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Code multiplexing using linear block codes

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Abstract. This paper explores the application of code multiplexing using linear block codes in communication systems. Through a comprehensive analysis of contemporary literature on switching methods and signal modeling, the study investigates the principles of code channel division switching. The research proposes novel approaches for synthesizing orthogonal encoding and decoding matrices, enabling efficient channel division through simplified schemes. The study focuses on the implementation of code division multiplexing using block codes, highlighting its potential for enhancing communication efficiency. Additionally, the paper discusses the dual benefit of this approach, noting its capacity for simultaneous error correction during the channel division process. This feature underscores the method's potential for improving both the reliability and efficiency of data transmission in various communication systems

1 Introduction

In the contemporary global landscape, including Russia, the significance and demand for information technology are experiencing substantial growth. The escalating volume of data transmitted through switched communication channels, encompassing space and satellite networks, has created a pressing need for innovation. This surge in data transmission has prompted the development of more efficient switching device schemes, with a focus on reducing the number of mathematical operations required compared to existing alternatives.

Until recently, there was a clear division in telecommunications into switching systems and transmission systems. However, now with the development and widespread use of digital technologies, there is an interpenetration of these areas of telecommunications, which leads to the need to consider the transmission and switching of signals in communication systems together [1]. Depending on the form of presentation of the information transmitted through the system, digital and analog switching are distinguished. Digital switching refers to the process, in which connections between the input and output of a system are established by manipulating a digital signal without converting it to an analog signal.

There are two switching principles – with path switching (channel switching) and with information memorization (memory switching) [2]. Channel switching is used mainly in networks that have two main requirements: the time to establish a connection should be significantly less than the communication session time, and, in addition, information delays

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during transmission should be minimal. Usually these are networks where it is necessary to provide an interactive work. With this method, the connecting path between the input and output of the system is provided for the time required to transfer all the information. Channel switching is a way to organize a direct communication between two or more subscribers for the exchange of information in a real time. The establishment of a channel switching connection is carried out by dialing the number by the calling subscriber. Memory switching is based on the transfer of information previously recorded in the memory of the switching node. In this case, the data can be converted (change the transmission rate, change the code, add or remove the service information). Memory switching is used, as a rule, in digital networks and is subdivided into message switching and packet switching.

Therefore, the goal of the research is to develop principles for constructing schemes for implementing code channel combining on the transmitting side and code channel division on the receiving side of the communication system.

2 Channel separation methods

In the context of a basic network comprising two endpoints connected by N digital channels, the independent transmission of signals requires channel separation. This separation can be achieved through various methods [3]:

- Spatial Separation: Utilizing distinct physical media for each channel.
- Temporal Separation: Allocating different time slots for signal transmission in each channel.
- Frequency Separation: Assigning specific frequency bands within the linear path's range to individual channels.
- Wavelength Separation: Employing different wavelengths in optical fiber to create separate digital channels.
- Code-Based Separation: Applying unique code values to distinguish signals.
- Modal Separation: Exploiting various electromagnetic wave modes in waveguides and optical fibers.
- Polarization-Based Separation: Leveraging different polarizations of electromagnetic waves in waveguides and optical cables.

It's important to note that channel division between two nodes doesn't necessarily involve a unified electromagnetic signal propagation medium. To enable signal transmission through a single medium, channels separated by any method (except spatial) are typically combined or multiplexed, resulting in a digital transmission system.

In the realm of digital switching systems, time-division multiplexing is the predominant technique for signal combination and separation. Within telephony, this approach is defined as a method for distributing telephone channels temporally over a single physical communication line, often employing a form of pulse modulation.

Code Division Multiple Access (CDMA) technology offers several advantages in communication systems:

- Enhanced noise resistance in the communication channel;
- Improved data confidentiality;
- High data transfer speeds;
- Increased system throughput.

These benefits make CDMA a valuable technology in modern telecommunications, particularly in scenarios requiring robust and secure data transmission [4-6].

3 Code division using linear block codes

The general scheme of code division of channels can be described as follows. Let there be N sources of information. The output of each source is encoded with some block code having the length of N binary symbols and the rate of 1/N bits per transmitted symbol. This is a simple code containing only two code words: one word has always only zero characters, and the second word is nonzero. The results of encoding of one bit of each source are vectors of dimension N and are added bitwise modulo two and transmitted sequentially, character by character, over some binary communication channel. Any N vectors forming the basis of an N-dimensional space over a binary field can be used as nonzero code words.

On the receiving side, the received sequence is decomposed into compound vectors in this basis. In this case, the expansion coefficients are those symbols that are given by various recipients of information.

Let's consider a simple example. Let there be four sources of information and four receivers. Let's compose some matrix A of size (4 x 4) of the following form

$$A = \begin{pmatrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 \end{pmatrix} \tag{1}$$

This matrix has the nonzero determinant in the field of residues modulo two and, therefore, the rows of this matrix form a basis in a four-dimensional vector space consisting of binary vectors. Matrix A defines the four simplest codes at a rate of 1/4 bit per symbol. Each code contains a code word of all zeros and one more word, which is a row of matrix A. If we assume that four sources of information transmit their information bits simultaneously, then they can be represented as a four-dimensional row vector:

$$u = (u_1\ u_2\ u_3\ u_4) \tag{2}$$

It is assumed that at the next moment in time such a vector will contain the following information bits of four sources, and so on.

The encoding consists in multiplying of some row vector by the matrix A. The resulting vector

$$v = (v_1\ v_2\ v_3\ v_4) \tag{3}$$

is transmitted over the communication channel.

Of course, it is assumed that the transmitter is equipped with the P/S type converter (a parallel code is converted to a serial one) and the receiver is equipped with the S/P type converter (a serial code is converted to a parallel one).

Note that the chosen matrix A has the property of self-orthogonality, that is

$$A \cdot A^{-1} = A \cdot A = I \tag{4}$$

where I is the order four identity matrix and A^{-1} is the inverse matrix of A.

On the receiving side of the communication system, the received vector is multiplied by the matrix A again, and the result is a vector consisting of user information bits.

A similar approach was used to synthesize orthogonal matrices for the purpose of constructing codes and ensuring noise immunity of communication systems [7].

Note that if some pairs of subscribers are inactive, it is possible to introduce control over the presence of errors during a transmission over the communication channel [8, 9]. If some pairs of subscribers are inactive, then only zero symbols will be transmitted over the channel in the corresponding bits of the vector, and the appearance of unitary symbols in these bits indicates the presence of transmission errors. In this case, some rows in the matrix A can be eliminated, and as a result, we obtain a generator matrix of linear codes with error detection and correction.

Hence, we can conclude that the considered class of linear transformations of signals is closely related to the structures of linear codes and the orthogonality properties of both individual pairs of vectors and the orthogonality of subspaces.

4 Conclusion

The paper considers two basic principles of switching – with path switching (channel switching) and with information memorization (memory switching storage). It is shown that in the simplest network of two points, between which N digital channels are organized, independent transmission of signals over these channels is possible if they are separated from each other.

Code division of channels using block codes is considered. The possibility of error correction simultaneously with code division of channels is also noted.

The practical significance of the proposed method is confirmed by the correspondence of the simulation results to the theoretical proposals.

The research results can be applied in space and satellite communications technologies, in real-time systems, in distributed systems in on-board equipment complexes, to ensure reliable information transmission.

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