$, δ_i, a_0, a_1)</td><td>176</td><td>D1: broadcasting in pages 1~24 of subframe 4 and pages 1~6 of subframe 5, repeated every 12 minutes.
D2: broadcast in pages 37~60, 95~100 of subframe 5, repeated every 6 minutes.
Updating period: less than 7 days.</td></tr>
<tr><td>Week number of alamanac (WN_a)</td><td>8</td><td rowspan="2">D1: broadcast in pages 7~8 of subframe 5, repeated every 12 minutes.
D2: broadcast in pages 35~36 of subframe 5, repeated every 6 minutes.
Updating period: less than 7 days.</td></tr>
<tr><td>Health information for 30 satellites（Hea_i, i=1~30）</td><td>9×30</td></tr>
</table>

Message information content		No. of Bits	Broadcasting	
Time offsets from other systems	Time parameters relative to UTC (A_{0UTC}, A_{1UTC}, Δt_{LS}, Δt_{LSF}, WN_{LSF}, DN)	88	D1: broadcast in pages 9~10 of subframe 5, repeating every 12 minutes. D2: broadcast in pages 101~102 of subframe 5, repeated every 6 minutes. Updating period: less than 7 days.	
	Time parameters relative to GPS time (A_{0GPS}, A_{1GPS})	30		
	Time parameters relative to Galileo time (A_{0Gal}, A_{1Gal})	30		
	Time parameters relative to GLONASS time(A_{0GLO}, A_{1GLO})	30		
Page number for basic NAV information (Pnum1)		4	D2: broadcast in pages 1~10 of subframe 1.	Integrity and differential correction information and ionospheric grid information are broadcast by GEO satellites only.
Page number for integrity and differential correction information (Pnum2)		4	D2: broadcast in pages 1~6 of subframe 2.	
Satellite health flag for integrity and differential correction information (SatH2)		2	D2: broadcast in pages 1~6 of subframe 2. Updating rate: every 3 seconds.	
BDS Satellite identification for integrity and differential correction information ($BDID_i$, i=1~30)		1×30	D2: broadcast in pages 1~6 of subframe 2. Updating rate: every 3 seconds.	
Integrity and differential correction information of BDS	User differential range error index ($UDREI_i$, i=1~18)	4×18	D2: broadcast in subframe 2. Updating rate: every 3 seconds.	
	Regional user range accuracy index ($RURAI_i$, i=1~18)	4×18	D2: broadcast in subframe 2 and subframe 3. Updating rate: every 18 seconds.	
	Equivalent clock correction (Δt_i, i=1~18)	13×18		
Ionospherc grid informatioin	Vertical ionospheric delay at grid point (dτ)	9×320	D2: broadcast in pages 1~13, 61~73 of subframe 5. Updating rate: every 6 minutes.	
	Grid ionospheric vertical delay error indiex (GIVEI)	4×320		

5.1.3 Data Error Correction Coding Mode

The NAV message encoding involves both error control of BCH(15,11,1) and interleaving. The BCH code is 15 bits long with 11 information bits and error correction capability of 1 bit. The generator polynomial is $g(X)=X^4+X+1$.

The NAV message bits are grouped every 11 bits in sequence first. The serial/parallel conversion is made and the BCH(15,11,1) error correction encoding is performed in parallel. Parallel/serial conversion is then carried out for every two parallel blocks of BCH codes by turns of 1 bit to form an interleaved code of 30 bits length. The implementation is shown in Figure 5-1.

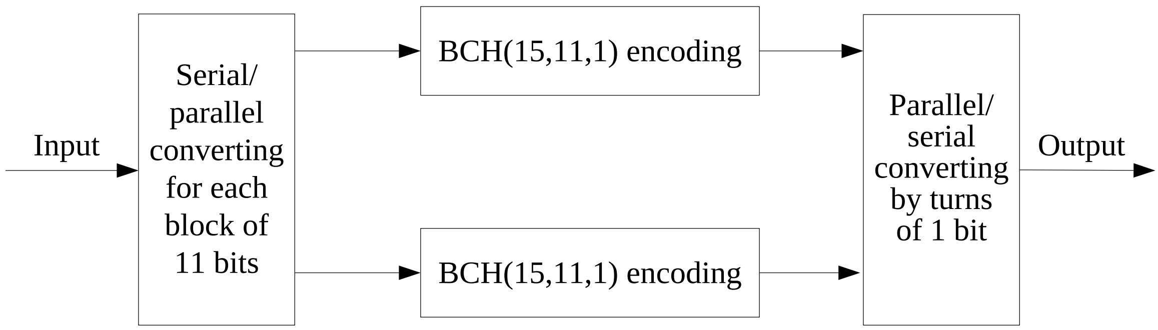


Fig 5-1 Error correction encoding and interleaving of down-link NAV message

The implementation of BCH (15,11,1) encoder is shown in Figure 5-2. Initially the four stages of the shift register are all reset to zero, Gate1 is on and Gate2 is off. The 11 bits of information block X are sent into a dividing circuit g(X). Meantime the information bits are sent out of the encoder through gate "or" as the output. The dividing operation finishes when all the 11 bits have been sent in and then the states of the four register stages represent the parity check bits. Now switch Gate 1 off and Gate 2 on. The four parity check bits are shifted out of the encoder through gate "or" to form a 15 bits code in combination with the output 11 bits of information block. Then switch Gate1 on and Gate2 off and send in the next information block and the procedure above is repeated again.

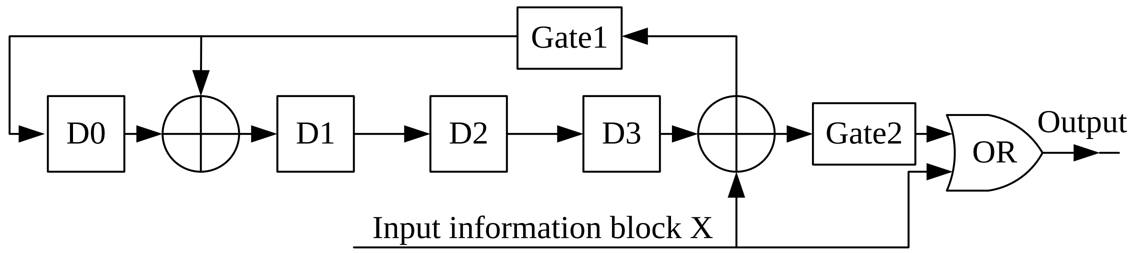


Fig 5-2 BCH(15, 11, 1) encoder

For the received NAV message by receivers near ground a serial/parallel conversion by turns of 1 bit is required first, followed by an error correction decoding of BCH(15,11,1) in parallel. Then a parallel/serial conversion is carried out for each 11 bits block to form a 22 bits information code in sequence. The processing is shown in Figure 5-3.

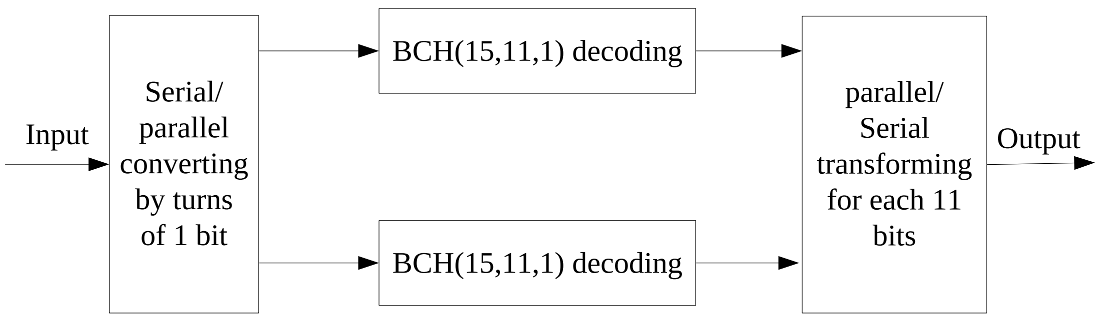


Fig 5-3 Processing of received down-link NAV message

The decoding logic of BCH(15,11,1) is shown in Figure 5-4. The initial states of the four register stages are all zeros. BCH codes are sent in bit by bit into a division circuit and a fifteen stages buffer simultaneously. When all fifteen bits of a BCH code are inputted, the ROM list circuit forms a fifteen-bit table based on the states D3, D2, D1 and D0 of the four register stages. Then the 15 bits in the table and 15 bits in the buffer are Modulo-2 added and an error corrected information code obtained is output. The ROM table list is shown in Table 5-2.

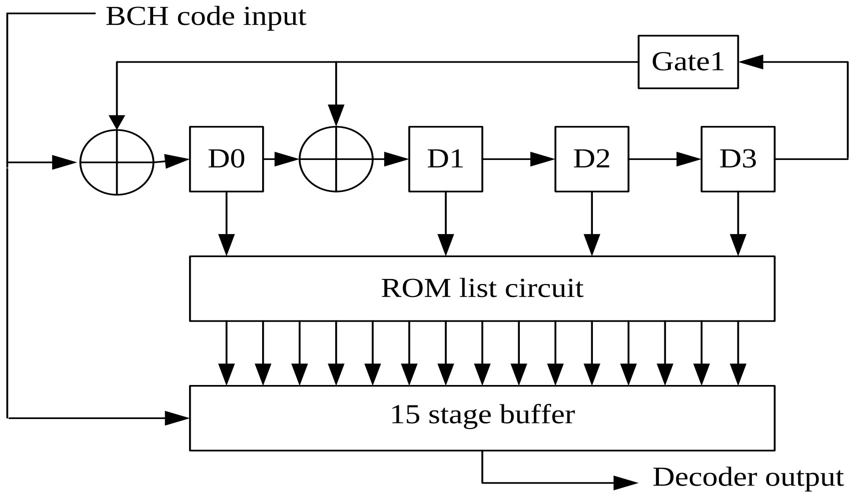


Fig 5-4 BCH(15,11,1) decoding logic

Table 5-2 ROM table list for error correction

$D_3D_2D_1D_0$	15 bits data for error correction
0000	000000000000000
0001	000000000000001
0010	000000000000010
0011	000000000010000
0100	000000000000100
0101	000000100000000
0110	000000000100000
0111	000010000000000
1000	000000000001000
1001	100000000000000
1010	000001000000000
1011	000000010000000
1100	000000001000000
1101	010000000000000
1110	000100000000000
1111	001000000000000

The interleaving pattern of 30 bits code is as follows:

X_1^1	X_2^1	X_1^2	X_2^2	…	X_1^{11}	X_2^{11}	P_1^1	P_2^1	P_1^2	P_2^2	P_1^3	P_2^3	P_1^4	P_2^4

where X_i^j is the information bit, subscript i stands for the bit in BCH code of block i and i=1 or 2; superscript j stands for the information bit j in block i and j=1 to 11; P_i^m is the check parity bit, subscript i stands for the bit in BCH code of block i and i=1 or 2; superscript m stands for the parity bit m in BCH code of block i and m=1 to 4.

5.2 D1 NAV Message

5.2.1 Secondary Code Modulated on D1

For D1 NAV message in format D1 of rate 50 bps a secondary code of Neumann-Hoffman (NH) code is modulated on ranging code. The period of NH code is selected as long as the duration of a NAV message bit. The bit duration of NH code is the same as one period of the ranging code. Shown as in Figure 5-5, the duration of one NAV message bit is 20 milliseconds and the ranging code period is 1 millisecond. Thus the NH code (0, 0, 0, 0, 0, 1, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 1, 1, 0) with length of 20 bits, rate 1 kbps and bit duration of 1 millisecond is adopted. It is modulated on the ranging code synchronously with NAV message bit.

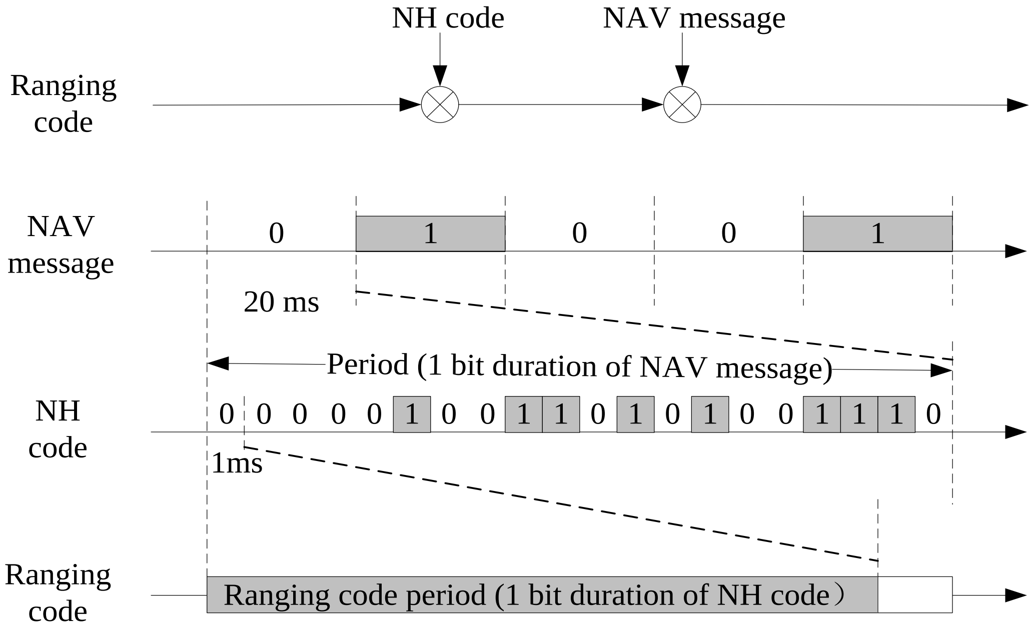


Fig 5-5 Secondary code and its timing

5.2.2 D1 NAV Message Frame Structure

The NAV message in format D1 is structured in the superframe, frame and subframe. Every superframe has 36000 bits and lasts 12 minutes. Every superframe is composed of 24 frames (24 pages). Every frame has 1500 bits and lasts 30 seconds. Every frame is composed of 5 subframes. Every subframe has 300 bits and lasts 6 seconds. Every subframe is composed of 10 words. Every word has 30 bits and lasts 0.6 second.

Every word consists of NAV message data and parity bits. In the first word of every subframe, the first 15 bits is not encoded and the following 11 bits are encoded in BCH(15,11,1) for error correction. So there is only one group of BCH code contained and there are altogether 26 information bits in the word. For all the other 9 words in the subframe both BCH(15,11,1) encoding for error control and interleaving are involved. Each of the 9 words of 30 bits contains two blocks of BCH codes and there are altogether 22 information bits in it. (reference paragraph 5.1.3)

The frame structure in format D1 is shown in Figure 5-6.

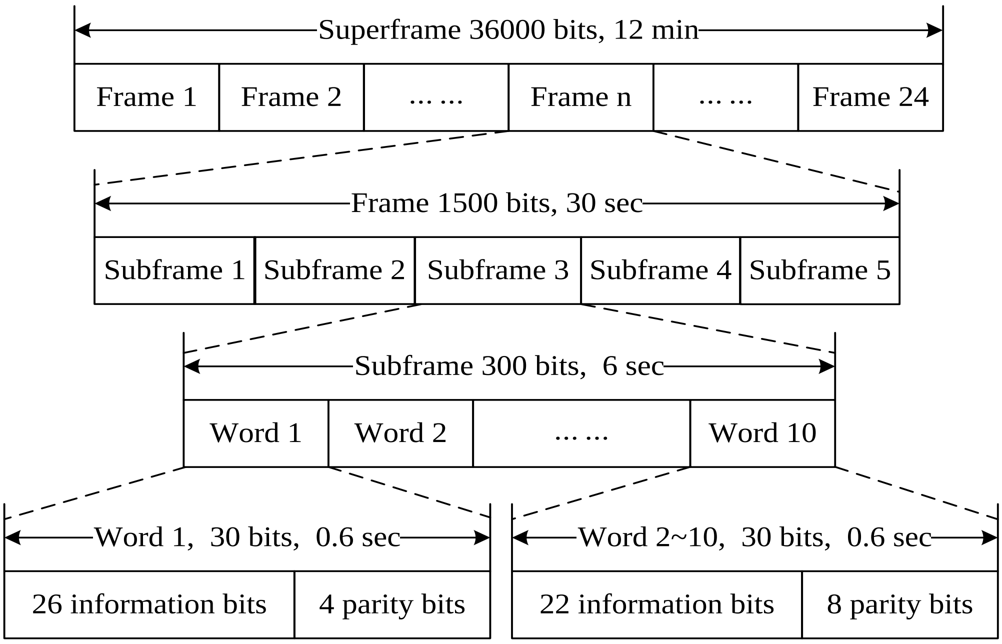


Fig 5-6 Frame structure of NAV message in format D1

5.2.3 D1 NAV Message Detailed Structure

The main information contents of NAV message in format D1 are basic NAV information, including fundamental NAV information of the broadcasting satellites (seconds of week, week number, user range accuracy index, autonomous satellite health flag, ionospheric delay model parameters, satellite ephemeris parameters and their age, satellite clock correction parameters and their age and equipment group delay differential), almanac and BDT offsets from other systems (UTC and other navigation satellite systems). It takes 12 minutes to transmit the whole NAV message.

The D1 frame structure and information contents are shown in Figure 5-7. The fundamental NAV information of the broadcasting satellite is in subframes 1, 2 and 3. The information contents in subframes 4 and 5 are subcommutated 24 times each via 24 pages. Pages 1~24 of subframe 4 and pages 1~10 of subframe 5 shall be used to broadcast almanac and time offsets from other systems. Pages 11~24 of subframe 5 are reserved.

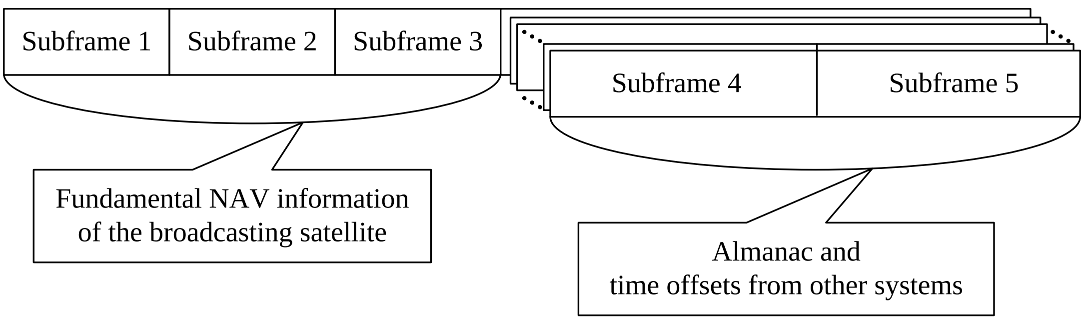


Fig 5-7 Frame structure and information contents of NAV message in format D1

The bits allocations of format D1 are shown in Figure 5-8~5-11.

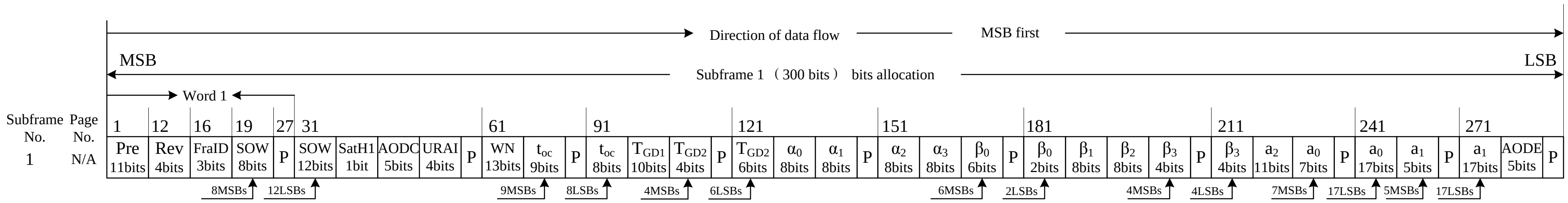


Fig 5-8 Bits allocation of subframe 1 in format D1

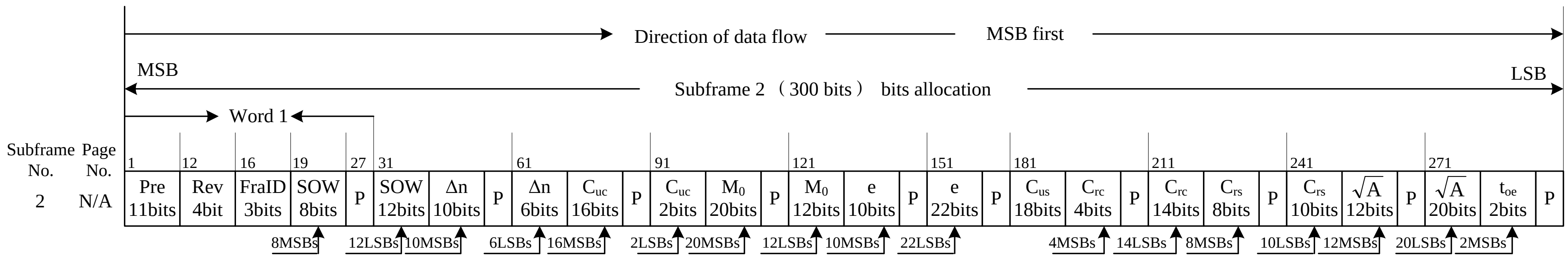
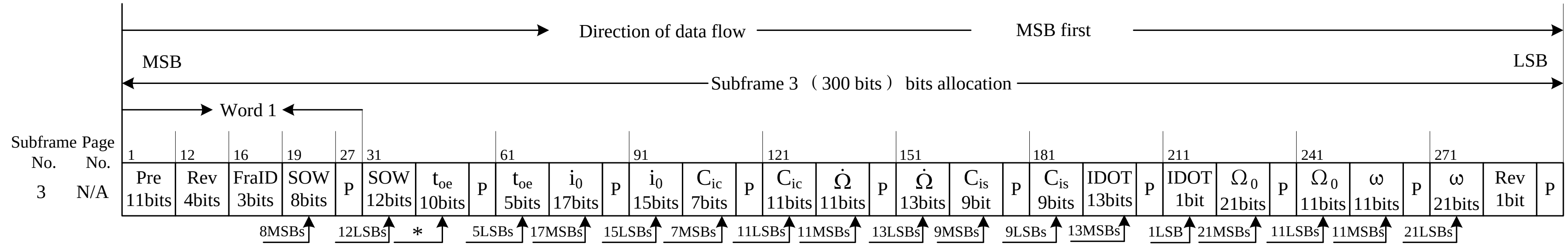


Fig 5-9 Bits allocation of subframe 2 in format D1



* These are data bits next to MSBs and before LSBs.

Fig 5-10 Bits allocation of subframe 3 in format D1

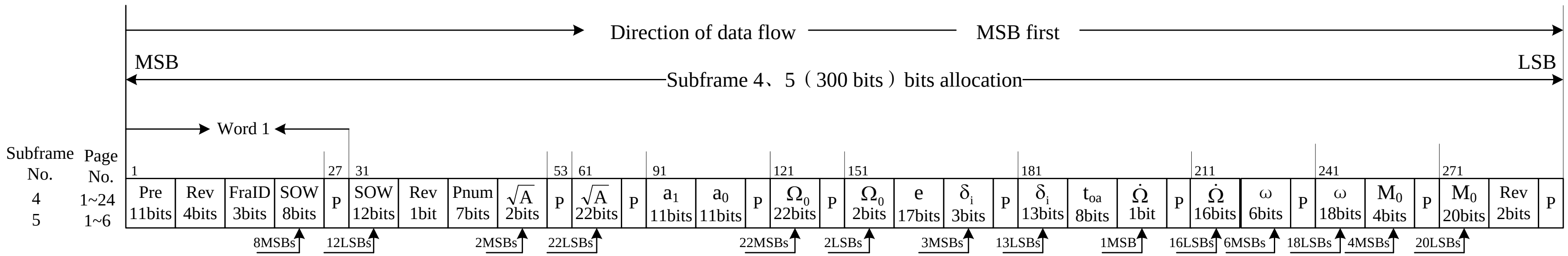


Fig 5-11-1 Bits allocation of pages 1 through 24 in subframe 4 and pages 1 through 6 in subframe 5 of format D1

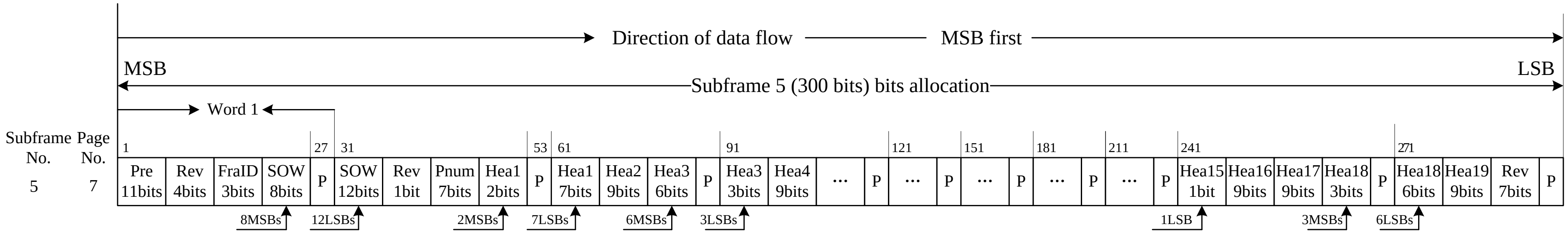


Fig 5-11-2 Bits allocation of page 7 in subframe 5 of format D1

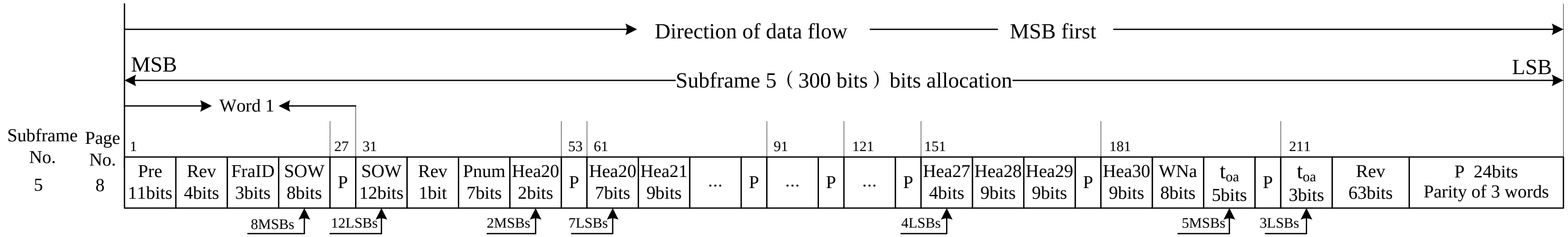


Fig 5-11-3 Bits allocation of page 8 in subframe 5 of format D1

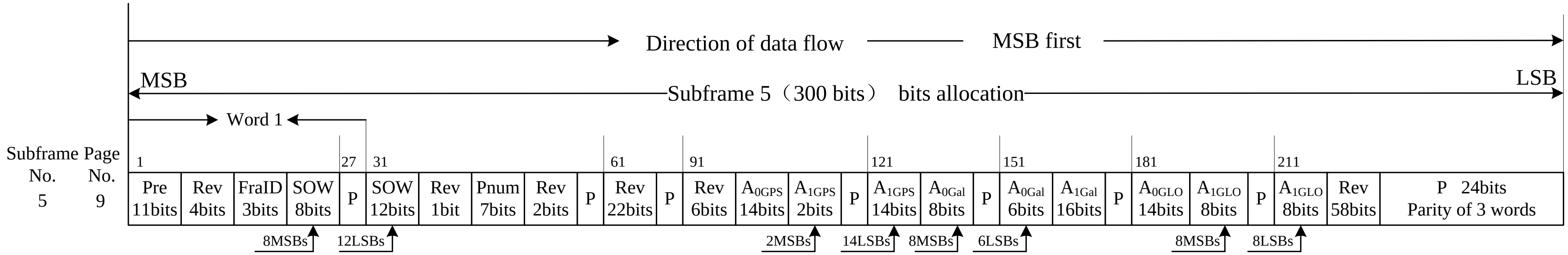


Fig 5-11-4 Bits allocation of page 9 in subframe 5 of format D1

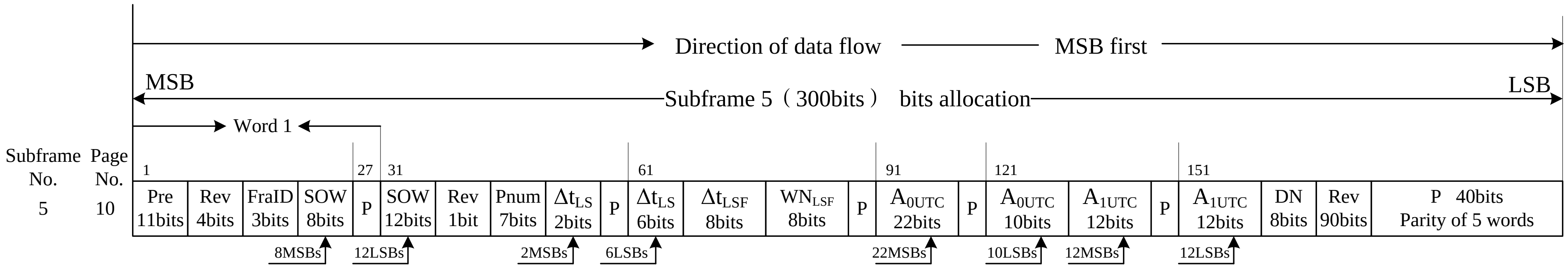


Fig 5-11-5 Bits allocation of page 10 in subframe 5 of format D1

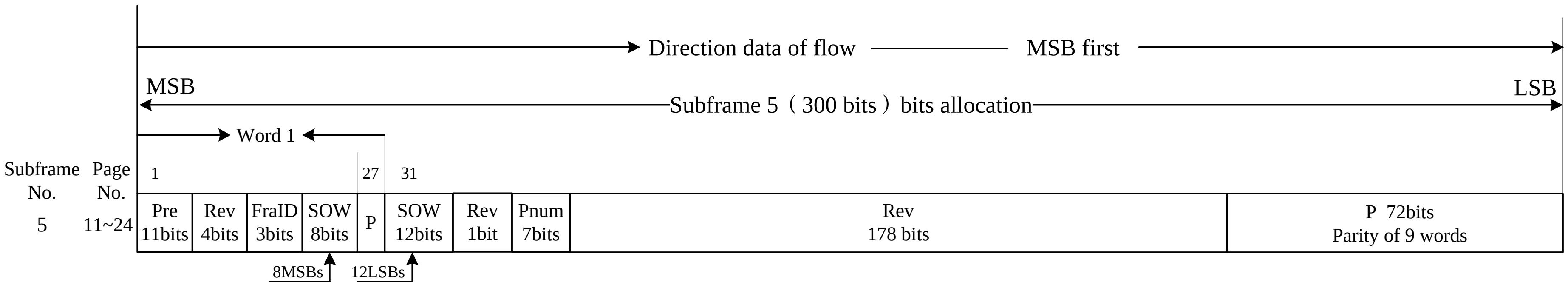


Fig 5-11-6　Bits allocation of reserved pages 11~24 in format D1 subframe

5.2.4 D1 NAV Message Content and Algorithm

5.2.4.1 Preamble (Pre)

The bits 1~11 of every subframe are preamble (Pre) of "11100010010" from modified Barker code of 11 bits. SOW count occurs at the leading edge of the preamble first bit which is for time scale synchronization.

5.2.4.2 Subframe identification (FraID)

The bits 16, 17 and 18 of every subframe are for subframe identification (FraID). The detailed definitions are as follows:

Table 5-3 FraID definitions

Code	001	010	011	100	101	110	111
Identification of subframe	1	2	3	4	5	Rev	Rev

5.2.4.3 Seconds of Week (SOW)

The bits 19~26 and bits 31~42, altogether 20 bits of the each subframe are for seconds of week (SOW) which is defined as the number of seconds that have occurred since the last Sunday, 00:00:00 of BDT. The SOW count occurs at the leading edge of preamble first bit of the subframe.

5.2.4.4 Week Number (WN)

There are altogether 13 bits for week number (WN) which is the integral week count of BDT with the range of 0 through 8191. Week number count started from zero at 00:00:00 on Jan. 1, 2006 of BDT.

5.2.4.5 User Range Accuracy Index (URAI)

The user range accuracy (URA) is used to describe the signal-in-space accuracy in meters. There are 4 bits for the user range accuracy index (URAI). The range of URAI is from 0 to 15. See Table 5-4 for the corresponding relationship between URAI and URA.

Table 5-4 Corresponding relationship between URAI and URA

Code	URAI (N)	URA range (meters, 1σ)
0000	0	0.00 < URA ≤ 2.40
0001	1	2.40 < URA ≤ 3.40
0010	2	3.40 < URA ≤ 4.85
0011	3	4.85 < URA ≤ 6.85
0100	4	6.85 < URA ≤ 9.65
0101	5	9.65 < URA ≤ 13.65
0110	6	13.65 < URA ≤ 24.00
0111	7	24.00 < URA ≤ 48.00
1000	8	48.00 < URA ≤ 96.00
1001	9	96.00 < URA ≤ 192.00
1010	10	192.00 < URA ≤ 384.00
1011	11	384.00 < URA ≤ 768.00
1100	12	768.00 < URA ≤ 1536.00
1101	13	1536.00 < URA ≤ 3072.00
1110	14	3072.00 < URA ≤ 6144.00
1111	15	URA > 6144.00

When an URAI is received by the user, the corresponding URA (X) is computed by the following equations:

If $0 \le N < 6$, $X = 2^{N/2+1}$;

If $6 \le N < 15$, $X = 2^{N-2}$;

If N=15, it means the satellite is in maneuver or there is no accuracy prediction;

If N=1, 3 and 5, X should be rounded to 2.8, 5.7, and 11.3 meters, respectively.

5.2.4.6 **Autonomous Satellite Health flag (SatH1)**

The autonomous satellite health flag (SatH1) occupies 1 bit. “0” means broadcasting satellite is good and “1” means not.

5.2.4.7 **Ionospheric Delay Model Parameters (α_n, β_n)**

There are 8 parameters, altogether 64 bits for ionospheric delay model. All the 8 parameters are in two’s complement. See Table 5-5 for details.

Table 5-5 Ionospheric delay model parameters

Parameter	No. of bits	Scale factor (LSB)	Units
α_0	8*	2^{-30}	s
α_1	8*	2^{-27}	s/π
α_2	8*	2^{-24}	s/π^2
α_3	8*	2^{-24}	s/π^3
β_0	8*	2^{11}	s
β_1	8*	2^{14}	s/π
β_2	8*	2^{16}	s/π^2
β_3	8*	2^{16}	s/π^3
* Parameters so indicated are two’s complement, with the sign bit (+ or –) occupying the MSB.			

The user computers the vertical ionospheric delay correction $I'_z(t)$ with the 8 parameters and Klobuchar model as follows:

$$I'_z(t) = \begin{cases} 5\times10^{-9} + A_2\cos[\dfrac{2\pi(t-50400)}{A_4}], & |t-50400| < A_4/4 \\ 5\times10^{-9}, & |t-50400| \geq A_4/4 \end{cases}$$

Where $I'_z(t)$ is the vertical ionospheric delay in seconds for B1I, t is the local time (range 0~86400 sec) for the place under the intersection point (M) of ionosphere and the direction from receiver to satellite.

A_2 is the amplitude of Klobuchar cosine curve in the day time computed from the α_n.

$$A_2 = \begin{cases} \sum_{n=0}^{3} \alpha_n |\phi_M|^n , & A_2 \geq 0 \\ 0 , & A_2 < 0 \end{cases}$$

A_4 is the period of cosine curve in seconds. It is computed from the β_n..

$$A_4 = \begin{cases} 172800 , & A_4 \geq 172800 \\ \sum_{n=0}^{3} \beta_n |\phi_M|^n , & 172800 > A_4 \geq 72000 \\ 72000 , & A_4 < 72000 \end{cases}$$

Where, ϕ_M is the geographic latitude of earth projection of the ionosphere intersection point in semi-circles (π). The geographic latitude ϕ_M and longitude λ_M of the intersection point M are computed as:

$$\phi_M = \arcsin(\sin\phi_u \cdot \cos\psi + \cos\phi_u \cdot \sin\psi \cdot \cos A)$$

$$\lambda_M = \lambda_u + \arcsin\left(\frac{\sin\psi \cdot \sin A}{\cos\phi_M}\right)$$

Where, ϕ_u is the user's geographic latitude in radians. A is the satellite azimuth from the user location in radians. ψ is the earth's central angle in radians between the user location and ionospheric intersection point. It is computed as:

$$\psi = \frac{\pi}{2} - E - \arcsin\left(\frac{R}{R+h} \cdot \cos E\right)$$

Where,R is the mean radius of the earth (6378 km). E is the satellite elevation from the user's location in radians. h is the height of ionosphere (375 km).

$I'_z(t)$ can be converted to the ionospheric delay along the B1I propagation path $I_{B1I}(t)$ through the equation as follows and the unit is seconds.

$$I_{B1I}(t) = \frac{1}{\sqrt{1-\left(\frac{R}{R+h}\cdot\cos E\right)^2}} \cdot I'_z(t)$$

For B2I, users need to multiply a factor k(f) to calculate the ionospheric delay along the B2I propagation path, and its value is as follows:

$$k(f) = \frac{f_1^2}{f_2^2} = \left(\frac{1561.098}{1207.140}\right)^2$$

Where, f_1 refers to the nominal carrier frequency of B1I, f_2 refers to the nominal carrier frequency of B2I, and the unit is MHz.

The dual-frequency (B1I and B2I) user shall correct for the group delay due to ionospheric effects by applying the expression:

$$PR = \frac{PR_{B2I}\text{-}k(f)\cdot PR_{B1I}}{1\text{-}k(f)} - \frac{C\cdot(T_{GD2}\text{-}k(f)\cdot T_{GD1})}{1-k(f)}$$

where，

PR: pseudorange corrected for ionospheric effects;

PR_{B1I}: pseudorange measured on B1I(corrected by the satellite clock correction parameters ,but not by T_{GD1});

PR_{B2I}: pseudorange measured on B2I(corrected by the satellite clock correction parameters, but not by T_{GD2});

T_{GD1}: equipment group delay differential on B1I;

T_{GD2}: equipment group delay differential on B2I;

C: the light speed, and its value is 2.99792458×10^8 m/s.

Note: When user adopts the ionospheric delay model in the south hemisphere, the ionospheric correction accuracy is slightly worse than that in the north.

5.2.4.8 Equipment Group Delay Differential (T_{GD1}, T_{GD2})

The equipment group delay differential (T_{GD1},T_{GD2}) in the satellite is 10 bits long respectively. It is in two’s complement with sign bit (+ or –) occupying MSB. Sign bit “0” means positive and “1” means negative. The scale factor is 0.1 and the unit is nanoseconds，and the detailed algorithm is defined in paragraph 5.2.4.10.

5.2.4.9 Age of Data, Clock (AODC)

Age of data, clock (AODC) is the extrapolated interval of clock correction parameters. It indicates the time difference between the reference epoch of clock correction parameters and the last observation epoch for extrapolating clock correction parameters. AODC is updated at the start of each hour in BDT, and it is 5 bits long with definitions as follows:

Table 5-6 AODC definitions

AODC	Definition
< 25	Age of the satellite clock correction parameters in hours
25	Age of the satellite clock correction parameters is two days
26	Age of the satellite clock correction parameters is three days
27	Age of the satellite clock correction parameters is four days
28	Age of the satellite clock correction parameters is five days
29	Age of the satellite clock correction parameters is six days
30	Age of the satellite clock correction parameters is seven days
31	Age of the satellite clock correction parameters is over seven days

5.2.4.10 Clock Correction Parameters (t_{oc}, a_0, a_1, a_2)

Clock correction parameters are t_{oc}, a_0, a_1 and a_2 in 74 bits altogether.

t_{oc} is the reference time of clock parameters in seconds with the effective range of 0~604792. Other 3 parameters are two's complement.

The definitions of clock correction parameters are listed in Table 5-7.

Table 5-7 Clock correction parameters

Parameter	No. of bits	Scale factor (LSB)	Effective range	Units
t_{oc}	17	2^{3}	604792	s
a_0	24*	2^{-33}	—	s
a_1	22*	2^{-50}	—	s/s
a_2	11*	2^{-66}	—	s/s^2
* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.				

The system time computation is as follows:

The user is able to compute BDT at time of signal transmission as:

$$t = t_{sv} - \Delta t_{sv}$$

where, t is BDT in seconds at time of signal transmission;

t_{sv} is the effective satellite ranging code phase time in seconds at time of signal transmission;

Δt_{sv} is the offset of satellite ranging code phase time in seconds and is given by the equation:

$$\Delta t_{sv} = a_0 + a_1(t - t_{oc}) + a_2(t - t_{oc})^2 + \Delta t_r$$

Where, t can be replaced by t_{sv} regardless of its sensitivity.

Δt_r is the correction term to relativistic effect with value of

$$\Delta t_r = F \cdot e \cdot \sqrt{A} \cdot \sin E_k$$

e is the orbit eccentricity, which is given in ephemeris of the broadcasting satellite;

$\sqrt{A}$ is the square root of semi-major axis of satellite orbit, which is given in ephemeris of the broadcasting satellite;

E_k is eccentric anomaly of satellite orbit, which is given in ephemeris of the broadcasting satellite;

$F = -2\mu^{1/2}/C^2$;

$\mu = 3.986004418 \times 10^{14}$ m^3/s^2, is the value of earth's universal gravitational constant;

$C = 2.99792458 \times 10^8$ m/s, is the light speed.

The B1I user should make a further correction as follows:

$$(\Delta t_{sv})_{B1I} = \Delta t_{sv} - T_{GD1}$$

The B2I user should make a further correction as follows:

$$(\Delta t_{sv})_{B2I} = \Delta t_{sv} - T_{GD2}$$

5.2.4.11 **Age of Data, Ephemeris (AODE)**

Age of data, ephemeris (AODE) is the extrapolated interval of ephemeris parameters. It indicates the time difference between the reference epoch of ephemeris parameters and the last observation epoch for extrapolating ephemeris parameters. AODE is updated at the start of each hour in BDT, and it is 5 bits long with definitions as follows:

Table 5-8 AODE definitions

AODE	Definition
< 25	Age of the satellite ephemeris parameters in hours
25	Age of the satellite ephemeris parameters is two days
26	Age of the satellite ephemeris parameters is three days
27	Age of the satellite ephemeris parameters is four days
28	Age of the satellite ephemeris parameters is five days
29	Age of the satellite ephemeris parameters is six days
30	Age of the satellite ephemeris parameters is seven days
31	Age of the satellite ephemeris parameters is over seven days

5.2.4.12 Ephemeris Parameters (t_{oe}, $\sqrt{A}$, e, ω, Δn, M_0, Ω_0, $\dot{\Omega}$, i_0, IDOT, C_{uc}, C_{us}, C_{rc}, C_{rs}, C_{ic}, C_{is})

The ephemeris parameters describe the satellite orbit during the curve fit interval, including 15 orbit parameters and an ephemeris reference time. The update rate of ephemeris parameters is one hour.

The definitions of ephemeris parameters are listed in Table 5-9.

Table 5-9 Ephemeris Parameters definitions

Parameter	Definition
t_{oe}	Ephemeris reference time
$\sqrt{A}$	Square root of semi-major axis
e	Eccentricity
ω	Argument of perigee
Δn	Mean motion difference from computed value
M_0	Mean anomaly at reference time
Ω_0	Longitude of ascending node of orbital of plane computed according to
$\dot{\Omega}$	Rate of right ascension
i_0	Inclination angle at reference time
IDOT	Rate of inclination angle
C_{uc}	Amplitude of cosine harmonic correction term to the argument of latitude
C_{us}	Amplitude of sine harmonic correction term to the argument of latitude
C_{rc}	Amplitude of cosine harmonic correction term to the orbit radius
C_{rs}	Amplitude of sine harmonic correction term to the orbit radius
C_{ic}	Amplitude of cosine harmonic correction term to the angle of inclination
C_{is}	Amplitude of sine harmonic correction term to the angle of inclination

Characteristics of ephemeris parameters are shown in Table 5-10.

Table 5-10 Ephemeris parameters characteristics

Parameter	No. of Bits	Scale factor (LSB)	Effective Range	Units
t_{oe}	17	2^{3}	604792	s
$\sqrt{A}$	32	2^{-19}	8192	$m^{1/2}$
e	32	2^{-33}	0.5	—
ω	32*	2^{-31}	±1	π
Δn	16*	2^{-43}	$\pm3.73\times10^{-9}$	π/s
M_0	32*	2^{-31}	±1	π
Ω_0	32*	2^{-31}	±1	π
$\dot{\Omega}$	24*	2^{-43}	$\pm9.54\times10^{-7}$	π/s
i_0	32*	2^{-31}	±1	π
IDOT	14*	2^{-43}	$\pm9.31\times10^{-10}$	π/s
C_{uc}	18*	2^{-31}	$\pm6.10\times10^{-5}$	rad
C_{us}	18*	2^{-31}	$\pm6.10\times10^{-5}$	rad
C_{rc}	18*	2^{-6}	±2048	m
C_{rs}	18*	2^{-6}	±2048	m
C_{ic}	18*	2^{-31}	$\pm6.10\times10^{-5}$	rad
C_{is}	18*	2^{-31}	$\pm6.10\times10^{-5}$	rad
* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.				

The user receiver shall compute the satellite antenna phase center position in coordinate system CGCS2000 according to the received ephemeris parameters. The algorithms are listed in Table 5-11.

Table 5-11 Ephemeris algorithm for user

Computation	Description
$\mu = 3.986004418 \times 10^{14}\ m^3/s^2$	Value of the earth's universal gravitational constant of CGCS2000
$\dot{\Omega}_e = 7.2921150 \times 10^{-5}$ rad/s	Value of the earth's rotation rate of CGCS2000
$\pi = 3.1415926535898$	Ratio of a circle's circumference to its diameter
$A = \left(\sqrt{A}\right)^2$	Computed semi-major axis
$n_0 = \sqrt{\frac{\mu}{A^3}}$	Computed mean motion (radians/sec)
$t_k = t - t_{oe}{}^*$	Computed time from ephemeris reference epoch
$n = n_0 + \Delta n$	Corrected mean motion
$M_k = M_0 + nt_k$	Computed mean anomaly
$M_k = E_k - e\sin E_k$	Kepler's Equation for Eccentric anomaly solved by iteration (radians)
$\begin{cases} \sin v_k = \frac{\sqrt{1-e^2}\sin E_k}{1-e\cos E_k} \\ \cos v_k = \frac{\cos E_k - e}{1-e\cos E_k} \end{cases}$	Computed true anomaly
$\phi_k = v_k + \omega$	Computed argument of latitude
$\begin{cases} \delta u_k = C_{us}\sin(2\phi_k) + C_{uc}\cos(2\phi_k) \\ \delta r_k = C_{rs}\sin(2\phi_k) + C_{rc}\cos(2\phi_k) \\ \delta i_k = C_{is}\sin(2\phi_k) + C_{ic}\cos(2\phi_k) \end{cases}$	Argument of latitude correction Radius correction Inclination correction
$u_k = \phi_k + \delta u_k$	Corrected Argument of latitude parameters
$r_k = A(1 - e\cos E_k) + \delta r_k$	Corrected radius
$i_k = i_0 + IDOT \cdot t_k + \delta i_k$	Corrected inclination
$\begin{cases} x_k = r_k \cos u_k \\ y_k = r_k \sin u_k \end{cases}$	Computed satellite positions in orbital plane

Computation	Description
$\Omega_k = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_e)t_k - \dot{\Omega}_e t_{oe}$ $\begin{cases} X_k = x_k \cos\Omega_k - y_k \cos i_k \sin\Omega_k \\ Y_k = x_k \sin\Omega_k + y_k \cos i_k \cos\Omega_k \\ Z_k = y_k \sin i_k \end{cases}$	Corrected longitude of ascending node in CGCS2000; MEO/IGSO satellite coordinates in CGCS2000
$\Omega_k = \Omega_0 + \dot{\Omega} t_k - \dot{\Omega}_e t_{oe}$ $\begin{cases} X_{GK} = x_k \cos\Omega_k - y_k \cos i_k \sin\Omega_k \\ Y_{GK} = x_k \sin\Omega_k + y_k \cos i_k \cos\Omega_k \\ Z_{GK} = y_k \sin i_k \end{cases}$ $\begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} = R_Z(\dot{\Omega}_e t_k) R_X(-5^\circ) \begin{bmatrix} X_{GK} \\ Y_{GK} \\ Z_{GK} \end{bmatrix}$ Where, $R_X(\varphi) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & +\cos\varphi & +\sin\varphi \\ 0 & -\sin\varphi & +\cos\varphi \end{pmatrix}$ $R_Z(\varphi) = \begin{pmatrix} +\cos\varphi & +\sin\varphi & 0 \\ -\sin\varphi & +\cos\varphi & 0 \\ 0 & 0 & 1 \end{pmatrix}$	Corrected longitude of ascending node in inertial coordinate system; GEO satellite coordinates in user-defined inertial system; GEO satellite coordinates in CGCS2000
* In the equations, "t" is the time of signal transmission in BDT. "t_k" is the total time difference between t and ephemeris reference time t_{oe} after taking account of beginning or end of a week crossovers. That is, subtract 604800 seconds from t_k if t_k is greater than 302400, add 604800 seconds to t_k if t_k is less than -302400 seconds.	

5.2.4.13 **Page number (Pnum)**

The bits 44 through 50, 7 bits altogether of subframe 4 and subframe 5 are for page numbers (Pnum). subframe 4 and subframe 5 are subcommutated 24 times via pages 1 through 24. Pnum identifies the page number of the subframe.

The almanac information of SV ID 1 through 24 is arranged in pages 1 through 24 of subframe 4. The almanac information of SV ID 25 through 30 is arranged in pages 1 through 6 of subframe 5. The page number corresponds to the SV ID one by one.

5.2.4.14 Almanac Parameters （t_{oa}, $\sqrt{A}$, e, ω, M_0, Ω_0, $\dot{\Omega}$, δ_i, a_0, a_1）

Almanac parameters are updated within every 7 days.

Definitions, characteristics and user algorithms of almanac parameters are listed in Tables 5-12, 5-13 and 5-14 respectively.

Table 5-12 Almanac parameters definitions

Parameter	Definition
t_{oa}	Almanac reference time
$\sqrt{A}$	Square root of semi-major axis
e	Eccentricity
ω	Argument of Perigee
M_0	Mean anomaly at reference time
Ω_0	Longitude of ascending node of orbital plane computed according to reference time
$\dot{\Omega}$	Rate of right ascension
δ_i	Correction of orbit reference inclination at reference time
a_0	Satellite clock bias
a_1	Satellite clock rate

Table 5-13 Almanac parameters characteristics

Parameter	No. of Bits	Scale factor (LSB)	Effective range	Units
t_{oa}	8	2^{12}	602112	s
$\sqrt{A}$	24	2^{-11}	8192	$m^{1/2}$
e	17	2^{-21}	0.0625	—
ω	24*	2^{-23}	±1	π
M_0	24*	2^{-23}	±1	π
Ω_0	24*	2^{-23}	±1	π
$\dot{\Omega}$	17*	2^{-38}	—	π/s
δ_i	16*	2^{-19}	—	π
a_0	11*	2^{-20}	—	s
a_1	11*	2^{-38}	—	s/s
* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.				

Table 5-14 Almanac algorithms for users

Computation	Description
$\mu = 3.986004418 \times 10^{14}$ m^3/s^2	Earth's universal gravitational constant of CGCS2000
$\dot{\Omega}_e = 7.2921150 \times 10^{-5}$ rad/s	Value of the earth's rotation rate of CGCS2000
$A = (\sqrt{A})^2$	Computed semi-major axis
$n_0 = \sqrt{\dfrac{\mu}{A^3}}$	Computed mean motion (rad/sec)
$t_k = t - t_{oa}$ *	Computed time from Almanac reference epoch
$M_k = M_0 + n_0 t_k$	Computed mean anomaly
$M_k = E_k - e \sin E_k$	Kepler's equation for eccentric anomaly by iteration (radians)
$\begin{cases} \sin v_k = \dfrac{\sqrt{1-e^2} \sin E_k}{1 - e\cos E_k} \\ \cos v_k = \dfrac{\cos E_k - e}{1 - e\cos E_k} \end{cases}$	Computed true anomaly
$\phi_k = v_k + \omega$	Computed argument of latitude
$r_k = A(1 - e\cos E_k)$	Corrected radius
$\begin{cases} x_k = r_k \cos\phi_k \\ y_k = r_k \sin\phi_k \end{cases}$	Computed satellite positions in orbital plane
$\Omega_k = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_e) t_k - \dot{\Omega}_e t_{oa}$	Corrected longitude of ascending node in CGCS2000
$i = i_0 + \delta_i$ **	Orbit inclination at reference time
$\begin{cases} X_k = x_k \cos\Omega_k - y_k \cos i \sin\Omega_k \\ Y_k = x_k \sin\Omega_k + y_k \cos i \cos\Omega_k \\ Z_k = y_k \sin i \end{cases}$	Computed GEO/MEO/IGSO satellite coordinates in CGCS2000

* In the equations, "t" is the time of signal transmission in BDT. "t_k" is the total time offset between time t and Almanac reference time t_{oa} taking account of beginning or end of a week crossover. That is, subtract 604800 seconds from t_k if t_k is greater than 302400, add 604800 seconds to t_k if t_k is less than -302400.

** For MEO/IGSO satellites, i_0=0.30 semi-circles; for GEO satellites, i_0=0.00.

Almanac time computation is as follows:

$$t = t_{sv} - \Delta t_{sv}$$

where

t is BDT in seconds at time of signal transmission;

t_{sv} is the effective satellite ranging code phase time in seconds at time of signal transmission;

Δt_{sv} is the offset of satellite ranging code phase time in seconds and is given by the equation:

$$\Delta t_{sv} = a_0 + a_1(t - t_{oa})$$

Where t can be replaced by t_{sv} regardless of its sensitivity. The almanac reference time t_{oa} is counted from the starting time of almanac week number (WN_a).

5.2.4.15 **Almanac Week Number (WN_a)**

Almanac week number (WN_a) of 8 bits is the BDT integer week count (Modulo 256) with effective range of 0 to 255.

5.2.4.16 **Satellite Health Information (Hea_i, i=1~30)**

The satellite health information (Hea_i) occupies 9 bits. The 9th bit indicates the satellite clock health flag, while the 8^{th} bit indicates the B1I signal health status. The 7th bit indicates the B2I signal health status,and the 2th bit indicates the information health status. The definitions are in Table 5-15.

Table 5-15 Satellite health information definitions

Bit allocation	Information code	Health information definition
Bit 9 (MSB)	0	Satellite clock OK
	1	*
Bit 8	0	B1I Signal OK
	1	B1I Signal Weak**
Bit 7	0	B2I Signal OK
	1	B2I Signal Weak**
Bit 6~3	0	Reserved
	1	Reserved
Bit 2	0	NAV Message OK
	1	NAV Message Bad (IOD over limit)
Bit 1 (LSB)	0	Reserved
	1	Reserved

* the satellite clock is unavailable if the other 8 bits are all "0"; the satellite is in failure or permanently shut off if the last 8bits are all "1"; the definition is reserved if the other 8 bits are in other values.

** The signal power is 10 dB lower than nominal value.

5.2.4.17 Time Parameters relative to UTC （A_{0UTC}, A_{1UTC}, Δt_{LS}, WN_{LSF}, DN, Δt_{LSF}）

These parameters indicate the relationship between BDT and UTC. Definition of the parameters are listed in Table 5-16.

Table 5-16 Parameters relative to UTC

Parameter	No. of bits	Scale factor(LSB)	Effective range	Units
A_{0UTC}	32*	2^{-30}	—	s
A_{1UTC}	24*	2^{-50}	—	s/s
Δt_{LS}	8*	1	—	s
WN_{LSF}	8	1	—	week
DN	8	1	6	day
Δt_{LSF}	8*	1	—	s

* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.

A_{0UTC}: BDT clock bias relative to UTC;

A_{1UTC}: BDT clock rate relative to UTC;

Δt_{LS}: Delta time due to leap seconds before the new leap second effective;

WN_{LSF}: Week number of the new leap second;

DN: Day number of week of the new leap second;

Δt_{LSF}: Delta time due to leap seconds after the new leap second effective;

Conversion from BDT into UTC:

The broadcast UTC parameters, the WN_{LSF} and DN values make users compute UTC with error not greater than 1 microsecond.

Depending upon the relationship of the effectivity time of leap second event and user's current BDT, the following three different cases of UTC/BDT conversion exist.

1) Whenever the effectivity time indicated by the WN_{LSF} and the DN values is not in the past (relative to the user's present time), and the user's current time t_E is prior to DN+2/3, the UTC/BDT relationship is given by:

$$t_{UTC} = (t_E - \Delta t_{UTC})[\text{modulo } 86400], \text{ seconds}$$

$$\Delta t_{UTC} = \Delta t_{LS} + A_{0UTC} + A_{1UTC} \times t_E, \text{ seconds}$$

Where, t_E is the SOW in BDT computed by user.

2) Whenever the user's current time t_E falls within the time span of DN+2/3 to DN+5/4, proper accommodation of leap second event with possible week number transition is provided by the following equation for UTC:

$$t_{UTC} = W[\text{modulo}(86400 + \Delta t_{LSF} - \Delta t_{LS})], \text{ seconds}$$

where,

$$W = (t_E - \Delta t_{UTC} - 43200)[\text{modulo } 86400] + 43200, \text{ seconds}$$

$$\Delta t_{UTC} = \Delta t_{LS} + A_{0OUT} + A_{1UTC} \times t_E, \text{ seconds}$$

3) Whenever the effectivity time of leap second event, as indicated by the WN_{LSF} and DN values, is in the past (relative to the user's current time), and the user's current time t_E is after DN+5/4, the UTC/BDT relationship is given by:

$$t_{UTC} = (t_E - \Delta t_{UTC})[\text{modulo}86400], \text{ seconds}$$

where,

$$\Delta t_{UTC} = \Delta t_{LSF} + A_{0UTC} + A_{1UTC} \times t_E, \text{ seconds}$$

The parameter definitions are the same with those in case 1).

5.2.4.18 Time Parameters relative to GPS time （A_{0GPS}, A_{1GPS}）

These parameters indicate the relationship between BDT and GPS time as in Table 5-17. (Not broadcast temporarily)

Table 5-17 Time parameters relative to GPS time

Parameter	No. of Bits	Scale factor (LSB)	Units
A_{0GPS}	14*	0.1	ns
A_{1GPS}	16*	0.1	ns/s
* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.			

A_{0GPS}: BDT clock bias relative to GPS time;

A_{1GPS}: BDT clock rate relative to GPS time.

The relationship between BDT and GPS time is as follows:

$$t_{GPS} = t_E - \Delta t_{GPS}$$

where, $\Delta t_{GPS} = A_{0GPS} + A_{1GPS} \times t_E$;

t_E is the SOW in BDT computed by user.

5.2.4.19 Time Parameters relative to Galileo time(A_{0Gal}, A_{1Gal})

These parameters indicate the relationship between BDT and Galileo time as in Table 5-18. (Not broadcast temporarily)

Table 5-18 Time parameters relative to Galileo time

Parameter	No. of Bits	Scale factor (LSB)	Units
A_{0Gal}	14*	0.1	ns
A_{1Gal}	16*	0.1	ns/s
* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.			

A_{0Gal}: BDT clock bias relative to Galileo system time;

A_{1Gal}: BDT clock rate relative to Galileo system time.

Relationship between BDT and Galileo system time is as follows:

$$t_{Gal} = t_E - \Delta t_{Gal}$$

where $\Delta t_{Gal} = A_{0Gal} + A_{1Gal} \times t_E$;

t_E is the SOW in BDT computed by user.

5.2.4.20 Time Parameters relative to GLONASS time (A_{0GLO}, A_{1GLO})

These parameters indicate the relationship between BDT and GLONASS time as in Table 5-19. (Not broadcast temporarily)

Table 5-19 Time parameters relative to GLONASS time

Parameter	No. of Bits	Scale factor (LSB)	Units
A_{0GLO}	14*	0.1	ns
A_{1GLO}	16*	0.1	ns/s
* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.			

A_{0GLO}: BDT clock bias relative to GLONASS time;

A_{1GLO}: BDT clock rate relative to GLONASS time.

Relationship between BDT and GLONASS time is as follows:

$$t_{GLO} = t_E - \Delta t_{GLO}$$

where $\Delta t_{GLO} = A_{0GLO} + A_{1GLO} \times t_E$;

t_E is the SOW in BDT computed by user.

5.3 D2 NAV Message

5.3.1 D2 NAV Message Frame Structure

The NAV message in format D2 is structured with superframe, frame and subframe. Every superframe is 180000 bits long, lasting 6 minutes. Every superframe is composed of 120 frames each with 1500 bits and lasting 3 seconds. Every frame is composed of 5 subframes, each with 300 bits and lasting 0.6 second. Every subframe is composed of 10 words, each with 30 bits and lasting 0.06 second.

Every word is composed of NAV message data and parity bits. The first 15 bits in word 1 of every subframe is not encoded, and the last 11 bits is encoded in BCH(15,11,1) for error correction. For the other 9 words of the subframe both BCH(15,11,1) encoding and interleaving are involved. Thus there are 22 information bits and 8 parity bits in each word. See Figure 5-12 for the detailed structure.

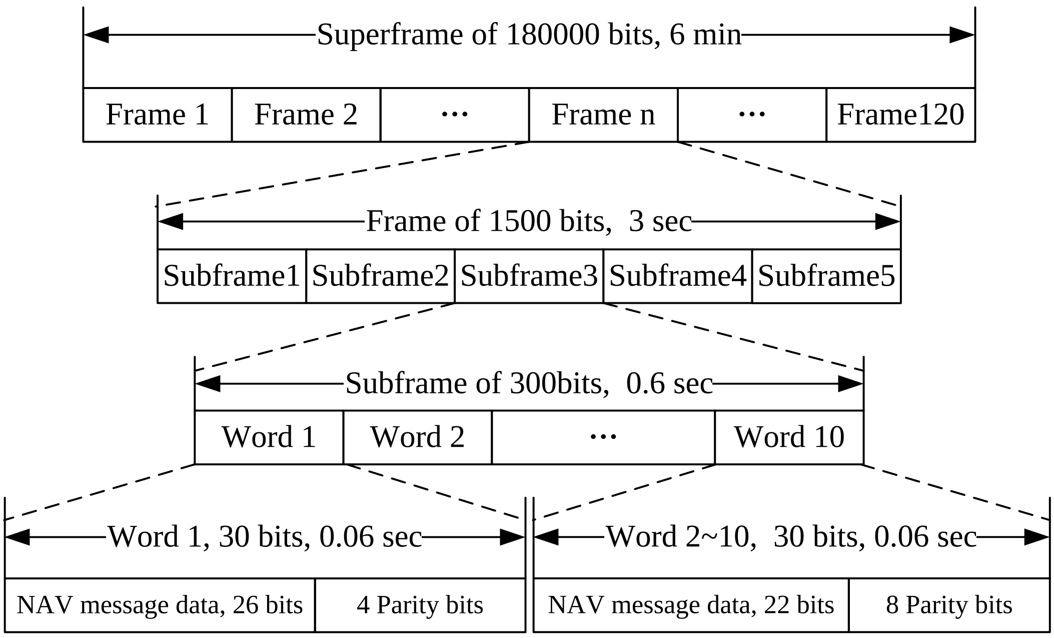


Fig 5-12 Structure of NAV message in format D2

5.3.2 D2 NAV Message Detailed structure

Information in format D2 includes: the basic NAV information of the broadcasting satellite, almanac, time offset from other systems, integrity and differential correction information of BDS and ionospheric grid information as shown in Figure 5-13. The subframe 1 shall be subcommutated 10 times via 10 pages. The subframe 2, subframe 3 and subframe 4 shall be subcommutated 6 times each via 6 pages. The subframe 5 shall be subcommutated 120 times via 120 pages.

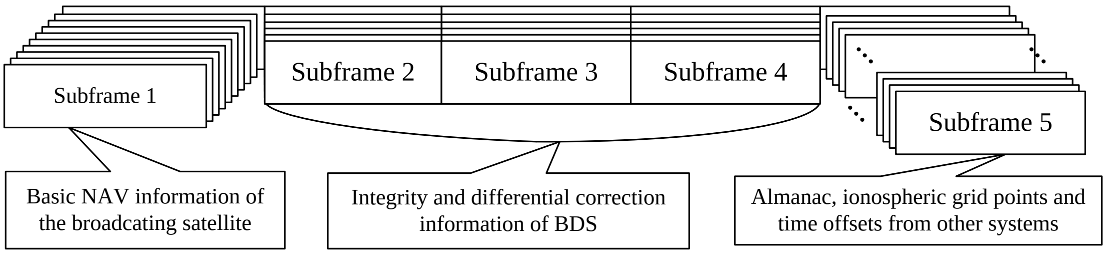


Fig 5-13 Frame structure and information contents of NAV message in format D2

The bit allocation of each subframe in format D2 is shown in Figures 5-14 through 5-18. The 150 LSBs of pages 1 through 10 in subframe 1, pages 1 through 6 of subframe 4, pages 14 through 34, pages 74 through 94 pages and 103 through 120 of subframe 5 in format D2 are to be reserved.

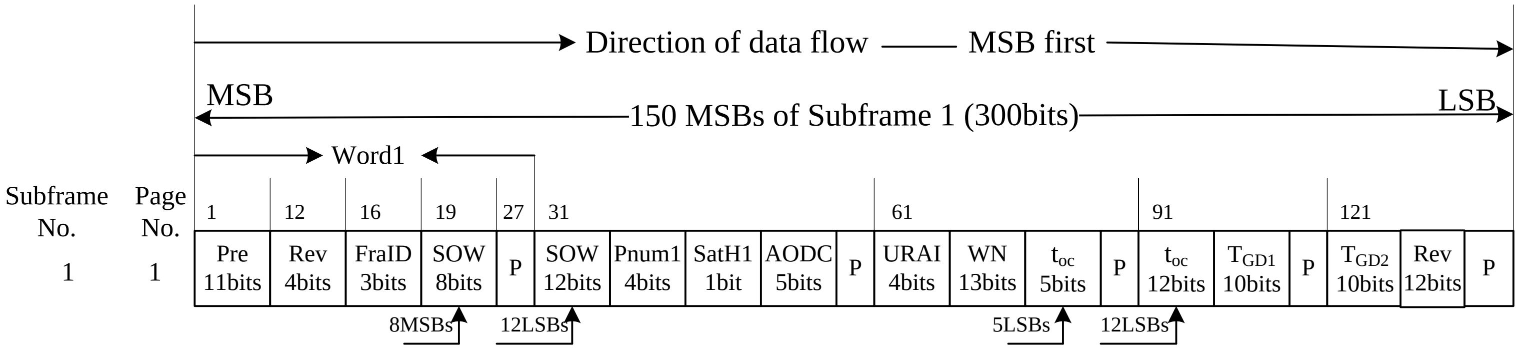


Fig 5-14-1 Bits allocation of 150 MSBs of page 1 in subframe 1 of format D2

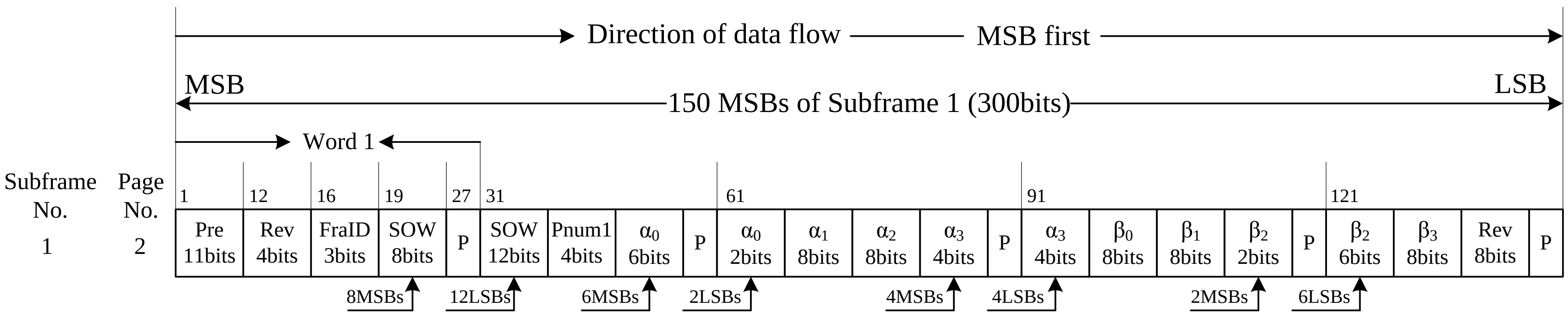


Fig 5-14-2 Bits allocation of 150 MSBs of page 2 in subframe 1 of format D2

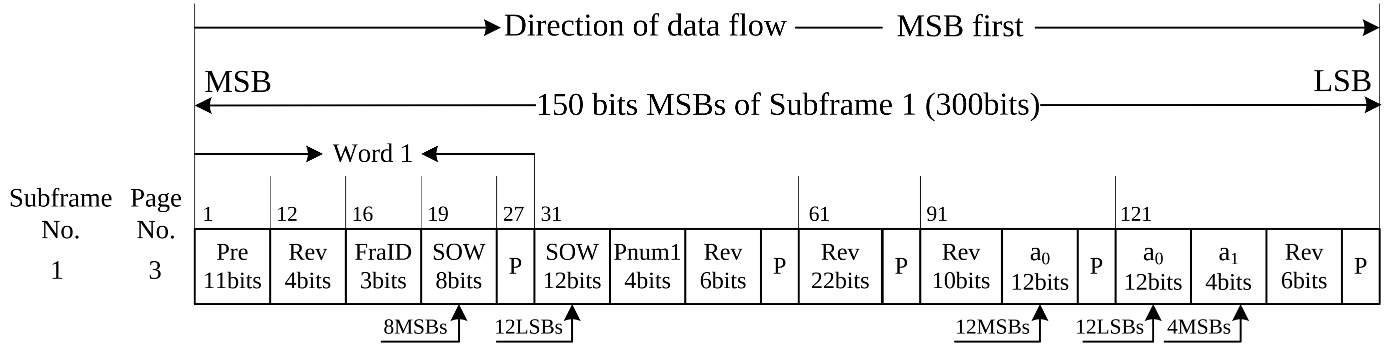
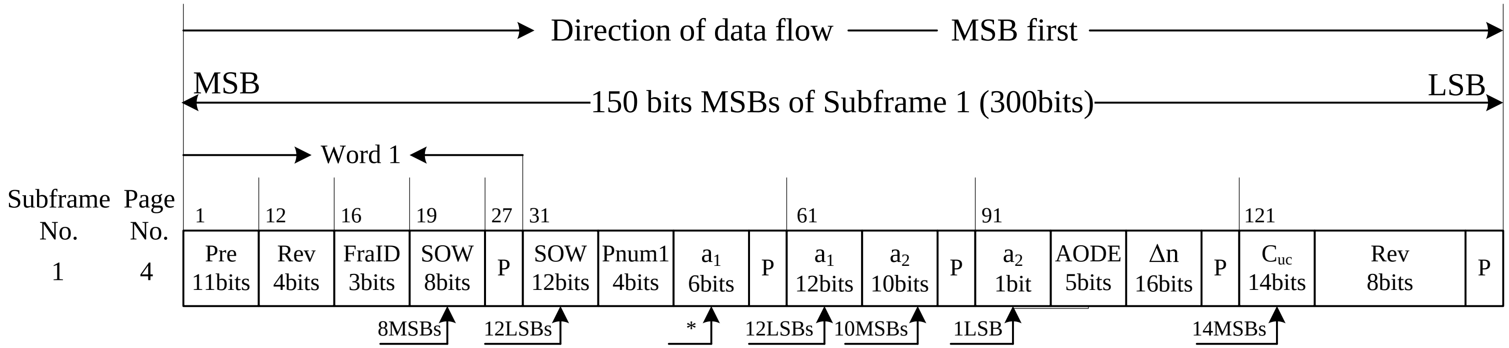
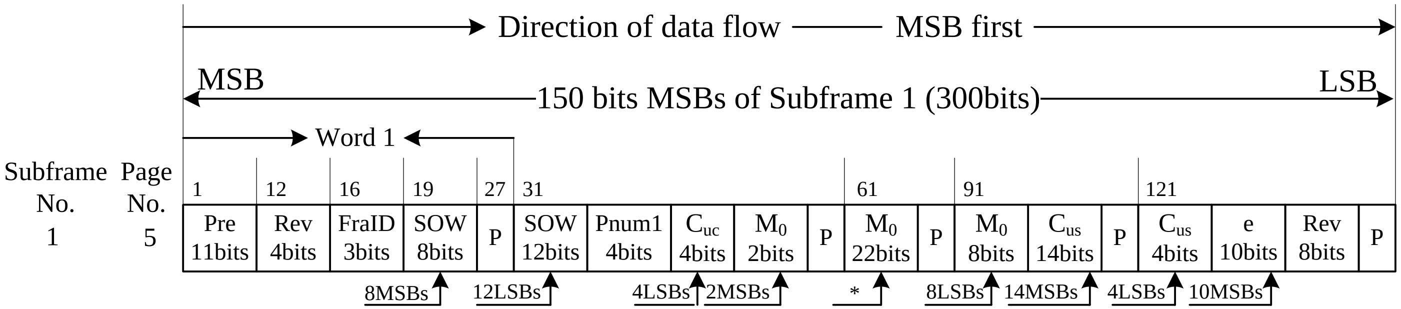


Fig 5-14-3 Bits allocation of 150 MSBs of page 3 in subframe 1 of format D2



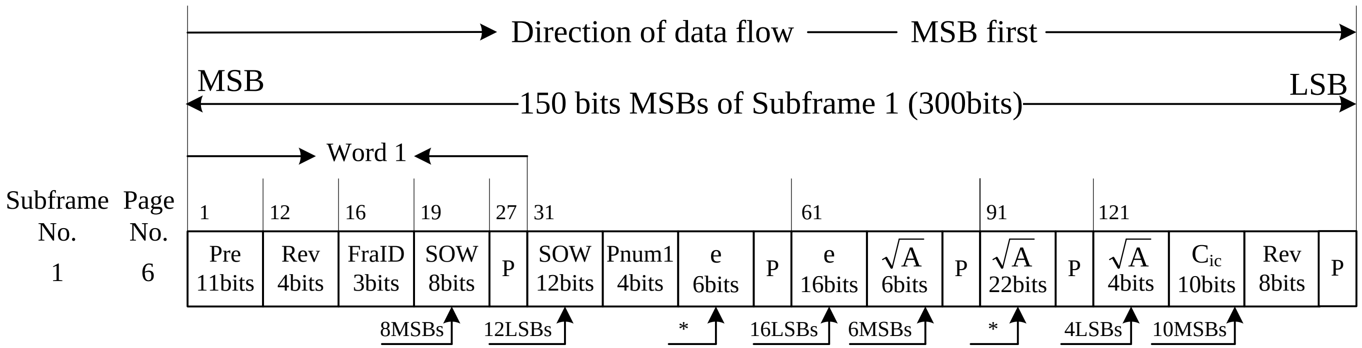
* These are data bits next to MSBs and before LSBs.

Fig 5-14-4 Bits allocation of 150 MSBs of page 4 in subframe 1 of format D2



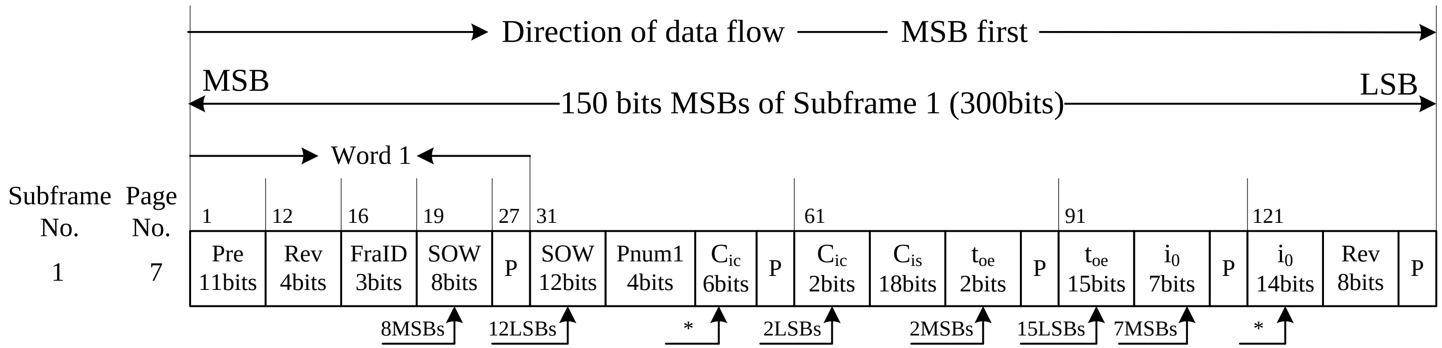
* These are data bits next to MSBs and before LSBs.

Fig 5-14-5 Bits allocation of 150 MSBs of page 5 in subframe 1 of format D2



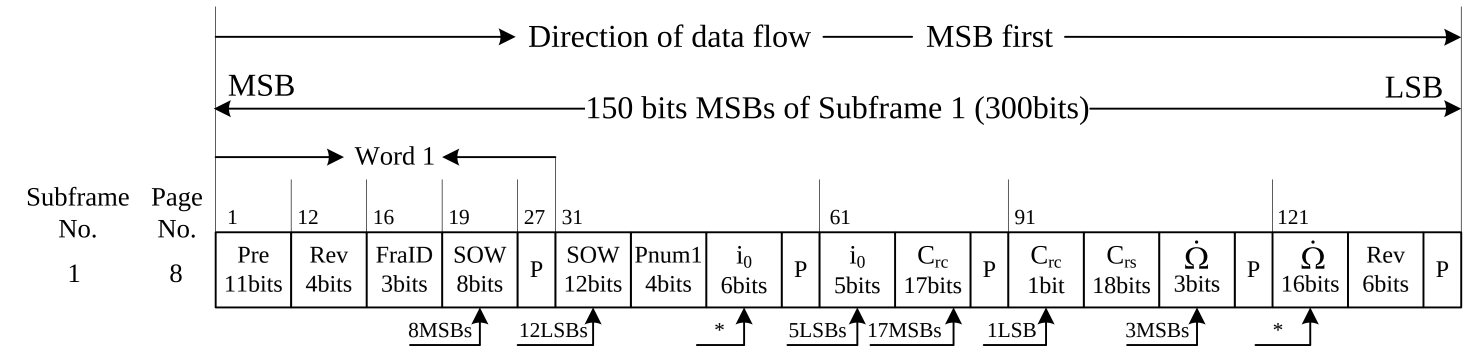
* These are data bits next to MSBs and before LSBs.

Fig 5-14-6 Bits allocation of 150 MSBs of page 6 in subframe 1 of format D2



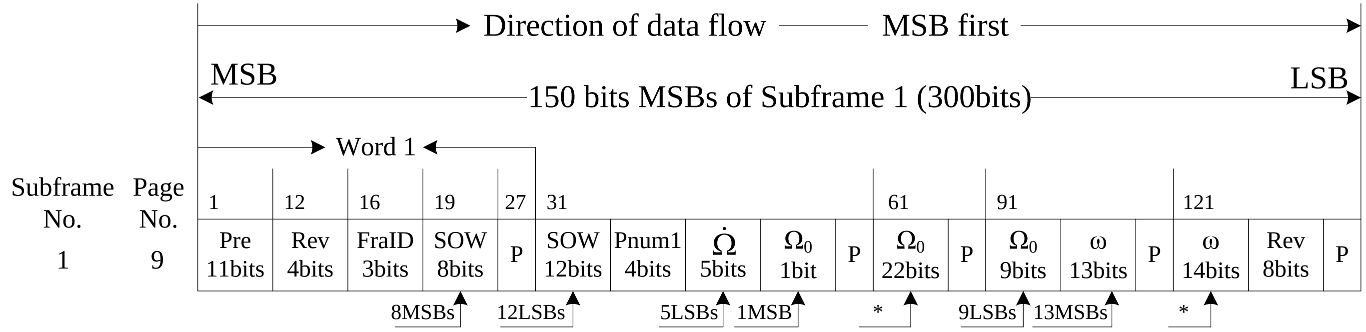
*   These are data bits next to MSBs and before LSBs.

Fig 5-14-7   Bits allocation of 150 MSBs of page 7 in subframe 1 of format D2



* These are data bits next to MSBs and before LSBs.

Fig 5-14-8   Bits allocation of 150 MSBs of page 8 in subframe 1 of format D2



* These are data bits next to MSBs and before LSBs.

Fig 5-14-9 Bits allocation of 150 MSBs of page 9 in subframe 1 of format D2

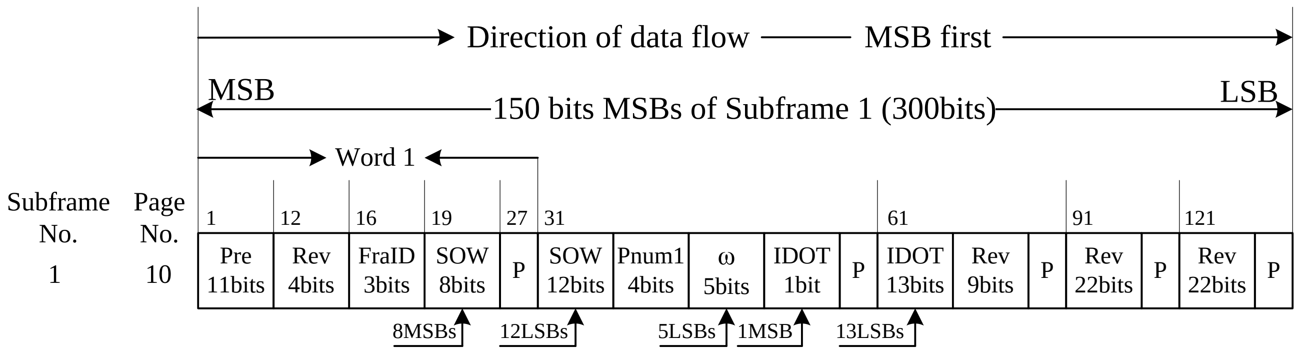


Fig 5-14-10 Bits allocation of 150 MSBs of page 10 in subframe 1 of format D2

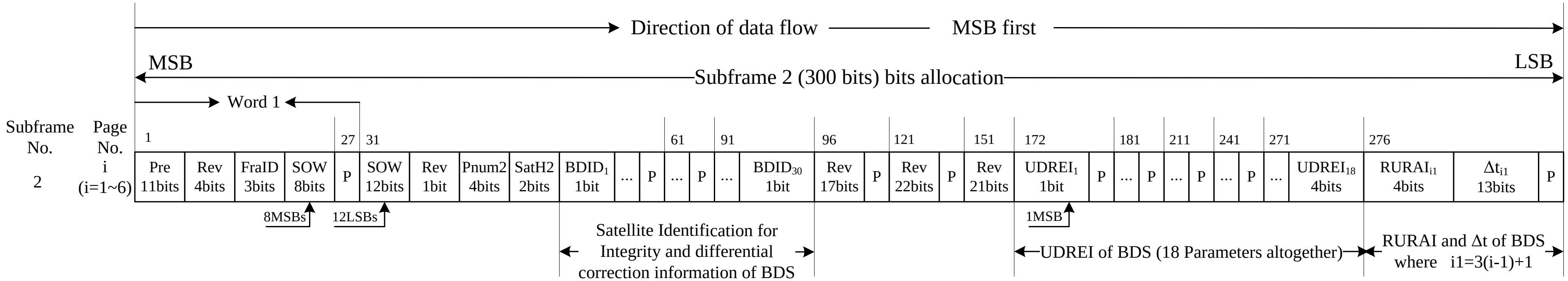


Fig 5-15 Bits allocation of subframe 2 of format D2

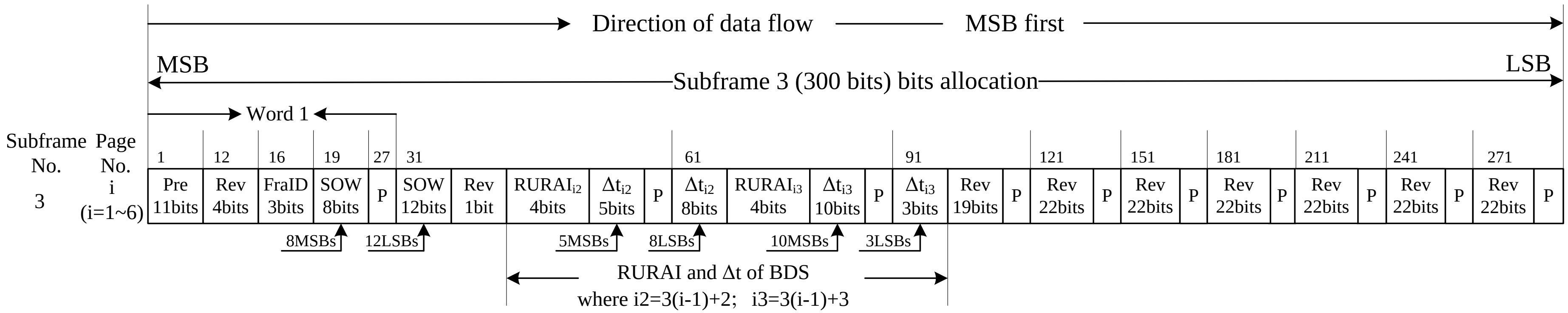


Fig 5-16 Bits allocation of subframe 3 of format D2

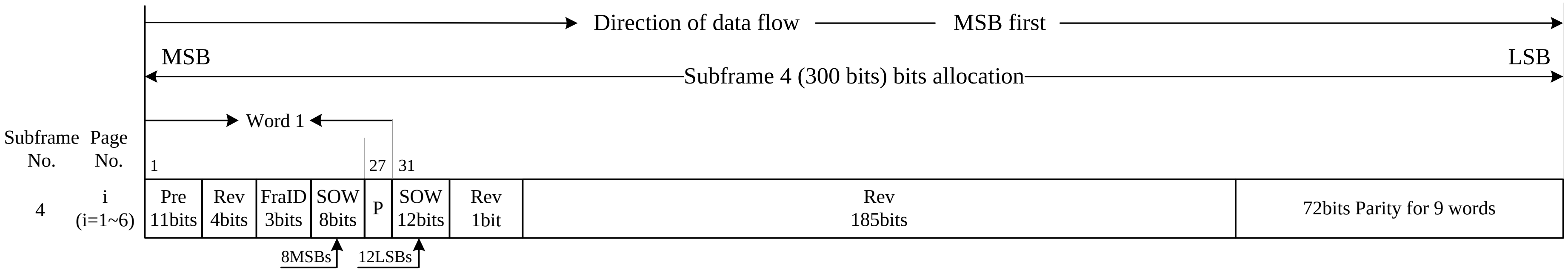


Fig 5-17 Bits allocation of subframe 4 of format D2

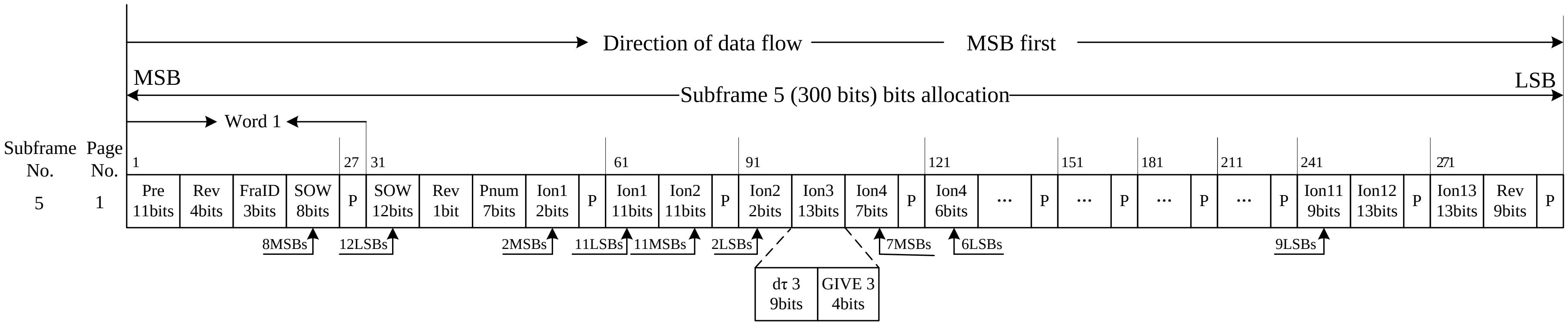


Fig 5-18-1 Bits allocation of page 1 of subframe 5 in format D2

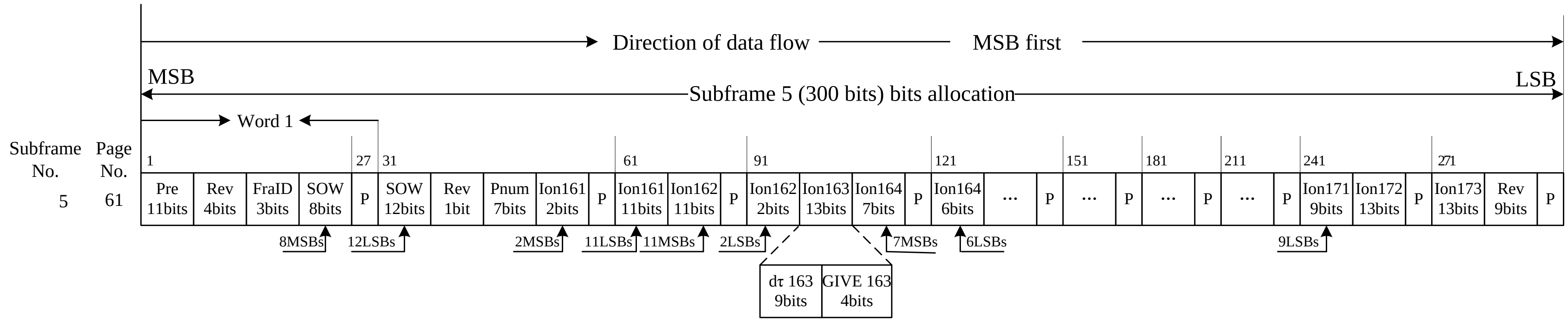


Fig 5-18-2 Bits allocation of page 61 of subframe 5 in format D2

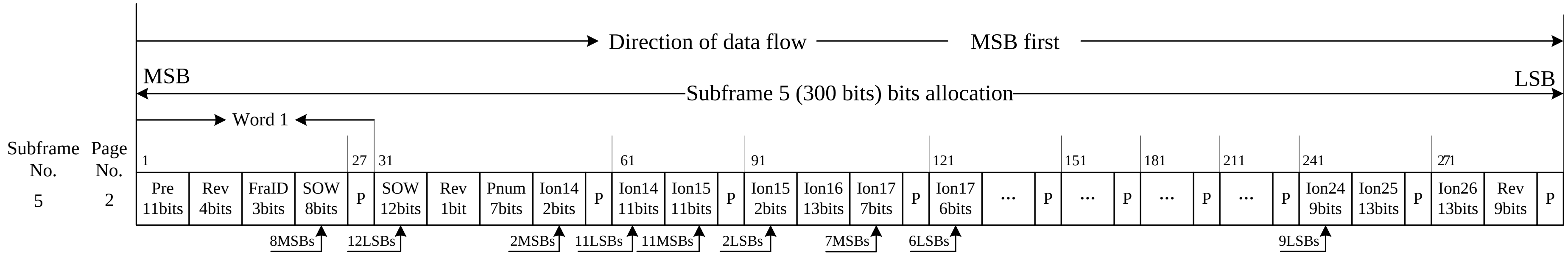


Fig 5-18-3 Bits allocation of page 2 of subframe 5 in format D2

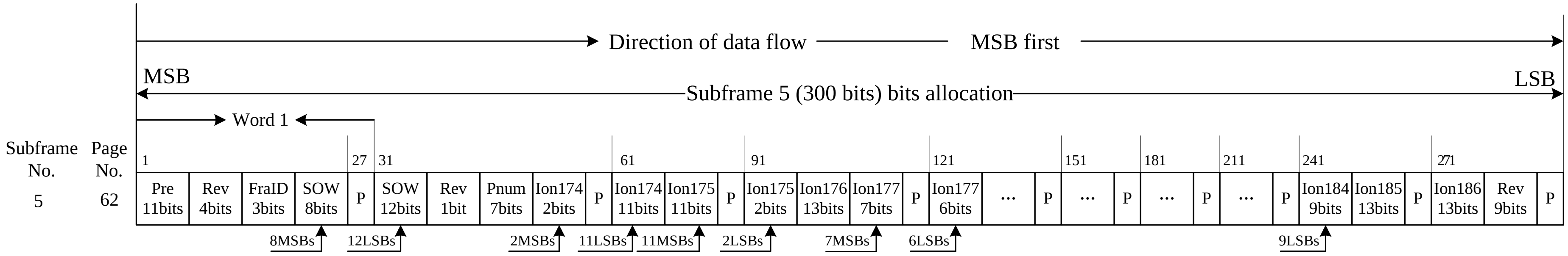


Fig 5-18-4 Bits allocation of page 62 of subframe 5 in format D2

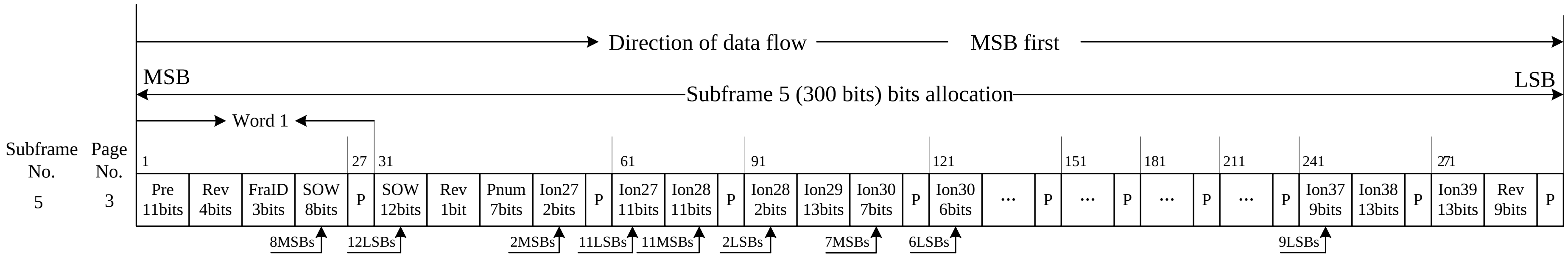


Fig 5-18-5 Bits allocation of page 3 of subframe 5 in format D2

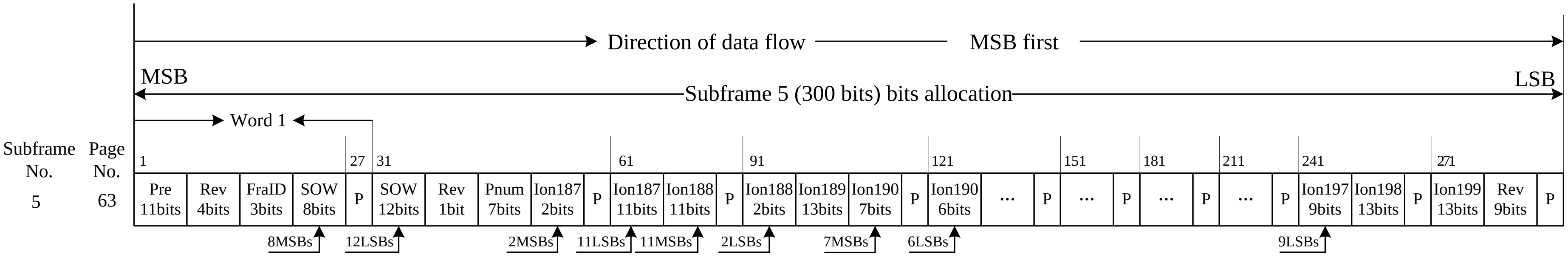


Fig 5-18-6　Bits allocation of page 63 of subframe 5 in format D2

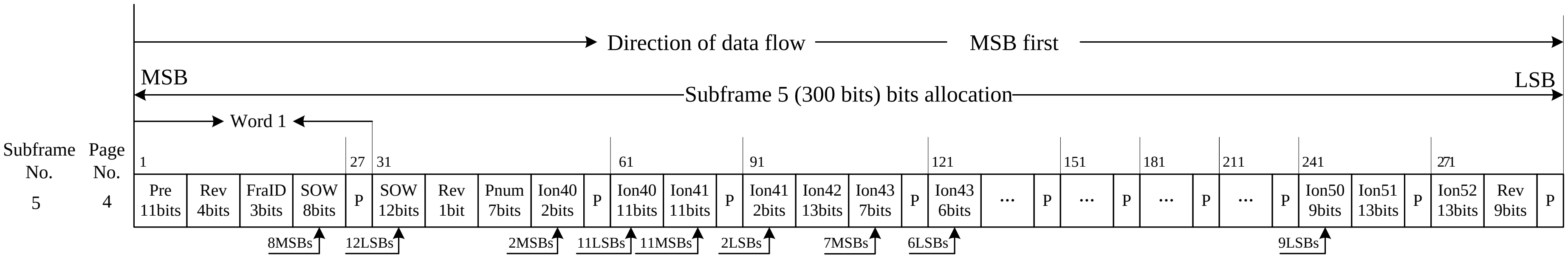


Fig 5-18-7　Bits allocation of page 4 of subframe 5 in format D2

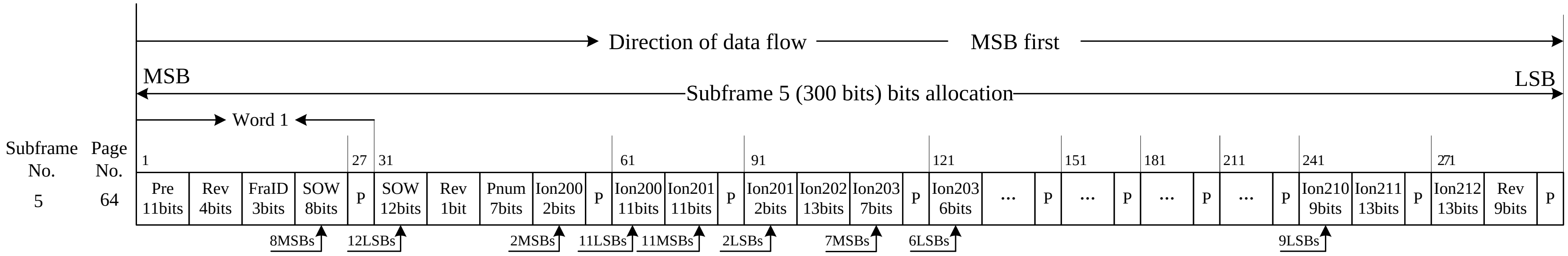


Fig 5-18-8 Bits allocation of page 64 of subframe 5 in format D2

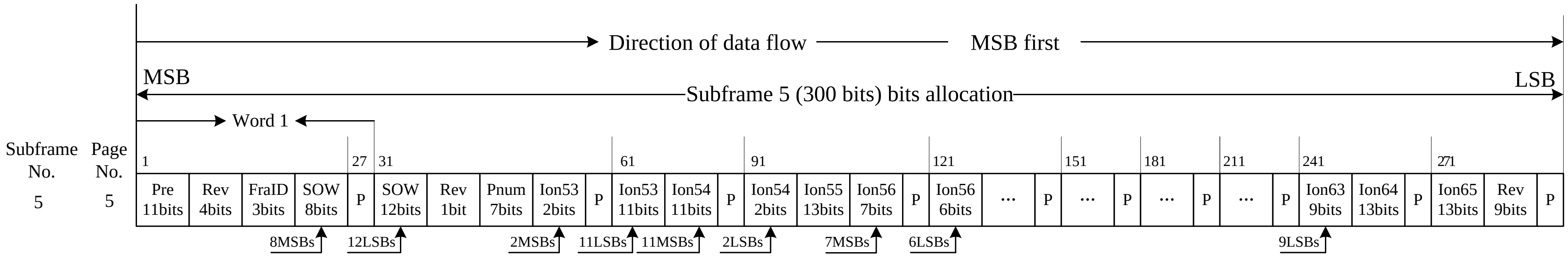


Fig 5-18-9 Bits allocation of page 5 of subframe 5 in format D2

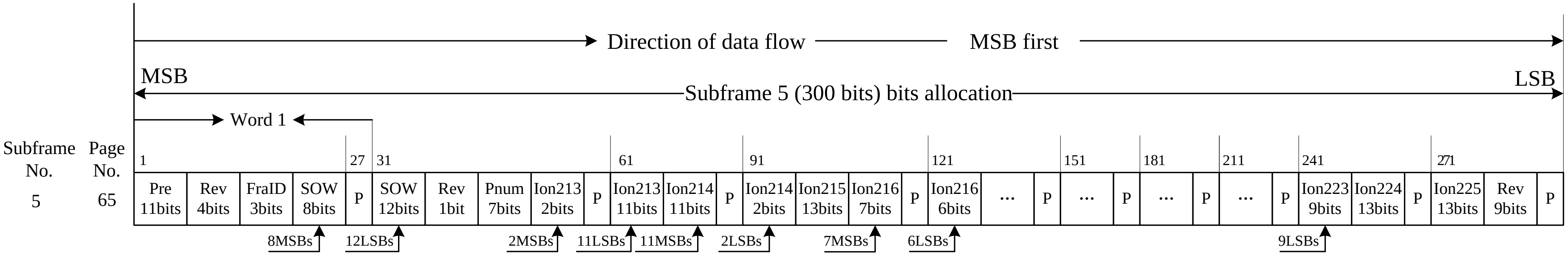


Fig 5-18-10 Bits allocation of page 65 of subframe 5 in format D2

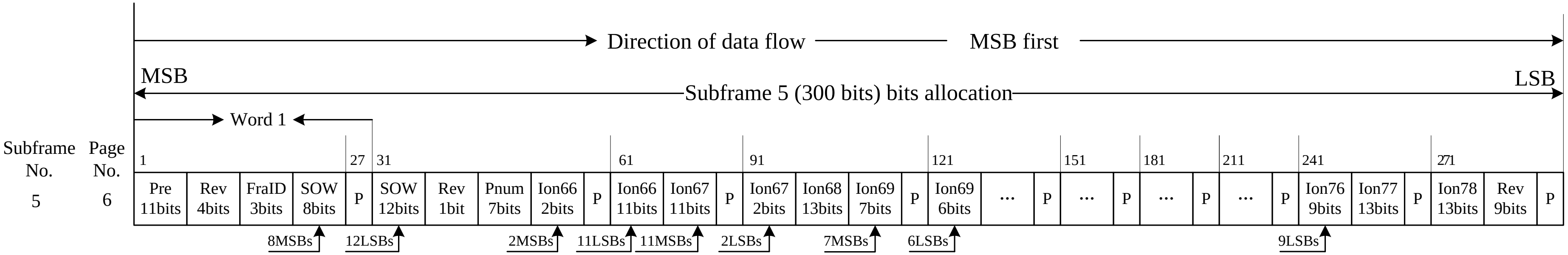


Fig 5-18-11 Bits allocation of page 6 of subframe 5 in format D2

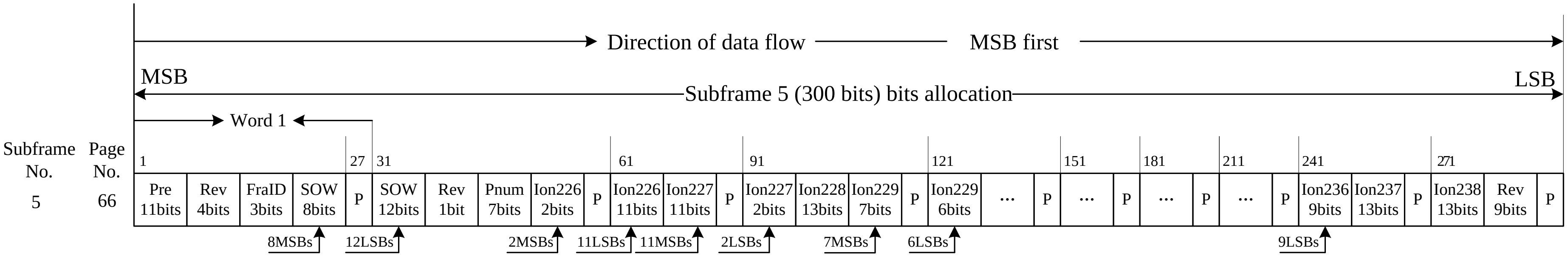


Fig 5-18-12 Bits allocation of page 66 of subframe 5 in format D2

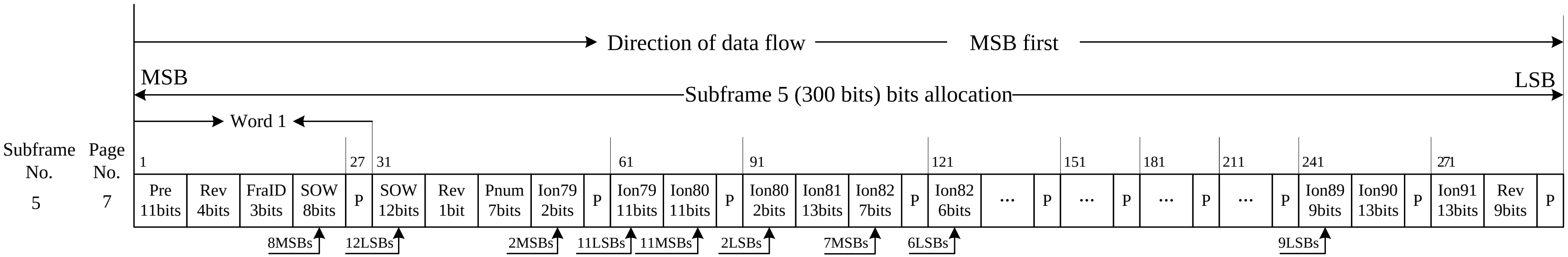


Fig 5-18-13 Bits allocation of page 7 of subframe 5 in format D2

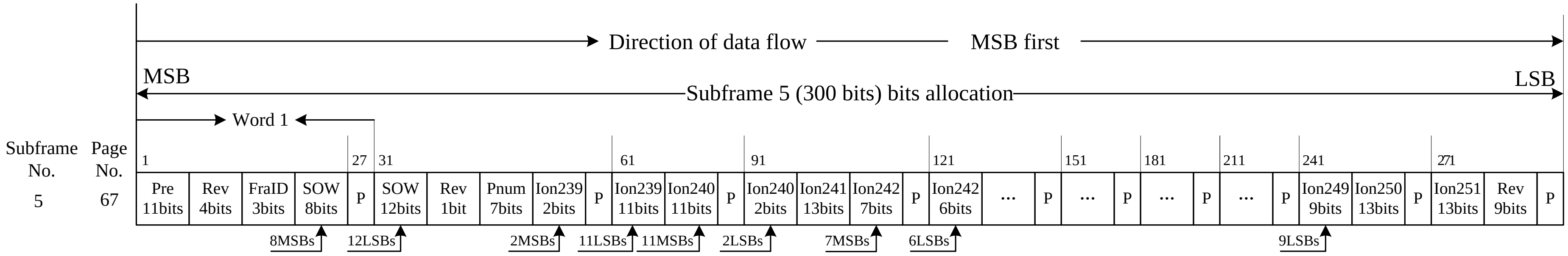


Fig 5-18-14 Bits allocation of page 67 of subframe 5 in format D2

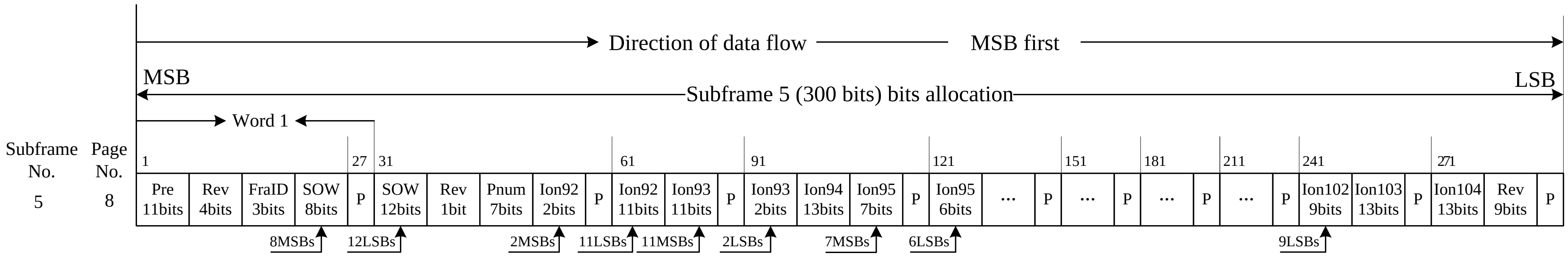


Fig 5-18-15 Bits allocation of page 8 of subframe 5 in format D2

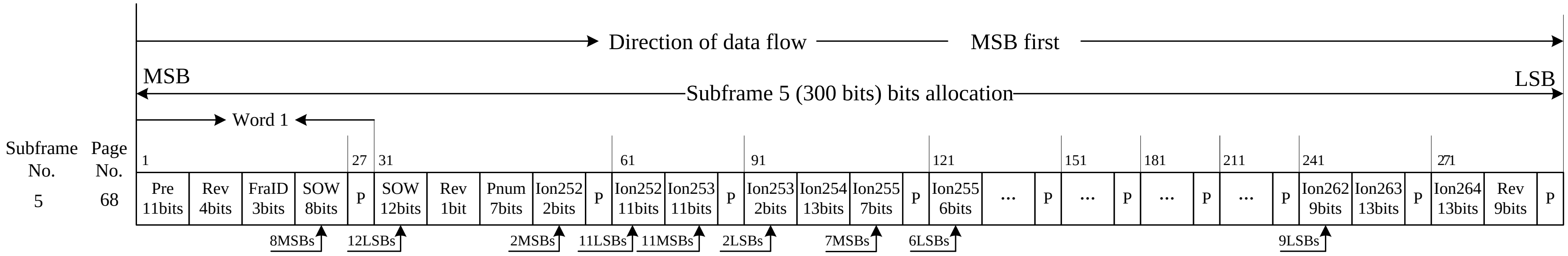


Fig 5-18-16 Bits allocation of page 68 of subframe 5 in format D2

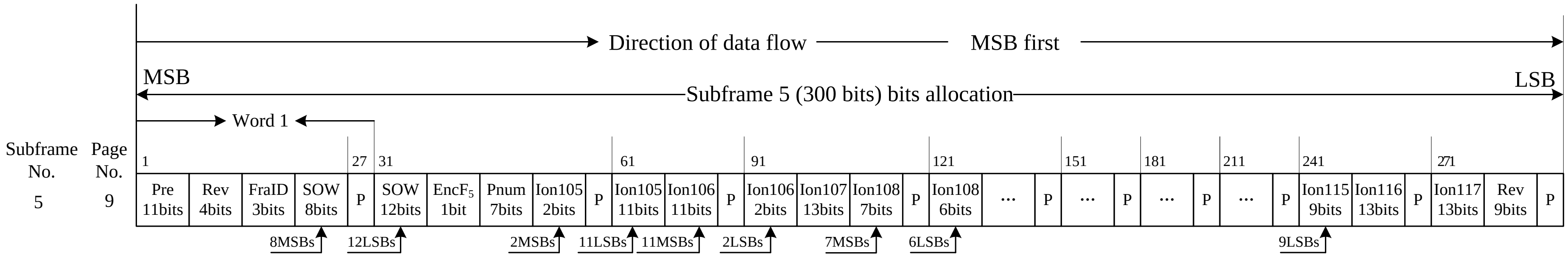


Fig 5-18-17 Bits allocation of page 9 of subframe 5 in format D2

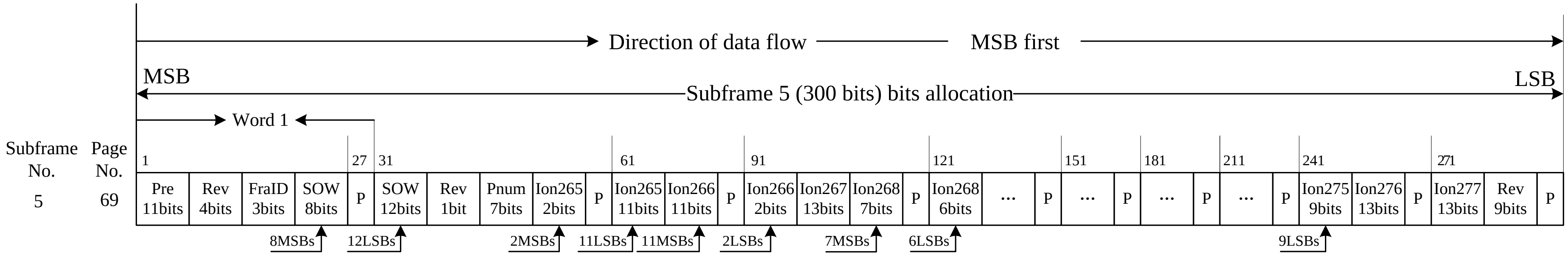


Fig 5-18-18 Bits allocation of page 69 of subframe 5 in format D2

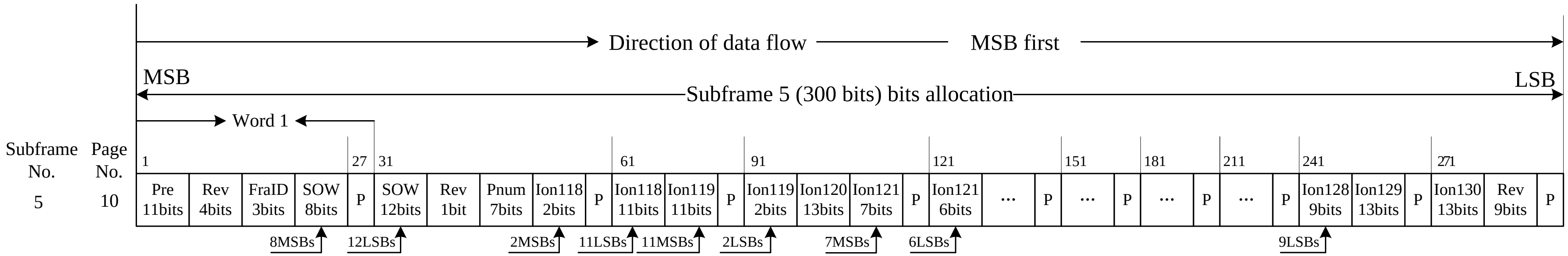


Fig 5-18-19 Bits allocation of page 10 of subframe 5 in format D2

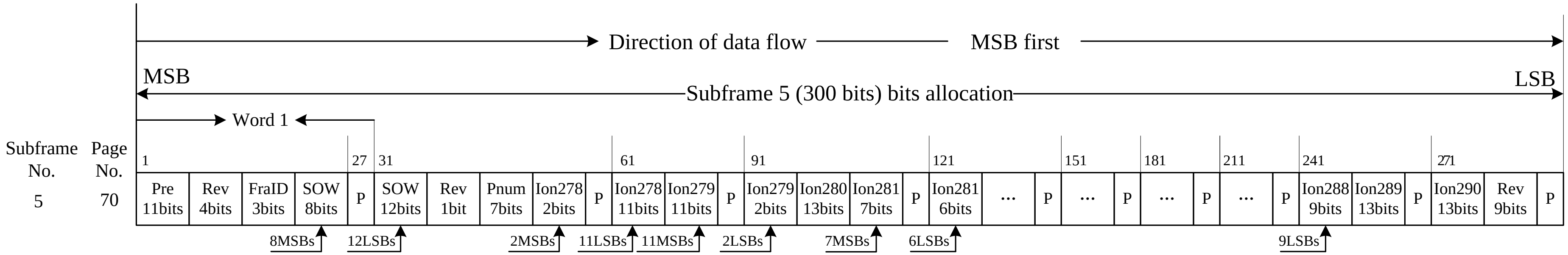


Fig 5-18-20 Bits allocation of page 70 of subframe 5 in format D2

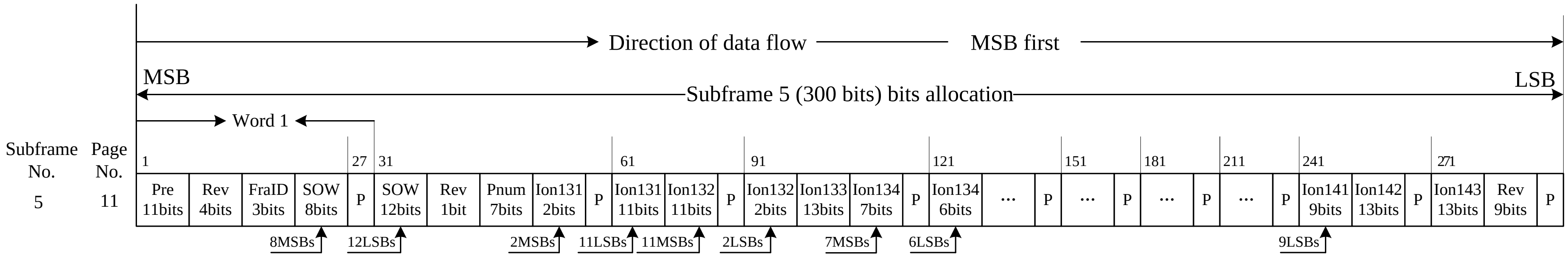


Fig 5-18-21 Bits allocation of page 11 of subframe 5 in format D2

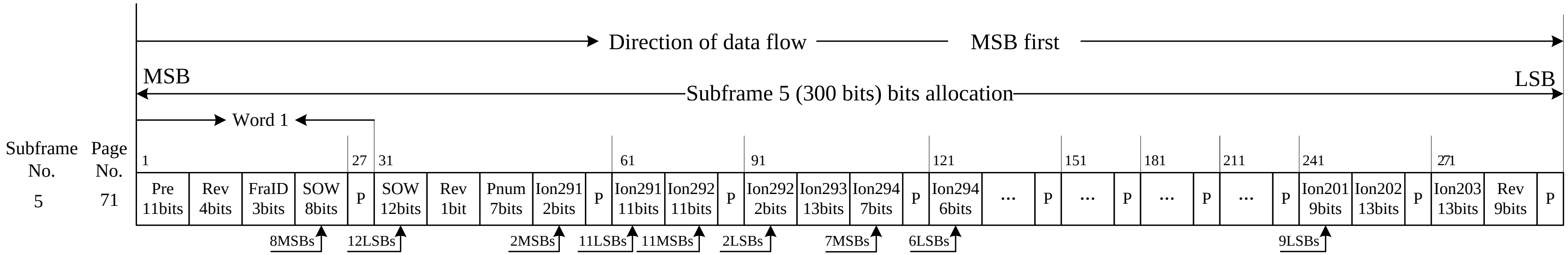


Fig 5-18-22　Bits allocation of page 71 of subframe 5 in format D2

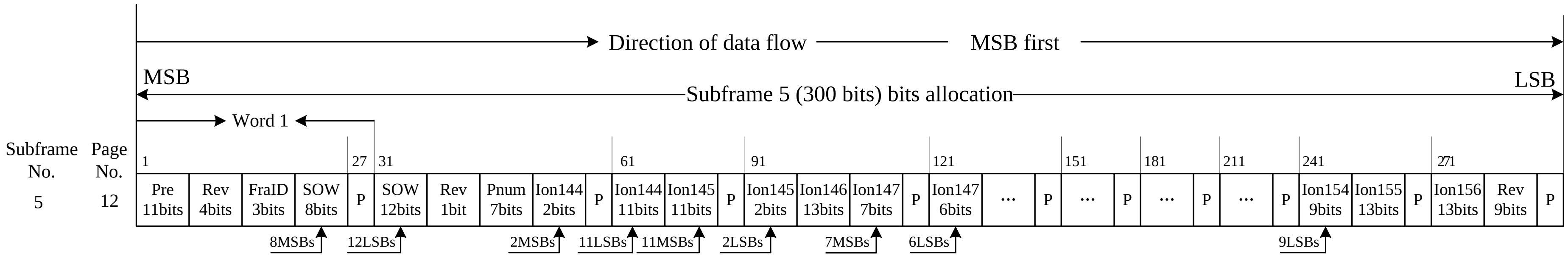


Fig 5-18-23　Bits allocation of page 12 of subframe 5 in format D2

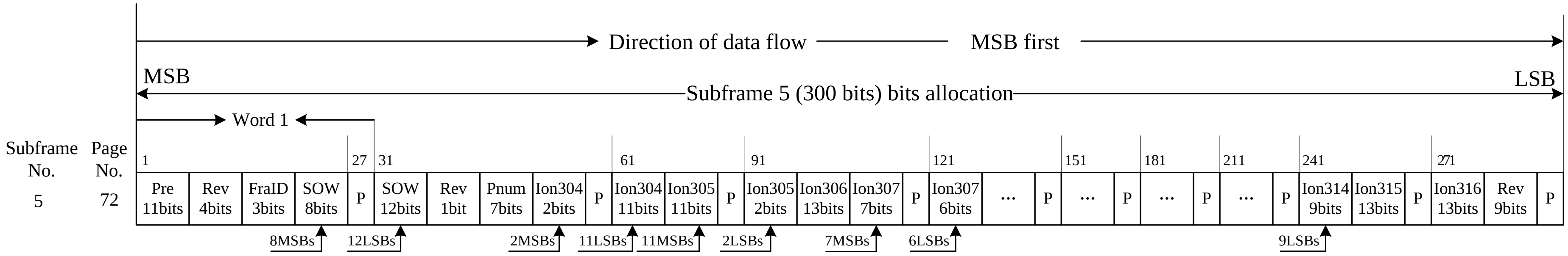


Fig 5-18-24 Bits allocation of page 72 of subframe 5 in format D2

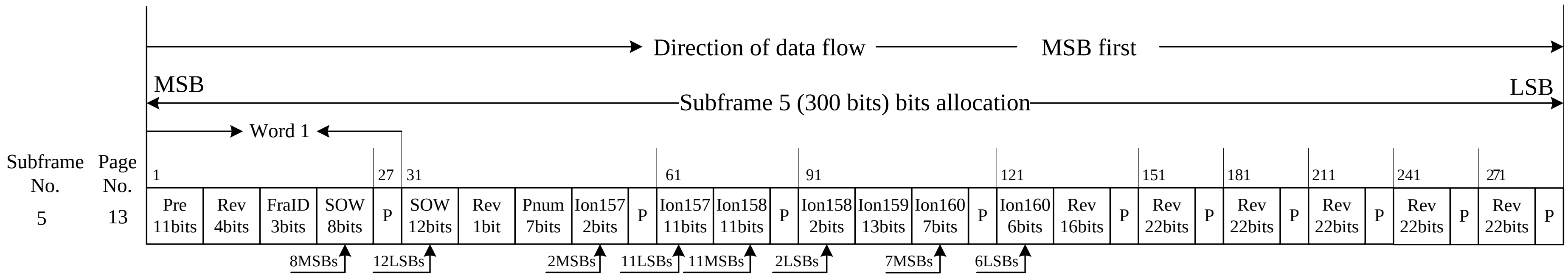


Fig 5-18-25 Bits allocation of page 13 of subframe 5 in format D2

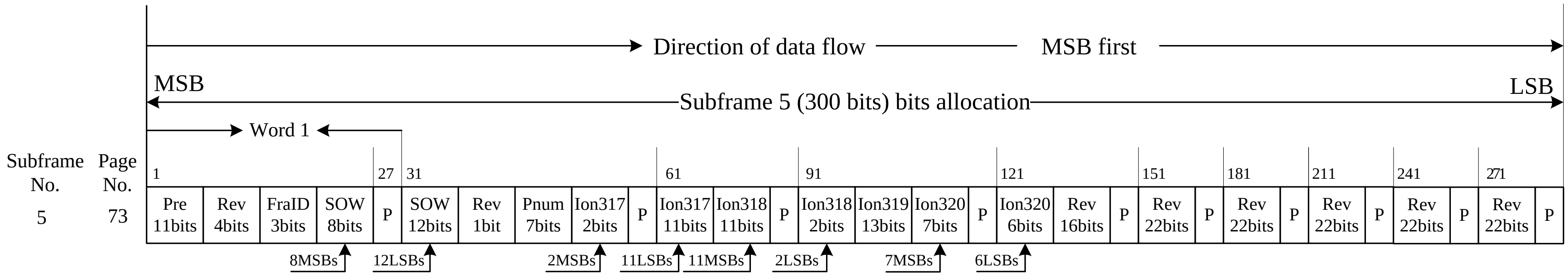


Fig 5-18-26 Bits allocation of page 73 of subframe 5 in format D2

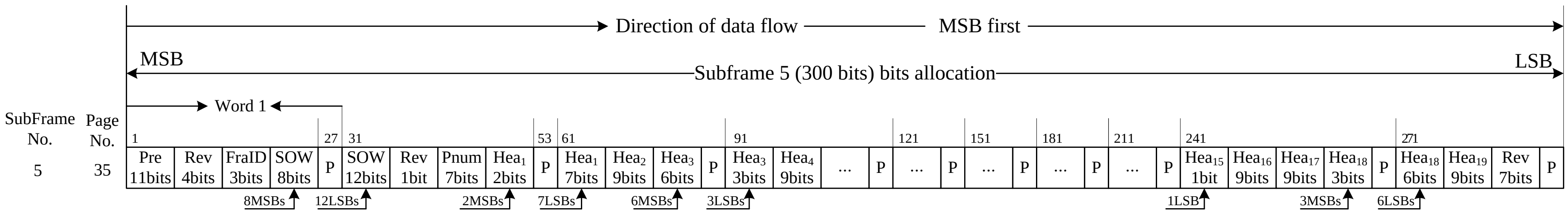


Fig 5-18-27 Bits allocation of page 35 of subframe 5 in format D2

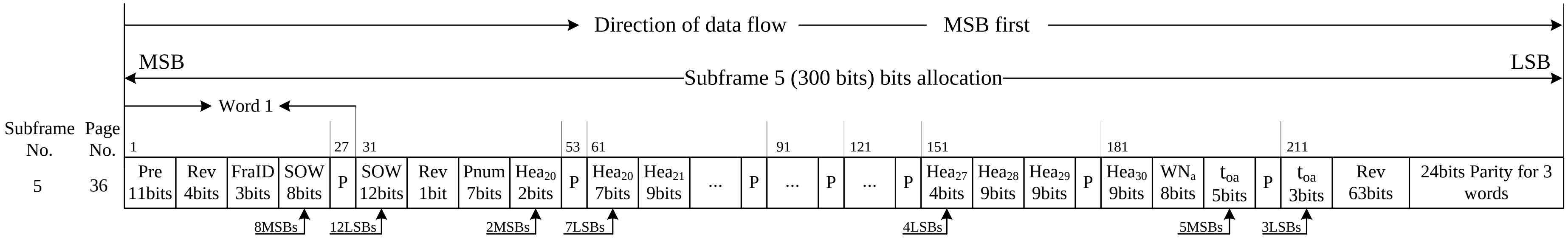


Fig 5-18-28 Bits allocation of page 36 of subframe 5 in format D2

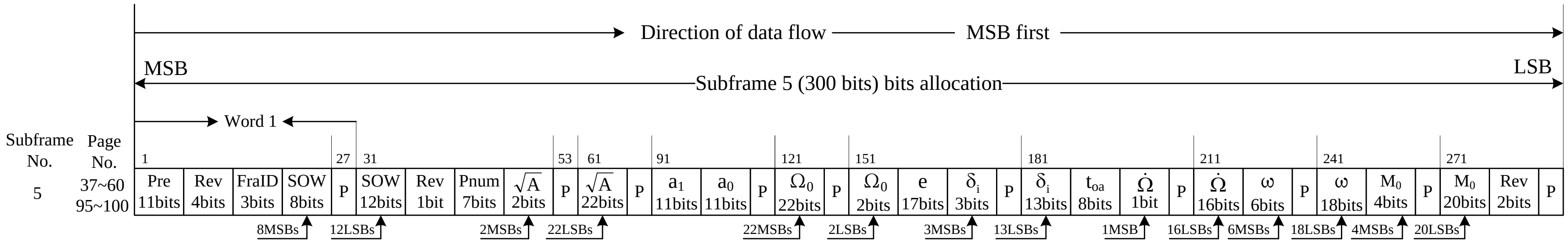


Fig 5-18-29 Bits allocation of pages 37 through 60 and pages 95 through 100 of subframe 5 in format D2

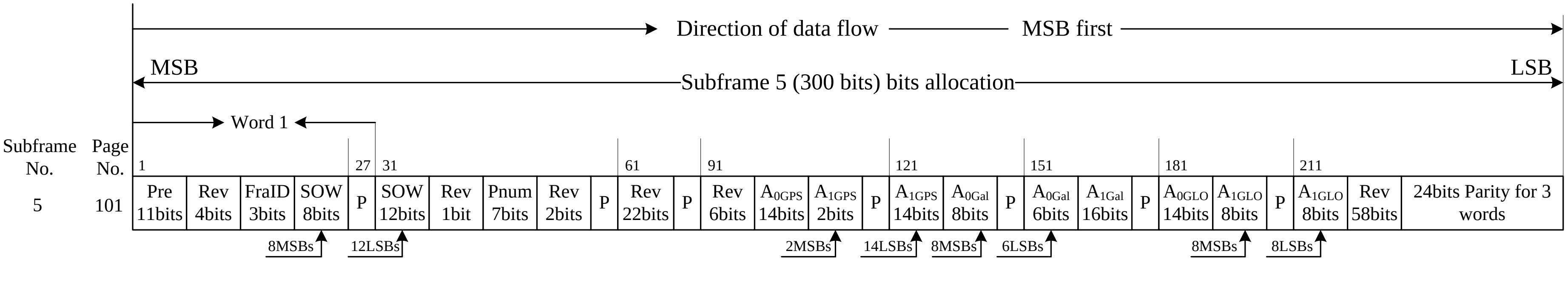


Fig 5-18-30 Bits allocation of page 101 of subframe 5 in format D2

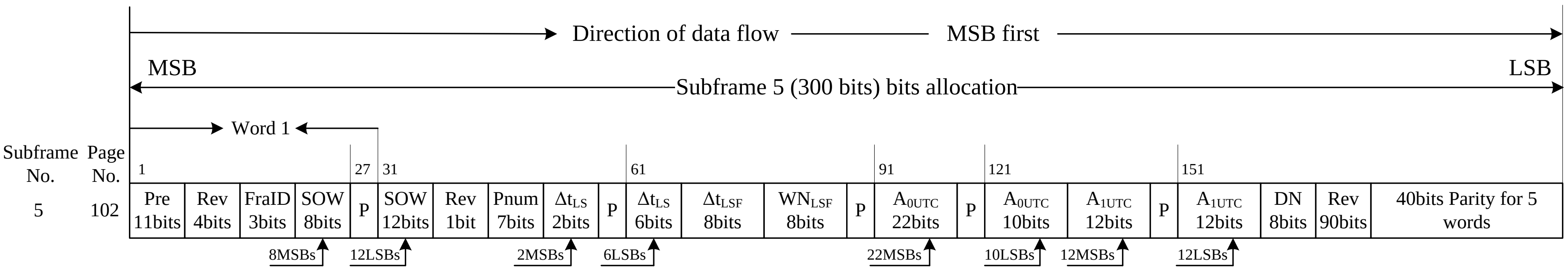


Fig 5-18-31 Bits allocation of page 102 of subframe 5 in format D2

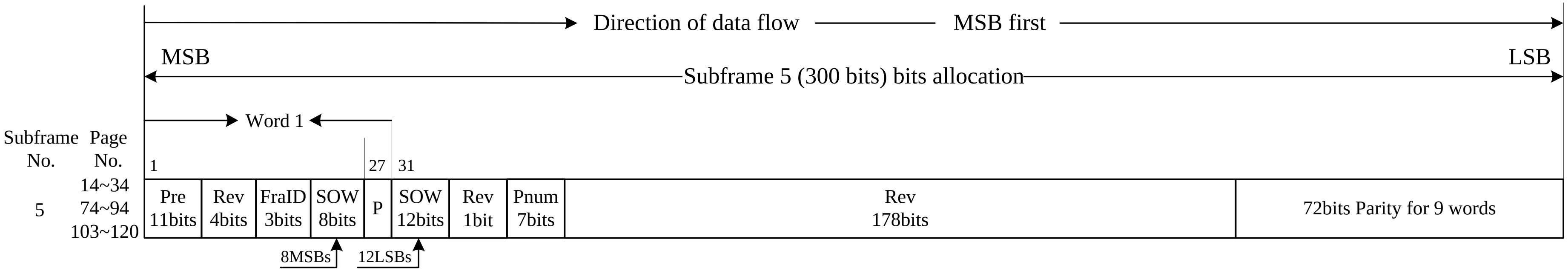


Fig 5-18-32 Bits allocation of reserved pages 14 through 34, pages 74 through 94 and pages103 through 120 of subframe 5 in format D2

5.3.3 D2 NAV Message Content and Algorithm

D2 NAV message contains basic NAV information and augmentation service information.

5.3.3.1 Basic NAV Information

D2 NAV message contains all the basic NAV information as follows:

Fundamental NAV information of the broadcasting satellite:

- Preamble (Pre)
- Subframe identification (FraID)
- Seconds of week (SOW)
- Week number (WN)
- User range accuracy index (URAI)
- Autonomous satellite health flag (SatHl)
- Ionospheric delay model parameters (α_n, β_n, n=0~3)
- Equipment group delay differential (T_{GD1},T_{GD2})
- Age of data, clock (AODC)
- Clock correction parameters (t_{oc}, a_0, a_1, a_2)
- Age of data, ephemeris (AODE)
- Ephemeris parameters (t_{oe}, $\sqrt{A}$, e, ω, Δn, M_0, Ω_0, $\dot{\Omega}$, i_0, IDOT, C_{uc}, C_{us}, C_{rc}, C_{rs}, C_{ic}, C_{is})

Page number (Pnum)

Almanac information:

- Almanac parameters (t_{oa}, $\sqrt{A}$, e, ω, M_0, Ω_0, $\dot{\Omega}$, δ_i, a_0, a_1)
- Almanac week number (WN_a)
- Satellite health information (Hea_i, i=1~30)

Time offsets from other systems:

- Time parameters relative to UTC (A_{0UTC}, A_{1UTC}, Δt_{LS}, WN_{LSF}, DN,

Δt_{LSF})

- Time parameters relative to GPS time (A_{0GPS}, A_{1GPS})
- Time parameters relative to Galileo time (A_{0Gal}, A_{1Gal})
- Time parameters relative to GLONASS time (A_{0GLO}, A_{1GLO})

The definition of basic NAV information is the same as that in format D1, except the page number (Pnum), seconds of week (SOW), which are different from those in format D1. Thus only the meanings of Pnum and SOW are given as follows.

(1) Page number (Pnum)

In format D2, the information of subframe 5 is broadcast via 120 pages and the page number is identified by Pnum.

(2) Seconds of week (SOW)

In format D2, the bits 19 through 26 and the bits 31 through 42, altogether 20 bits of every subframe are for the seconds of week (SOW). SOW count starts from zero at 00:00:00 of BDT on every Sunday.

In format D2, SOW refers to the leading edge of preamble first bit in subframe 1 of each frame.

5.3.3.2 Page Number for Basic NAV Information (Pnum1)

The bits 43 through 46, altogether 4 bits of subframe 1 are for page number of the basic NAV information (Pnum1). Pnum1 is broadcast in pages 1 through 10 of subframe 1.

5.3.3.3 Page Number for Integrity and Differential Correction Information (Pnum2)

The bits 44 through 47, altogether 4 bits of the subframe 2 are for the page number of the integrity and differential correction information (Pnum2). Pnum2 are broadcast in pages 1 through 6 of subframe 2.

5.3.3.4 Satellite Health Flag for Integrity and Differential Correction Information (SatH2)

The satellite health flag for integrity and differential correction information SatH2 is in 2 bits. The MSB indicates the check result of the satellite for the received up-link regional user range accuracy (RURA), user differential range error (UDRE) and equivalent clock correction (Δt). The LSB indicates the check result of the satellite for received up-link ionospheric grid information.

See Table 5-20 for detailed definitions.

Table 5-20 SatH2 definitions

Bit allocation	Code	Definition of SatH2
MSB	0	RURA, UDRE and Δt are good by check
	1	RURA, UDRE and Δt are bad by check
LBS	0	Ionospheric grid information is good by check
	1	Ionospheric grid information is bad by check

5.3.3.5 BDS Satellite Identification for Integrity and differential correction information ($BDID_i$)

The BDS satellite identification for integrity and differential correction information ($BDID_i$, i=1~30) is in 30 bits to identify BDS satellites for which the integrity and differential information are broadcast. Every bit identifies one satellite. "1" means the integrity and differential correction information for the satellite are broadcast and "0" means not.

For BDS the integrity and differential correction information of 18 satellites at most can be broadcast once continuously. Integrity and differential correction information are allocated in ascending order of the SV ID.

5.3.3.6 BDS Regional User Range Accuracy Index (RURAI)

Regional User Range Accuracy (RURA), the BDS satellite signal integrity information, is used to describe the satellite signal pseudo-range error in meters. The satellite signal integrity information is indicated with the Regional User

Range Accuracy Index (RURAI). It occupies 4 bits for each satellite so the effective range of RURAI is 0 to 15. The update rate is 18 seconds. See Table 5-21 for the corresponding relationship between RURAI and RURA.

Table 5-21 RURAI definitions

RURAI	RURA（meters, 99.9%）
0	0.75
1	1.0
2	1.25
3	1.75
4	2.25
5	3.0
6	3.75
7	4.5
8	5.25
9	6.0
10	7.5
11	15.0
12	50.0
13	150.0
14	300.0
15	> 300.0

5.3.3.7 BDS Differential Correction and Differential Correction Integrity Information (Δt, UDREI)

5.3.3.7.1 Equivalent Clock Correction (Δt)

The BDS differential correction information is expressed in equivalent clock correction (Δt). It occupies 13 bits for each satellite with the unit and scale factor of meter and 0.1 respectively and is expressed with two's complement. The MSB is for the sign bit (+ or –). The update rate of Δt is every 18 seconds.

The user adds the value of Δt to the observed pseudorange to correct the residual error of the satellite clock offset and ephemeris.

The equivalent clock correction Δt broadcasted on B1I and B2I is respectively related to its own carrier frequency. It is not necessary that Δt broadcasted on B1I and B2I is the same. It means the Δt is not available if the value is -4096.

5.3.3.7.2 User Differential Range Error Index (UDREI)

User differential range error (UDRE), the BDS differential correction integrity, is used to describe the error of equivalent clock correction in meters. It is indicated by user differential range error index (UDREI). It occupies 4 bits for each satellite within the range of 1~15 and the update rate is 3 seconds. The corresponding relationship between UDRE and UDREI is shown in Table 5-22. The user shall lookup UDRE in the table to determine the accuracy of the differential correction for the satellite.

Table 5-22 UDREI definitions

UDREI	UDRE（meters, 99.9%）
0	1.0
1	1.5
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	8.0
8	10.0
9	15.0
10	20.0
11	50.0
12	100.0

UDREI	UDRE（meters, 99.9%）
13	150.0
14	Not monitored
15	Not available

5.3.3.8 Ionospheric Grid Information (Ion)

The information about each ionospheric grid point (Ion) consists of the vertical delay at grid point (dτ) and its error index (GIVEI), occupying 13 bits altogether. The data arrangement and definitions are as follows.

Table 5-23 Ion definitions

Parameter	dτ	GIVEI
No. of bits	9	4

The ionospheric grid covers 70 to 145 degrees east longitude and 7.5 to 55 degrees north latitude. This area is divided into 320 grids of 5×2.5 degrees. The definition of ionospheric grid point (IGP) numbers less than or equal to 160 is listed in Table 5-24-1. Pages 1 through 13 broadcast ionospheric grid correction information according to this table.

Table 5-24-1 IGP numbers

E-Log. / N-Lat.	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145
55	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
50	9	19	29	39	49	59	69	79	89	99	109	119	129	139	149	159
45	8	18	28	38	48	58	68	78	88	98	108	118	128	138	148	158
40	7	17	27	37	47	57	67	77	87	97	107	117	127	137	147	157
35	6	16	26	36	46	56	66	76	86	96	106	116	126	136	146	156
30	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155
25	4	14	24	34	44	54	64	74	84	94	104	114	124	134	144	154
20	3	13	23	33	43	53	63	73	83	93	103	113	123	133	143	153
15	2	12	22	32	42	52	62	72	82	92	102	112	122	132	142	152
10	1	11	21	31	41	51	61	71	81	91	101	111	121	131	141	151

When IGP≤160, the corresponding longitudes and latitudes are:

$$L = 70 + INT((IGP - 1)/10) \times 5$$

$$B = 5 + (IGP - INT((IGP - 1)/10) \times 10) \times 5$$

Where INT(*) refers to round down.

The definition of ionospheric grid point (IGP) numbers more than 160 is shown in Table 5-24-2. Pages 60 through 73 broadcast grid ionospheric correction information according to this table.

Table 5-24-2 IGP numbers

E-Log. / N-Lat.	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145
52.5	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320
47.5	169	179	189	199	209	219	229	239	249	259	269	279	289	299	309	319
42.5	168	178	188	198	208	218	228	238	248	258	268	278	288	298	308	318
37.5	167	177	187	197	207	217	227	237	247	257	267	277	287	297	307	317
32.5	166	176	186	196	206	216	226	236	246	256	266	276	286	296	306	316
27.5	165	175	185	195	205	215	225	235	245	255	265	275	285	295	305	315
22.5	164	174	184	194	204	214	224	234	244	254	264	274	284	294	304	314
17.5	163	173	183	193	203	213	223	233	243	253	263	273	283	293	303	313
12.5	162	172	182	192	202	212	222	232	242	252	262	272	282	292	302	312
7.5	161	171	181	191	201	211	221	231	241	251	261	271	281	291	301	311

When IGP > 160, the corresponding longitudes and latitudes are:

$$L = 70 + INT((IGP - 161)/10) \times 5$$

$$B = 2.5 + (IGP - 160 - INT((IGP - 161)/10) \times 10) \times 5$$

Where INT(*) refers to round down.

5.3.3.8.1 Vertical Delay at Ionospheric Grid Points (dτ)

$d\tau_i$ is the vertical ionosphere delay on B1I signal at the i^{th} grid point, expressed in scale factor of 0.125 and with unit of meters. The effective range of $d\tau_i$ is between 0 to 63.625 meters. IGP is not monitored when the $d\tau_i$ is 111111110 (=63.750meters) and vertical ionosphere delay is not available when the $d\tau_i$ is 111111111 (=63.875meters).

Making use of the ionospheric correction at grid points, the users compute the ionospheric correction for the intersection point of ionosphere and direction from user to observed satellite by interpolation and add it to the observed pseudo-range. The reference altitude of ionosphere is 375 km.

5.3.3.8.2 Grid Ionospheric Vertical Error Index (GIVEI)

The grid ionosphere vertical error (GIVE) describes the delay correction accuracy at ionosphere grid points and is indicated with GIVEI. See Table 5-25 for the relationship between GIVEI and GIVE.

Table 5-25 GIVEI definitions

GIVEI	GIVE (meters, 99.9%)
0	0.3
1	0.6
2	0.9
3	1.2
4	1.5
5	1.8
6	2.1
7	2.4
8	2.7
9	3.0
10	3.6
11	4.5
12	6.0
13	9.0
14	15.0
15	45.0

5.3.3.8.3 Suggestions on User Grid Ionospheric Correction Algorithm

The user can select effective data of the grid points adjacent to or nearby the observed intersection point with $d\tau_i$ and GIVEI to design the model and compute the delay correction for ionospherc pierce point (IPP) by interpolation. The guiding fitting algorithm for user grid ionospheric correction is given as follows:

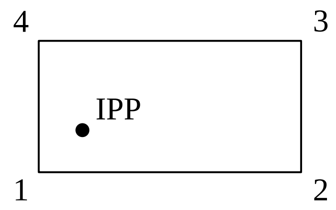


Fig 5-19 User IPP and Grid Points

Fig 5-19 illustrates the user IPP and its surrounding grid points. IPP, represented with geographic latitudes and longitudes as (ϕ_p, λ_p), is the geographic location where the line-of-sight between the user and the satellite intersects with the ionospheric layer. The positions of the four surrounding grid points are represented with (ϕ_i, λ_i, i=1~4) and the vertical ionospheric delays on the grid points are represented with $VTEC_i$(i=1~4) respectively. And ω_i(i=1~4) shows the distance weight between IPP and the four grid points.

As long as there are at least three grid points surrounding the user IPP are available and effective, the IPP ionospheric delay can be calculated from the vertical ionospheric delay of these effective grid points through the bilinear interpolation algorithm.

$$\mathrm{Ionodelay}_p = \frac{\sum_{i=1}^{4} \omega_i \cdot \mathrm{VTEC}_i}{\sum_{i=1}^{4} \omega_i}$$

Where $x_p = \dfrac{\lambda_p - \lambda_1}{\lambda_2 - \lambda_1}$, $y_p = \dfrac{\phi_p - \phi_1}{\phi_4 - \phi_1}$,

$$\omega_1 = (1 - x_p)\cdot(1 - y_p), \quad \omega_2 = x_p \cdot (1 - y_p), \quad \omega_3 = x_p \cdot y_p, \quad \omega_4 = (1 - x_p)\cdot y_p$$

If any grid point of this observation epoch is marked as ineffective, its weight is zero.

For B2I, users need to multiply a factor k(f) to calculate the grid ionospheric correction, and its value is as follows:

$$k(f) = \frac{f_1^2}{f_2^2} = \left(\frac{1561.098}{1207.140}\right)^2$$

Where, f_1 refers to the nominal carrier frequency of B1I, f_2 refers to the nominal carrier frequency of B2I, and the unit is MHz.

6 Acronyms

BDS	BeiDou Navigation Satellite System
BDT	BeiDou Navigation Satellite System Time
bps	bits per second
CDMA	Code Division Multiple Access
CGCS2000	China Geodetic Coordinate System 2000
dBW	Decibel with respect to 1 watt
GEO	Geostationary Earth Orbit
GIVE	Grid point Ionospheric Vertical delay Error
GIVEI	Grid point Ionospheric Vertical delay Error Index
GLONASS	GLObal Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
ID	Identification
IERS	International Earth Rotation and Reference Systems Service
IGP	Ionospheric Grid Point
IGSO	Inclined Geosynchronous Satellite Orbit
AODC	Age of Data, Clock
AODE	Age of Data, Ephemeris
IPP	Ionospheric Pierce Point
IRM	IERS Reference Meridian
IRP	IERS Reference Pole
Mcps	Mega chips per second
MEO	Medium Earth Orbit
MHz	Megahertz
N/A	Not Applicable
NAV	Navigation
MSB	Most Significant Bit
NTSC	National Time Service Center
QPSK	Quadrature Phase Shift Keying

RHCP	Right-Handed Circularly Polarized
RURA	Regional User Range Accuracy
RURAI	Regional User Range Accuracy Index
SOW	Seconds of Week
SV	Space Vehicle
UDRE	User Differential Range Error
UDREI	User Differential Range Error Index
URA	User Range Accuracy
UTC	Coordinated Universal Time
WN	Week Number

BeiDou Navigation Satellite System

Open Service

Performance Standard

(Version 1.0)

China Satellite Navigation Office

December 2013

Foreword

The space constellation of BeiDou Navigation Satellite System (BDS) will consist of 35 satellites to provide open services to global users. With a space constellation of 14 operational satellites in orbit, BDS has been in full service to provide open services to the most part of the Asia-Pacific region since December 27, 2012.

This document specifies the BDS open service performance standard at the current stage.

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List of Tables

1 Scope

This document specifies the open service performance standard for BDS B1I signal at the current stage.

2 References

BDS-SIS-ICD-2.0 *"BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal(Version 2.0)* "

3 Terms, Definitions and Acronyms

3.1 Terms and Definitions

The BeiDou Navigation Satellite System Open Service is the radio navigation satellite service using the BDS open service signals to determine a user's position, velocity and time, etc.

3.2 Acronyms

The following acronym definitions are applicable to this document:

BDS - BeiDou Navigation Satellite System;

BDT - BeiDou Navigation Satellite System Time;

CGCS 2000 - China Geodetic Coordinate System 2000;

GEO - Geostationary Earth Orbit;

ICD - Interface Control Document;

IGSO - Inclined Geosynchronous Orbit;

MEO - Medium Earth Orbit;

NAV- Navigation (as in "NAV data" or "NAV message");

OS - Open Service;

PDOP - Position Dilution Of Precision;

RF- Radio Frequency;

SIS - Signal In Space;

TGD - Group Delay Time correction;

URAE - User Range Acceleration Error;

URE - User Range Error;

URRE - User Range Rate Error;

UTC - Coordinated Universal Time;

UTCOE - UTC Offset Error.

4 BDS Overview

BDS consists of the space segment, the ground control segment and the user segment.

4.1 Space Segment

The current BDS space segment consists of 5 GEO satellites, 5 IGSO satellites and 4 MEO satellites. The respective positions of satellites are shown in Figure 1.

The GEO satellites are operating in orbit with an altitude of 35,786 kilometers and positioned at 58.75°E, 80°E, 110.5°E, 140°E and 160°E respectively.

The IGSO satellites are operating in orbit with an altitude of 35,786 kilometers and an inclination of 55° to the equatorial plane. The phase difference of right ascensions of ascending nodes of those orbital planes is 120°. The sub-satellite tracks for three of those IGSO satellites are coincided while the longitude of the intersection point is at 118°E. The sub-satellite tracks for the other two IGSO satellites are coincided while the longitude of the intersection point is at 95°E.

The MEO satellites are operating in orbit with an altitude of 21,528 kilometers and an inclination of 55° to the equatorial plane. The satellite recursion period is 13 rotations within 7 days. The phase is selected from the Walker24/3/1 constellation, and the right ascension of ascending node of the satellites in the first orbital plane is 0°. The current 4 MEO satellites are in the 7^{th} and 8^{th} phases of the first orbital plane, and in the 3^{rd} and 4^{th} phases of the second orbital plane respectively.

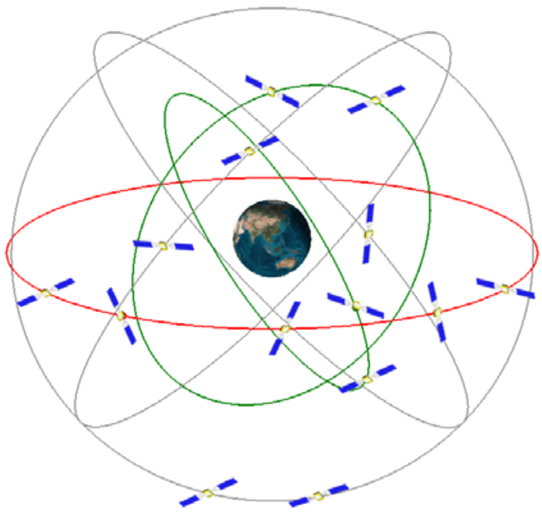

Figure 1 BDS Space Constellation

4.2 Ground Control Segment

The ground control segment is responsible for the BDS operation and control. It consists of the Master Control Station (MCS), Time Synchronization/Upload Stations (TS/US) and Monitor Stations (MS).

The MCS is the operation and control center of BDS with the main tasks including:

a) to collect observation data of NAV signals from each TS/US and MS, to process data, to generate satellite NAV messages;

b) to perform mission planning and scheduling, to conduct system operations, management and control;

c) to observe and calculate the satellite clock bias, to upload satellite NAV messages;

d) to monitor the satellite payload and analyze anomalies, etc.

The main tasks of TS/US are to measure satellite clock biases and to upload satellite NAV messages.

The main tasks of MS are to continuously observe satellite NAV signals, and to provide real-time data to the MCS.

4.3 User Segment

The user segment encompasses various types of BDS terminals, including those compatible with other navigation systems.

4.4 BDS OS Service Volume

The BDS OS service volume is defined as the OS SIS coverage of the BDS satellites where both the BDS OS horizontal and vertical position accuracy are better than 10 meters (probability of 95%). At the current stage, the BDS regional service capability has been achieved, which can provide continuous OS to the area as shown in Figure 2 & Figure 3, including the most part of the region from 55°S to 55°N, 70°E to150°E.

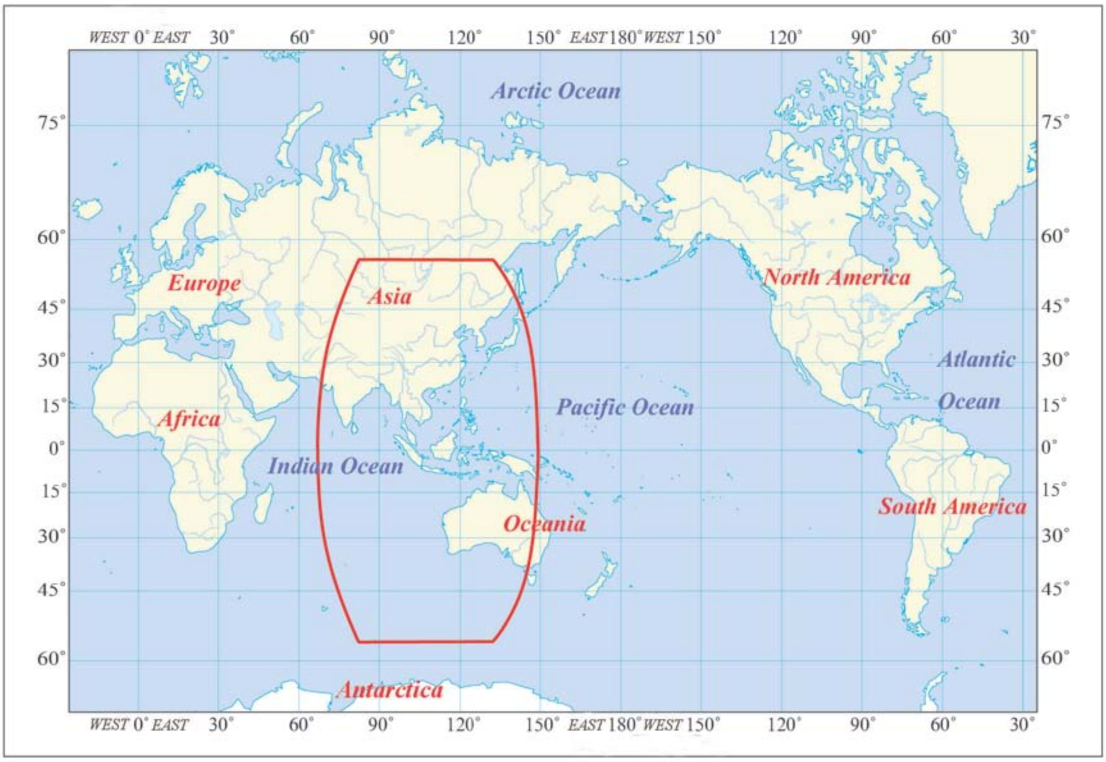

Figure 2 The BDS Service Area

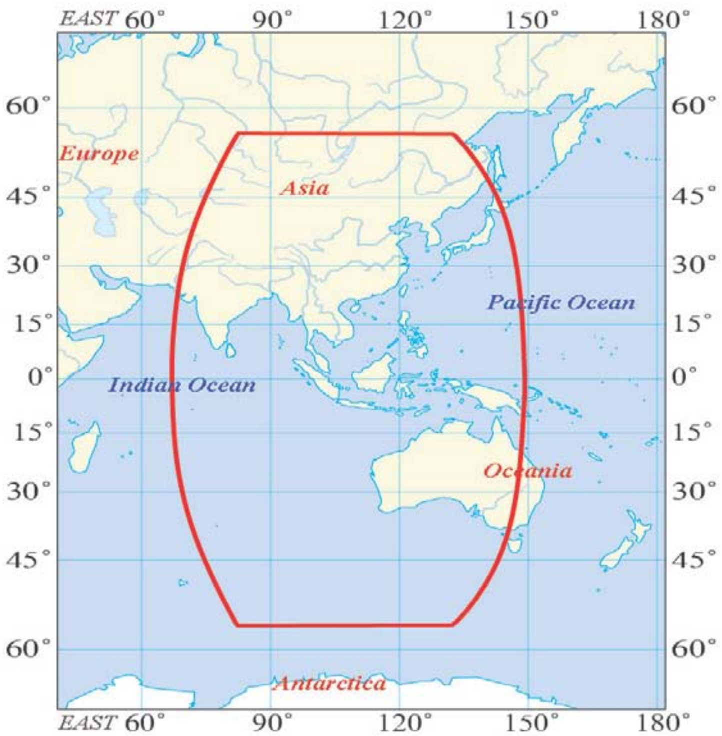

Figure 3 The BDS Service Area(partial enlarged detail)

5 BDS OS SIS Characteristics

5.1 BDS OS SIS Interface Characteristics

5.1.1 BDS OS SIS RF Characteristics

BDS broadcasts right-handed circularly polarized (RHCP) L-band signals. In particular, the B1 frequency has the nominal value of 1561.098MHz, while the signals at this frequency are modulated through Quadrature Phase Shift Keying (QPSK). For more details, please refer to *BDS-SIS-ICD-2.0*.

5.1.2 BDS OS SIS NAV Message Characteristics

5.1.2.1 BDS OS SIS NAV Message Structure

BDS OS SIS NAV messages are formatted in D1 and D2 based on their data rates and structures. D1, with the data rate of 50 bps, is broadcasted by the MEO/IGSO satellites, while D2, with the data rate of 500 bps, is broadcasted by the GEO satellites.

The BDS OS SIS NAV message D1 is broadcasted in the form of superframes. Each superframe consists of 24 frames. Each frame consists of 5 subframes with 10 words in each subframe. It takes 12 minutes to transmit the whole NAV message D1. More specifically, subframes 1 to 3 are used to broadcast fundamental NAV information of the broadcasting satellite; while pages 1 to 24 in subframe 4 and pages 1 to 10 in subframe 5 are used to broadcast the almanac of all satellites and time synchronization information with other navigation systems.

The BDS OS SIS NAV message D2 is broadcasted in the form of superframes. Each superframe consists of 120 frames. Each frame consists of 5 subframes with 10 words in each subframe. It takes 6 minutes to transmit the whole NAV message D2. More specifically, subframe 1 is used to broadcast fundamental NAV information of the broadcasting satellite, while subframe 5 is used to broadcast the almanac of all satellites and time synchronization information with other navigation systems.

The BDS OS SIS NAV message is updated hourly. For the detailed frame format, please refer to *BDS-SIS-ICD-2.0*.

5.1.2.2 BDS OS NAV Message Data

The BDS OS NAV message data mainly includes:

a) satellite ephemeris parameters;

b) satellite clock offset parameters;

c) ionospheric delay model correction parameters;

d) satellite health status;

e) user range accuracy index;

f) constellation status (almanac information), etc.

For more details, please refer to *BDS-SIS-ICD-2.0*.

5.2 BDS OS SIS Performance Characteristics

5.2.1 BDS OS SIS Coverage

The BDS OS SIS coverage is described by the per-satellite coverage, which comprises the portion of the near-Earth region which extends from the surface of the Earth up to an altitude of 1,000 kilometers above the surface of the Earth which is visible from the satellite's orbital position.

5.2.2 BDS OS SIS Accuracy

The BDS OS SIS accuracy is defined as the statistical value of errors (95% probability) for any healthy satellite in normal operation.

The BDS OS SIS accuracy includes four parameters:

a) User Range Error (URE);

b) User Range Rate Error (URRE);

c) User Range Acceleration Error (URAE);

d) UTC Offset Error (UTCOE).

5.2.2.1 BDS OS SIS URE

The BDS OS SIS URE is described by a statistical measurement of the instantaneous SIS URE data.

An instantaneous SIS URE is the difference between the pseudorange measured at a given location assuming a receiver clock that is perfectly calibrated to BDT and the expected pseudorange as derived from the NAV message data for the given location and the assumed receiver clock. The instantaneous SIS URE includes only those pseudorange data set error budget components assigned to the BDS Space and Ground Control Segments (i.e., not including the error budget components assigned to the BDS User Segment such as the troposphere delay compensation error, multipath, and receiver noise).

5.2.2.2 BDS OS SIS URRE

The BDS OS SIS URRE is defined as the time derivative of the BDS OS SIS URE.

5.2.2.3 BDS OS SIS URAE

The BDS OS SIS URAE is defined as the second time derivative of the BDS OS SIS URE.

5.2.2.4 BDS OS SIS UTCOE

The BDS OS SIS UTCOE is defined as the accuracy of the offset between BDT and UTC. The offset between BDT and UTC is less than 100 nanoseconds.

5.2.3 BDS OS SIS Continuity

The BDS OS SIS continuity is defined as the probability that a healthy BDS OS SIS will continue working without unscheduled interruptions over a specified time interval. The BDS OS SIS continuity is closely correlated to unscheduled interruptions.

5.2.4 BDS OS SIS Availability

The BDS OS SIS availability is described by the per-slot availability, which is defined as the probability that a specific slot in the BDS constellation will be occupied by a BDS satellite transmitting a healthy OS SIS.

6 BDS OS Performance Characteristics

6.1 User Assumptions

The position, velocity and time performance standards in this document are based on the assumption of using a representative BDS OS receiver that:

a) is designed in accordance with *BDS-SIS-ICD-2.0*, which can correctly track and process the BDS OS signals, and conduct position, velocity and time solution;

b) uses a mask angle of 10°;

c) accomplishes satellite position and geometric range computations in CGCS2000;

d) only considers the errors related to the space segment and ground control segment. Those errors include the satellite orbit error, the satellite clock offset error and TGD error.

6.2 BDS OS Accuracy

The BDS OS accuracy includes those of position, velocity and time.

The BDS OS position accuracy is defined as the statistical difference between the user's position derived from BDS OS SIS and its true position, under the BDS user assumptions. The position accuracy includes horizontal and vertical measurements.

The BDS OS velocity accuracy is defined as the statistical difference between the user's velocity derived from the BDS OS SIS and its true velocity, under the BDS user assumptions.

The BDS OS time accuracy is defined as the statistical difference between the user's time derived from BDS OS SIS and that value from UTC, under the BDS user assumptions.

6.3 BDS OS Availability

The BDS OS availability is defined as the percentage of the available service time to the expected service time. The available service time refers to the period when the service accuracy meets the specified performance standards within a given service volume.

The BDS OS availability in this document includes PDOP availability and positioning service availability.

The PDOP availability is defined as the percentage of time when PDOP value meets the requirements of PDOP threshold, under specified conditions, within a specified time period and service volume.

The positioning service availability is defined as the percentage of time when horizontal and vertical position accuracy meets the specified requirements of accuracy threshold, under specified conditions, within a specified time period and service volume.

7 BDS OS SIS Performance Standards

7.1 BDS OS SIS Coverage Standards

The BDS OS SIS coverage standards are shown in Table 1.

Table 1 The BDS OS SIS Per-Satellite Coverage Standards

Satellite Type	Coverage Standard
GEO/IGSO/MEO	100% of the BDS OS SIS coverage; The minimum user-received signal power is greater than -161 dBW.

7.2 BDS OS SIS Accuracy Standards

7.2.1 BDS OS SIS URE Accuracy Standards

The BDS OS SIS URE accuracy standards are shown in Table 2.

Table 2 The BDS OS SIS URE Accuracy Standards

Satellite Type	SIS Accuracy Standard (95% probability)	Constraints
GEO/IGSO/MEO	URE≤2.5m	For any healthy OS SIS; Neglecting single-frequency ionospheric delay model errors.

Note: When a MEO satellite enters the view of the service volume, the SIS accuracy may deteriorate due to the age of data before the new NAV message is uploaded. It is recommended to use the updated NAV message.

7.2.2 BDS OS SIS URRE Accuracy Standards

The BDS OS SIS URRE accuracy standards are shown in Table 3.

Table 3 The BDS OS SIS URRE Standards

Satellite Type	SIS Accuracy Standard (95% probability)	Constraints
GEO/IGSO/MEO	URRE≤0.006m/s	For any healthy OS SIS; Neglecting single-frequency ionospheric delay model errors; Neglecting all psuedorange step changes caused by NAV message data cutovers.

7.2.3 BDS OS SIS URAE Accuracy Standards

The BDS OS SIS URAE accuracy standards are shown in Table 4.

Table 4 The BDS OS SIS URAE Standards

Satellite Type	SIS Accuracy Standard (95% probability)	Constraints
GEO/IGSO/MEO	URAE≤0.002m/s^2	For any healthy OS SIS; Neglecting single-frequency ionospheric delay model errors; Neglecting all psuedorange step changes caused by NAV message data cutovers.

7.2.4 BDS OS SIS UTCOE Accuracy Standards

The BDS OS SIS UTCOE standards are shown in Table 5.

Table 5 The BDS OS SIS UTCOE Standards

Satellite Type	SIS Accuracy Standard (95% probability)	Constraints
GEO/IGSO/MEO	UTCOE≤2ns	For any healthy OS SIS.

7.3 BDS OS SIS Continuity Standards

The BDS OS SIS continuity standards are shown in Table 6.

Table 6 The BDS OS SIS Continuity Standards

Satellite Type	**SIS Continuity Standard**	**Constraints**
GEO	≥0.995/h	Given that the OS SIS is available from the slot at the start of the hour; Calculated as an annual statistical value for each type of satellite.
IGSO	≥0.995/h	
MEO	≥0.994/h	

7.4 BDS OS SIS Availability Standards

The BDS OS SIS availability standards are shown in Table 7.

Table 7 The BDS OS SIS Availability Standards

Satellite Type	**SIS Availability Standard**	**Constraints**
GEO	≥0.98	Calculated as an annual statistical value for each type of satellite
IGSO	≥0.98	
MEO	≥0.91	

8 BDS OS Performance Standards

8.1 BDS OS Service Accuracy

The BDS OS position/velocity/time accuracy standards within its service volume are shown in Table 8.

Table 8 The BDS OS Position/Velocity/Time Accuracy Standards

Service Accuracy		Standard (95% probability)	Constraints
Position Accuracy	Horizontal	≤10m	Calculate the statistical position/velocity/time error for any point in the service volume over any 24-hour interval.
	Vertical	≤10m	
Velocity Accuracy		≤0.2m/s	
Time Accuracy (multi-SISs)		≤50ns	

8.2 BDS OS Service Availability Standards

8.2.1 BDS OS PDOP Availability Standards

The BDS OS PDOP availability standards within its service volume are shown in Table 9.

Table 9 The BDS OS PDOP Availability Standards

Service Availability	Standard	Constraints
PDOP Availability	≥0.98	PDOP≤6; Calculate at any point within the service volume over any 24-hour interval.

8.2.2 BDS OS Position Service Availability Standards

The BDS OS position service availability standards within its service volume are shown in Table 10.

Table 10 The BDS OS Position Service Availability Standards

Service Availability	Standard	Constraints
Positioning Availability	≥0.95	Horizontal position accuracy≤10m (95% probability); Vertical position accuracy≤10m (95% probability); Calculate at any point within the service volume over any 24-hour interval.

9 Additional Observations

At present, in addition to the specified open service volume, in the most part of the area within 55°S~55°N, 55°E~160°E, the BDS could provide open services with the horizontal and vertical position accuracy better than 20 meters; in the most part of the area within 55°S~55°N, 40°E~180°E, the BDS could provide open services with the horizontal and vertical position accuracy better than 30 meters. As a user moves away from the nominal service volume, the service accuracy and availability will decrease accordingly.