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Frame synchronization algorithm plays an important role in the recovery process of telemetry data transmitted over a communication channel with noise, and it significantly affects the entire process efficiency. In particular, frame synchronization is important in the case when the nature of noise in the communication channel and methods of processing the transmitted information allow for both omission of the reliable messages and insertion of the false ones into the telemetry data stream, as well as interruption and resuming transmission at irregular intervals. In general, the frame synchronization process provides a decommutation ability of telemetry information parameters in the stream. A necessary theoretical description of the frame synchronization system model is given, as well as techniques for selecting basic parameters of the synchronizer. The selection criteria for these parameters are defined. In the experiments with real telemetry data of IRIG-106 format, the model of a communication channel with noise allowing for both inversion and bit omissions is used. The obtained experimental results are compared with theoretical estimations of the synchronizer parameters.

Keywords: telemetry information, frame synchronization, synchronization code, synchronization threshold, Search mode, Test mode, Capture modes, IRIG-106 standard, symmetric binary channel with missing bits.

Data synchronization is a detection of a cycling group of characters in a stream of digital telemetry information (TMI). A synchronizer can be represented as a finite state machine with three modes [1–4]:

- “Search” mode — is a state in which the synchronizer scans the entire input data stream to detect a synchronization code;
- “Test” mode — is a state in which the synchronizer confirms the initial detection of the synchronization code using a predetermined number of successful checking detections of the synchronization code;
- “Capture” mode — is a synchronizer operation condition in which the synchronization code is detected with a high degree of accuracy based on the initial detection and a sufficient number of checks.

Theoretical calculation of the frame synchronization system parameters introduced in well-known publications [1–7] is based on the fact that an information component of the frames is filled with random values distributed according to the normal law. The frames in the stream are divided by bit sequences of the synchronization codes. Transmission of TMI stream through a signal channel distorts both the information component of the frame and the synchronization codes due to noise. In general, this leads to a loss of the real synchronization codes and emerging of the false ones in the stream. The probability of the false synchronization codes occurrence depends on the structure and the content of an information part of the frame and it may differ from the one theoretically calculated. This paper

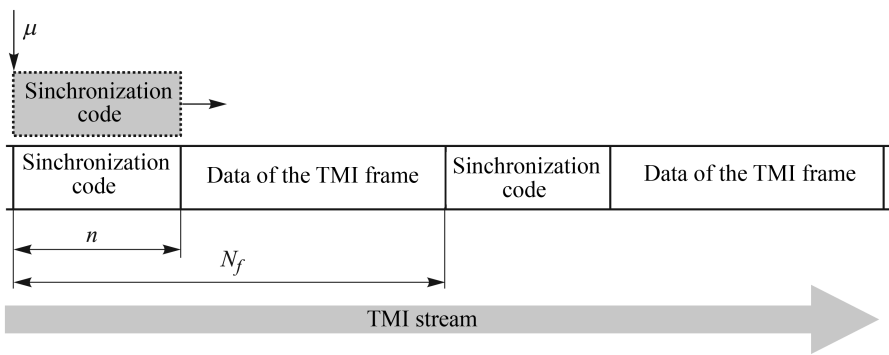


Fig. 1. The structure of the synchronized TMI frame

presents the results of the research into the frame synchronization recovery system in the TMI stream of IRIG-106 standard filled with information from sensors. Parameters of the synchronization system are chosen based on experimental data and they are compared with the theoretically obtained values.

In all operational modes the synchronization code detection is typically performed using a correlation process in which an input message is being continuously compared with the synchronization code known by the correlation algorithm. With a relatively high correlation between the synchronization code and the messages symbols, the code is considered to be detected.

The task of the synchronization code detection is to determine the location of the synchronization code in each TMI frame (Fig. 1) in the received bitstream:

$$\mu_{s,l} = \underset{\mu_l \in [(l-1)N_f + 1; lN_f]}{\operatorname{argmax}} L(\mu), \quad (1)$$

where μ is the location of the detected synchronization code in the bitstream $d = \{d_1, d_2, d_3, \dots\}$; $S = \{s_1, s_2, \dots, s_n\}$ — is n -bit synchronization code being used; l — is a serial number of the detected frame in the stream d ; N_f — is the TMI frame length; $L(\mu)$ — is a correlation process described in [5–7], which is defined by the formula

$$L(\mu) = \sum_{k=1}^n s_k d_{k+\mu}. \quad (2)$$

The correlation coefficient in each state of the synchronizer is continuously compared with a predetermined threshold ε for each state. While this value does not exceed the threshold value, the synchronizer remains in its current state, but when the threshold is exceeded, the synchronizer proceeds to the previous one.

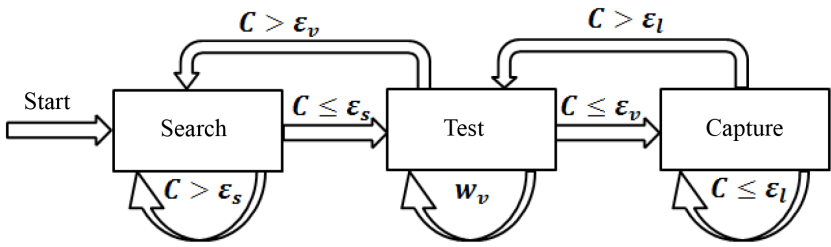


Fig. 2. Transition between the TMI stream frame synchronizer states

Fig. 2 shows transitions between the synchronizer states: “Search”, “Test” and “Capture”, where ϵ_s is the synchronizer threshold in the “Search” mode, ϵ_v – in the “Test” mode, and ϵ_l – in the “Capture” mode; C is a correlation coefficient, equal to the value $L(\mu)$ calculated based on formula (2). In each state, if the value of the correlation coefficient C is either less than or equal to the threshold of the current state, the synchronization code is considered to be detected and vice versa.

At the beginning of its operation, the synchronizer is in the “Search” state. If the synchronizer detects the synchronization code ($C \leq \epsilon_s$), it proceeds to the “Test” state. If in the “Test” state the number of detected consecutive synchronization codes ($C \leq \epsilon_v$) reaches a predetermined value w_v , the synchronization system proceeds to the “Capture” state, otherwise, the system returns to the “Search” mode. In the “Capture” mode the frame synchronization is provided. When the synchronization code exceeds the threshold ϵ_l , the synchronizer returns to the “Test” mode. In the “Search” mode the synchronizer reads bits until it detects the synchronization code in a stream, and then in the “Test” and “Capture” modes it shifts in the stream to a step length. A step length is equal to the TMI frame length, as it is shown in Fig. 3.

The purpose of this work is to develop methods of calculation and selection of frame synchronizer parameters, including thresholds ϵ_s for the “Search” state, ϵ_v – for the “Test” state and ϵ_l – for the “Capture” state, as well as the average synchronizer latency w_v in the “Test” mode, where the value w_v is represented by the average number of frames. The synchronization system parameters are selected for the telemetry frame of

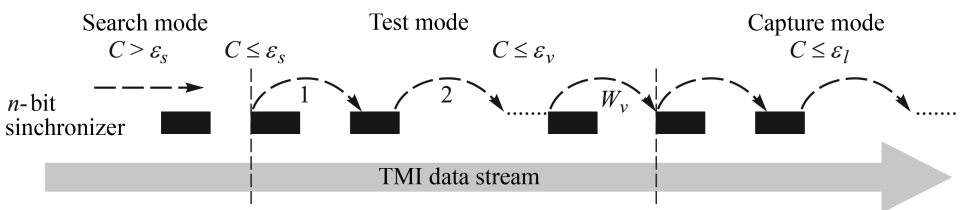


Fig. 3. Shift of the synchronizer in telemetry data stream in various operating modes

the N_f -bit length generated by the switching system on an telemetry object with a predetermined synchronization code of the n -bit length.

This article presents the algorithm for frame synchronization and the equations describing the operating states of the synchronizer [1, 2], with regard to the problem of frame synchronization in a stream of TMI.

The performance of the frame synchronization system in the “Search” and “Test” states is determined by the probability of correct detection of both the synchronization code and the average time required for the procedure. In the “Capture” state the performance is determined by the average time of false synchronization detection after the transition to the “Capture” mode.

The selection of low thresholds for the state transitions increases the likelihood of correct detection of the synchronization code. However, this increases the synchronization recovery time. Methods of synchronization parameter selection are based on the analysis of correlation of these two indicators.

TMI synchronization systems are described in such works as [1–4]. They are based on transmission of the telemetry stream as random data over the communication channel with noise, model of which allows for only the occasional inversions. This paper describes the experiments carried out by transmitting the telemetry stream containing the real telemetry data, generated in the IRIG-106 standard [8], over the communication channel with noise, the model of which allows for not only the occasional inversions, but also for the occasional missing bits [9]. This kind of errors significantly affects the quality of the frame synchronization in the TMI stream. Usefulness of the IRIG-106 standard is proved by its wide use in the aerospace industry.

Due to the fact that the actual telemetry data used in the experiments can affect the quality of solving the proper detection problem of the synchronization code in the stream, the experimental results may differ from those obtained theoretically, but it is shown that the best results are obtained in the experiments with the same selection of synchronizer parameters as for the best theoretical results.

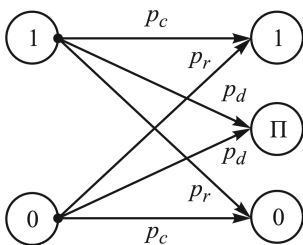


Рис. 4. Model of symmetrical binary channel with missing bits ($p_c + p_r + p_d = 1$)

Fig. 4 shows a model of the communication channel, allowing for random inversion and missing bits: p_c — is the probability of correct bit transmission (0 or 1), p_r — is the probability of bit inversion during transmission ($0 \rightarrow 1, 1 \rightarrow 0$), p_d — is the possibility of missing the current bit (loss of bit 0 or 1).

To ensure the frame synchronization, one of 18 markers listed in the IRIG-106 standard is selected. The selected marker is used as the synchronization code and is added to each frame [8]. The list of markers is shown in Table 1.

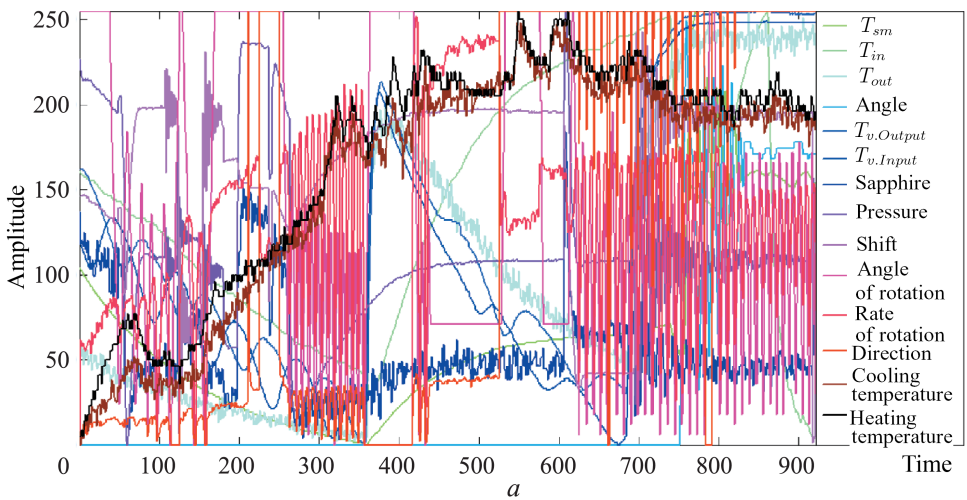
Table 1

Standard synchronization codes of TMI in the IRIG-106 standard

Optimal frame synchronization codes of TMI in the IRIG-106 standard	
Code length	Code format
16	111 0101110010000
17	111 10011010100000
18	111 100110101000000
19	111 1100110010100000
20	111 01101111000100000
21	111 011101001011000000
22	111 1001101101010000000
23	111 10101110011010000000
24	111 110101111001100100000
25	111 1100101101110001000000
26	111 110100110101100110000000
27	111 110101101001100110000000
28	111 1010111100101100110000000
29	111 10101111001100110100000000
30	111 110101111001100110100000000
31	111 1111001101111101010000100000
32	111 11110011010110010100001000000
33	111 110111010011101001010010011000

Preparing data for the experiments. Digitized analog sensory data were included in the frame of telemetry data. The sensors measured typical parameters for the telemetry system: temperature, pressure, positional values. These parameters were obtained in the laboratory, examples of the signals are shown in Fig. 5, *a*. The frame structure shown in Fig. 5, *b* was developed for the experiments, the test telemetry data bitstream was formed on its basis.

A frame contains 14 channels. Digitized analog sensor readings are transmitted over each channel. The frame also contains service information, which provides frame synchronization in the telemetry stream. The service information of the frame is composed of the selected synchronization code (the marker), and the registration time in the IRIG-106 standard [8]. The frame stream to be used in the experiments was formed with the help of a telemetry data simulator [10].



TMI frame structure														
SYNC_F	CD1	CD2	CD3	CD4	CD5	CD6	CD7	CD8	CD9	CD10	CD11	CD12	CD13	CD14
SYNC16	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14

b

Fig. 5. Telemetry parameters (a) and telemetry frame structure (b):

D.W. — is a data word, D1:D14 — are samples of the signals shown in figure (a)

The telemetry word length of a frame is 8 bits. A quantized sensor sample in the range of 0...255 is stored in the word. The service information consists of the marker and 48 bits being used to store the time in the IRIG-106 standard. The total length of the reduced frame (see Fig. 5, b) is 176 bits.

Analysis of the synchronizer in the “Search” mode. In the “Search” mode, the synchronization code is considered to be detected, if comparing n successive message symbols with the known synchronization code, the number of mismatches doesn't exceed a threshold value ε_s . The probability of correct detection of the synchronization code in the “Search” mode at an acceptable threshold ε_s in the presence of noise $p_r \neq 0$ can be written as

$$p_{cs} = \sum_{i=0}^{\varepsilon_s} \binom{n}{i} (1 - p_r)^{n-i} p_r^i, \quad (3)$$

where n is the length of the synchronization code; $\binom{n}{i} = \frac{n!}{i!(n-i)!}$;

$$p_{fs} = \frac{\sum_{i=0}^{\varepsilon_s} \binom{n}{i}}{2^n} \quad (4)$$

is the probability of the false synchronization code emerging among the message characters in the “Search” mode with an acceptable number of errors ε_s .

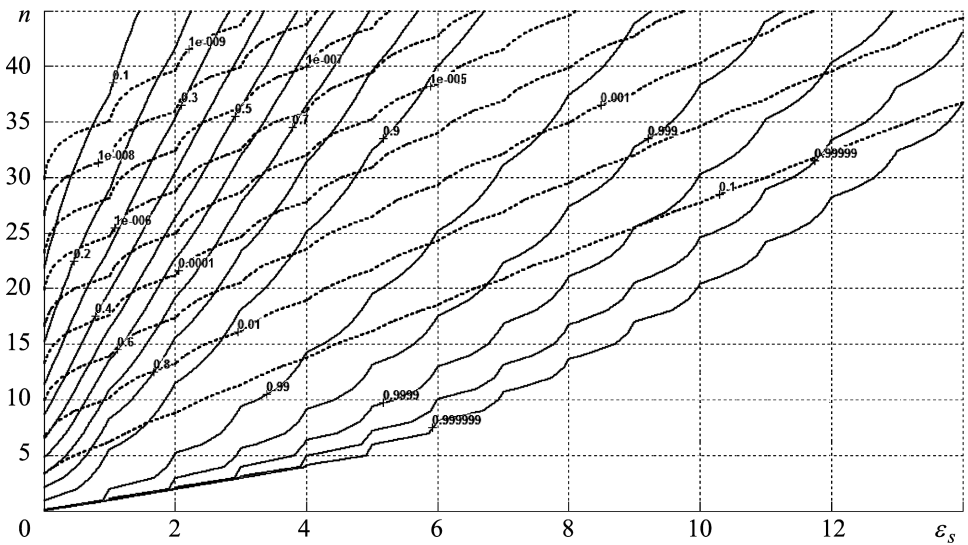


Fig. 6. Values p_{cs} and p_{fs} at $p_r = 0, 1$ and at different values of n and ε_s

In Fig. 6 the curves intersect at certain values of n and ε_s . Thus, the selection of n and ε_s affects the values p_{cs} and p_{fs} . In case of false detection of n -bit sequence of the synchronization code in the data frame space, the length of which is b bits, the probability of false synchronization is calculated by the formula

$$F = 1 - (1 - p_{fs})^b, \quad (5)$$

where

$$b = N_f - (n) - (n - 1), \quad (6)$$

N_f is the total length of the frame, n – is the length of the synchronization code (Fig. 7).

The probability of making the right decision in the “Search” mode can be written as:

$$T = \frac{p_{cs}(1 - F)}{F + p_{cs}(1 - F)}; \quad (7)$$

the probability of making a wrong decision in the “Search” mode has the following form

$$W = \frac{F}{F + p_{cs}(1 - F)}, \quad (8)$$

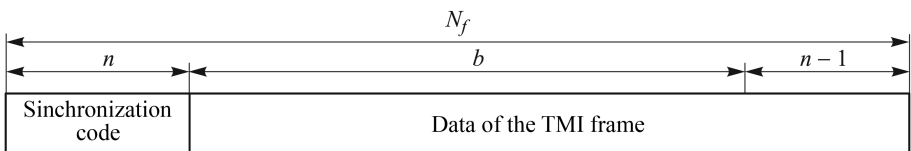


Fig. 7. TMI frame structure

where

$$W + T = 1. \quad (9)$$

The average number of frames required for making the right decision in the “Search” mode is

$$w_s = \frac{1}{p_{cs}(1 - F)}, \quad (10)$$

where a value w_s should be as small as possible.

Table 2 shows values w_s when $p_r = 0,1$, $n = 16$, $b = 145$ and at different values ε_s .

Table 2

Values w_s in the “Search” mode for $p_r = 0.1$

p_r	n	ε_s	b	p_{cs}	p_{fs}	F	T	W	w_s
0.1	16	0	145	0.185	$1.53 \cdot 10^{-5}$	0.002	0.988	0.011	5.408
0.1	16	1	145	0.514	0.0002	0.036	0.930	0.069	2.017
0.1	16	2	145	0.789	0.002	0.261	0.690	0.309	1.716
0.1	16	3	145	0.931	0.010	0.787	0.200	0.799	5.059
0.1	16	4	145	0.982	0.038	0.996	0.003	0.996	297.625
0.1	16	5	145	0.996	0.105	1	$1.02 \cdot 10^{-7}$	1	9796884
0.1	16	6	145	0.999	0.227	1	$1.11 \cdot 10^{-16}$	1	$9.01 \cdot 10^{15}$

From these data it follows that for $\varepsilon_s = 0$ the value T is maximum, but w_s is also of great importance. Therefore, it is required to select a set ST consisting of some values T close to the maximum value, in this case it is $ST = \{0.988; 0.930\}$ when $\varepsilon_s = \{0, 1\}$, and then to select the value ε_s for which w_s is minimal. In the above example $\varepsilon_s = 1$ is selected, for which $T = 0.930$ and $w_s = 2.017$.

The criterion for the selection of the parameter ε_s in the “Search” mode is:

$$\varepsilon_s = \arg \max_{\varepsilon_s} \{T(\varepsilon_s) = \max(T), w_s(\varepsilon_s) = \min(w_s)\}. \quad (11)$$

In Table 3. values w_s with $p_r = 10^{-2}$ and $p_r = 10^{-3}$ are given additionally to illustrate the dependencies of the parameters.

The results of the experiments with telemetry data in the IRIG-106 format are shown in Table 4. The experiments were performed for $p_r = 0.1$ and for different probability values of bit missing $p_d = \{0, 10^{-4}, 10^{-3}, 10^{-2}\}$. The synchronization code of the IRIG-106 standard with the 16-bit length was used.

Table 3

Values w_s in the “Search” mode at $p_r = 10^{-2}$ and $p_r = 10^{-3}$

n	ε_s	b	p_{cs}	p_{fs}	F	T	W	w_s
$p_r = 10^{-2}$								
16	0	145	0.851	$1.53 \cdot 10^{-5}$	0.002	0.997	0.002	1.177
16	1	145	0.989	0.0002	0.036	0.962	0.037	1.049
16	2	145	0.999	0.002	0.261	0.738	0.261	1.355
16	3	145	0.999	0.010	0.787	0.212	0.787	4.713
16	4	145	1	0.0384	0.996	0.003	0.996	292.564
16	5	145	1	0.105	1	$1.02 \cdot 10^{-7}$	1	9764587
16	6	145	1	0.227	1	$1.11 \cdot 10^{-16}$	1	$9.01 \cdot 10^{15}$
$p_r = 10^{-3}$								
16	0	145	0.9849	$1.53 \cdot 10^{-5}$	0.002	0.997	0.002	1.018
16	1	145	0.999	0.0002	0.036	0.963	0.036	1.038
16	2	145	0.999	0.002	0.261	0.738	0.261	1.354
16	3	145	1	0.010	0.787	0.212	0.787	4.713
16	4	145	1	0.038	0.996	0.003	0.996	292.564
16	5	145	1	0.105	1	$1.02 \cdot 10^{-7}$	1	9764587
16	6	145	1	0.227	1	$1.11 \cdot 10^{-16}$	1	$9.01 \cdot 10^{15}$

Table 4

Value w_s in the “Search” state

$p_r = 0.1$	ε_s	Theoretical values w_s		Experimental values w_s		
		$p_d = 0$	$p_d = 0$	$p_d = 10^{-4}$	$p_d = 10^{-3}$	$p_d = 10^{-2}$
	0	5.408549	5.15	5.4	4.4	5
1	2.017249	1.69	2.12	1.76	1.84	

It should be noted that the parameters of the synchronizer calculated from the experimental data match the theoretical ones.

For the considered case in the “Search” mode it is recommended to select $\varepsilon_s = 1$.

Analysis of the synchronizer in the “Test” mode. Upon detecting the synchronization code in the “Search” mode, the synchronizer enters the “Test” mode. If the number of the detected successive markers reaches a predetermined value in the “Test” mode, the system switches to the “Capture” mode.

Let

$$R = \frac{\text{probability of exiting the “Search” and “Test” modes with the false synchronization decision after } \omega_v \text{ frames}}{\text{“Search” and “Test” modes with the correct synchronization decision after } \omega_v \text{ frames}}$$

$$R = \frac{W}{T} \left(\frac{p_{fv}}{p_{cv}} \right)^{w_v}, \quad (12)$$

where p_{cv} – is the probability of correct detection of the synchronization code in the “Test” mode at the threshold value ε_v , and p_{fv} – is the probability of false detection of the synchronization code in the message symbols in the “Test” mode at ε_v . The value R should be as small as possible.

Table 5 shows the values R at the selected value ε_s and at different ε_v and w_v .

Table 5

Values R in the “Test” mode

Values R at $p_r = 0.1, n = 16, b = 145$ and $\varepsilon_s = 1$					
ε_v	$w_v = 1$	$w_v = 2$	$w_v = 3$	$w_v = 4$	$w_v = 5$
0	$6.13 \cdot 10^{-6}$	$5.05 \cdot 10^{-10}$	$4.158 \cdot 10^{-14}$	$3.424 \cdot 10^{-18}$	$2.819 \cdot 10^{-22}$
1	$3.75 \cdot 10^{-5}$	$1.89 \cdot 10^{-8}$	$9.532 \cdot 10^{-12}$	$4.803 \cdot 10^{-15}$	$2.420 \cdot 10^{-18}$
2	0.000197	$5.22 \cdot 10^{-7}$	$1.383 \cdot 10^{-9}$	$3.665 \cdot 10^{-12}$	$9.708 \cdot 10^{-15}$
3	0.00085	$9.71 \cdot 10^{-6}$	$1.108 \cdot 10^{-7}$	$1.265 \cdot 10^{-9}$	$1.444 \cdot 10^{-11}$
4	0.00291	0.000114	$4.441 \cdot 10^{-6}$	$1.735 \cdot 10^{-7}$	$6.780 \cdot 10^{-9}$
5	0.00785	0.000827	$8.721 \cdot 10^{-5}$	$9.192 \cdot 10^{-6}$	$9.689 \cdot 10^{-7}$
6	0.016933	0.00385	0.000875	0.000199	$4.524 \cdot 10^{-5}$

In Table 5, for example, the pairs (ε_v, w_v) are selected for the synchronization system in such a way that at the required value R_T the value R does not exceed the predetermined R_T ($R \leq R_T$).

In this example, at the given acceptable probability value $R_T = 10^{-6}$, $R = \{5.22 \cdot 10^{-7}; 1.108 \cdot 10^{-7}; 1.735 \cdot 10^{-7}; 9.689 \times 10^{-7}\}$ are selected for the pair values $(\varepsilon_v, w_v) = \{(2, 2), (3, 3), (4, 4), (5, 5)\}$, respectively.

The probability of outcoming from the states “Search” and “Test” in the case of correct detection of the synchronization code is as follows:

$$p_{tc} = \left(p_{cs} (1 - F) \frac{(1 - q^{w_s})}{(1 - q)} \right) (p_{cv})^{w_v}, \quad (13)$$

where

$$q = (1 - p_{cs}) (1 - F). \quad (14)$$

Table 6 shows the values p_{tc} for the chosen value ε_s and different ε_v and w_v .

The values $p_{tc} = \{0.454; 0.602; 0.681; 0.718\}$ correspond to the selected values R . It should be noted that while increasing the value of the pair (ε_v, w_v) from (2, 2) to (3, 3) it increases p_{tc} (from 0.602 to 0.454) by 0.148, but while increasing it from the value (3, 3) to (4, 4), it increases p_{tc} only

Values p_{tc} in the “Test” mode

Values p_{tc} at $p_r = 0.1, n = 16, b = 145$ и $\varepsilon_s = 1$					
ε_v	$w_v = 1$	$w_v = 2$	$w_v = 3$	$w_v = 4$	$w_v = 5$
0	0.135	0.025	0.004	0.0008	0.0001
1	0.375	0.193	0.099	0.051	0.026
2	0.576	0.454	0.358	0.283	0.223
3	0.680	0.633	0.602	0.549	0.512
4	0.717	0.705	0.693	0.681	0.670
5	0.727	0.725	0.722	0.720	0.718
6	0.729	0.729	0.728	0.728	0.728

by 0.079, and the increase from the value (4, 4) to (5, 5), it increases p_{tc} by 0.038, etc. Based on this, we selected $(\varepsilon_v, w_v) = (3, 3)$.

Thus, the selection of parameters (ε_v, w_v) for “Test” mode consists of two steps. First, the required value R_T is given and two sets m_1, m_2 are selected according the following conditions:

$$m_1 = \{(\varepsilon_v, w_v) : R(\varepsilon_v, w_v) \leq R_T\}; \quad (15)$$

$$m_2 = \{p_{tc} \{m_1\}\} = \{p_{tc1}(m_1 \{1\}), p_{tc2}(m_1 \{2\}), \dots, p_{tcl}(m_1 \{l\})\}, \quad (16)$$

where l is the number of elements m_1 .

Then, parameters (ε_v, w_v) for the “Test” mode are calculated by the formula

$$(\varepsilon_v, w_v) = \arg \max_p \{d_p : p_{tc}(\varepsilon_v, w_v) \in m_2, \varepsilon_v > \varepsilon_s\}, \quad (17)$$

where $d_p = p_{tci} - p_{tci-1}, i = 2, \dots, l$.

The results of the experiments with telemetry data are shown in Table 7. The experiments were performed at $p_r = 0.1$, the selected value ε_s , and for different values of the probability of bit missing $p_d = \{0, 10^{-4}, 10^{-3}, 10^{-2}\}$ and for different values ε_v and w_v .

Table 7

Parameters ε_v and w_v in the “Test” state

Parameters	Theoretical values p_{tc}	Experimental values p_{tc}			
	$p_d = 0$	$p_d = 0$	$p_d = 10^{-4}$	$p_d = 10^{-3}$	$p_d = 10^{-2}$
$\varepsilon_v = 2, w_v = 2$	0.454762	0.7972	0.7777	0.6613	0.1203
$\varepsilon_v = 3, w_v = 3$	0.60248714	0.9308	0.923	0.7916	0.124
$\varepsilon_v = 4, w_v = 4$	0.68165127	0.9876	0.967	0.8112	—
$\varepsilon_v = 5, w_v = 5$	0.718099482	0.9900	0.9752	0.838	—

The experimental values of the synchronizer parameters (ε_v, w_v) also match the theoretical ones.

For the case under consideration, in the “Test” mode, it is recommended to select the parameter values $\varepsilon_v = 3$ and $w_v = 3$.

Analysis of the synchronizer in the “Capture” mode. In the “Capture” state, the synchronizer controls only the group of n characters in the position where the synchronization code should be placed. If the number of errors in code checking exceeds the threshold ε_l , the synchronizer returns to the “Test” state.

The performance of the synchronizer in the “Capture” mode is estimated by the relative value of information loss DL caused by any synchronization failure in the presence of noise. The value DL is calculated using the formula

$$DL = \frac{L}{L + K} \% \tag{18}$$

where

$$L = \left(\frac{1/(1 - q) + w_v}{p_{tc}} \right) + (JR) \tag{19}$$

— is the average time required for correct detection of the synchronization code;

$$J = \frac{1}{1 - p_{fl}} \tag{20}$$

— is the average number of synchronization codes necessary for making a decision on erroneous detection of the synchronization code in false synchronization (p_{fl} — is the probability of the false synchronization code in the “Capture” mode at the threshold value ε_l); q, R, w_v and p_{tc} are calculated in the “Test” mode;

$$K = \frac{1}{1 - p_{cl}} \tag{21}$$

Table 8

Values DL , % in the “Capture” synchronization state

Values DL , %, at $p_r = 0,1, n = 16, b = 145, \varepsilon_s = 1, \varepsilon_v = 3$ и $w_v = 3$				
ε_l	J	K	L	DL , %
0	1.000015	1.227	8.263	87.066
1	1.000259	2.060	8.263	80.039
2	1.002095	4.744	8.263	63.523
3	1.01075	14.618	8.263	36.113
4	1.03994	58.809	8.263	12.319
5	1.117389	303.328	8.263	2.651
6	1.294078	1982.025	8.263	0.415

Table 9

Values DL , % in the “Capture” mode

ε_l	Values DL at $p_r = 0, 1, n = 16, \varepsilon_s = 1, \varepsilon_v = 3$ and $w_v = 3$														
	Theoretical values			Theoretical values											
	$p_d = 0$			$p_d = 0$			$p_d = 10^{-4}$			$p_d = 10^{-3}$			$p_d = 10^{-2}$		
	K	L	DL	K	L	DL	K	L	DL	K	L	DL	K	L	DL
3	14.618	8.263	36.11	60.687	5.8	8.723	24.44	6.8	21.76	8.6	9.2	51.69	307.4	295	48.97
4	58.80	8.263	12.319	357.75	5.8	1.595	28.8	6.8	19.1	8.84	9.2	51	307.48	295	48.96
5	303.32	8.263	2.6519	643.5	5.8	0.893	29.04	6.8	18.97	8.92	9.2	50.77	307.48	295	48.96
6	1982.02	8.263	0.415	881.602	5.8	0.653	29.24	6.8	18.86	9.04	9.2	50.44	307.68	295	48.95

— is the average number of synchronization codes required to make a decision about the absence of the synchronization code (p_{cl} — is the probability of correct detection of the synchronization code in the “Capture” state at the threshold value ε_l).

From Table 8 it is possible to select the value ε_l at which the calculated value $DL \leq DL_T$. For example, if the desired value is $DL_T = 1\%$, then $DL = 0.415$ can be selected and the threshold value $\varepsilon_l = 6$ is considered to be the best one.

Therefore, the criterion for selecting ε_l of the “Capture” mode is as follows:

$$\varepsilon_l = \arg \max_{\varepsilon_l} \{DL : DL(\varepsilon_l) \leq DL_T\}, \quad (22)$$

where DL_T is the required minimum value of the information loss.

The results of the experiments with telemetry data (IRIG-106) are shown in Table 9. The experiments were performed at $p_r = 0.1$, the selected values $\varepsilon_s, \varepsilon_v, w_v$ and for different values of the probability of bit missing $p_d = \{0, 10^{-4}, 10^{-3}, 10^{-2}\}$ and ε_l .

In the case under consideration, it is recommended to select the parameter value $\varepsilon_l = 6$ for the “Capture” synchronization mode.

Conclusions. The theoretical model of the frame synchronization of the digital telemetry data stream is considered. The system is represented as a final state machine with three states. The basic model parameters determining the conditions of transition between the synchronizer states are given. The methods of selecting such synchronizer parameters are specified. The experiments with real telemetry data of the IRIG-106 format are carried out. A comparative analysis of the obtained results with theoretical estimates of the parameters of the synchronization system is performed. It shows that the proposed method of selecting synchronizer parameters leads to the same results both for the theoretical TMI stream model and for the real telemetry data, despite the difference in quantitative estimates of the intermediate results.

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