 https://doi.org/10.1051/e3sconf/202562704008

Algorithms to improve system reliability

Odil Jumaev[1*], *Dzmitry* Karpovich[2], *Muhriddin* Ismoilov[1], *Giyosjon* Makhmudov[1], and *Ramil* Sayfulin[1]

[1]Navoi State University of Mining and Technologies, Navoi, Uzbekistan
[2]Belarusian State Technological University, Minsk, Belarus

Abstract. This article provides a detailed description of the main stages of information processing, specifically, the data on discretization, coding and modulation, as well as the structural analysis of discrete communication systems, which include methods of transmitting information over a distance via discrete interface channels. Based on the study of the main characteristics of the signal, the parameters of the information channel are analyzed. Attention is paid to the methods of signal processing during the reception of the signal by the system interface. The technical parameters of the communication channel are determined by this parameter and the processes of adapting it to the requirements of data transmission are analyzed. Methods for optimizing the considered parameters to ensure high throughput, minimize the signal arrival time, and increase the reliability of communication systems are studied.

1 Introduction

Currently, all information about technological processes is received in the form of signals. Data is analysed through signals. Digital processing of signals allows you to adapt information to transmission channels, and allows you to maximize the characteristics of the transmission channel. The main form of signal processing is modulation. Modulation helps to eliminate the disadvantages associated with the width of the communication channel and the frequency of data transmission. This is extremely important for ensuring the integrity and quality of data transmitted over a distance. To achieve this result, various methods of modulators can be used. These include amplitude modulation, frequency modulation, phase-frequency modulation, phase-pulse modulation and various other modulation methods. The choice of one of the modulation methods in communication control processes is determined by the requirements for the characteristics of the communication channel, interfaces, communication protocols, and data transmission efficiency [1].

2 Materials and methods

If we consider the modulation process, it first starts with analyzing the signals. Later in the process, the modulator begins to analyze and divide the signals into the desired frequencies.

* Corresponding author: jumaev5216@mail.ru

This includes establishing the required amplitude, phase, and frequency, which will be superimposed on the carrier wave to form the final signal S(t). This signal is then transmitted over the communication channel, where it must be delivered with minimal distortion and loss. As a result, the received oscillation $U(t)$ will be represented by the formula:

$$U(t) = \varepsilon S(\text{t-}\tau,\text{Y}(\lambda(t))+\text{n}(t)) \quad (1)$$

where ε denotes signal attenuation; τ are time delays; $n(t)$ are disturbing interference in communication channels.

The functions of the receiver on the channel of transmission and processing of information consist in exact reconstruction of the transmitted message on the basis of the received oscillation U(t)), be it (λ(t) or $\vec{\Lambda}$ However, due to interference, which is inevitably present in any communication channel, the reproduced message often differs from the sent one. This reproduced message is usually called an estimate and is designated in the same way as the original message, but with the addition of the asterisk symbol: *: $\lambda^*(t)$ or $\vec{\Lambda}^*$.

The accuracy of the transmitted message reproduction critically depends on the quality and characteristics of the communication channel, as well as on the efficiency of signal processing algorithms on the receiving side. The receiver uses various error correction and signal quality improvement methods to minimize the impact of interference and other distortions caused by the transmission channel [2-3].

Uninterrupted signal transmission is ensured only when the signal volume does not exceed the channel capacity, i.e. when the signal “fits” into the available channel capacity (Figure 1). This condition is key to ensuring high-quality communication without unwanted distortions and data losses.

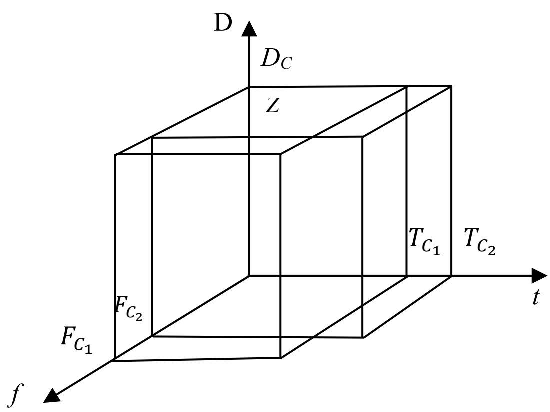

Fig. 1. Channel capacity.

The speed of transmitted information is the average number of the volume of information that is transmitted over a given communication interface per unit of time. Analytically, it can be expressed as follows:

$$C = \bar{I}(Z,Y) = \lim_{T\to\infty} I(Z,Y)/T \quad (2)$$

where $I(Z,Y)$ is a certain numerical value of information transmitted over time T.

Also, the throughput of this channel can be determined: $C = \max\{\bar{I}(Z,Y)\}$.

The current rate of information input is defined as an analytical expression describing the average flow of information supplied to the channel input relative to the duration of the message:

$$\bar{I}(X) = \lim_{T\to\infty} I(X)/T \quad (3)$$

where $I(X)$ is the average amount of information transmitted at the channel input; T is the duration of the message.

$$\bar{I}(X) \leq C \tag{4}$$

This condition guarantees that the information flow will be transmitted without overloads and losses, ensuring the reliability and efficiency of the communication network. Interference in an interface system is any unwanted process or phenomenon that affects the useful signal, making it difficult to receive accurately [4].

Multiplicative interference, unlike additive interference, changes the amplitude or other parameters of the signal, which depends on the current state of the interface channel. For example, it can be caused by gain fluctuations in amplifiers or other changes in transmission modules that affect the signal as it propagates.

In the field of data processing, we need to be able to assess the impact of the noise under consideration on the capacity of the communication channel. The maximum capacity of the communication channel K is the relationship between the signal strength and the strength of the external noise, which can be determined by the following logarithmic expression:

$$K = C_{log\,2}(1 + P/N) \tag{5}$$

In this formula, B is the channel bandwidth, S is the average signal strength, and N is the average noise strength. From this equation, we can see that the communication capacity of the channel depends on the signal strength and noise strength, as well as on the transmission capacity of the communication channel. The above methods

are able to eliminate noise in the signal that determines the state of objects in technological processes and serve as the basis for ensuring the quality of information transmitted through communication channels.

Through the created filters and noise suppression methods, digital television, mobile communications, and other modern communication systems, taking into account these theoretical data, serve to ensure high-quality and reliable transmission of information even under existing disturbances.

From the general characteristics of existing discrete communication channels, it is clear that digital signals, having a digital form and encoded, contain transmitted channel elements [5].

Description of the main characteristics of a discrete communication channel:

1. Input alphabet $B_{ê} = (b_1; b_2; \dots; b_i; \dots; b_{m-1})$,

A set of symbols, such as 0, 1, 2, ..., used to encode information at the channel input.

2. The output signal value $B'_{ê} = (b'_1; b'_2; \dots; b'_i; \dots; b'_{m-1})$ differs from the input signal value and can be expressed by additional expressions in the event of information corruption and errors. In particular the output alphabet may include additional symbols to indicate errors or for use in error correction.

3. Transmission rate V_k Determined by the characteristics of the continuous channel, including its throughput capabilities and "memory", that is, the ability to retain information for a certain time.

4. Transition matrix: It is a set of conditional probabilities $P(b'_i/b_j)$, which describe the probability of receiving the symbol b'_i at the output, given that the symbol b_j was fed to the input. This matrix is a key element in assessing the quality of the channel and its ability to correct errors.

Thus, the discrete channel ensures the transmission of information by converting input discrete signals into output signals through an intermediate continuous channel, (Figure 2.) where they are exposed to various interferences, which requires appropriate correction and adaptation at the demodulation stage.

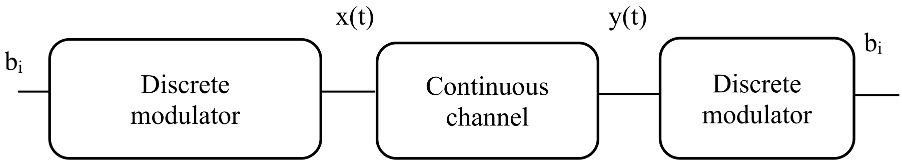

Fig. 2. General view of a discrete channel.

3 Results

In addition to the characteristics mentioned above, the main parameters of a discrete channel also include its throughput and the amount of information transmitted. The amount of information transmitted is measured in bits or symbols and indicates the total amount of data successfully transmitted through the channel during a given time interval. One of the important models of a discrete channel is a binary symmetric memoryless channel.

In this case, p and q have the property: $p = p_{11} = p_{22}$ and $q = p_{12} = p_{21}$. A feature of such a symmetric interface is that interference is not directly related to the type of transmitted signals. This means that interference acts equally on any of the transmitted symbols, regardless of their original value. This type of mathematical model is effective for determining the characteristics of the system because it uniformly reflects errors and creates the possibility of using existing types of error correction. The above figures, namely in Figure 3, represent the transition states for this type of channel. These figures represent the probability distribution between the existing representations of the communication signal. This is an effective method for analyzing the characteristics of existing interfaces and organizing a data transmission system.

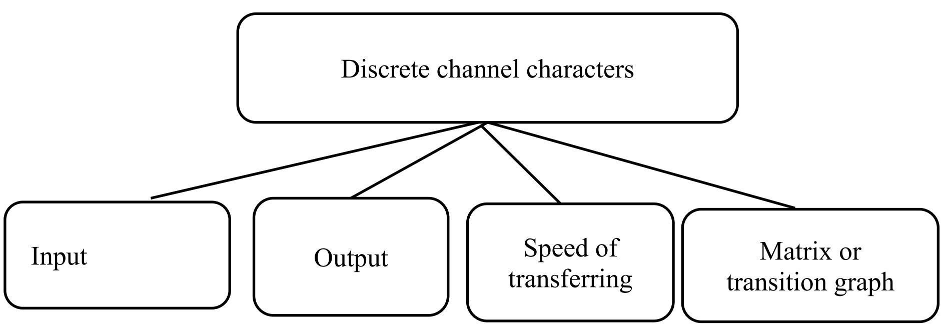

Fig. 3. Data transmission channel characters.

In such figures, we can see the probabilities depicted on the p and q axes. Through q, we can conclude how the signal changes and its correct transmission are related to the probability p. This allows us to understand the changes in signal parameters in various possible processes. It allows us to assess how changes in the characteristics of the communication channel can affect the reliability of the information transmission system over a distance. One of the important tasks is the analysis of a symmetric digital interface system. It provides a model in which the signal changes are uniformly distributed. This analysis is simple and predictable. This model provides the ability to correct errors and the ability to test the system through the model. A symmetric communication channel serves as the basic model for complex scenarios with varying intensity in various external disturbances.Communication system designers can modify the base model by introducing additional parameters or conditions to approximate real operating conditions. Thus, the study and modeling of a symmetric binary channel not only simplifies the initial analysis and design of data transmission systems, but also serves as a basis for a deeper understanding and improvement of communication technologies, contributing to the increase in the overall stability and reliability of modern communication systems (Figure 4).

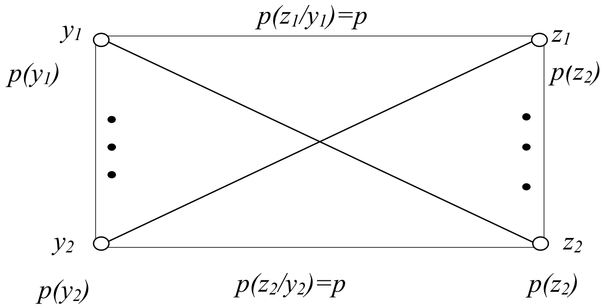

Fig. 4. Graphical representation of transition states for a digital symmetric interface with existing interference.

The established speeds of transmitted information in a digital interface with interference can be formulated by the following entropy expressions:

$$\bar{I}(Z,Y) = \bar{U}_Y[H(Y) - H(Y/Z) \quad (6)$$

where H(Y/Z) is an additional component of the output signal entropy, dependent on the effect of interference. An alternative approach to determining the speed of transmitted information is the following expression:

$$\bar{I}(Z,Y) = \bar{U}_Y[H(Y) - H(Y/Z) \quad (7)$$

The above expressions allow signal processing in a communication channel without a memory device. This allows us to perform calculations much easier. It greatly simplifies the use of natural methods for analyzing the speed of information transmitted over a distance and the performance of communication channels [6].

This makes it possible to identify random errors that occur, especially during signal transmission over a distance, as a result of external influences and disturbances.

Understanding the concepts of mutual information through the methods and techniques thus defined plays an important role in the development of communication technologies.

$$\bar{I}(Z,Y) = \bar{U}_Y\left[-\sum_{i=1}^{n} p(y_i)\, log_2\, p(y_i) + \sum_{i=1}^{n}\sum_{j=1}^{n} p\,(z_i)p\,(y_i/z_i)\, log_2\, p\,(y_i/z_i)\right] \quad (8)$$

$$\bar{I}(Z,Y) = \bar{U}_Y\left[-\sum_{i=1}^{n} p(z_i)\, log_2\, p(z_i) + \sum_{i=1}^{n}\sum_{j=1}^{n} p\,(y_i)p\,(z_i/y_i)\, log_2\, p\,(z_i/y_i)\right] \quad (9)$$

Let us consider a binary digital system that defines the content of signals with input Y and output Z:

$$Y = \{y_1, y_2\}; Z = \{z_1, z_2\}. \quad (10)$$

We define the probability of an error as follows:

$$p(z_1/y_1) = 1; p(z_2/y_2) = q_2 \quad (11)$$

Accordingly, we note that the state of correct transmission will be $p(z_1/y_1) = 1 - q_2; p(z_2/y_2) = 1 - q_1$, To determine the best a priori states $p(y_1)$ and $p(y_2)$, it is necessary to take into account that the sum of these probabilities must be equal to 1, i.e. $p(y_1) + p(y_2)$ = 1. In this context, the problem of maximizing the mutual information $\bar{I}(Z,Y)$ is reduced to finding such values of $p(y_1)$ and $p(y_2)$, that maximize this indicator.

The physical meaning of channel symmetry is to select a threshold level in the discrete demodulator, also known as the first calculation circuit, that is placed exactly between the average values of the signals corresponding to logical zero and one. This ensures an equal probability of erroneous reception of each of the symbols under interference. If the threshold were shifted closer to zero, this would lead to an increase in the probability of erroneous reception of zero as one due to interference, which would make the channel asymmetric.

4 Conclusion

These calculations allow a more accurate estimate of the true value of the transmitted signal, minimizing the probability of error in the presence of interference.

$$P(0/0') = P(0)P(0'/0)/[P(0)P(0'/0) + P(1)P(0'/1)];$$
$$P(0)\ {}^{\circ}P(y'/0)$$
$$P(1)\ {}''P(0/1')$$
$$P(0)^{\circ}0'P(0/0')$$
$$P(1/0')$$

Illustration of transition graphs in a binary channel. The probability of each hypothesis in such a communication channel is calculated by the probability value when determining the overall probability sign. This allows for the determination of channel performance indicators. In this case, we can take the symbol, albeit with a small probability. When the probabilities of a correct and erroneous junction are similar, this determines the unsatisfactory operating mode of the channel. To improve the accuracy and efficiency of the channel, it is necessary to take measures to correct the boundary levels. For instance, shifting the beginning level so that the a priori possibility of reception a zero when communicating a unit $P(0'/1)$ is significantly less than the probability of receiving a unit $P(1)$ will help reduce the number of erroneous transitions and improve the quality of data transmission over the channel. This is especially important in conditions where reception accuracy is critical and errors can lead to serious consequences.

References

1. A.N. Denisenko Signals, *Theoretical radio engineering* (Moscow: Hotline - Telecom) (2005).
2. M.C. Jeruchim, P. Balaban, K.S. Shanmugan, *Simulation of communication systems: modeling, methodology and techniques* (Springer Science & Business Media, 2006). https://link.springer.com/book/10.1007/b117713
3. J.N. Lygouras, V. Kodogiannis, T.P. Pachidis, G.C. Sirakoulis, Microprocess. Microsyst **33**, 453-460 (2009).
4. E.G. Kravchenko, *Reliability of technical systems in mechanical engineering* (KnAGTU, 2014).
5. W. Ahmad, O. Hasan, U. Pervez, J. Qadir, Journal of Network and Computer Applications **78**, 191-215 (2017).
6. S. Berber, *Discrete communication systems* (Oxford university press, 2021).