# BeiDou Navigation Satellite System
# Signal In Space
# Interface Control Document
## Precise Point Positioning Service Signal PPP-B2b

(Version 1.0)

**China Satellite Navigation Office**

**July, 2020**

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# 1 Statement

China Satellite Navigation Office is responsible for the preparation, revision, distribution, and retention of the BeiDou Navigation Satellite System (BDS) Signal In Space Interface Control Documents (hereinafter referred to as SIS ICD), and reserves the rights for final interpretation of this document.

# 2 Scope

The construction and development of the BeiDou Navigation Satellite System is divided into three phases: BDS-1, BDS-2, and BDS-3 in sequence.

This document defines the characteristics of the BDS Precise Point Positioning (PPP) Service Signal PPP-B2b. Transmitted by the BDS-3 Geostationary Earth Orbit (GEO) satellites, the PPP-B2b signal serves as the data broadcasting channel for correction parameters, such as satellite precise orbit and clock offset parameters of BDS-3 and other Global Navigation Satellite Systems (GNSS), and provides PPP services for users in China and surrounding areas.

# 3 BDS Overview

## 3.1 Space Constellation

The nominal space constellation of BDS-3 consists of 3 GEO satellites, 3 IGSO satellites, and 24 MEO satellites. According to actual situation, spare satellites may be deployed in orbit. The GEO satellites operate in orbit at an altitude of 35,786 kilometers and are located at 80°E, 110.5°E, and 140°E respectively. The IGSO satellites operate in orbit at an altitude of 35,786 kilometers and an inclination of the orbital planes of 55 degrees with reference to the equatorial plane. The MEO satellites operate in orbit at an altitude of 21,528 kilometers and an inclination of the orbital planes of 55 degrees with reference to the equatorial plane.

## 3.2 Coordinate System

BDS adopts the BeiDou Coordinate System (BDCS) whose definition complies with the standards of the International Earth Rotation and Reference System Service (IERS). The definition is also consistent with that of the China Geodetic Coordinate System 2000(CGCS2000). BDCS and CGCS2000 have the same reference ellipsoid parameters, which is defined as follows:

(1) Definition of origin, axis and scale

The origin is located at the Earth’s center of mass. The Z-Axis is the direction of the IERS Reference Pole (IRP). The X-Axis is the intersection of the IERS Reference Meridian (IRM) and the plane passing through 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 length unit is the international system of units (SI) meter.

(2) Definition of the BDCS Reference Ellipsoid

The geometric center of the BDCS Reference Ellipsoid coincides with the Earth’s center of mass, and the rotational axis of the BDCS Reference Ellipsoid is the Z-Axis. The parameters of the BDCS Reference Ellipsoid are shown in Table 3-1.

Table 3-1 Parameters of the BDCS Reference Ellipsoid

| **No.** | **Parameter** | **Definition** |
|---|---|---|
| 1 | Semi-major axis | $a=6378137.0$ m |
| 2 | Geocentric gravitational constant | $\mu=3.986004418\times10^{14}$ $m^3/s^2$ |
| 3 | Flattening | $f=1/298.257222101$ |
| 4 | Earth’s rotation rate | $\dot{\Omega}_e=7.2921150\times10^{-5}$ rad/s |

## 3.3 Time System

The BeiDou Navigation Satellite System Time (BDT) is adopted by the BDS as time reference. BDT adopts the second of the international system of units (SI) as the base unit, and accumulates continuously without leap seconds. The start epoch of BDT is 00:00:00 on January 1, 2006 of Coordinated Universal Time (UTC). BDT connects with UTC via UTC (NTSC), and the deviation of BDT to UTC is maintained within 50 nanoseconds (modulo 1 second). The leap second information is broadcast in the navigation message.

# 4 Signal Characteristics

This chapter specifies the signal characteristics of the I-component of the PPP-B2b signal with a center frequency of 1207.14MHz and a bandwidth of 20.46MHz.

## 4.1 Signal Structure

PPP service information is broadcast on the open service signal PPP-B2b. The carrier frequency, modulation, and symbol rate of the PPP-B2b are shown in Table 4-1.The PPP-B2b signal broadcasts the I-component and the Q-component, and the first three BDS-3 GEO satellites only broadcast the I-component. This document only describes the characteristics of the PPP-B2b I-component (PPP-B2b_I).

Table 4-1 Structure of the PPP-B2b signal

| **Signal** | **Component** | **Carrier frequency (MHz)** | **Modulation** | **Symbol rate (sps)** | **The first three GEOs** | **Subsequent GEOs** |
|---|---|---|---|---|---|---|
| PPP-B2b | I | 1207.14 | BPSK(10) | 1000 | available | available |
| | Q | 1207.14 | TBD | TBD | N/A | available |

## 4.2 Signal Modulation

The PPP-B2b_I signal $s_{\mathrm{B2b\_I}}(t)$ is generated by modulating the navigation message data $D_{\mathrm{B2b\_I}}(t)$ and the range code $C_{\mathrm{B2b\_I}}(t)$. The mathematical expression of $s_{\mathrm{B2b\_I}}(t)$ is as follows:

$$s_{\mathrm{B2b\_I}}(t)=\frac{1}{\sqrt{2}}D_{\mathrm{B2b\_I}}(t)\cdot C_{\mathrm{B2b\_I}}(t) \tag{4-1}$$

where $D_{\mathrm{B2b\_I}}(t)$ is as follows:

$$D_{\mathrm{B2b\_I}}(t)=\sum_{k=-\infty}^{\infty} d_{\mathrm{B2b\_I}}[k]\,p_{T_{\mathrm{B2b\_I}}}\left(t-kT_{\mathrm{B2b\_I}}\right) \tag{4-2}$$

where $d_{\mathrm{B2b\_I}}$ is the navigation message data code; $T_{\mathrm{B2b\_I}}$ is the chip width of the corresponding data code; and $p_{T_{\mathrm{B2b\_I}}}(t)$ is a rectangle pulse with width of $T_{\mathrm{B2b\_I}}$.

The mathematical expression of range code $C_{\mathrm{B2b\_I}}$ is as follows:

$$C_{\mathrm{B2b\_I}}(t)=\sum_{n=-\infty}^{\infty}\sum_{k=0}^{N_{\mathrm{B2b\_I}}-1} c_{\mathrm{B2b\_I}}[k]\,p_{T_{c\_\mathrm{B2b\_I}}}\left(t-\left(N_{\mathrm{B2b\_I}}n+k\right)T_{c\_\mathrm{B2b\_I}}\right) \tag{4-3}$$

where $c_{\mathrm{B2b\_I}}$ is a PPP-B2b_I ranging code sequence (possible values are ± 1); $N_{\mathrm{B2b\_I}}$ is the ranging code length with a value of 10230; $T_{\mathrm{c\_B2b\_I}}=1/R_{\mathrm{c\_B2b\_I}}$ is the PPP-B2b_I chip period of the ranging code, and $R_{\mathrm{c\_B2b\_I}}$ = 10.23 Mbps is the PPP-B2b_I chipping rate; and $p_{T_{\mathrm{c\_B2b\_I}}}(t)$ is a rectangle pulse with duration of $T_{c\_\mathrm{B2b\_I}}$.

## 4.3 Logic Levels

The correspondence between the logic level code bits used to modulate the signal and the signal level is shown in Table 4-2.

Table 4-2 Logic to signal level assignment

| Logic level | Signal level |
|---|---|
| 1 | -1.0 |
| 0 | +1.0 |

## 4.4 Signal Polarization

The transmitted signals are Right-Hand Circularly Polarized (RHCP).

## 4.5 Carrier Phase Noise

The phase noise spectral density of the un-modulated carrier will allow a third-order phase locked loop with 10 Hz one-sided noise bandwidth to track the carrier to an accuracy of 0.1 radians( RMS).

## 4.6 Spurious

The transmitted spurious signal shall not exceed -50dBc.

## 4.7 Correlation Loss

The correlation loss due to satellite-transmitted signal distortions shall not exceed 0.6dB.

## 4.8 Data/Code Coherence

The edge of each data symbol shall be aligned with the edge of the corresponding ranging code chip. The start of the first chip of the periodic ranging codes shall be aligned with the start of a data symbol.

## 4.9 Signal Coherence

The time difference between the ranging code phases of all signal components shall not exceed 10 nanoseconds.

## 4.10 Received Power Levels on Ground

The minimum received power level of the PPP-B2b_I on ground is -160dBW. It is measured at the output of a 0 dBi RHCP user receiving antenna (or 3 dBi linearly polarized user receiving antenna) when the satellites are above a 5-degree elevation angle.

The PPP-B2b_I has the following characteristics: the off-axis relative power shall not decrease by more than 2dB from the edge of the Earth to nadir.

# 5 Ranging Code Characteristics

The PPP-B2b_I ranging code chip rate is 10.23 Mcps, and the code length is 10230 chips. Each ranging code is obtained by expanding the Gold code that is generated by the modulo-2 addition of the shifted output of the two 13-stage linear feedback shift registers. The generator polynomials for each PPP-B2b_I ranging code are

$$\begin{aligned} g_1(x) &= 1 + x + x^9 + x^{10} + x^{13} \\ g_2(x) &= 1 + x^3 + x^4 + x^6 + x^9 + x^{12} + x^{13} \end{aligned} \tag{5-1}$$

The implementation of the PPP-B2b_I ranging code generators is shown in Figure 5-1.

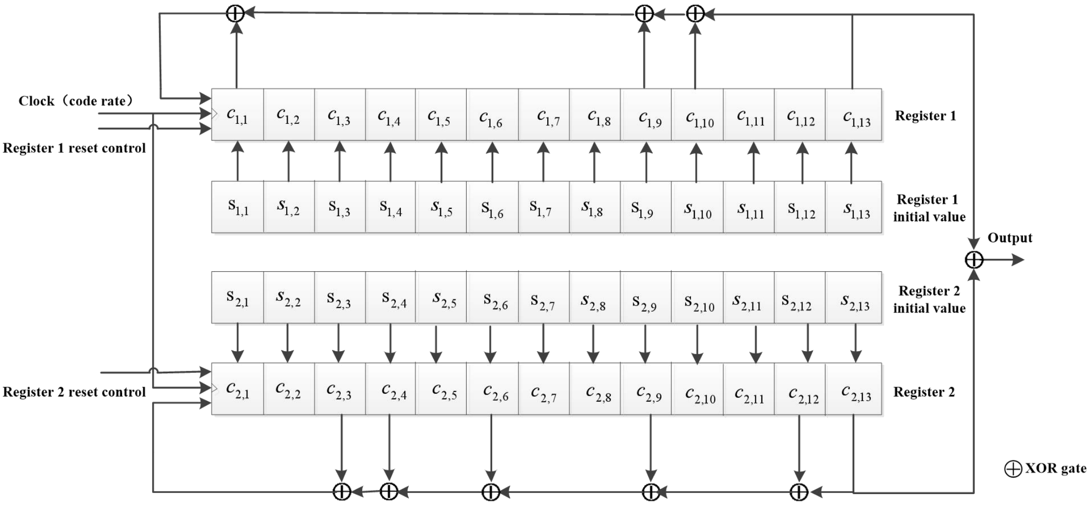

Figure 5-1 Ranging code generator of the PPP-B2b_I

In a code generator, the initial bit values of register 1 are all "1" and the initial bit values of register 2 are given in Table 5-1, arranged as $\left[ s_{2,1}, s_{2,2}, s_{2,3}, \ldots, s_{2,13} \right]$. At the start of each ranging code period, both register 1 and register 2 are simultaneously reset to their corresponding initial bit values. Furthermore, register 1 is reset at the end of the 8190th chip in each period of a ranging code. A ranging code with the length of 10230 chips is finally obtained by repeating the above procedure.

There are a total of 10 ranging codes for the PPP-B2b_I. The detailed parameters are shown in Table 5-1, in which, the values of both the first 24 chips and the last 24 chips are expressed in an octal form. The MSB (i.e., the first chip of the ranging codes) is transmitted first.

Table 5-1 Ranging code parameters of the PPP-B2b_I

| **PRN** | **Initial bit values of register 2 (binary)** | **The first 24 chips (octal)** | **The last 24 chips (octal)** |
|---|---|---|---|
| 1 | 1 0 0 0 0 0 0 1 0 0 1 0 1 | 26773275 | 01362377 |
| 2 | 1 0 0 0 0 0 0 1 1 0 1 0 0 | 64773151 | 54270774 |
| 3 | 1 0 0 0 0 1 0 1 0 1 1 0 1 | 22571523 | 41305112 |
| 4 | 1 0 0 0 1 0 1 0 0 1 1 1 1 | 03270234 | 26377564 |
| 5 | 1 0 0 0 1 0 1 0 1 0 1 0 1 | 25271603 | 71754171 |
| 59 | 1 1 1 1 0 1 1 1 1 1 1 1 1 | 00100015 | 65447760 |
| 60 | 1 1 1 1 1 1 0 1 1 0 1 0 1 | 24402044 | 14703362 |
| 61 | 1 1 1 1 1 1 0 1 1 1 1 0 1 | 20402615 | 26526364 |
| 62 | 0 1 0 1 1 1 0 0 0 0 1 0 1 | 27426631 | 23410705 |
| 63 | 0 1 0 1 1 0 0 1 1 1 0 1 1 | 10625632 | 34572376 |

# 6 Navigation Message Structure

## 6.1 Message Format

### 6.1.1 Brief Description

The basic frame structure of the PPP-B2b_I navigation message is defined in Figure 6-1.

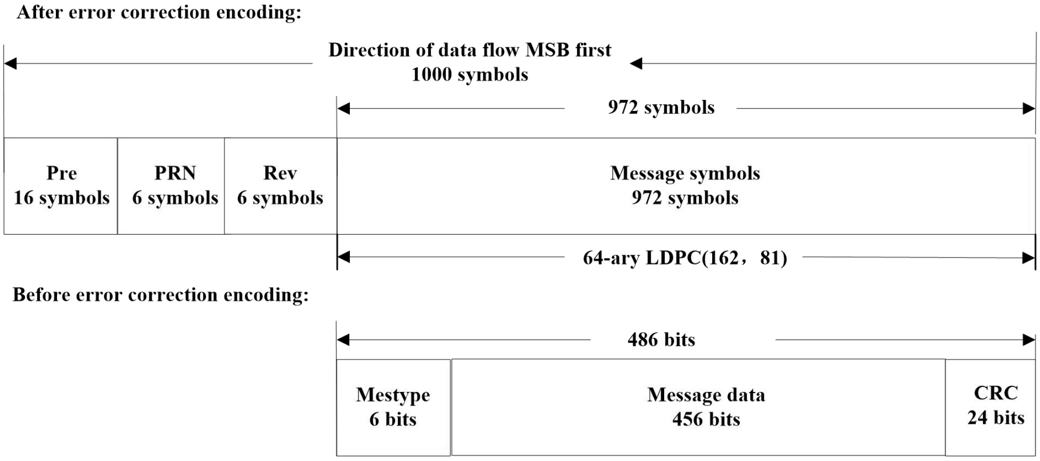

Figure 6-1 The PPP-B2b_I navigation message frame structure

Each message has a length of 486 bits, wherein the highest 6 bits (MesType ID) indicate the message type, the lowest 24 bits are CRC, and the remaining 456 bits are the message data and its specific contents may vary depending on different message types.

After 64-ary LDPC(162, 81) encoding, the frame length shall be 972 symbols. These symbols will be concatenated together with 16 symbols of the preamble, 6 symbols of the PRN and 6 symbols of the reserved flags to form 1000 symbols in total. The front of the first symbol of each frame (i.e. the first symbol of the synchronization head) is aligned with the edge of whole second of the satellite time, and the broadcast time of each frame is 1 second, wherein:

The first 16 symbols of each frame is preamble (Pre) with the value of 0xEB90 in hexadecimal (i.e., 1110 1011 1001 0000 in binary). The MSB is transmitted first. The PRN in figure 6-1 is the PRN number of the GEO satellite that is broadcasting the message.

The reserved flags are only used to identify the status of the PPP service: the "1" in the highest bit of the reserved flags means the PPP service of this satellite is unavailable and the "0" in the highest bit of the reserved flags means the PPP service of this satellite is available.

Other symbols are reserved for future purposes. The status of the reserved flags rarely changes, so that users can minimize demodulation error by superimposing multiple frames of information.

### 6.1.2 Cyclic Redundancy Check

The CRC check is performed by bit for the 6 bits message type and the 456 bits message data. The generator polynomial of CRC is:

$$\mathrm{g}(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^{7} + x^{6} + x^{5} + x^{4} + x^{3} + x + 1 \tag{6-1}$$

### 6.1.3 Coding Methods and Coding Parameters

Each frame of the PPP-B2b_I navigation message before error correction encoding has a length of 486 bits, containing Message Type (Mestype, 6 bits), message data (456 bits), and CRC check bits (24 bits). The encoding scheme adopts 64-ary LDPC(162, 81). Each codeword symbol is composed of 6 bits and defined in GF($2^6$) domain with a primitive polynomial of $p(x)=1+x+x^6$ . A vector representation (MSB first) is used to describe the mapping relationship between non-binary symbols and binary bits. The message length $k$ is equal to 81 code word symbols, i.e., 486 bits. The check matrix is a sparse matrix $\mathbf{H}_{81,162}$ of 81 rows and 162 columns defined in GF($2^6$) domain with the primitive polynomial of $p(x)=1+x+x^6$, of which the first 81×81 part corresponds to the information symbols and the last 81×81 part corresponds to the check symbols. The locations of its non-zero elements are defined as follows:

$\mathbf{H}_{81,162,\text{index}}$=[

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 67 | 109 | 130 | 27 | 71 | 85 | 161 | 31 | 78 | 96 | 122 | 2 | 44 | 83 | 125 |
| 26 | 71 | 104 | 132 | 30 | 39 | 93 | 154 | 4 | 46 | 85 | 127 | 21 | 62 | 111 | 127 |
| 13 | 42 | 101 | 146 | 18 | 66 | 108 | 129 | 27 | 72 | 100 | 153 | 29 | 70 | 84 | 160 |
| 23 | 61 | 113 | 126 | 8 | 50 | 89 | 131 | 34 | 74 | 111 | 157 | 12 | 44 | 100 | 145 |
| 22 | 60 | 112 | 128 | 0 | 49 | 115 | 151 | 6 | 47 | 106 | 144 | 33 | 53 | 82 | 140 |
| 3 | 45 | 84 | 126 | 38 | 80 | 109 | 147 | 9 | 60 | 96 | 141 | 1 | 43 | 82 | 124 |
| 20 | 77 | 88 | 158 | 37 | 54 | 122 | 159 | 3 | 65 | 104 | 149 | 5 | 47 | 86 | 128 |
| 0 | 42 | 81 | 123 | 32 | 79 | 97 | 120 | 35 | 72 | 112 | 158 | 15 | 57 | 93 | 138 |
| 22 | 75 | 107 | 143 | 24 | 69 | 102 | 133 | 1 | 50 | 116 | 152 | 24 | 57 | 119 | 135 |
| 17 | 59 | 95 | 140 | 7 | 45 | 107 | 145 | 34 | 51 | 83 | 138 | 14 | 43 | 99 | 144 |
| 21 | 77 | 106 | 142 | 16 | 58 | 94 | 139 | 20 | 68 | 110 | 131 | 2 | 48 | 114 | 150 |
| 10 | 52 | 91 | 133 | 25 | 70 | 103 | 134 | 32 | 41 | 95 | 153 | 14 | 56 | 91 | 137 |
| 33 | 73 | 113 | 156 | 28 | 73 | 101 | 154 | 4 | 63 | 102 | 147 | 6 | 48 | 87 | 129 |
| 8 | 46 | 105 | 146 | 30 | 80 | 98 | 121 | 41 | 68 | 119 | 150 | 35 | 52 | 81 | 139 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 63 | 114 | 124 | 13 | 55 | 90 | 136 | 31 | 40 | 94 | 155 | 10 | 61 | 97 | 142 |
| 36 | 56 | 121 | 161 | 29 | 74 | 99 | 155 | 5 | 64 | 103 | 148 | 18 | 75 | 89 | 156 |
| 36 | 78 | 110 | 148 | 19 | 76 | 87 | 157 | 15 | 65 | 116 | 123 | 11 | 53 | 92 | 134 |
| 25 | 58 | 117 | 136 | 39 | 66 | 117 | 151 | 11 | 62 | 98 | 143 | 9 | 51 | 90 | 132 |
| 38 | 55 | 120 | 160 | 7 | 49 | 88 | 130 | 17 | 64 | 115 | 125 | | | | |
| 28 | 69 | 86 | 159 | 23 | 76 | 105 | 141 | 12 | 54 | 92 | 135 | | | | |
| 40 | 67 | 118 | 152 | 37 | 79 | 108 | 149 | 26 | 59 | 118 | 137 | | | | |

],

where each element is a non-binary symbol in GF($2^6$) domain. The elements are described by a vector representation as follows:

$\mathbf{H}_{81,162,\text{element}}$=[

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 45 | 44 | 15 | 15 | 24 | 50 | 37 | 24 | 50 | 37 | 15 | 15 | 32 | 18 | 61 |
| 58 | 56 | 60 | 62 | 37 | 53 | 61 | 29 | 46 | 58 | 18 | 6 | 36 | 19 | 3 | 57 |
| 54 | 7 | 38 | 23 | 51 | 59 | 63 | 47 | 9 | 3 | 43 | 29 | 56 | 8 | 46 | 13 |
| 26 | 22 | 14 | 2 | 63 | 26 | 41 | 12 | 17 | 32 | 58 | 37 | 38 | 23 | 55 | 22 |
| 35 | 1 | 31 | 44 | 44 | 51 | 35 | 13 | 30 | 1 | 44 | 7 | 27 | 5 | 2 | 62 |
| 16 | 63 | 20 | 9 | 27 | 56 | 8 | 43 | 1 | 44 | 30 | 24 | 5 | 26 | 27 | 37 |
| 42 | 47 | 37 | 32 | 38 | 12 | 25 | 51 | 43 | 34 | 48 | 57 | 39 | 9 | 30 | 48 |
| 63 | 13 | 54 | 10 | 2 | 46 | 56 | 35 | 47 | 20 | 33 | 26 | 62 | 54 | 56 | 60 |
| 1 | 21 | 25 | 7 | 43 | 58 | 19 | 49 | 28 | 4 | 52 | 44 | 46 | 44 | 14 | 15 |
| 41 | 48 | 2 | 27 | 49 | 21 | 7 | 35 | 40 | 21 | 44 | 17 | 24 | 23 | 45 | 11 |
| 46 | 25 | 22 | 48 | 13 | 29 | 53 | 61 | 52 | 17 | 24 | 61 | 29 | 41 | 10 | 16 |
| 60 | 24 | 4 | 50 | 32 | 49 | 58 | 19 | 43 | 34 | 48 | 57 | 29 | 7 | 10 | 16 |
| 25 | 11 | 7 | 1 | 32 | 49 | 58 | 19 | 42 | 14 | 24 | 33 | 39 | 56 | 30 | 48 |
| 13 | 27 | 56 | 8 | 53 | 40 | 61 | 18 | 8 | 43 | 27 | 56 | 18 | 40 | 32 | 61 |
| 60 | 48 | 2 | 27 | 50 | 54 | 60 | 62 | 58 | 19 | 32 | 49 | 9 | 3 | 63 | 43 |
| 53 | 35 | 16 | 13 | 23 | 25 | 30 | 16 | 18 | 6 | 61 | 21 | 15 | 1 | 42 | 45 |
| 20 | 16 | 63 | 9 | 27 | 37 | 5 | 26 | 29 | 7 | 10 | 16 | 11 | 60 | 6 | 49 |
| 43 | 47 | 18 | 20 | 42 | 14 | 24 | 33 | 43 | 22 | 41 | 20 | 22 | 15 | 12 | 33 |
| 9 | 41 | 57 | 58 | 5 | 31 | 51 | 30 | 9 | 3 | 63 | 43 | | | | |
| 37 | 53 | 61 | 29 | 6 | 45 | 56 | 19 | 33 | 45 | 36 | 34 | | | | |
| 19 | 24 | 42 | 14 | 1 | 45 | 15 | 6 | 8 | 43 | 27 | 56 | | | | |

].

The above matrix shall be read in a top-down process, and in a left-to-right order between columns. In the same column, the four numbers of each row correspond to four non-zero elements in the matrix. The reading rules for $\mathbf{H}_{81,162}$ are shown in Figure 6-2.

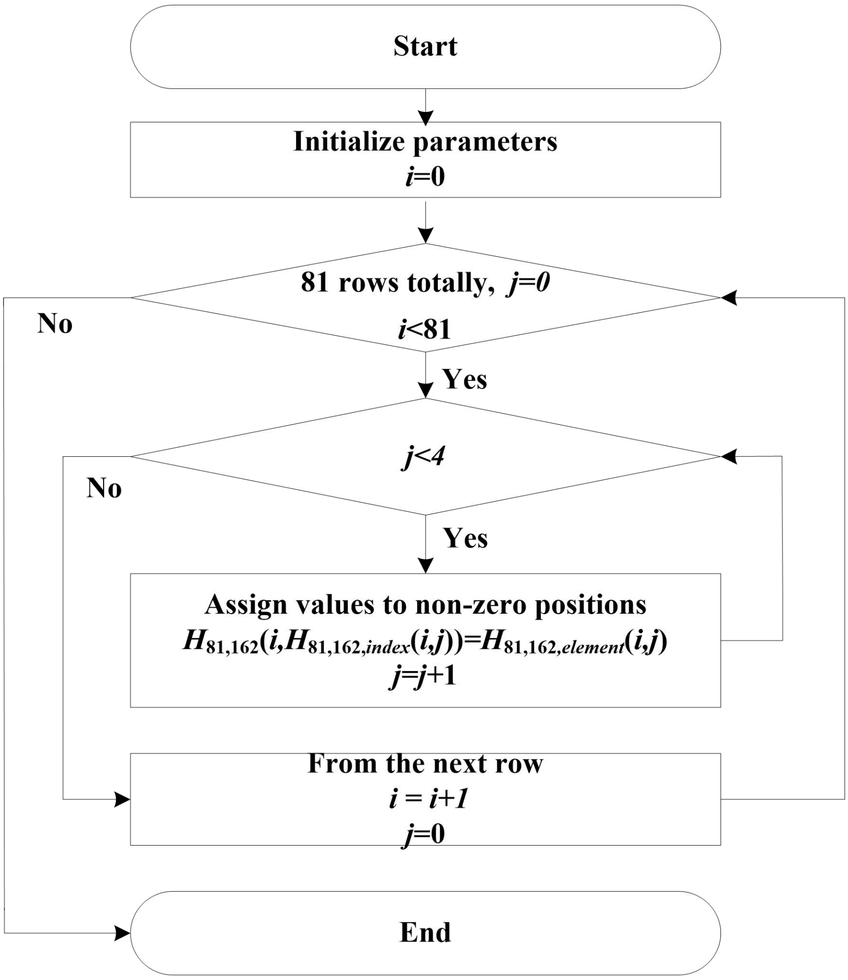

Figure 6-2 $\mathbf{H}_{81,162}$ reading flow chart

See Annex for more information about the encoding and decoding methods.

## 6.2 Message Content

### 6.2.1 Message Type Description

6.2.1.1 Message Type Definition

The message type is used to distinguish the information contents broadcast in the valid data field. The defined message types are shown in Table 6-1, and others are reserved.

Table 6-1 Defined message types

| Message types (in decimal) | Information content |
|---|---|
| 1 | Satellite mask |
| 2 | Satellite orbit correction and user range accuracy index |
| 3 | Differential code bias |
| 4 | Satellite clock correction |

| **Message types (in decimal)** | **Information content** |
|---|---|
| 5 | User range accuracy index |
| 6 | Clock correction and orbit correction - combination 1 |
| 7 | Clock correction and orbit correction - combination 2 |
| 8-62 | Reserved |
| 63 | Null message |

#### 6.2.1.2 Message Type Inter-Relationship

To ensure the inter-relationship among the information contents of different message types, the information is identified with a group of IOD. These IODs include:

1) IOD SSR: This IOD indicates the issue number of the State Space Representation (SSR) data. This field is included in all currently defined message types. If the IOD SSR in different message types is the same, the corresponding data can be used together; if the IOD SSR is different, the corresponding data cannot be used. In general, IOD SSR shall be updated only when the system configuration changes.

2) IODP: This IOD indicates the issue number of the satellite mask. IODP is broadcast in message type 1, message type 4, message type 5, and message type 6. Users can use this field to decide whether the data in the above-mentioned message types are matched.

3) IODN: This IOD indicates the issue number of satellite clock and ephemeris broadcast by the downlink signals of GNSS. It is included in message type 2. Users can use IODN to judge whether the ephemeris and clock parameters of the broadcast navigation message match with the orbit correction in message types 2, 6 and 7. Another IOD, known as IOD Corr, is also included in message types 2, 6 and 7 simultaneously, which is used to associate with the clock correction in message types 4, 6 and 7. Users can use IODN and IOD Corr to decide whether clock correction parameters of the broadcast navigation message match with the clock correction in message types 4, 6 and 7.

4) IOD Corr: This IOD identifies the issue number of the orbit correction and the clock correction. It is included in message types 2, 4, 6 and 7. For the same satellite, when the IOD Corr of the clock correction is same as that of the orbit correction, the two are matched. (Note: the IOD Corr is not in a one-to-one correspondence with the parameter contents. When the

clock correction or orbital correction changes, the IOD Corr may not change. When the IOD Corr of multiple groups of parameters is identical, the user should use the latest parameters available.)

### 6.2.2 Message Type 1 ( Satellite Mask)

#### 6.2.2.1 Message Layout

The format of message type 1 is shown in Figure 6-3.

Message type 1 Satellite mask

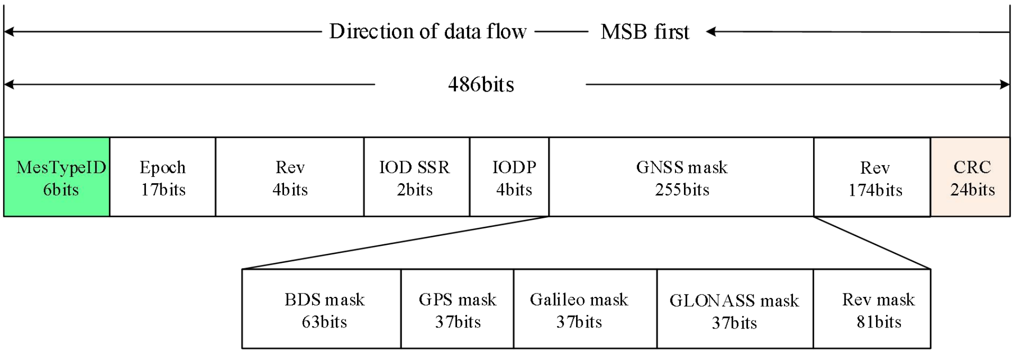

Figure 6-3 Bit allocation of message type 1

#### 6.2.2.2 Content Description

Message type 1 is satellite mask information. The mask contains 255 ID positions, each of which occupies one bit. The "1" in a bit means the differential information of the corresponding satellite is broadcast; the "0" in a bit means the differential information of the corresponding satellite is not broadcast. The unassigned (reserved mask) ID bit should be set to "0". The satellite mask assignment and other information contents of the message type 1 are described in Table 6-2.

Table 6-2 Parameters of message type 1

| **Field** | **Name** | **Length (bit)** | **Scale factor** | **Range** | **Unit** | **Basic description** |
|---|---|---|---|---|---|---|
| MesTypeID | Message type | 6 | 1 | 0～63 | -- | See Table 6-1 |
| Epoch | Epoch | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| Reserved | Reserved | 4 | 1 | 0～15 | -- | -- |
| IOD SSR | IOD of SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| IODP | IOD of PRN | 4 | 1 | 0～15 | -- | Issue Of Data of PRN |

| Field | Name | Length (bit) | Scale factor | Range | Unit | Basic description |
|---|---|---|---|---|---|---|
| | mask | | | | | mask |
| BDS mask | Satellite slot 1 | 1 | 1 | 0～1 | -- | Broadcasting ID of the first satellite of BDS |
| | to slot 63 | 1 | 1 | 0～1 | -- | Broadcasting ID of the 63rd satellite of BDS |
| GPS mask | Satellite slot 64 | 1 | 1 | 0～1 | -- | Broadcasting ID of the first satellite of GPS |
| | to slot 100 | 1 | 1 | 0～1 | -- | Broadcasting ID of the 37th satellite of GPS |
| Galileo mask | Satellite slot 101 | 1 | 1 | 0～1 | -- | Broadcasting ID of the first satellite of Galileo |
| | to slot137 | 1 | 1 | 0～1 | -- | Broadcasting ID of the 37th satellite of Galileo |
| GLONASS mask | Satellite slot 138 | 1 | 1 | 0～1 | -- | Broadcasting ID of the first satellite of GLONASS |
| | to slot 174 | 1 | 1 | 0～1 | -- | Broadcasting ID of the 37th satellite of GLONASS |
| Reserved mask | Satellite slot 175 | 1 | 1 | 0～1 | -- | Reserved |
| | to slot 255 | 1 | 1 | 0～1 | -- | Reserved |
| Reserved bits | Reserved bits | 174 | 1 | -- | -- | -- |
| CRC | CRC bits | 24 | -- | -- | -- | -- |

The above information is described as follows:

1) Epoch

It identifies the epoch corresponding to the observation data used to calculate differential message, expressed in seconds within one BDT day. Unless specified elsewhere, the data at the latest epoch should be selected to use for all types of data.

2) IOD SSR

Changes of IOD SSR indicate that the data generation configuration has changed. Different types of data can be used together only when they have same IOD SSR.

3) IODP

IODP represents the IOD of PRN mask. If the mask content changes, the IODP will change accordingly in a sequential cycle of 0, 1, 2, 3, …, 14, 15, and 0. IODP is also included in message type 4, 5 and 6 to identify the corresponding relationship between the data and the mask. When it is consistent with the IODP parameter of message type 1, it means they are the same set of data.

When the IODP parameter in message type 1 is inconsistent with that in message type 4, 5 and 6, users should not use message type 1 until the IODP of all involved types are consistent.

During the period while IODP parameter is changing, users should use the old mask until the IODP in other types is updated to the same value. When it is detected that the IODP in other message types has changed first, users should not use these message types until they receive a new mask.

### 6.2.3 Message Type 2 (Orbit Correction Parameters and User Range Accuracy Index)

#### 6.2.3.1 Message Layout

The format of message type 2 is shown in Figure 6-4.

Message type 2 Satellite orbit correction

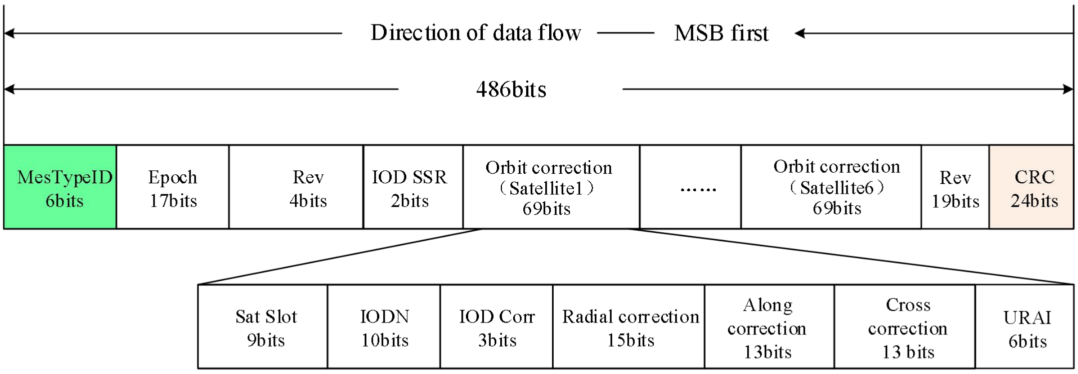

Figure 6-4 Bit allocation of message type 2

#### 6.2.3.2 Content Description

Message type 2 broadcasts the orbit correction parameters of the satellite. Its information contents are described in Table 6-3.

Table 6-3 Parameters of message type 2

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| MesType ID | Message type | 6 | 1 | 0～63 | -- | See Table 6-1 |
| Epoch | Epoch | 17 | 1 | 0～86399 | s | BDT seconds within a day |

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| Reserved | Reserved | 4 | 1 | 0～15 | -- | -- |
| IOD SSR | IOD of SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| Orbit correction parameters of satellite 1 | Sat Slot | 9 | 1 | 1～255 | -- | Position ID of the mask |
| | IODN | 10 | 1 | -- | -- | IOD of the broadcast navigation message |
| | IOD Corr | 3 | 1 | 0～7 | -- | IOD of the correction |
| | Radial correction | 15* | 0.0016 | ±26.2128 | m | Radial orbit correction |
| | Along-track correction | 13* | 0.0064 | ±26.208 | m | Along orbit correction |
| | Cross-track correction | 13* | 0.0064 | ±26.208 | m | Cross orbit correction |
| | URAI: $\mathrm{URA}_{\mathrm{CLASS}}$ | 3 | 1 | 0～7 | -- | User Range Accuracy Index of this satellite |
| | URAI: $\mathrm{URA}_{\mathrm{VALUE}}$ | 3 | 1 | 0～7 | -- | |
| Orbit correction parameters of satellite 2 | -- | 69 | -- | -- | -- | The orbit correction parameters of the 2nd satellite of this type |
| … | … | … | … | … | … | … |
| Orbit correction parameters of satellite 6 | -- | 69 | -- | -- | -- | The orbit correction parameters of the 6th satellite of this type |
| Rev | -- | 19 | -- | -- | -- | -- |
| CRC | CRC bits | 24 | -- | -- | -- | -- |

*Note: Represents a binary complement code.

Please refer to message type 1 for the definitions of "Epoch", "SSR update interval" and "IOD SSR" in Table 6-3. Other parameters are described as follows.

Message type 2 broadcasts the orbit correction parameters of 6 satellites. The orbit correction parameters of each satellite include Sat Slot, IODN, IOD Corr, radial correction, along correction, and cross correction. User Range Accuracy Index is broadcast simultaneously.

1) Sat Slot

Sat Slot indicates the location of the satellite in the mask. The starting value is 1 and the effective range is 1~255;

2) IODN

IODN is used for the IOD corresponding to the orbit and clock correction parameters in GNSS. If the IODN broadcast by PPP-B2b does not match the IOD broadcast by GNSS, it means that the GNSS has updated its navigation message. Users should continue to use the previous navigation message until the IODN in PPP-B2b signals gets updated and matches the IOD from GNSS.

The correspondence relationship between IODN and the broadcast navigation message information of GNSS are as follows:

(1) BDS: corresponding to the IODC in CNAV1 message;

(2) GPS: corresponding to the IODC in LNAV message;

(3) Galileo: corresponding to IOD Nav in I/NAV message;

(4) GLONASS: corresponding to Tb in L1OCd message.

3) IOD Corr

Please see the description of message type 4 for the definition and usage of IOD Corr.

4) Radial, along and cross correction

See section 7.4 for algorithms.

5) User Range Accuracy Index (URAI)

The URAI parameter of a satellite has 6 bits in total. The highest 3 bits are defined as user range accuracy class ($\mathrm{URA_{CLASS}}$), and the lowest 3 bits are defined as user range accuracy value ($\mathrm{URA_{VALUE}}$). The formula for calculating URA is:

$$\mathrm{URA}\left[\mathrm{mm}\right] \leq 3^{\mathrm{URA_{CLASS}}}\left(1+0.25\times \mathrm{URA_{VALUE}}\right)-1 \tag{6-2}$$

where URA is the user range accuracy in mm;

When URAI = 000000(binary), it means that URA is undefined or unknown, and the corresponding satellite correction is not reliable.

When URAI = 111111(binary), it means that URA > 5466.5 mm.

### 6.2.4 Message Type 3 (Differential Code Bias Correction)

#### 6.2.4.1 Message Layout

The format of message type 1 is shown in Figure 6-5.

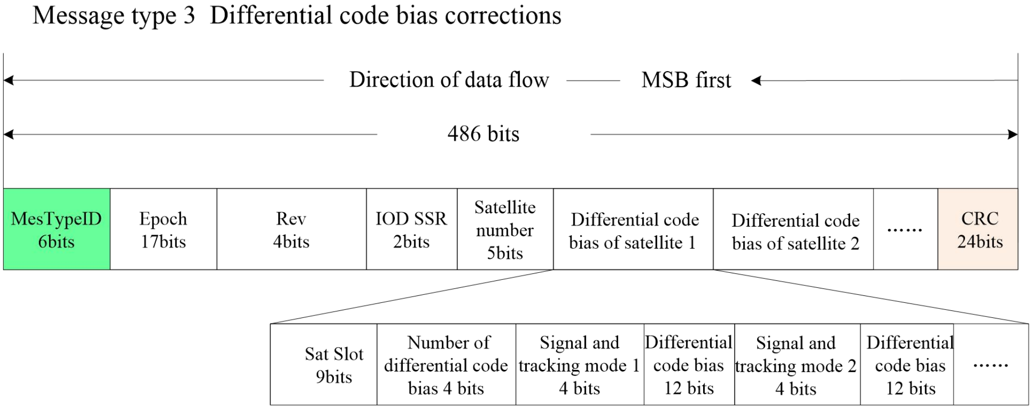

Figure 6-5 Bit allocation of message type 3

#### 6.2.4.2 Content Description

The contents of message type 3 are described in Table 6-4.

Table 6-4 Parameters of message type 3

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| MesTypeID | Message type | 6 | 1 | 0～63 | -- | See Table 6-1 |
| Epoch | Epoch | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| Reserved | Reserved | 4 | 1 | 0～15 | -- | -- |
| IOD SSR | IOD of SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| Number of satellite(s) | Number of satellite(s) | 5 | 1 | 0～31 | -- | Number of the satellite contained in this message |
| Differential code bias of | Sat Slot | 9 | 1 | 1～255 | -- | The slot location of satellite 1 |

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| satellite 1 | Number of differential code bias(es) | 4 | 1 | -- | -- | Number of differential code bias(es) contained in satellite 1 |
| | Signal and tracking mode 1 | 4 | 1 | 0～15 | -- | The signal component and processing mode of the 1st differential code bias value |
| | Differential code bias 1 | 12* | 0.017 | ±35.746 | m | The 1st differential code bias value |
| | Signal and tracking mode 2 | 4 | 1 | 0～15 | -- | The signal component and processing mode of the 2nd differential code bias value |
| | Differential code bias 2 | 12* | 0.017 | ±35.746 | m | The 2nd differential code bias value |
| | …… | …… | …… | …… | …… | …… |
| | …… | …… | …… | …… | …… | …… |
| …… | -- | -- | -- | -- | -- | -- |
| CRC | CRC bits | 24 | -- | -- | -- | -- |
| *Note: Represents a binary complement code. | | | | | | |

Please refer to message type 1 for the definitions of "Epoch", "SSR update interval" and "IOD SSR" and message type 2 for the definition of "Sat Slot" in Table 6-4. Other parameters are described as follows.

Message type 3 broadcasts the differential code bias correction parameters of the signal components of the satellites involved. The number of satellites contained in each message and the number of differential code bias of each satellite are variable. Users should analyze dynamically according to the "number of satellites" and the "number of differential code bias(es)" of each satellite.

The "signal and tracking mode" indicates the signal component corresponding to the differential code bias and the signal-receiving mode of that component. See Table 6-5 for specific definitions.

Table 6-5 Definitions of signal and tracking modes

| ID of signal and tracking mode | BDS | GPS | GLONASS | Galileo |
|---|---|---|---|---|
| 0 | B1I | L1 C/A | G1 C/A | Reserved |
| 1 | B1C(D) | L1 P | G1 P | E1 B |
| 2 | B1C(P) | Reserved | G2 C/A | E1 C |
| 3 | Reserved | Reserved | Reserved | Reserved |
| 4 | B2a(D) | L1C(P) | Reserved | E5a Q |
| 5 | B2a(P) | L1C(D+P) | Reserved | E5a I |
| 6 | Reserved | Reserved | Reserved | Reserved |
| 7 | B2b-I | L2C(L) | Reserved | E5b I |
| 8 | B2b-Q | L2C(M+L) | Reserved | E5b Q |
| 9 | Reserved | Reserved | Reserved | Reserved |
| 10 | Reserved | Reserved | Reserved | Reserved |
| 11 | Reserved | L5 I | Reserved | E6 C |
| 12 | B3 I | L5 Q | Reserved | Reserved |
| 13 | Reserved | L5 I+Q | Reserved | Reserved |
| 14 | Reserved | Reserved | Reserved | Reserved |
| 15 | Reserved | Reserved | Reserved | Reserved |

The "differential code bias" in this message type is the pseudo-range code biases between the ranging signal and the clock offset reference signal adopted by the corresponding system. Users need to correct the differential code bias accordingly when they are using the signals other than the reference signal, otherwise the convergence time of precise point positioning may be affected. Please refer to section 7.3 for the user algorithms of differential code bias corrections.

### 6.2.5 Message Type 4 (Clock Correction Parameters)

#### 6.2.5.1 Message Layout

Message type 4 is used to broadcast clock correction and its message format is shown in Figure 6-6.

Message type 4 Satellite clock correction

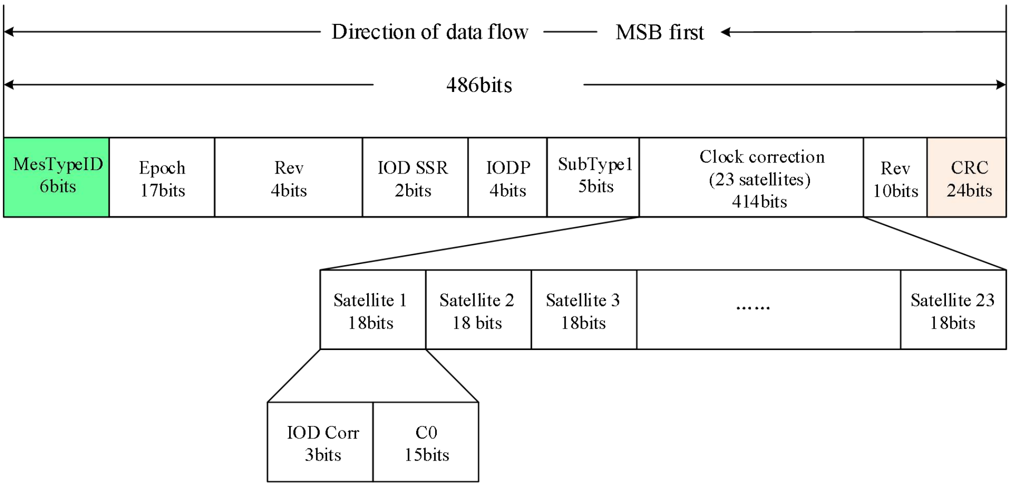

Figure 6-6 Bit allocation of message type 4

#### 6.2.5.2 Content Description

The parameters of message type 4 are described in Table 6-6.

Table 6-6 Parameters of message type 4

| **Field** | **Name** | **Length (bit)** | **Scale factor** | **Range** | **Unit** | **Description** |
|---|---|---|---|---|---|---|
| MesTypeID | Message type | 6 | 1 | 0～63 | -- | See Table 6-1 |
| Epoch | Epoch | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| Reserved | Reserved | 4 | 1 | 0～15 | -- | -- |
| IOD SSR | IOD of SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| IODP | IOD of PRN mask | 4 | 1 | 0～15 | -- | Issue Of Data of PRN mask |
| SubType1 | Subtype ID 1 | 5 | 1 | 0～31 | -- | Indicates the corresponding relationship between the satellite and the mask. |
| Clock offset correction of satellite 1 | IOD Corr | 3 | 1 | 0～7 | -- | Issue Of Data correction |
| | $C_0$ | 15* | 0.0016 | ±26.2128 | m | Invalid if the value exceeds the effective range. |
| Clock correction of satellite 2 | -- | 18 | -- | -- | -- | The clock correction of the 2nd satellite of this type. |
| Clock correction of satellite 3 | -- | 18 | -- | -- | -- | The clock correction of the 3rd satellite of this type. |
| … | … | 18 | -- | -- | -- | … |
| Clock correction of satellite 23 | -- | 18 | -- | -- | -- | The clock correction of the 23rd satellite of this type. |

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| Rev | Reserved | 10 | -- | -- | -- | Reserved bits |
| CRC | CRC bits | 24 | -- | -- | -- | -- |
| *Note: Represents a binary complement code. | | | | | | |

Please refer to message type 1 for the definitions of "Epoch ", "SSR update interval", "IOD SSR" and "IODP" in Table 6-6. Other parameters are described as follows.

In message type 4, Users use the message type, mask (broadcast in message type 1), and subtype (SubType1) to determine the satellite corresponding to the clock correction: all satellites whose masks are set to 1 are compressed in order of their slot locations in the mask. See Table 6-7 for the correspondence of SubType1 and satellites.

Table 6-7 Correspondence of SubType1 and satellites in message type 4

| SubType1 | Corresponding satellites |
|---|---|
| 0 | The 1st ~ 23rd of the satellites whose masks are set to "1". |
| 1 | The 24th ~ 46th of the satellites whose masks are set to "1". |
| 2 | The 47th ~ 69th of the satellites whose masks are set to "1". |
| 3 | The 70th ~ 92nd of the satellites whose masks are set to "1". |
| 4 | The 93rd ~ 115th of the satellites whose masks are set to "1". |
| 5 | The 116th ~ 138th of the satellites whose masks are set to "1". |
| 6 | The 139th ~ 161st of the satellites whose masks are set to "1". |
| 7 | The 162nd ~ 184th of the satellites whose masks are set to "1". |
| 8 | The 185th ~ 207th of the satellites whose masks are set to "1". |
| 9 | The 208th ~ 230th of the satellites whose masks are set to "1". |
| 10 | The 231st ~ 253rd of the satellites whose masks are set to "1". |
| 11 | The 254th ~ 255th of the satellites whose masks are set to "1". |
| Other values | Reserved |

According to the actual number of satellites, the system only broadcasts the necessary message types. For example, if there are 30 satellites whose masks are set to 1, only the information subtypes 0 and 1 will be broadcast and other types will not be broadcast. (Note: In such a case, the subtype 0 of message type 4 can also be broadcast together with message type 6. Please refer to the description of message type 6 for more details.)

The clock correction parameters of each satellite include IOD Corr and $C_0$.

IOD Corr is the IOD correction, which is also broadcast in message type 2. For the correction of the same satellite, the IOD Corr in message type 2 and that in message type 4 is identical, which means that $C_0$ matches the orbit correction (broadcast in message type 2) and $C_0$ matches the IODN in the orbit correction (see the description of message type 2), so that the orbit and clock correction can be used in combination. If the IOD Corr of message type 2 and 4 are not identical, the $C_0$ and orbital corrections cannot be used in a consistent way.

$C_0$ is the clock correction of 15 bits binary complement with a quantization unit of 0.0016 m, and the effective range is ±26.2128 m. See section 7.5 for user algorithms.

### 6.2.6 Message Type 5 (User Range Accuracy Index)

#### 6.2.6.1 Message Layout

Message type 5 broadcasts user range accuracy index. Its message format is shown in Figure 6-7.

Message type 5 User range accuracy

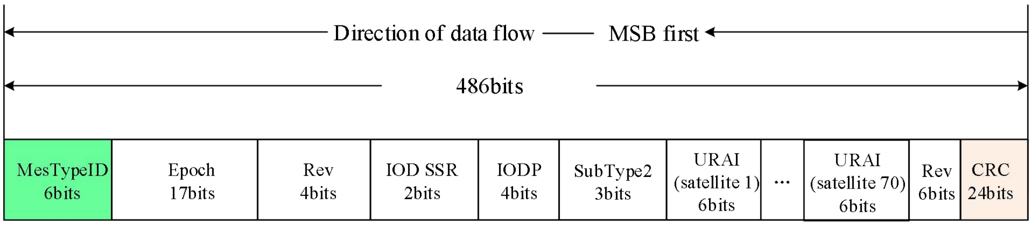

Figure 6-7 Bit allocation of message type 5

#### 6.2.6.2 Content Description

The parameters of message type 5 are described in Table 6-8.

Table 6-8 Parameters of message type 5

| **Field** | **Name** | **Length (bit)** | **Scale factor** | **Range** | **Unit** | **Description** |
|---|---|---|---|---|---|---|
| MesTypeID | Message type | 6 | 1 | 0～63 | -- | See Table 6-1 |
| Epoch | Epoch | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| Reserved | Reserved | 4 | 1 | 0～15 | -- | -- |
| IOD SSR | IOD of SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| IODP | IOD of PRN mask | 4 | 1 | 0～15 | -- | Issue Of Data of PRN mask |
| SubType2 | Subtype 2 | 3 | 1 | 0～7 | -- | Identify satellite ID. |

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| URAI (Satellite 1) | URA$_{\text{CLASS}}$ | 3 | 1 | 0～7 | -- | User range accuracy index of the 1st satellite in this type |
| | URA$_{\text{VALUE}}$ | 3 | 1 | 0～7 | -- | |
| URAI (Satellite 2) | -- | 6 | 1 | -- | -- | User range accuracy index of the 2nd satellite in this type |
| …… | …… | …… | …… | …… | …… | …… |
| URAI (Satellite 70) | -- | 6 | 1 | -- | -- | User range accuracy index of the 70th satellite in this type |
| Rev | Reserved | 6 | -- | -- | -- | Reserved bits |
| CRC | CRC bits | 24 | -- | -- | -- | -- |

Please refer to message type 1 for the definitions of "Epoch", "SSR update interval", "IOD SSR" and "IODP" in Table 6-8. Other parameters are described as follows.

In message type 5, users use the message type, mask (broadcast in message type 1), and subtype (SubType2) to determine the satellite corresponding to the range accuracy: all satellites whose masks are set to 1 are arranged after compression in order of their slot locations in the mask. See Table 6-9 for the correspondence of SubType2 and satellites.

Table 6-9 Correspondence of SubType2 and satellites in message type 5

| SubType2 | Corresponding satellite |
|---|---|
| 0 | The 1st ～ 70th of the satellites whose masks are set to "1". |
| 1 | The 71st ～ 140th of the satellites whose masks are set to "1". |
| 2 | The 141st ～ 210th of the satellites whose masks are set to "1". |
| 3 | The 211th ～ 255th of the satellites whose masks are set to "1". |
| Other values | Reserved |

According to the actual number of the satellites, the system only broadcasts the necessary message types. For example, if there are 32 satellites whose masks are set to 1, only the subtype 0 will be broadcast and other types will not be broadcast. Please refer to the description of message type 2 for the definition of "URAI".

## 6.2.7 Message Type 6 (Clock Correction and Orbit Correction - combination 1)

### 6.2.7.1 Message Layout

Message type 6 is used to broadcast the clock correction and orbit correction parameters in combination. The message format of Message type 6 is shown in Figure 6-8.

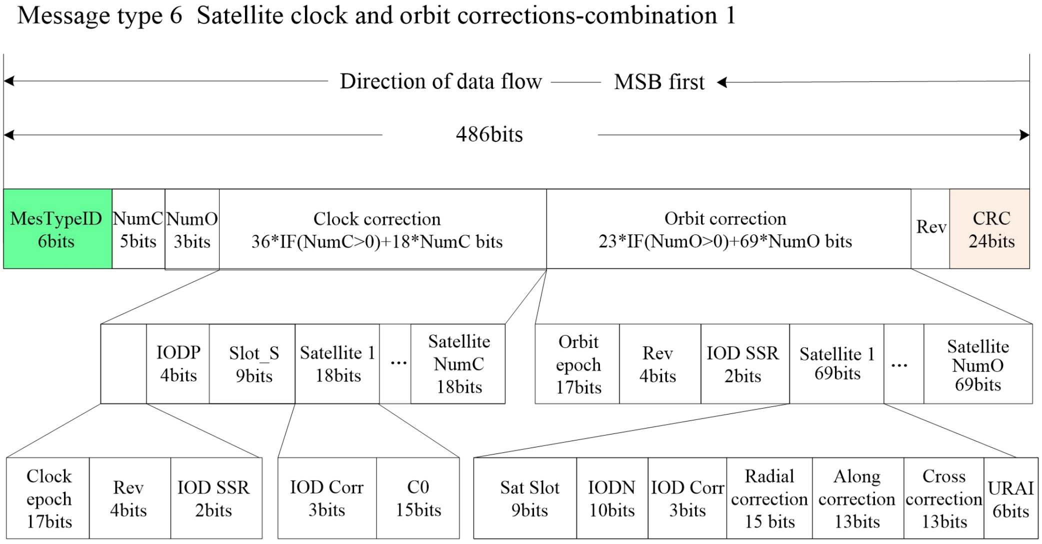

Figure 6-8 Bit allocation of message type 6

### 6.2.7.2 Content Description

The parameters of message type 6 are described in Table 6-10.

Table 6-10 Parameters of message type 6

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
| MesTypeID | Message type | 6 | 1 | 0～63 | -- | See Table 6-1 |
| NumC | Number of satellites with clock corrections | 5 | 1 | 0～22 | -- | -- |
| NumO | Number of satellites with orbit corrections | 3 | 1 | 0～6 | -- | -- |
| Content of clock corrections | Epoch of clock corrections | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| | Reserved | 4 | 1 | 0～15 | -- | -- |
| | IOD SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| | IODP | 4 | 1 | 0～15 | -- | IOD of PRN mask |
| | Slot_S | 9 | 1 | 0～255 | -- | The location of the 1st |

| Field | Name | Length (bit) | Scale factor | Range | Unit | Description |
|---|---|---|---|---|---|---|
|  |  |  |  |  |  | satellite in the sequence of satellites whose masks are set to "1" |
|  | Clock corrections for satellite 1 | 18 | 1 | -- | -- | The clock correction for the 1st satellite in this type |
|  | …… | …… | …… | …… | …… | …… |
|  | Clock corrections for satellite NumC | 18 | 1 | -- | -- | The clock correction for the NumC-th satellite in this type |
| Content of orbit correction | Epoch of orbit corrections | 17 | 1 | 0～86399 | s | BDT seconds within a day |
|  | Reserved | 4 | 1 | 0～15 | -- | -- |
|  | IOD SSR | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
|  | Orbit correction for satellite 1 | 69 | 1 | -- | -- | The orbit correction for the 1st satellite in this type |
|  | …… | …… | …… | …… | …… | …… |
|  | Orbit correction for satellite NumO | 69 | 1 | -- | -- | The orbit correction for the NumO-th satellite in this type |
| …… | …… | …… | …… | …… | …… | …… |
| CRC | CRC bits | 24 | -- | -- | -- | -- |

Please refer to message type 1 for the definitions of "Epoch", "SSR update interval", "IOD SSR" and "IODP" in Table 6-10. Other parameters are described as follows.

NumC is the number of satellites corresponding to the satellite clock correction in this type, with an effective range of 0～22. NumC can be used to determine the bit length occupied by the satellite clock correction: when NumC = 0, the number of bits occupied by the clock correction is 0; when NumC > 0, the number of bits occupied by the clock correction is 36+NumC×18.

NumO is the number of satellites corresponding to the satellite orbit correction in this type, with an effective range of 0～6. NumO can be used to determine the bit length occupied by the satellite orbit correction: when NumO = 0, the number of bits occupied by the orbit correction is 0; when NumO > 0, the number of bits occupied by the orbit correction is 23+ NumO×69.

Slot_S indicates the slot location of the first satellite with clock corrections in this type in the sequence of all satellites whose masks are set to "1". The satellites with clock corrections broadcast in message type 6 are the satellites numbered from Slot_S to Slot_S+NumC-1 in the sequence of all satellites whose masks are set to "1". For example, assuming there are 48 satellites whose masks are set to "1", the clock corrections of the 1$^{st}$ to the 46th satellites will be broadcast in message type 4, and the 47$^{th}$ and 48$^{th}$ satellites will be broadcast in message type 6. Then the Slot_S in the message type 6 should be 47, and the NumC should be 2.

The 18 bits clock correction of each satellite includes 3 bits IOD Corr and 15 bits C0; please refer to message type 4 for details. For the format and the definition of 69 bits orbit correction parameters of each satellite, see the contents of message type 2.

### 6.2.8 Message Type 7 (Clock Correction and Orbit Correction - combination 2)

#### 6.2.8.1 Message Layout

Message type 7 is used to broadcast the clock correction and orbit correction in combination. It differs from message type 6 in that the correspondence between the satellite clock correction and the satellite is through Sat Slot instead of mask.

The message format of Message type 7 is shown in Figure 6-9.

Message type 7 Satellite clock and orbit corrections-combination 2

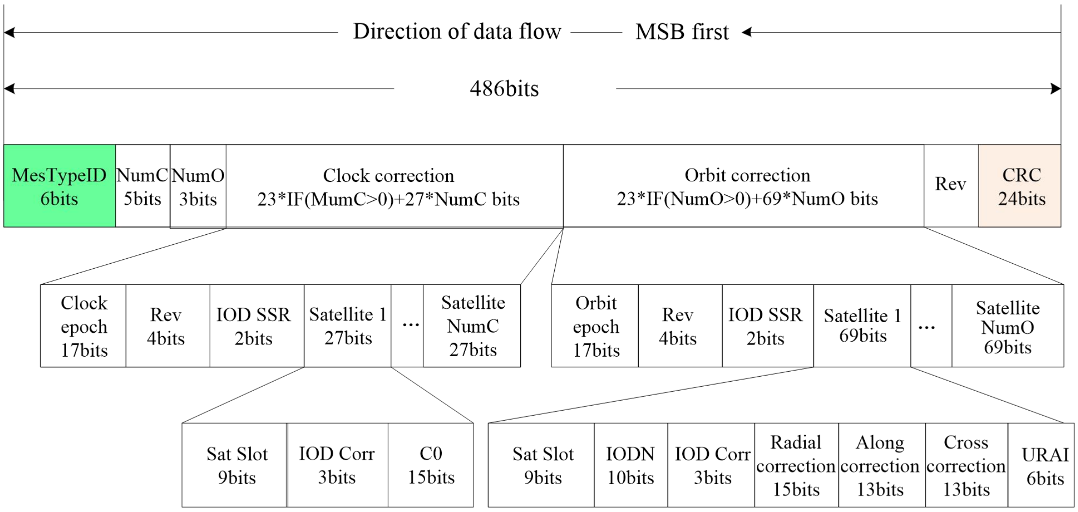

Figure 6-9 Bit allocation of message type 7

### 6.2.8.2 Content Description

The parameters of message type 7 are described in Table 6-11.

Table 6-11 Parameters of message type 7

| **Field** | **Name** | | **Length (bit)** | **Scale factor** | **Range** | **Unit** | **Description** |
|---|---|---|---|---|---|---|---|
| MesTypeID | Message type | | 6 | 1 | 0～63 | -- | See Table 6-1 |
| NumC | Number of satellites of clock correction | | 5 | 1 | 0～15 | -- | -- |
| NumO | Number of satellites of orbit correction | | 3 | 1 | 0～6 | -- | -- |
| Content of clock correction | Epoch of clock correction | | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| | Reserved | | 4 | 1 | 0～15 | -- | -- |
| | IOD SSR | | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| | The clock correction of satellite 1 | Sat Slot | 9 | 1 | -- | -- | The clock correction of the 1st satellite in this type |
| | | IOD Corr | 3 | | | | |
| | | C$_0$ | 15 | | | | |
| | …… | | …… | …… | …… | …… | …… |
| | The clock correction of satellite NumC | | 27 | 1 | -- | -- | The clock correction of the NumC-th satellite in this type |
| Content of orbit correction | Epoch of orbit correction | | 17 | 1 | 0～86399 | s | BDT seconds within a day |
| | Reserved | | 4 | 1 | 0～15 | -- | -- |
| | IOD SSR | | 2 | 1 | 0～3 | -- | Change as the system configuration changes. |
| | Orbit correction of satellite 1 | | 69 | 1 | -- | -- | The orbit correction of the 1st satellite in this type |
| | …… | | …… | …… | …… | …… | …… |
| | Orbit correction of satellite NumO | | 69 | 1 | -- | -- | The orbit correction of the NumO-th satellite in this type |
| …… | …… | | …… | …… | …… | …… | …… |
| CRC | CRC bits | | 24 | -- | -- | -- | -- |

Please refer to message type 1 for the definitions of "Epoch ", "SSR update interval", "IOD SSR" and "IODP" in Table 6-11. Other parameters are described as follows.

NumC is the number of satellites corresponding to the satellite clock correction in this type. NumC can be used to determine the bit length occupied by the satellite clock correction: when NumC = 0, the number of bits occupied by the clock correction is 0; when NumC > 0, the number of bits occupied by the clock correction is 23+NumC×27.

NumO is the number of satellites corresponding to the satellite orbit correction in this type, with an effective range of 0～6. NumO can be used to determine the bit length occupied by the satellite orbit correction: when NumO = 0, the number of bits occupied by the orbit correction is 0; when NumO > 0, the number of bits occupied by the orbit correction is 23+ NumO×69.

The 27 bits clock correction of each satellite includes 9 bits Sat Slot, 3 bits IOD Corr and 15 bits C0. Sat Slot indicates the position of the satellite in the mask. IOD Corr and C0 are referred to message type 4. For the format and definition of the 69 bits orbit correction parameters of each satellite, see the contents of message type 2.

### 6.2.9 Message Types 63

Message type 63 is null message. When broadcast information is unavailable, it is used for blank filling.

## 6.3 Information Validity

The nominal validities of various kinds of information in the PPP-B2b_I are listed in Table 6-12.

Table 6-12 Nominal validity

| Information content | Message type | Nominal validity(s)[*] |
|---|---|---|
| Satellite mask | 1 | -- |
| Orbit correction | 2,6,7 | 96 |
| Differential code bias | 3 | 86400 |
| Clock correction | 4,6,7 | 12 |
| User range accuracy index | 2,5,6,7 | 96 |
| *Note: " Nominal validity " gives the time range suggestion, the messages which out of the range cannot ensure the data quality. | | |

# 7 User Algorithms

## 7.1 The Target Systems for the PPP-B2b Service

The PPP-B2b signal is designed to provide PPP service for GNSS and their combinations. For each satellite navigation system, the reference broadcast navigation messages corresponding to various corrections are:

1) BDS: PPP-B2b information is used to correct the CNAV1 navigation messages of B1C signal.

2) GPS: PPP-B2b information is used to correct the LNAV navigation messages.

3) Galileo: PPP-B2b information is used to correct the I/NAV navigation messages.

4) GLONASS: PPP-B2b information is used to correct the L1OCd navigation messages.

## 7.2 Time and Space Coordinate System

The PPP-B2b signal and PPP services information use BDT, and the coordinate system is BDCS. See Chapter 3 for details.

## 7.3 Differential Code Bias Correction

Due to different satellite tracking modes, each observed value has an offset related to the signal tracking mode. During the synchronous processing of signals at different frequencies, the first step is to eliminate such DCB correction to realize the synchronous processing. The correction algorithm formula is shown in (7-1):

$$\tilde{l}_{sig} = l_{sig} - DCB_{sig} \tag{7-1}$$

Where:

$\tilde{l}_{sig}$ —— The observed value of $sig$ signal after correction;

$l_{sig}$ —— The observed value of $sig$ signal directly captured by signal receiver;

$DCB_{sig}$ —— The differential code bias corresponding to the signal。

For example:

If the range signal are B1Cp and B2ap at the user end for BDS, the differential code bias of the B1Cp signal broadcast in PPP-B2b message is $DCB_{B1Cp}$, and the differential code bias of B2ap signal is $DCB_{B2ap}$, the corresponding differential code bias correction are as follows:

$$\tilde{l}_{B1Cp} = l_{B1Cp} - DCB_{B1Cp} \tag{7-2}$$

$$\tilde{l}_{B2ap} = l_{B2ap} - DCB_{B2ap} \tag{7-3}$$

The observed values of dual-frequency ionosphere-free combination are:

$$\tilde{l}_{IF} = \frac{\gamma \tilde{l}_{B1Cp} - \tilde{l}_{B2ap}}{\gamma - 1} = \frac{\gamma l_{B1Cp} - l_{B2ap}}{\gamma - 1} - \frac{\gamma DCB_{B1Cp} - DCB_{B2ap}}{\gamma - 1} \tag{7-4}$$

Where $\gamma = \frac{f_{B1Cp}^2}{f_{B2ap}^2}$; $f_{B1Cp}$ is the center frequency of B1Cp carrier; and $f_{B2ap}$ is the center frequency of B2ap carrier.

## 7.4 Orbit Correction

The parameters included in the orbit correction information are the components of the orbit correction vector $\delta O$ in radial, along, and cross directions. The orbit correction value is used to calculate the satellite position correction vector $\delta X$ and in combination with the satellite position vector $X_{broadcast}$ calculated by broadcast ephemeris. The corrected calculation formula is as follows:

$$X_{orbit} = X_{broadcast} - \delta X \tag{7-5}$$

Where:

$X_{orbit}$ —— The satellite position corrected by the orbit correction message;

$X_{broadcast}$ —— The satellite position calculated by the broadcast ephemeris, its IOD matches with the IODN of the orbit correction message;

$\delta X$ —— The satellite position correction.

The satellite position correction $\delta X$ is calculated with formulas （7-6）～(7-9):

$$e_{radial} = \frac{r}{|r|} \tag{7-6}$$

$$e_{cross} = \frac{r \times \dot{r}}{|r \times \dot{r}|} \tag{7-7}$$

$$e_{along} = e_{cross} \times e_{radial} \tag{7-8}$$

$$\delta X = \begin{bmatrix} e_{radial} & e_{along} & e_{cross} \end{bmatrix} \delta O \tag{7-9}$$

Where :

$r = X_{broadcast}$ —— The satellite position vector of broadcast ephemeris;

$\dot{r} = \dot{X}_{broadcast}$ —— The satellite velocity vector of broadcast ephemeris;

$e_i$ —— Direction unit vector, $i = \{radial, along, cross\}$ corresponds to the radial, along and cross directions respectively;

$\delta O$ —— The orbit correction vector obtained from PPP information in order of radial, along and cross components.

## 7.5 Clock Correction

The parameter included in the clock correction message is the correction parameter relative to the clock offset of the broadcast ephemeris. See formula (7-10) for how to use this correction parameter:

$$t_{satellite} = t_{broadcast} - \frac{C_0}{c} \tag{7-10}$$

Where:

$t_{broadcast}$ —— The satellite clock offset parameters calculated from the broadcast ephemeris;

$t_{satellite}$ ——The satellite clock offset parameters corrected by the clock correction message;

$c$ —— Velocity of light;

$C_0$ ——The clock correction parameters obtained from PPP-B2b message.

## 7.6 User Range Accuracy Index (URAI)

The parameter URAI of each satellite is 6 bits. The highest 3 bits are defined as user range accuracy class ($\mathrm{URA}_{\mathrm{CLASS}}$), and the lowest 3 bits are defined as user range accuracy value ($\mathrm{URA}_{\mathrm{VALUE}}$). The calculation formula of URA is:

$$\mathrm{URA}[\mathrm{mm}] \le 3^{\mathrm{URA}_{\mathrm{CLASS}}}\left(1+0.25*\mathrm{URA}_{\mathrm{VALUE}}\right)-1 \tag{7-11}$$

Where: URA is the user range accuracy in mm (millimeter);

When URAI =000000 (binary), it means URA is undefined or unknown, and the SSR correction of the corresponding satellite is not reliable.

When URAI = 111111 (binary), it means that URA > 5466.5 mm.

## 7.7 System Time Solution

All of the correction parameters broadcast by PPP-B2b signal use BDT as their time reference. When users use multiple navigation systems to perform precise positioning resolution, it is necessary to set different receiver clock offset parameters for different navigation systems at each epoch.

# 8 Abbreviations

| | |
|---|---|
| BDCS | BeiDou Coordinate System |
| BDS | BeiDou Navigation Satellite System |
| BDT | BeiDou Navigation Satellite System Time |
| bps | bits per second |
| BPSK | Binary Phase Shift Keying |
| CGCS2000 | China Geodetic Coordinate System 2000 |
| CRC | Cyclic Redundancy Check |
| GEO | Geostationary Earth Orbit |
| GLONASS | Global Navigation Satellite System |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| ICD | Interface Control Document |
| IERS | International Earth Rotation and Reference Systems Service |
| IGSO | Inclined Geo-Synchronous Orbit |
| IOD | Issue of Data |
| IODC | Issue of Data, Clock |
| IODN | Issue of Data, Navigation |
| IODP | Issue of Data, PRN mask |
| IOD SSR | Issue of Data, SSR |
| IRM | IERS Reference Meridian |
| IRP | IERS Reference Pole |
| LDPC | Low Density Parity Check |
| MEO | Medium Earth Orbit |
| NTSC | National Time Service Center |
| OS | Open Service |
| PPP | Precise Point Positioning |

| | |
|---|---|
| PRN | Pseudo-Random Noise |
| RHCP | Right-Hand Circular Polarization |
| RMS | Root Mean Square |
| sps | symbols per second |
| SSR | State Space Representation |
| URA | User Range Accuracy |
| URAI | User Range Accuracy Index |
| UTC | Universal Time Coordinated |
| WN | Week Number |

# Annex Non-binary LDPC Encoding and Decoding Methods

## 1. Non-binary LDPC Encoding

The generator matrix **G** is obtained from the parity-check matrix $\mathbf{H} = [\mathbf{H}_1, \mathbf{H}_2]$ of the non-binary LDPC（$n$,$k$） code. And then, the codeword **c** of length $n$ can be generated by encoding the input information sequence **m** of length $k$ with the generator matrix **G**, i.e., $\mathbf{c} = (\mathbf{c}_0, \mathbf{c}_1, \ldots, \mathbf{c}_{n-1}) = \mathbf{m} \cdot \mathbf{G} = [\mathbf{m}, \mathbf{p}]$ , where, $\mathbf{c}_j \ (0 \le j < n)$ is the $j^{th}$ codeword symbol, and $\mathbf{p} = \mathbf{m} \cdot (\mathbf{H}_2^{-1} \cdot \mathbf{H}_1)^{\mathrm{T}}$ is the check sequence.

The method for generating the generator matrix **G** is given as follows:

Step 1: The matrix **H** of size (n-k) × n is expressed as: $\mathbf{H} = [\mathbf{H}_1, \mathbf{H}_2]$, where the size of $\mathbf{H}_1$ is (n-k) × k, and the size of $\mathbf{H}_2$ is (n-k) × (n-k).

Step 2: Convert the matrix **H** into the systematic form, i.e., multiply **H** with $\mathbf{H}_2^{-1}$ from the left to generate a parity-check matrix $\hat{\mathbf{H}} = [\mathbf{H}_2^{-1} \cdot \mathbf{H}_1, \mathbf{I}_{n-k}]$, where $\mathbf{I}_{n-k}$ is a unit matrix of size (n-k) × (n-k).

Step 3: The generator matrix is computed as $\mathbf{G} = [\mathbf{I}_k, (\mathbf{H}_2^{-1} \cdot \mathbf{H}_1)^{\mathrm{T}}]$, where $\mathbf{I}_k$ is a unit matrix of size k×k.

### (1) Encoding Example

The B-CNAV3 message data are encoded by one 64-ary LDPC(162, 81) code. Assume that the input information is

[001010 110010 010011 100001 001010 100110 010000 101001 101100 101111 011100 000101 001110 111010 001001 110100 100010 111111 000101 011100 000110 111101 000000 110001 110100 110111 000101 011001 010000 110011 011011 111010 001011 010000 001001 001000 110111 100101 100011 001001 110110 100111 010110 100000 011001 000100 001111 000111 001011 001111 011010 000011 111001 111100 011111 011111 010101 111001 010111 000111 110001 011000 001111 011001 000110 001000 111100 111101 100100 000011 001111 010110 110100 000000 000010 001010 101001 101110 101001 011100 100011];

The corresponding 64-ary information is

[10 50 19 33 10 38 16 41 44 47 28 5 14 58 9 52 34 63 5 28 6 61
0 49 52 55 5 25 16 51 27 58 11 16 9 8 55 37 35 9 54 39 22

32 25 4 15 7 11 15 26 3 57 60 31 31 21 57 23 7 49 24 15 25
6 8 60 61 36 3 15 22 52 0 2 10 41 46 41 28 35];

After encoding, the output codeword is

[001010 110010 010011 100001 001010 100110 010000 101001 101100 101111 011100
000101 001110 111010 001001 110100 100010 111111 000101 011100 000110 111101
000000 110001 110100 110111 000101 011001 010000 110011 011011 111010 001011
010000 001001 001000 110111 100101 100011 001001 110110 100111 010110 100000
011001 000100 001111 000111 001011 001111 011010 000011 111001 111100 011111
011111 010101 111001 010111 000111 110001 011000 001111 011001 000110 001000
111100 111101 100100 000011 001111 010110 110100 000000 000010 001010 101001
101110 101001 011100 100011 100100 101110 111001 000000 110111 000001 010110
101101 110010 001001 011011 001001 011010 000011 001011 101001 010101 011111
001101 101011 011110 001101 111101 011111 010100 001000 000110 100100 000011
101101 001100 111001 111011 010111 001010 101011 101101 111111 000001 111100
001111 101111 001010 000110 101000 111000 011000 000010 010011 010011 101110
101011 010011 111101 011010 000001 000111 111101 001011 110111 110000 101011
110001 101100 110010 011011 011111 011011 001100 111100 110011 111010 001111
000110 011101 111101 100111 100110 000101 110101 100010];

The corresponding 64-ary codeword is

[10 50 19 33 10 38 16 41 44 47 28 5 14 58 9 52 34 63 5 28 6 61
0 49 52 55 5 25 16 51 27 58 11 16 9 8 55 37 35 9 54 39 22
32 25 4 15 7 11 15 26 3 57 60 31 31 21 57 23 7 49 24 15 25
6 8 60 61 36 3 15 22 52 0 2 10 41 46 41 28 35 36 46 57 0
55 1 22 45 50 9 27 9 26 3 11 41 21 31 13 43 30 13 61 31 20
8 6 36 3 45 12 57 59 23 10 43 45 63 1 60 15 47 10 6 40 56
24 2 19 19 46 43 19 61 26 1 7 61 11 55 48 43 49 44 50 27 31
27 12 60 51 58 15 6 29 61 39 38 5 53 34];

**(2) Mapping Relationship**

After 64-ary LDPC encoding, each codeword symbol is composed of 6 bits, which is defined over GF($2^6$) domain with the primitive polynomial of $p(x)=1+x+x^6$. Each element in Galois field can be described by the vector representation and power representation.

The mapping from the vector representation of 64 field elements to the power representation is shown as follows:

[∞ 0 1 6 2 12 7 26 3 32 13 35 8 48 27 18
4 24 33 16 14 52 36 54 9 45 49 38 28 41 19 56
5 62 25 11 34 31 17 47 15 23 53 51 37 44 55 40
10 61 46 30 50 22 39 43 29 60 42 21 20 59 57 58]

The mapping from the power representation of 63 non-zero elements to the vector representation is shown as follows:

[1 2 4 8 16 32 3 6 12 24 48 35 5 10 20 40
19 38 15 30 60 59 53 41 17 34 7 14 28 56 51 37
9 18 36 11 22 44 27 54 47 29 58 55 45 25 50 39
13 26 52 43 21 42 23 46 31 62 63 61 57 49 33] .

## 2. Non-binary LDPC Decoding

One codeword $\mathbf{c} = (\mathbf{c}_0, \mathbf{c}_1, \ldots, \mathbf{c}_{n-1})$ generated by the non-binary LDPC（$n,k$）encoding is transmitted over a channel with the modulation. On the receiving side, the corresponding sequence $\mathbf{y} = (\mathbf{y}_0, \mathbf{y}_1, \ldots, \mathbf{y}_{n-1})$ is received, where $\mathbf{y}_j = (y_{j,0}, y_{j,1}, \ldots, y_{j,r-1})$ is the received information corresponding to the $j^{th}$ codeword symbol $\mathbf{c}_j$ ( $\mathbf{c}_j \in \mathrm{GF}(q), q = 2^r$ , $0 \le j < n$ ).

The parity-check matrix $\mathbf{H}$ of the non-binary LDPC code can be used to check the correctness of the received sequence **y**. The specific method is described as follows:

A hard decision codeword $\hat{\mathbf{c}} = (\hat{\mathbf{c}}_0, \hat{\mathbf{c}}_1, \ldots, \hat{\mathbf{c}}_{n-1})$ is obtained by making hard decision on the received sequence **y** bit by bit. The check sum is calculated as $\mathbf{s} = \hat{\mathbf{c}}\mathbf{H}^{\mathrm{T}}$ . If $\mathbf{s} = \mathbf{0}$ , $\hat{\mathbf{c}}$ is output as the correct decoding, otherwise $\hat{\mathbf{c}}$ is erroneous.

The parity-check matrix $\mathbf{H}$ describes the connection relationship of the check node CN and the variable node VN, i.e., the reliability information can be transmitted between the connected CN and VN. For the parity-check matrix $\mathbf{H}$ of size $m \times n$ , each element $h_{i,j} \in \mathrm{GF}(q)$ is an element in $\mathrm{GF}(q)$ , while each row corresponds to a check node CN and each column corresponds to a variable node VN.

Two index sets are given as follows:

$$M_j = \{i : 0 \le i < m, h_{i,j} \ne 0\}, 0 \le j < n$$

$$N_i = \{j : 0 \le j < n, h_{i,j} \ne 0\}, 0 \le i < m$$

If $h_{i,j} \neq 0$, the check node $\mathrm{CN}_i$ is connected to the variable node $\mathrm{VN}_j$. The reliability vector transmitted from the variable node $\mathrm{VN}_j$ to the connected check node $\mathrm{CN}_i$ ( $i \in M_j$ ) is denoted as $\mathrm{V2C}_{j\to i}$, and can be used to calculate the check sum of $\mathrm{CN}_i$. The reliability vector transmitted from the check node $\mathrm{CN}_i$ to the connected variable node $\mathrm{VN}_j$ ( $j \in N_i$ ) is denoted as $\mathrm{C2V}_{i\to j}$, and can be used to estimate the symbol value of $\mathrm{VN}_j$. $\mathrm{V2C}_{j\to i}$ and $\mathrm{C2V}_{i\to j}$ are iteratively updated by using the reliability transmitting decoding algorithm to correct the received sequence $\mathbf{y}$, and then the codeword c is correctly estimated.

Two iterative reliability transmitting decoding algorithms used to estimate the codeword c are listed in the following contents.

**(1) Extended Min-Sum Method**

Set the mean noise value of the additive white Gaussian noise channel as zero and the variance as $\sigma^2$. The reliability vector $\mathbf{L_j}$ is calculated according to the received symbol vector $\mathbf{y_j}$ corresponding to each codeword symbol $\mathbf{c_j}$. The reliability vector $\mathbf{L_j}$ consists of all *q* Galois field elements $x \in \mathrm{GF}(q)$ and their logarithmic likelihood ratio (LLR) values $\mathrm{LLR}(x)$, where the $l^{th}$ ( $0 \le l < q$ ) element of $\mathbf{L_j}$ consists of the $l^{th}$ Galois field symbol *x* and its LLR value. The logarithmic likelihood ratio of the Galois field element *x* in the reliability vector $\mathbf{L_j}$ is

$$\mathrm{LLR}(x) = \log\left(\frac{P(\mathbf{y_j} \mid \hat{x})}{P(\mathbf{y_j} \mid x)}\right) = \frac{2\sum_{b=0}^{r-1} |y_{j,b}| \Delta_{j,b}}{\sigma^2}$$

where $\hat{x}$ is the element in $\mathrm{GF}(q)$ which maximizes the probability $P(\mathbf{y_j} \mid x)$, i.e., the hard decision symbol of $\mathbf{y_j}$. The bit sequences of the Galois field elements $x$ and $\hat{x}$ are $x = (x_0, x_1, ...., x_{r-1})$ and $\hat{x} = (\hat{x}_0, \hat{x}_1, ...., \hat{x}_{r-1})$, respectively. $\Delta_{j,b} = x_b \ \mathrm{XOR}\ \hat{x}_b$, where XOR is exclusive-OR operation, that is, if $x_b$ and $\hat{x}_b$ are the same, $\Delta_{j,b} = 0$, otherwise, $\Delta_{j,b} = 1$.

In the extended Min-Sum decoding algorithm, the length of each reliability vector $\mathbf{L_j}$ is reduced from *q* to $n_m$ $(n_m \ll q)$, i.e., truncating the $n_m$ most reliable field elements (i.e., the smallest LLR values) from the reliability vector. The extended Min-Sum decoding algorithm is shown as follows:

**Initialization:** Set the maximum number of iterations as $\mathrm{itr}_{\max}$ and the current iteration number itr as zero. The reliability vector $\mathbf{L_j}$ ( $0 \le j < n$ ) is calculated from the received vector $\mathbf{y_j}$. Initialize all $\mathrm{V2C}_{j\to i}$ vectors of each variable node $\mathrm{VN}_j$ with $\mathbf{L_j}$.

Step 1: For each variable node $\mathrm{VN}_j$ ( $0 \le j < n$ ), the decision symbol $\hat{\mathbf{c}}_\mathbf{j}$ and the reliability vector $\mathrm{V2C}_{j\to i}$ are calculated according to the variable node updating rule.

Step 2: Calculate the check sum $\mathbf{s} = \hat{\mathbf{c}}\mathbf{H}^{\mathrm{T}}$. If $\mathbf{s} = \mathbf{0}$, output the decision sequence $\hat{\mathbf{c}}$ as decoding result and exit the decoding, otherwise, go into Step 3.

Step 3: For each check node $\mathrm{CN}_i$ ( $0 \le i < m$ ), the reliability vector $\mathrm{C2V}_{i\to j}$ is calculated according to the check node updating rule.

Step 4: Let itr=itr+1. If $\mathrm{itr} = \mathrm{itr}_{\max}$, exit decoding and declare a decoding failure, otherwise, go into Step 1.

**1) Updating Rules of Variable Nodes**

If the current iteration number itr=0, the reliability vector $\mathbf{L_j}$ of each codeword symbol is arranged in ascending order according to its LLR values of the $q$ field elements. The first $n_m$ elements in the sorted $\mathbf{L_j}$ constitute the truncated reliability vector $\mathbf{L_{j,n_m}} = (\mathbf{x_{n_m}}, \mathrm{LLR}(\mathbf{x_{n_m}}))$. Initialize $\mathrm{V2C}_{j\to i}$ as $\mathbf{L'_{j,n_m}}$:

$$\mathrm{V2C}_{j\to i} = \mathbf{L'_{j,n_m}} = \mathbf{L_{j,n_m}} \,.\, h_{i,j} = (\mathbf{x_{n_m}} \,.\, h_{i,j}, \mathrm{LLR}(\mathbf{x_{n_m}}))$$

where $\mathbf{x_{n_m}}$ is the vector containing the $n_m$ truncated Galois field elements, and $\mathbf{x_{n_m}} \,.\, h_{i,j}$ is the Galois field multiplication of $h_{i,j}$ and $n_m$ Galois field elements in $\mathbf{x_{n_m}}$.

If the current iteration number $\mathrm{itr} \ne 0$, it is assumed that $\mathrm{C2V}_{f\to j}$ is the reliability vector of length $n_m$ which is transmitted from the check node $\mathrm{CN}_f$ to the connecting variable node $\mathrm{VN}_j$ and then the reliability vector $\mathrm{V2C}_{j\to i}$ can be calculated by using all the received reliability vectors, $\mathrm{C2V}_{f\to j}(f \in M_j, f \ne i)$, as follows:

$$\mathrm{V2C}_{j\to i} = h_{i,j} \,.\, \Big( \sum_{f\in M_j, f\ne i} \mathrm{C2V}_{f\to j} \,.\, h_{f,j}^{-1} + \mathbf{L_j} \Big)_{n_m} = (\mathbf{Rs}_{j\to i}, \mathbf{R}_{j\to i})$$

where the Galois field element $h_{f,j}^{-1}$ is the inverse element of $h_{f,j}$, i.e., $h_{f,j}^{-1}.h_{f,j} = 1$. In the above equation, the sum operation adds the LLR values of the same elements in each reliability vector $\mathrm{C2V}_{f\to j}.h_{f,j}^{-1}$. $(\bullet)_{n_m}$ operation indicates that the field elements in the reliability vector are sorted by ascending order and then the first $n_m$ different Galois field elements are truncated. $\mathbf{Rs}_{j\to i}$ is a vector consisting of the first $n_m$ Galois field elements, and $\mathbf{R}_{j\to i}$ is a vector consisting of the corresponding LLR values. The LLR of the $q - n_m$ Galois field elements discarded from the reliability vector $\mathrm{C2V}_{f\to j}$ is set as the sum of the maximum LLR value in $\mathrm{C2V}_{f\to j}$ and a fixed offset. After each reliability vector $\mathrm{V2C}_{j\to i}$ is calculated, the LLR value of each element in the reliability vector subtracts $\mathrm{LLR}_{\min}$ which is the minimum LLR value in this reliability vector.

In addition, a decision should be made on each variable node in each iteration. The Galois field element corresponding to $\mathrm{LLR}_{\min}$ in the reliability vector $\{\sum_{f\in M_j}\mathrm{C2V}_{f\to j}\cdot h_{f,j}^{-1}+\mathbf{L_j}\}$ of length $q$ is selected as a decision value. The related decision formula is

$$\hat{\mathbf{c}}_{\mathbf{j}}=\arg\min_{x\in\mathrm{GF}(q)}\{\sum_{f\in M_j}\mathrm{C2V}_{f\to j}\cdot h_{f,j}^{-1}+\mathbf{L_j}\},0\le j<n$$

The decision symbol $\hat{\mathbf{c}}_{\mathbf{j}}$ is transmitted together with the reliability vector $\mathrm{V2C}_{j\to i}$ to the corresponding check node. It is checked whether the current iteration decoding vector $\hat{\mathbf{c}}=(\hat{\mathbf{c}}_{\mathbf{0}},\hat{\mathbf{c}}_{\mathbf{1}},\ldots,\hat{\mathbf{c}}_{\mathbf{n-1}})$ satisfies that $\mathbf{s}=\hat{\mathbf{c}}\mathbf{H}^{\mathrm{T}}$ is a zero vector.

**2) Updating Rules of Check Nodes**

For each check node $\mathrm{CN}_i$ ($0\le i<m$), all reliability vectors $\mathrm{V2C}_{j\to i}$ from the connected variable nodes are received. The reliability vector $\mathrm{C2V}_{i\to j}$ is calculated by

$$\mathrm{C2V}_{i\to j}=\sum_{\gamma\in N_i,\gamma\ne j}\mathrm{V2C}_{\gamma\to i}$$

where, each sum operation is defined as the basic calculation of the check node; when two reliability vectors containing $n_m$ Galois field elements and their LLR vectors are inputted, the candidate elements are obtained by the sum of the Galois field elements of different reliability vectors, and their LLR values are calculated at the same time. The LLR values of the candidate elements are sorted by ascending order and then the first $n_m$ LLR values are truncated. The output reliability vector consists of the $n_m$ LLR values and their Galois field elements.

The two input reliability vectors of the check nodes is given as $(\mathbf{U_s},\mathbf{U})$ and $(\mathbf{Q_s},\mathbf{Q})$, and the output reliability vector is given as $(\mathbf{V_s},\mathbf{V})$, where $\mathbf{U}$, $\mathbf{Q}$, $\mathbf{V}$ are the LLR vectors of length $n_m$ arranged in ascending order, and $\mathbf{U_s}$, $\mathbf{Q_s}$, $\mathbf{V_s}$ are the corresponding Galois field element vectors. According to the input reliability vectors, the reliability matrix $\mathbf{M}$ of size $n_m\times n_m$ and the Galois field element matrix $\mathbf{M_s}$ are constructed as follows:

$$M_s[d,\rho]=U_s[d]\oplus Q_s[\rho]$$

$$M[d,\rho]=U[d]+Q[\rho]$$

where, $d,\rho \in \{0,1,...,n_m-1\}$ and $\oplus$ is the Galois field addition operation.

The basic formula for the check node is

$$V[\varepsilon] = \min_{d,\rho\in[0,1,...,n_m-1]} \{M[d,\rho]\}_{V_s[\varepsilon]=M_s[d,\rho]}, 0 \le \varepsilon < n_m$$

The implementation of the above equations can be completed by operating the register **S** of size $n_m$ as follows:

**Initialize:** Store the first column of **M** into **S**, and let $S[\zeta]=M[\zeta,0]$, $\zeta \in \{0,1,...,n_m-1\}$. Let $\varepsilon = 0$.

**Step 1:** Find the minimum value in **S**. (Suppose $M[d,\rho]$ is the smallest value of the corresponding **S**.)

**Step 2:** If the Galois field element corresponding to the found minimum value does not exist in **V**s, $V[\varepsilon]$ is filled with the minimum value in **S**, and $V_s[\varepsilon]$ is filled with the corresponding Galois field element, and $\varepsilon = \varepsilon + 1$. Otherwise, no action.

**Step 3:** Replace the minimum value in **S** by $M[d,\rho+1]$, i.e., the element on the right of the corresponding element in **M**.

**Step 4:** Go to Step 1 until $\varepsilon = n_m$.

**(2) Fixed Path Decoding Method**

The fixed path decoding method is an efficient decoding algorithm, and its algorithm procedure is consistent with that of the extended Min-Sum method, except that the check node updating rules are different. Take check nodes with row weight $d_c$=4 (i.e., each check node receives four input reliability vectors) as an example, the check node updating rules of the fixed path decoding method are described as follows:

For each check node $\mathrm{CN}_i$ ( $0 \le i < m$ ), the fixed path deviation value vector $\mathbf{E_i} = (\mathbf{Rs_i}, \mathbf{R_i})$ of length 8+2 $n_m$ is calculated by using four received reliability vectors $\mathrm{V2C}_{j\to i} = (\mathbf{Rs}_{j\to i}, \mathbf{R}_{j\to i})$ ( $j \in N_i$ ) transmitted from the connected variable nodes, where $\mathbf{Rs_i}$ is the Galois field element vector of length 8+2 $n_m$ (the vector may contain the same Galois field elements), and $\mathbf{R_i}$ is the corresponding LLR vector.

In order to compute each fixed path deviation value, the four reliability vectors $\mathrm{V2C}_{j\to i}$ are sorted in ascending order according to the LLR values $R_{j\to i}[1]$ of the second elements $\mathrm{V2C}_{j\to i}[1] = (Rs_{j\to i}[1], R_{j\to i}[1])$ (i.e., its subscript is “1”) of $\mathrm{V2C}_{j\to i}$. The four sorted vectors are defined as $\left(\mathbf{Rs_{l,i}},\mathbf{R_{l,i}}\right)$, $0 \le l < 4$, i.e., $R_{0,i}[1] \le R_{1,i}[1] \le R_{2,i}[1] \le R_{3,i}[1]$, where $\mathbf{Rs_{l,i}}$ is the Galois field element vector of length $n_m$, and $\mathbf{R_{l,i}}$ is the corresponding LLR vector. Then, the fixed path deviation value vector $\mathbf{E_i} = (\mathbf{Rs_i},\mathbf{R_i})$ is computed according to $\mathbf{Rs_{l,i}}$ and $\mathbf{R_{l,i}}$ which are calculated by the equations as follows:

$$Rs_i[e] = \begin{cases} \sum\limits_{0\le l<4} Rs_{l,i}[0], & e = 0 \\ Rs_{e-1,i}[1] \oplus \sum\limits_{0\le l<4, l\ne e-1} Rs_{l,i}[0], & 1 \le e \le 4 \\ Rs_{0,i}[1] \oplus Rs_{e-4,i}[1] \oplus \sum\limits_{1\le l<4, l\ne e-4} Rs_{l,i}[0], & 5 \le e \le 7 \\ Rs_{0,i}[0] \oplus Rs_{1,i}[1] \oplus Rs_{2,i}[1] \oplus Rs_{3,i}[0], & e = 8 \\ Rs_{0,i}[0] \oplus Rs_{1,i}[1] \oplus Rs_{2,i}[0] \oplus Rs_{3,i}[1], & e = 9 \\ Rs_{e-10,i}[2] \oplus \sum\limits_{0\le l<4, l\ne e-10} Rs_{l,i}[0], & 10 \le e < 14 \\ Rs_{\theta,i}[e-11] \oplus \sum\limits_{0\le l<4, l\ne \theta} Rs_{l,i}[0], & 14 \le e < 11+n_m \\ Rs_{\beta,i}[e-8-n_m] \oplus \sum\limits_{0\le l<4, l\ne \beta} Rs_{l,i}[0], & 11+n_m \le e < 8+2n_m \end{cases}$$

$$R_i[e] = \begin{cases} 0, & e = 0 \\ R_{e-1,i}[1], & 1 \le e \le 4 \\ R_{0,i}[1] + R_{e-4,i}[1], & 5 \le e \le 7 \\ R_{1,i}[1] + R_{e-6,i}[1], & 8 \le e \le 9 \\ R_{e-10,i}[2], & 10 \le e < 14 \\ R_{\theta,i}[e-11], & 14 \le e < 11+n_m \\ R_{\beta,i}[e-8-n_m], & 11+n_m \le e < 8+2n_m \end{cases}$$

Where, $\theta$ and $\beta$ represent the subscripts *l* of the vector $\mathbf{R_{l,i}}$ whose ( $\lfloor n_m/2 \rfloor + 1$ )$^{th}$ LLR values (i.e., its subscript is $\lfloor n_m/2 \rfloor$ ) are the minimum and second smallest values, respectively. The sum operation and $\oplus$ in the above equation are the Galois field addition operation.

Set two flag vectors **T** and $\overline{\mathbf{T}}$ of length 8+2 $n_m$ and initialize them to all “1” vectors. The updating rules for the first $0 \le k_R < 8+2n_m$ values of the flag vectors **T** and $\overline{\mathbf{T}}$ are defined by the following equations:

$$T[k_R] = \begin{cases} 1, R_i[k_R] \le R_{\theta,i}[\lfloor n_m/2 \rfloor] \\ 0, R_i[k_R] > R_{\theta,i}[\lfloor n_m/2 \rfloor] \end{cases}$$

$$\overline{T}[k_R] = \begin{cases} 1, R_i[k_R] \le R_{\beta,i}[\lfloor n_m/2 \rfloor] \\ 0, R_i[k_R] > R_{\beta,i}[\lfloor n_m/2 \rfloor] \end{cases}$$

According to the fixed path deviation vector and the flag vectors, four output reliability vectors $(\mathbf{Us}_{\mathbf{i,l}},\mathbf{U}_{\mathbf{i,l}})$ of length $n_m$ are updated by the following equations:

$$\mathbf{Us}_{\mathbf{i,l}} = (Rs_i[w] \oplus Rs_{l,i}[0])_{n_m}$$

$$\mathbf{U}_{\mathbf{i,l}} = (R_i[w])_{n_m}$$

where, $0 \le l < 4$, and the value range of $w$ is determined by the different cases. In the case of $l = 0$, if $\theta \ne 0$, the value range of $w$ is

$$\{w \mid T[w]=1\} \cap \{\{w=0\} \cup \{1<w\le 4\} \cup \{8 \le w < 10\} \cup \{10 < w < 11+n_m\}\}$$

otherwise, the value range of $w$ is

$\{w \mid \bar{T}[w]=1\} \cap \{\{w=0\} \cup \{1<w\le 4\} \cup \{8 \le w < 10\} \cup \{10 < w < 14\} \cup \{w \ge 11+n_m\}\}$ In the case of $1 \le l < 4$, if $l = \theta$, the value range of $w$ is

$\{w \mid \bar{T}[w]=1\} \cap \{\{0 \le w \le 7\} \cup \{10 \le w < 14\} \cup \{w \ge 11+n_m\}\} \cap \{\{w \ne l+1\} \cap \{w \ne 4+l\} \cap \{w \ne 10+l\}\}$ otherwise, the value range of $w$ is

$\{w \mid T[w]=1\} \cap \{\{0 \le w \le 7\} \cup \{10 \le w < 11+n_m\}\} \cap \{\{w \ne l+1\} \cap \{w \ne 4+l\} \cap \{w \ne 10+l\}\}$ $Us_{i,l}[z]$ ($0 \le z < n_m$) corresponds to $Rs_i[w] \oplus Rs_{l,i}[0]$ calculated by the $n_m$ smallest values of $w$, which doesn't need to eliminate the same symbols of $Us_{i,l}[z]$. Meanwhile, $U_{i,l}[z]$ is the corresponding LLR value of $Us_{i,l}[z]$.

The order of the four reliability vectors $(\mathbf{Us}_{\mathbf{i,l}},\mathbf{U}_{\mathbf{i,l}})$ is aligned with the four sorted input vectors $(\mathbf{Rs}_{\mathbf{l,i}},\mathbf{R}_{\mathbf{l,i}})$. Each input vector $(\mathbf{Rs}_{\mathbf{l,i}},\mathbf{R}_{\mathbf{l,i}})$ corresponds to a $\mathrm{V2C}_{j\to i}$ vector. Each reliability vector $\mathrm{C2V}_{i\to j} = (\mathbf{Us}_{\mathbf{i,l}},\mathbf{U}_{\mathbf{i,l}})$, ($j \in N_i$) is updated and output according to the sequence order between $(\mathbf{Rs}_{\mathbf{l,i}},\mathbf{R}_{\mathbf{l,i}})$ and $\mathrm{V2C}_{j\to i}$.