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Error detection and correction in one mBnB class code

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Abstract---*The article deals with the issues of error detection and correction in the second-order bi-pulse code. The analysis of the code generation algorithm is carried out, based on which it is shown that the code has 4 allowed four-bit combinations. The article considers its own resources of a code that allow detecting and correcting both single errors and packets of errors. It is shown that errors are detected with a probability of 1 when one, two, and three bits of the code combination are distorted, while the probability of their correction does not exceed 0.5, in the case of distortion of all four symbols, both detection and correction of errors is impossible. To increase the probability of error correction, it is proposed to use a well-known method based on determining the parity or oddness of the allowed combinations in separate fragments of a linear signal, a brief description of the method is given, and its analysis is carried out in relation to this code. It is shown that the use of this method makes it possible to correct all single, paired and three-time errors, as well as to detect all four-time errors, on the basis of which it can be concluded that it significantly improves the correcting properties of the signal under consideration.*
Keywords---*allowed combinations, error correction, error detection, forbidden combinations, linear codes*

Introduction

mBnB class codes are widely used in fiber-optic communication systems as linear signals that are highly redundant. To generate these codes, m-bit segments of the original signal are encoded using n-bit blocks, where n>m, and this produces redundancy. The main reason for using redundancy codes is to detect errors occurring in communication lines. As a rule, the process of error detection is closely related to the process of error correction. Due to the specifics of the code construction structure, classical error correction methods are inappropriate for mBnB codes (Garavan et al., 2002; Lee, 1997; Ding, 2019). Nevertheless, the presence of their own redundancy in them suggests that error correction can be carried out using non-traditional methods. One of the well-known codes of the mBnB class is a bipulse signal of the 2nd type, the formation algorithm of which is shown in Fig. 1: a pair of symbols of the source code (Fig. 1, a) located on two adjacent clock intervals T (one - block 10, zero - block 01), and the first symbols of the received blocks are sequentially located on the first clock interval, and the second - on the second (Fig. 1, b).

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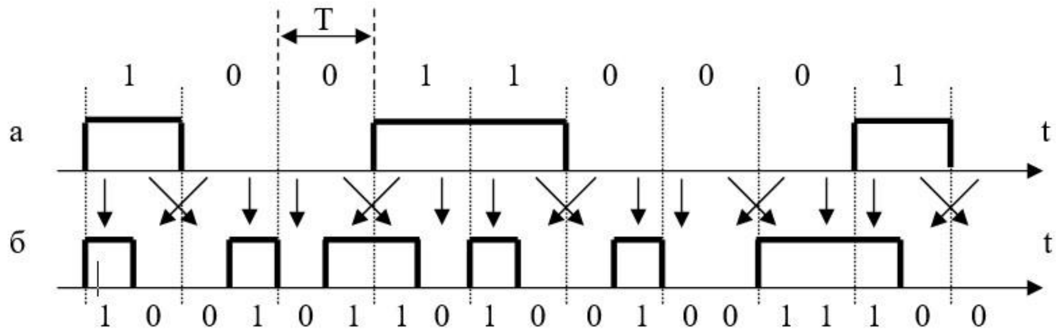

Figure 1. An algorithm for generating a bipulse signal of the second type

It is straightforward to establish correspondences between pairs of symbols in the original signal and the four-bit combinations that are allowed when analyzing this algorithm:

$$00 \longrightarrow 0011;\quad 01 \longrightarrow 0110;\quad 11 \longrightarrow 1100;\quad 10 \longrightarrow 1001.$$

Objective

The purpose of the study is to determine the capabilities of the code in terms of error detection and correction.

Material and Methods

Using the error detection method based on the detection of forbidden combinations. Table 1 shows all possible transformations of allowed combinations under the influence of single errors, as well as packets consisting of two, three and four errors (Sabapathi & Sundaravadivelu, 2011; Gertler & Singer, 1990). Analysis of the table shows that under the influence of one, two and three errors, forbidden combinations appear in the code, i.e., errors are found. At the same time, single and triple errors cause the formation of the same forbidden combinations, which does not allow us to judge the number of distorted symbols, while paired errors are unambiguously detected.

Table1
Transformation of allowed combinations under the influence of single errors and bursts of errors

Allowed combinations	Impact of one error	Impact of two errors	Impact of three errors	Impact of four errors
0011	1011 0111 0001 0010	1111 0101 0000	1101 0100	1100
0110	1110 0010 0100 0111	1010 0000 0101	1000 0001	1001
1100	0100 1000 1110 1101	0000 1010 1111	0010 1011	0011
1001	0001 1101 1011 1000	0101 1111 1010	0111 1110	0110

If all bits of the allowed combinations are distorted, other allowed combinations are always formed and, therefore, error detection does not occur. As a result, this code leaves much to be desired in terms of corrective abilities. Indeed, if we consider, for example, the case of the appearance of a forbidden combination 1101, we can only determine that either the combinations 1100 or 1001 were distorted by a single error or the combination 0011 was a triple one. The probability of accurate recovery of a distorted combination is small: for example, even if we assume that triple errors do not appear at all then it is equal to 0.5. In the presence of packets of three errors, this probability decreases in proportion to the increase in the probability of packet occurrence. In the case of pair errors, when any forbidden combination can appear when only two allowed combinations are distorted, the true combination can be restored with a probability of 0.5. In case of a four-time errors impact, there is no need to talk about correction. Let us examine the possibility of increasing the probability of error correction using the method proposed by us in. Rather than going into details about this method, we briefly describe its essence (Floris et al., 2021; Yu et al., 2006; Utomo & Darma, 2020).

On the transmitting side, the digital stream is presented in the form of fragments containing a certain number q of clock intervals. To fix the boundaries of the fragments, synchronization signals are used, which in the general case are a block consisting of two forbidden combinations. The fragment determines whether the number of each allowed combination is even or odd. At the end of the fragment, on specially allocated additional clock intervals, each of which is intended for a specific allowed combination, pre-selected combinations are placed, one of which indicates an even number, and the other indicates an odd number of allowed combinations.

On the receiving side the synchronization signal is detected and then the same processes take place as on the transmitting side, particularly determining the evenness or oddness of the number of each allowed combination within the fragments and the formation of the corresponding combinations on auxiliary time intervals. After that, a comparison is made of combinations located at single-valued positions of the auxiliary time intervals of the transmitter and receiver. If there is no error in the communication line, then the transmitted and received sequences are identical. Therefore, on additional time intervals of both sequences unambiguous combinations coincide (Ouertani et al., 2008; Alian et al., 2019; Jain, 2016).

If there is an error in the line, one of the allowed combinations turns into a forbidden one, i.e. the total number of this combination is reduced by one. Therefore, if this number was even on the transmitting side, then it will be odd on the receiving side and vice versa. Thus, on one of the additional clock intervals, the combinations generated in the transmitter and receiver will differ from each other, which indicates that the forbidden combination should be replaced by the allowed one, the information about the even or odd parity of which is located on this interval. Let us evaluate the efficiency of the proposed method for a bipulse code of the 2nd type.

Since the code has four allowed combinations, the number of auxiliary clock intervals is four. We will place on the I interval information about the even or odd number of combinations 0011, on II - combinations 0110, on III - combinations 1100 and on IV - combinations 1001. The even number of combinations will be denoted by the combination 1010, the oddness - by the combination 0101. As a synchronization signal, we use block 00001111. Let the number of each of the allowed combinations on the transmitting side be even (Bose & Ray-Chaudhuri, 1960; Arora et al., 1997).

Taking into consideration above mentioned, Fig. 2a shows one of the possible fragments of the signal generated in the transmitter. The error (Fig. 2b, 3rd information interval) caused distortion of the second digit of the allowed combination 0110 and the appearance of a forbidden combination 0010. However, the same result could have occurred if the fourth digit of the allowed combination 0011 was distorted or the first three digits were distorted (three-time error) of the 1100 combination, so any of these three can be a valid legal combination. Comparison of the auxiliary intervals of the transmitted and received (Fig. 2b) sequences shows that the combinations located on the second auxiliary intervals differ from each other.

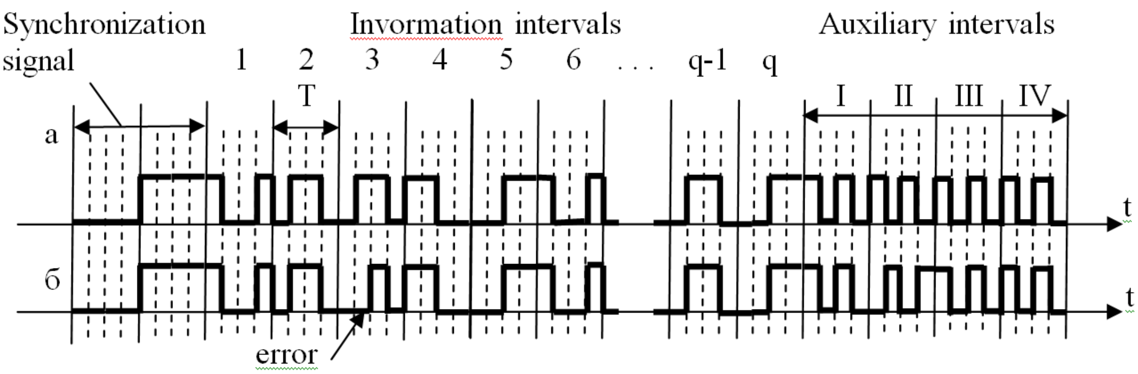

Figure 2. Error correction in 2nd order bi-pulse code

Knowing that the second interval contains information about the evenness or oddness of the combination number 0110, it is concluded that this combination was distorted and therefore, it should replace the forbidden combination on the 3rd clock interval, shown in Fig. 2b.

Results and Discussion

Therefore, for a given code, the proposed method allows correcting single and three-time errors with a probability of 1. The same can be said about paired errors: as can be seen from Table 1, each forbidden combination can appear when two allowed combinations are distorted, the truth of which can be found in the manner indicated above. As mentioned above, when all four digits are distorted, allowed combinations are formed, therefore, to detect and, even more so. these errors cannot be corrected. Nevertheless, this method has an advantage in this case too - it allows you to detect the presence of four-time errors since the number of allowed combinations on the two auxiliary intervals in the transmitter and receiver will not match.

Findings

Table 2 shows the probabilities of detecting and correcting errors in a bipulse code of the 2nd order, determined for both cases - without using the specified method and with its use. This table clearly shows the advantages that take place in the second case.

Table 2
Probabilities of detection and correction of errors without and with the method of increasing the probability of a correction

Number of mistakes	Without method		With method	
	Detection probability	Correction probability	Detection probability	Correction probability
1	1	≤0,5	1	1
2	1	0.5	1	1
3	1	≤0.5	1	1
4	0	0	1	0

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