

# Chapter 2

## GNSS Message Structure Optimization

Yun Zhou, Yansong Meng, Xiaoxia Tao, Lei Wang and Zhe Su

**Abstract** The structure designing of satellite clock correction, ephemeris and system time parameters in navigation message directly affects navigating performance such as the time to first fix. Considering the message reading point as a random variable and creating ephemeris acquisition time as a function of the reading time, we integrated the acquisition time of the ephemeris in GPS L2C CNAV random data block and L1C CNAV2 stationary message structure by 95 % confidence level. The designing discrepancy of the GPS, Galileo data structure which is broadcasted on different frequency and its influence to the first time to access positioning information was emphatically discussed. Finally, we presented the key factor of navigation message structure designing to reduce the time to first fix that was ephemeris being consistent during effective time interval, almanac frame proportion of the total frame size should be appropriate and message parameters should be more compact.

**Keywords** GNSS message structure · Time to first fix

### 2.1 Introduction

Time to first fix (TTFF) is an important performance evaluating navigation message structure design. Satellite clock correction, ephemeris (CED) and system time (GST) directly affect the TTFF. Specifically, the acquisition time of CED, GST is determined by the total amount of data, broadcast rate, repetition and structure. Broadcasted on GPS L2C in the form of data blocks, CNAV message's CED and

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Y. Zhou (✉) · Y. Meng · X. Tao · L. Wang · Z. Su  
Institute of Space Radio Technology, Xi'an, China  
e-mail: nikkocho@163.com

Y. Meng  
e-mail: iamyantao@126.com

**Table 2.1** Max broadcast interval of GPS L2C CNAV

Message data	Message type	Max intervals (s)
Ephemeris	10, 11	48
Clock	Type 30's	48

*The 10, 11 and 30 data block arrangement situation within 48 seconds*

**Fig. 2.1** One arrangement of GPS L2C CNAV data block

GST parameters are designed in 10, 11 and 30 types of data blocks, according to requirement to broadcast, while CNAV2 on GPS L1C frequency planning to use three unequal sub-frame to broadcast messages, and positioning information such as CED and GST being designed for two parts which one varied and the other one does not in the active interval of time. For Galileo I /NAV and F /NAV adopt the way of page to broadcast messages.

Discussing the message structure differ from GPS and Galileo and its influence to TTFF, drawing lessons from the advantages of them, we proposed the message structure designing elements to reduce the time to first fix.

## 2.2 L2C CNAV Parameter Acquisition Time

Satellite clock correction, ephemeris and system time parameters of GPS L2C CNAV are arranged in paragraphs 10, 11 and 30 types of data blocks, each block lasting 12 s. Maximum broadcasting interval for each data block was shown in Table 2.1.

Assumed that type 10, 11 and 30 data block was broadcasted only once within 48 s, then had the following four conditions, which in addition to 10,11 and 30, the another data block called *other type*. A kind of arrangement situation was shown in Fig. 2.1.

Each data block of GPS L2C CNAV was arranged by data bits following parity bits, and one data bit not being obtained would lead to cyclic redundancy check (CRC) checksum failure that also resulted in the whole data block bit stream being invalid, as shown in Fig. 2.2. Then, we should emphatically analyze the acquisition time of CED and GST parameters at  $t = 0^+$ ,  $t = 12^+$ ,  $t = 24^+$ ,  $t = 36^+$  reading point. Specifically the following four cases were analyzed for the first mode of Fig. 2.1.

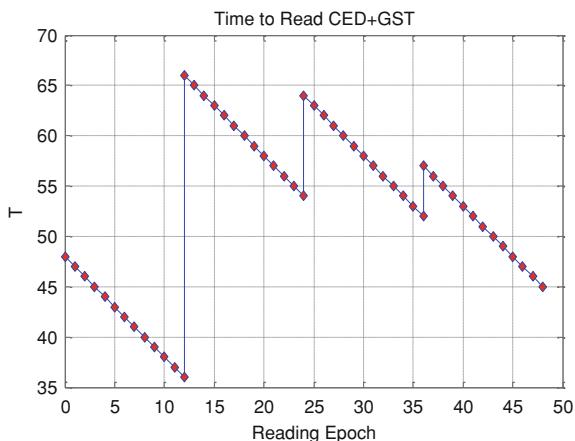
- Reading *other type* data block from  $t = 0^+$

Assuming that the 10, 11 and 30 data blocks were broadcasted only once within 48 s, so the  $T_{CED+GST}$  was equal to 48 s.



**Fig. 2.2** CNAV data block composition and reading point

**Fig. 2.3** CNAV reading point and CED, GST acquisition time



- Reading *type 10* data block from  $t = 12^+$ .  
of data blocks leading to the other bits being invalid, we should require the data from the next 48 s which was broadcasted by random way, so  $T_{10} = (12 + 24 + 36 + 48) \times 25\% = 30$  s where  $T_{10}$  was indicated for the acquisition time of data *type 10* within the next 48 s. Thus, reading from  $t = 12^+$ ,  $T_{CED+GST}$  was equal to 66 s ( $30 + 36$ ).
- Reading *type 11* data block from  $t = 24^+$ .  
The data *type 10* and *11* bits being invalid, we should obtain the parameters in data *type 10* and *11* from the next 48 s. The acquisition time of them was 24, 3, 48, 48, 48, 36 s respectively by six random arrangements, so  $T_{10+11} = 24 \times (1/6) + 36 \times (2/6) + 48 \times (3/6) = 40$  s. Thus,  $T_{CED+GST}$  was equal to 64 s ( $24 + 40$ ).
- Reading *type 11* data block from  $t = 36^+$ .  
The same as above, data *type 30* was ineffective, and we should obtain the parameters from the next 48 s, so  $T_{10+11+30} = 48 \times (3/4) + 36 \times (1/4) = 45$  s. Thus,  $T_{CED+GST}$  was equal to 57 s ( $12 + 45$ ).

Based on the above analysis of four cases, we draw the reading time  $t$  and  $T_{CED+GST}$ , shown in Fig. 2.3. The curve exhibited step at  $t = 0^+$ ,  $12^+$ ,  $24^+$ ,  $36^+$  corresponds to the results of the above analysis and the rest were linear monotonically decreasing.

Assuming that the reading point  $t$  was uniformly distributed on a full frame period (here, 48 s), we obtained the probability density function (PDF) by calculating the occurrence frequency of  $T_{CED+GST}$  within each section described as a

function where  $T$  indicated the value of  $x(t)$  that was the acquisition time of CED and GST parameters.

$$f(T) = \begin{cases} 1/48 & 36 \leq T < 45 \\ 2/48 & 45 \leq T < 48 \\ 1/48 & 48 \leq T < 52 \\ 2/48 & 52 \leq T < 54 \\ 3/48 & 54 \leq T < 57 \\ 2/48 & 57 \leq T < 64 \\ 1/48 & 64 \leq T \leq 66 \end{cases} \quad (2.1)$$

Based on 95 % confidence level, the probability density function substituted into the equation (2.2) [1] and we integrated the acquisition time of CED and GST parameters broadcasted on GPS L2C CNAV, and it was 63.8 s.

$$F(T_{CED+GST}) = \int_{-\infty}^{T_{CSE+GST}} f(t) dt = 0.95 \quad (2.2)$$

### 2.3 L1C CNAV2 Parameter Acquisition Time

The first sub-frame of GPS L1C CNAV2 message comprised the reference time, i.e., the numbers of 18 s interval within 2 hours epoch time, the rest GST parameters including second of week, week number and other system time information were arranged in the second sub-frame as well as the CED information [2]. So, the entire data of CED and GST should be decided by the whole bits in first and second sub-frame. For CNAV2, the data rate was 50 bps, encoded as 100sps. The first sub-frame of it lasted 0.52 s for a total 52 syb (corresponding 9 bits before encoding), the second sub-frame lasted 12 s for 1200 syb (600 bits before encoding), and the third sub-frame lasted 5.48 s for total 548 syb (274 bits before encoding). We considered the channel coding, cyclic redundancy check and the encoded symbol rate to analyze the acquisition time of the CED and GST parameters.

The CED parameters in second sub-frame of CNAV2 remained unchanged in a fairly long period of time (several minutes or even hours). Therefore, when some bits were missed, i.e., not reading the message from the beginning of the second sub-frame, only needed to re-read the missed message from the next corresponding position of the second sub-frame. For example, when reading the message from 1.52 s, the 52 symbols of the first sub-frame and the 100 symbols of the second sub-frame were not acquired, and then only needed to read the rest symbols of the

**Table 2.2** GPS L1C CNAV2 reading point and time to access CED and GST

Reading point	Time to CED GST	Reading point	Time to CED GST
0	12.52	9.52	18
0+	18.52	10.52	18
0.52	18	11.52	18
0.52+	18	12.52	18
1.52	18	12.52+	18
2.52	18	13.52	17
3.52	18	14.52	16
4.52	18	15.52	15
5.52	18	16.52	14
6.52	18	17.52	13
7.52	18	18	12.52
8.52	18	18+	18.52

frame and then read the missed 152 symbols from the next frame, because the 100 symbols of the next second sub-frame were identical to the corresponding positions of the previous frame (the parameters of the first sub-frame might be changed). Therefore, when the reading point from 1.52 s to 12.52 s, the  $T_{CED+GST}$  was equal to 18 s which were the interval time of CNAV2. All  $T_{CED+GST}$  values were shown in Table 2.2.

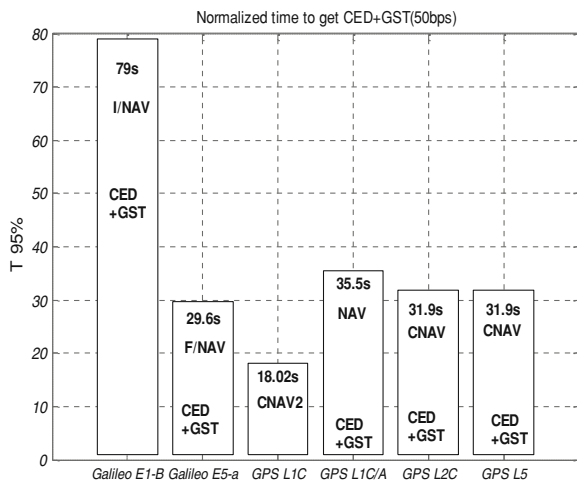
Assuming that the reading point  $t$  was uniformly distributed on a full frame period (here, 18 s), we obtained the PDF described in Eq. (2.3). Based on 95 % confidence level, we integrated the acquisition time of CED and GST parameters broadcasted on GPS L2C CNAV2, and it was 18.02 s, approximately same as the CNAV2 interval time. It was associated with CED and GST of CNAV2 being designed for two parts which one varied and the other one does not in the active interval of time.

$$f(T) = \begin{cases} 2/18 & 12.52 \leq T < 13 \\ 1/18 & 13 \leq T < 18 \\ 11/18 & T = 18 \\ 2/18 & 18 < T \leq 18.52 \end{cases} \quad (2.3)$$

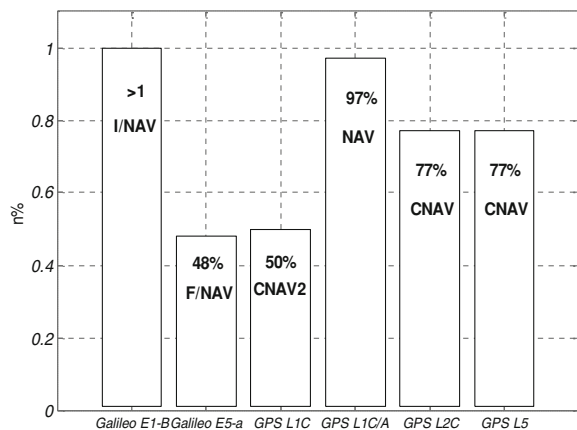
## 2.4 Galileo Parameter Acquisition Time

The relationship between message structure and TTFF of GPS NAV, Galileo F/NAV and I/NAV, *Marco Anghileria* proposed a detailed exposition and we only used the conclusion. To illustrate the impact of the message structure to TTFF, we normalized data rate to 50 bps to compare CED and GST acquisition time at 95 % confidence level. For I/NAV, the data rate was 125 bps, 2.5 times to 50 bps, so

**Fig. 2.4** CED and GST acquisition time for 50 bps of different data

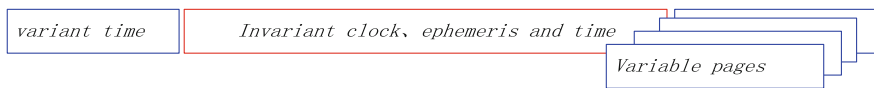


**Fig. 2.5** The coefficient for different GPS and Galileo data

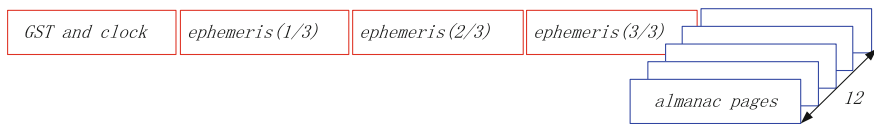


$T_{CED+GST}$  was 79 s, while for a data rate of 25 bps,  $T_{CED+GST}$  was half of the original value [3]. The normalized acquisition time of GPS and Galileo message broadcasted on different frequency was shown in Fig. 2.4. To get ephemeris and clock parameters, CNAV2 was only 18.02 s, while the I/NAV was 79 s for data rate of 50 bps.

Next, we emphatically analyze the relationship from the message structure, the amount of data, and the repeat time to TTFF. Defined a coefficient  $\eta$  where  $T_{data}$  was indicated the minimum time to get CED and GST theoretically, that was the reading point beginning from  $t = 0$ , and  $T_{CED+GST}$  was indicated the statistical time to get all CED and GST firstly by 95 % confidence level, considering the message reading point as a random variable. The coefficient  $\eta$  of different data was compared in Fig. 2.5.



**Fig. 2.6** Message structure of GPS L1C CNAV2



**Fig. 2.7** Message structure of Galileo F/NAV

$$\eta = |T_{CED+GST} - T_{data}| / T_{data} \times 100 \% \quad (2.4)$$

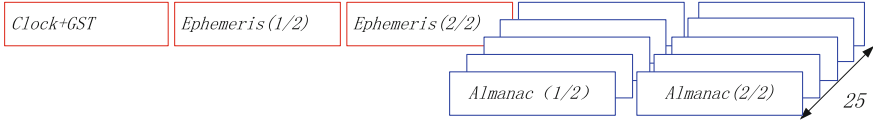
The coefficient of I/NAV was the largest ( $>1$ ), that was to say its structure design was the worst just from TTFF, and CNAV2 was approximate to F/NAV, being the best of all message structure. In fact, the coefficient also reflected the impact of the structure of almanac to TTFF.

## 2.5 GPS and Galileo Message Structure Analysis

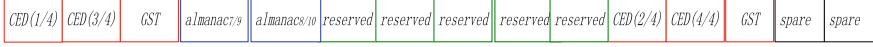
Comprehensive comparison of Figs. 2.4 and 2.5, the factor  $T_{CED+GST}$  of GPS L1C CNAV2 was 18.02 s and the coefficient  $\eta$  was 50 %, and the structure of it had very important reference value, redrawn in Fig. 2.6 [4]. The CED and GST of CNAV2 were compressed into a separate sub-frame of 600 bits which was equivalent to the 900 bits information in 1, 2 and 3 sub-frame of NAV and to the data type 10 and 11 of CNAV. The almanac parameters were designed in a separate sub-frame of 250–300 bits, broadcasted by the way of paging, which was different from the NAV that fourth and fifth sub-frame broadcasted almanac as well as the CNAV that broadcasted almanac by data block manner.

In addition, another important design idea of CNAV2 was considering the consistency of CED and part of GST during the active interval, so when some bits of CED and GST were missed, we could wait for about 56 s (when 50 bps) to obtain the remaining bits from the next frame for the bits obtained from the previous frame still valid. The coefficient  $\eta$  was 48 % for Galileo F/NAV and the structure of it was redrawn in Fig. 2.7 [5].

The frame structure of F/NAV almanac parameters was similar to CNAV2 and the difference was that the former was 250 bits and the later was 274 bits. That was to say, when the data rate was 50 bps, we could obtain the CED and GST parameters from the next frame after 5 s, and for CNAV2 just needed 5.48 s. This also explained the reason why the coefficient of F/NAV (48 %) was slightly lower



**Fig. 2.8** Message structure of GPS L1C/A NAV



**Fig. 2.9** Message structure of Galileo I/NAV

than CNAV2 (50 %). However,  $T_{CED+GST}$  of F/NAV was more than CNAV2 about 11.6 s with 50 bps data rate. The reason of it was the total bits of CED and GST of F/NAV more than CNAV2 about 400 bits. Furthermore, these bits of F/NAV were divided into four sub-frames to broadcast and each sub-frame utilized the 24-CRC, which caused the consistency decreased and redundancy increased.

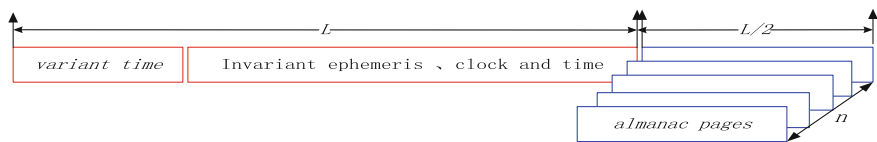
The frame structure analysis of GPS L1C CNAV2 and Galileo F/NAV showed that the design of almanac frame also had an important impact on CED and GST acquisition time. Then we analyzed the almanac frame structure of GPS L1C/A NAV and Galileo I/NAV which were redrawn in Figs. 2.8 and 2.9.

For L1C/A NAV, the almanac parameters were arranged in two sub-frames, which lasted 12 s, we needed to obtain the ephemeris parameters from the next frame if we did not require them, the time was about 2.4 times to CNAV2 and F/NAV, and about 2 times for the coefficient  $\eta$ . For Galileo I/NAV, shown in Fig. 2.9, the front five sub-frames had the similar structure with L1C/A NAV, the middle five were reserved pages, and the last five were for the remain bits of CED and GST as well as two blank pages. The structure of it was not designed compactly for CED and GST, which gone against reducing TTFF. This also explained the reason why it's coefficient  $\eta > 1$  and it's  $T_{CED+GST}$  was 79 s with data rate of 50 bps, which was the maximal of all message structure.

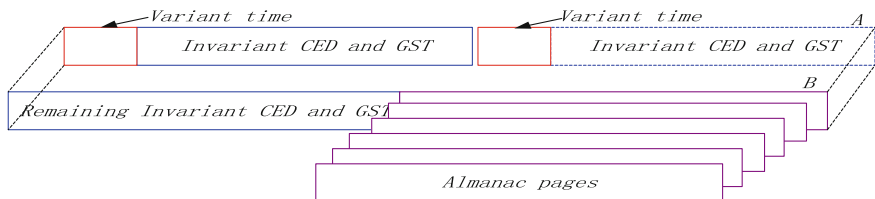
## 2.6 The Key Factor to Reduce TTFF

We presented some navigation message structure with low acquisition time of CED and GST as well as low TTFF. Firstly, we considered the factor of  $\eta$ , that was the almanac frame having appropriate proportion of the total frame size: too bigger was not conducive to reduce the CED and GST acquisition time and too small gone against the average speed to obtain the almanac and ionosphere parameters, which were all undesirable for navigating; Secondly, the consistency of the ephemeris parameters during the active interval time should be considered; Finally, the CED and GST parameters should be designed in a independent sub-frame to avoid being separated by the parity bits, that was to be designed more





**Fig. 2.10** Single structure of message



**Fig. 2.11** Dual structure of message

compactly, however, it was associated with the channel coding and message checking ways.

The two message structure, *Single* and *Dual* (J. W. Betz) were analyzed as followed. For *Single*, the almanac frame was about half of the size of CED and GST frame shown in Fig. 2.10, where  $\eta$  was about 50 %. The all ephemeris parameters were designed in a independent sub-frame and some GST parameters which changed during the effective interval were arranged in a previous sub-frame, which was similar to CNAV2 structure. The benefits of this design would not only help to reduce the TTFF, but also for the message robustness.

The two parts A and B of *Dual* structure were simultaneously broadcasted, shown in Fig. 2.11, where part A did not broadcast almanac pages and just repeated CED and GST information. For lower TTFF, the amount of essential data must be compendious, and if the total frame were 900, 450 bits needed for CED and GST in part A, and just 9 s with 50 bps data rate to first obtain positioning information, and then just 6 s with 75 bps. However, the reduction of the amount of data means that the accuracy of satellite orbit model would inevitably be reduced as well as the user positioning accuracy, which might lead to 5 m user range error (URE).

The remaining CED, GST and almanac parameters were broadcasted in part B. We should note that the almanac frame size in part B, with fewer remaining CED and GST, was longer than *Single* structure, that was to say the corresponding  $\eta$  may larger, however, the CED and GST were repeated twice in part A and the corresponding  $\eta$  of it almost equal to zero. So the impact of the longer almanac frame size in part B would not be considered.

Under the same conditions of 50 bps data rate and 900 bits frame size, the first time to get CED and GST of *Dual* structure was the shortest, only 9 s, compared to each message frame structure of GPS and Galileo.

Higher almanac rate was benefit for accessing to the constellation information rapidly, which would help reduce the capture time. For *Single* structure, the almanac average data rate was 15 bps where the frame length was set to 270 bits and the average time to get an almanac frame was 18 s. For *Dual*, the almanac data rate was 27.8 bps where the frame length was 500 bits and the time was 18 s which was arranged in part *B*. Comparative analysis shown that the *Dual* message structure had great reference value for lower TTFF.

## 2.7 Conclusion

We emphatically discussed the relationship between message structure design and TTFF. The basic conclusions were following. Firstly, under the conditions that the maximum broadcast interval was 48 s and the GPS L2C CNAV was broadcasted by the way of data block, the acquisition time of CED and GST was about 64 s. Secondly, the CNAV2 only needed 18.02 s that was the minimum time compared to other GPS and Galileo navigation message structure to obtain the CED and GST parameters at the same data rate and total amount, which was closely related to the almanac frame structure and the consistency of ephemeris parameters. Then, the first time to access to the positioning information of *Dual* structure was smaller, only 9 s, as well as a higher almanac average data rate, up to 27.8 bps. Finally, we presented the key factor of navigation message structure designing to reduce the TTFF which was mainly about the following three points: (1) the almanac frame proportion of the total frame size should be appropriate; (2) the ephemeris parameters should be consistent during the effective interval; (3) the message parameters should be more compact.

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