Method of Fractal Traffic Generation by a Model of Generator on the Graph

Hanna Drieieva [1 [0000-0002-8557-3443]], Oleksii Smirnov [1,3 [0000-0001-9543-874X]], Oleksandr Drieiev [1 [0000-0001-6951-2002]], Yuliia Polishchuk [2 [0000-0002-0686-2328]], Rashit Brzhanov [3 [0000-0001-8755-8207]] and Marek Aleksander [4 [0000-0003-2619-1063]]

[1] Central Ukrainian National Technical University, Ukraine, Kropyvnytskyi

[2] National Aviation University, Ukraine, Kyiv

[3] Yessenov University, Aktau, Kazakhstan

[4] Państwowa Wyższa Szkoła Zawodowa w Nowym Sączu, Nowy Sącz, Poland

gannadreeva@gmail.com, dr.SmirnovOA@gmail.com, drey.sanya@gmail.com,polischuk.yu.ya@gmail.com

Abstract. The problem of generating traffic with given fractal properties in order to use it in simulation processes of the computer network, which is carried out to predict the properties of the telecommunication system in the meantime delay of information packets and their likelihood of loss is dedicated in the paper. The subject of the research in the article is the method of generating fractal traffic using a generator model on the graph. The purpose of the research is to create a method for generating fractal traffic using a generator model on the graph. For this purpose, the following tasks were solved: defined fractal properties of telecommunication traffic and the consequences of fractality; were defined the fractal dimension of the numerical series and the distribution density of the elements of the series were determined; the estimation of the fractal properties of the generated binary sequences is carried out; the management mode of the intensity of generated traffic; suggested the generator was adjusted to match the sample traffic. The result of the work is the implementation of the method of generating fractal traffic using a generator model on the graph, due to the application of the following steps: the relevance of the problem of creating generators of fractal binary sequences without the use of infinite distributions is identified; the generator of a fractal binary sequence given by the Markov chain; the variability of the fractal dimension of the binary sequence and at different intensities τ is demonstrated; analytic expressions are derived for obtaining generator parameters with a given output bits density with the control of their fractal dimension.

Keywords: Network, Simulation, Traffic, Graph, Fractal, Qos, Markov Chain.

1 Introduction

In the process of developing the hardware and software components of telecommunication and computer network equipment, it is necessary to meet the requirements of quality of service (QoS). In order to ensure that the equipment meets the requirements of the quality of service of telecommunication equipment, it is necessary to have a mathematical model of information transfer processes where QoS parameters have an analytical estimate. Also, these estimates can be obtained as a result of simulation based on mathematical models of the developed telecommunication equipment, in case it is impossible to obtain analytical solutions.

2 Analysis of recent research and publications

In case of the presence of fractal telecommunication traffic in computer networks, the simulation should take into account fractal capabilities, so are used as sources generators of traffic on the basis of distributions with a “heavy tail” [1, p. 80]. Paper [1] presents the generation of the Method-Based Pareto-Modulated Poisson Processes (PMPP) based on the Pareto distribution. In this case, the research remains relevant and is considered in modern studies [2].

Modern telecommunication systems form increasingly complex structures, which leads to the unsuitability of analytical apparatus to optimize the parameters of telecommunication equipment. This leads to a lack of optimality of equipment and, consequently, deterioration in the quality of service on the requirements of QoS. To determine the optimal modes of operation of telecommunication equipment, simulation systems are used (in particular: OPNET, Emulab, NISTNET, NS, GTNeS, DummyNet, ModelNet, Ohio Network Emulator, ENDE, EMPOWER, NSE, NETWARS) that demonstrate the need for increasingly computational resources to optimize increasingly complex telecommunication systems [4-11]. Composite imitation systems are also simulators of the source of telecommunication traffic, which is divided by the properties into periodic, random and self-similar. The importance of reliable results of the process of mathematical simulation of the work of the telecommunications network of traffic generators has been confirmed by the consistent availability of reports on this topic at the IEEE MASCOTS International Symposium (Simulation, Analysis and Simulation of Computer and Telecommunication Systems) in the program. For example, in 2018. The following report is included [5]. In modern simulation, the following types of traffic sources are used [12-16]:

1. Poisson process - an example of a source of random traffic. These generators are well described analytically, which allows us to build analytical formulas for evaluating service quality indicators. Unfortunately, in modern systems this type of traffic is not widespread.
2. Generator of traffic based on the fractal Brownian motion [10].
3. Fractal Gaussian noise. Generation is based on the use of discrete wavelet transformation. Detailing wavelet coefficients at each of the levels are independent random variables with normal distribution. Approximation coefficients are the result of a fractal autoregression with a sliding middle process [9]. The advantages of models based on the fractal Brownian motion and the fractal Gaussian noise are the properties of self-sustainability and long-term dependence that are observed in experimental data. There is also the possibility of their analytical interpretation. The

disadvantages are insufficient means of selecting parameters for generating traffic with given properties. Therefore, these generators are not enough to generate plausible traffic.

4. Fractal movement Levy is a generalized Brownian motion, has a self-similar character, forms distributions with «heavy tails». Among the drawbacks it is worth noting the need to take into account several parameters that determine the state of the model for which there is no direct method of evaluation.
5. Autoregressive models assume that the current value of the process is the sum of a constant, weighted sum of previous values and model error. Autoregressive models are relatively simple, but they are inherent in the lack of simulation of nonlinearities. They are characterized by a burdensome mathematical apparatus and, as a result, the process of bringing to experimental traffic is time-consuming.
6. Neural network (NM) models are trained neural networks on experimental traffic in the prediction mode of a new element. The neural network contains several layers with a nonlinear activation function and an output linear neuron. But neural networks require training, they have a complex analysis of the trained network, the choice of learning algorithm and network architecture in most cases is selected. Also, strict requirements for the training sample are set.
7. Use of Markov chains. The use of Markov chains allows us to create a very simple, compared with previous methods, model for generating discrete traffic with a wide range of properties. Experiments show good correspondence with real traffic of the telecommunication network. To set up the model you need to set only five parameters, often for process description only two probabilities of change between unit and zero states. The use of the generator on the Markov chains also allows for analytical solutions that are a useful alternative to numerical simulation methods.

In view of the generators of telecommunication traffic, it can be noted that in most cases, the selection of the method of generating traffic is dependent on a particular situation, but in general, Mark-based generation methods are distinguished by less computational complexity and a wider range of applicability. Therefore, the task of improving the analytical methods of approaching the source of traffic model to real experimental data remains an urgent task that is solved in this article. Thus, the purpose of this work is to create a method for generating fractal traffic using a generator model on the graph.

3 Fractal properties of telecommunication traffic and the consequences of fractality

At the present stage of the development of the mathematical description of telecommunication processes, it is generally accepted to use fractal description of traffic, which is visually accompanied by the presence of abnormally large, compared with normal distribution, number of bursts [3].

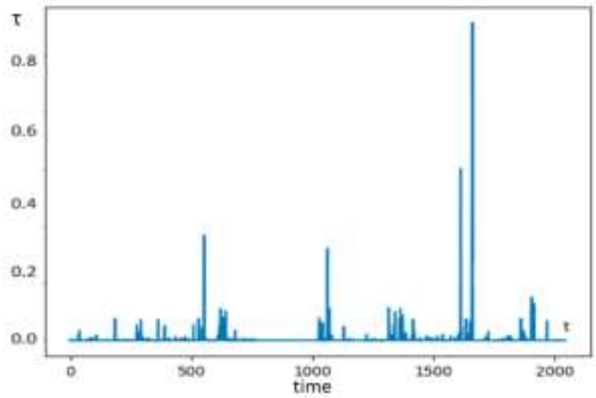


Fig. 1. An example of pulsating multifractal traffic [3]

In most cases, such pulsating processes are described by Pareto distribution [1-3].

4 The fractal dimension of the numerical series and the distribution density of the elements of the series

To identify the fractal dimension one can use one of the definitions, namely the dimension in the interpretation of Minkowski (1), [4]:

$$d = \lim_{\varepsilon \to 0} \frac{\ln(N_\varepsilon)}{-\ln(\varepsilon)} . \quad (1)$$

where the notations are used:

- ε is the size or diameter of the subset, which is covered by the set;
- Nε is the minimum number of sets needed to cover the entire set.

The binary set is not suitable for the direct application of formula (1), since its elements are counted but not continuous, therefore it is not possible to direct ε to zero. It is suggested to circumvent this restriction if the “width” of rectangles of height “1” and “0” in the binary sequence is directed to zero.

Therefore the coating will have an area S = 0, when 1 / ε of the elements of the generated series have a value only of 1 or only of 0, otherwise the coating will have an area S = 1 (Fig. 2).

It is assumed that the implementation of the binary sequence can be continued indefinitely, and then the mathematical expectation of the sum of partial squares S can be expressed using statistics based on mathematical expectation.

For this purpose we find the probability of obtaining a null covering p0(n) with n experiments; then the probability of a single covering will be p1(n) =1-p0(n).

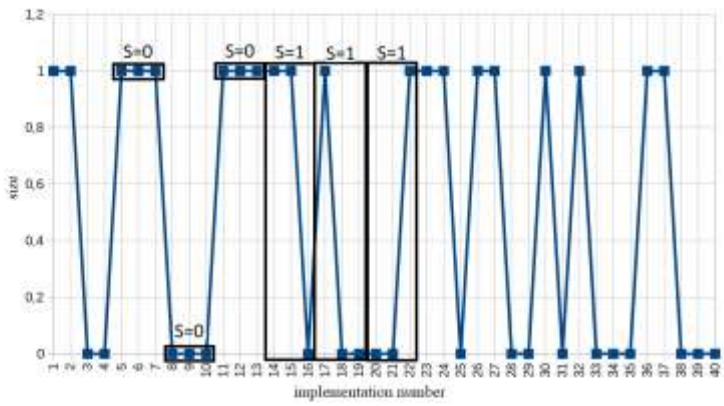


Fig. 2. Determination of the coverage area at 1 / ε = 3

Event p0(n) is possible in the case of a series of “1” or “0” implementations. We introduce a system whose state depends on the previous state, similar to that used in the PMPP system [1, p. 81, fig. 4.1] (Fig. 3).

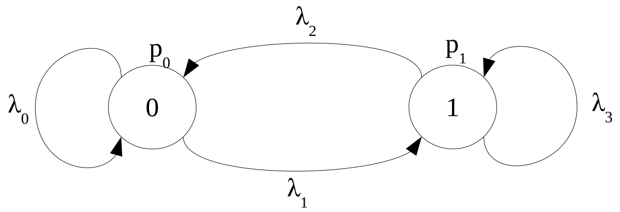


Fig. 3. Model of the generator of fractal traffic

The model uses a state that corresponds to the original generated value at the time. The next value is obtained by random transitions, where λ1 and λ2 are responsible for the probability of changing the state for the next quantum of time, and λ0 and λ3 are the probability of maintaining the current state.

As a result, the probability of a unit series for n quanta of time is (1-λ2)n. But here it is necessary to consider that the series begins with a single value that has the probability p1. Therefore, the probability of a single series eventually has the following form: p1(1-λ2)n. Similarly, the determination of the probability of obtaining a series of zero values is performed: p0(1-λ1)n.

The finite automaton on the basis of the graph (Figure 3) has two states “0” and “1”, with the probability of transition from “0” to “1” and from “1” to “0” in the general case may be different. For the probabilities of transitions λ must meet the following requirements:

$$\begin{cases} \lambda_0 + \lambda_1 = 1 \\ \lambda_2 + \lambda_3 = 1 \end{cases}, \qquad (2)$$

Under the condition λ1=λ2, the graph becomes symmetric and the probability p0=p1=0.5 with a long-term observation the system is equally likely in one of the states. In this case, the mathematical expectation of the generated series is M=0.5, and the dispersion is D=0.25. For rice fig. 3 the following differential equations with respect to the probability of system states are true:

$$\begin{cases} \frac{dp_0(t)}{dt} = -\lambda_1 p_0(t) + \lambda_2 p_1(t) - \lambda_0 p_0(t) + \lambda_0 p_0(t), \\ \frac{dp_1(t)}{dt} = \lambda_1 p_0(t) - \lambda_2 p_1(t) - \lambda_3 p_1(t) + \lambda_3 p_1(t). \end{cases} \quad (3)$$

If we take into account that finding a system in one of the states is a guaranteed event p0+p1=1 and use the condition of stationarity of the process in time (when the probabilities do not change their value and their derivatives are equal to zero), the transformation of system (3) gives the following system:

$$\begin{cases} \lambda_1 p_0(t) - \lambda_2 p_1(t) = 0, \\ p_0(t) + p_1(t) = 1. \end{cases}$$

From the last system you can get the probability of staying the system in the states «0» and «1» (4):

$$p_0 = \frac{\lambda_2}{\lambda_1 + \lambda_2};\ p_1 = \frac{\lambda_1}{\lambda_1 + \lambda_2}. \quad (4)$$

Accordingly, traffic intensity τ will coincide with the probability of receiving «1» at the output of the generator: τ=p1. If we take into account the symmetric condition of the graph λ=λ1=λ2, then the probabilities can be expressed as follows (5):

$$\left(\lambda = \lambda_1 = \lambda_2\right) \Rightarrow \left(p_0 = \frac{\lambda}{\lambda + \lambda};\ p_1 = \frac{\lambda}{\lambda + \lambda} \right) \Rightarrow \left(p_0 = p_1 = 0.5 \right). \quad (5)$$

In accordance with the obtained probabilities (4), it is finally possible to obtain a zero coverage area with length n as the sum of two mutually exclusive events of the unit and zero series (6):

$$p_0(n) = \frac{\lambda_2 (1-\lambda_1)^n + \lambda_1 (1-\lambda_2)^n}{\lambda_1 + \lambda_2}. \quad (6)$$

The unit area is the opposite of an event and is expressed by (7):

$$p_1(n) = 1 - \frac{\lambda_2 (1-\lambda_1)^n + \lambda_1 (1-\lambda_2)^n}{\lambda_1 + \lambda_2}. \quad (7)$$

It is obvious that the mathematical expectation, which in this case corresponds to the average coverage area, can be expressed as follows (8):

$$M(n) = 0 \frac{\lambda_2 (1-\lambda_1)^n + \lambda_1 (1-\lambda_2)^n}{\lambda_1 + \lambda_2} + 1 \left(1 - \frac{\lambda_2 (1-\lambda_1)^n + \lambda_1 (1-\lambda_2)^n}{\lambda_1 + \lambda_2} \right),$$

$$M(n) = 1 - \frac{\lambda_2 (1-\lambda_1)^n + \lambda_1 (1-\lambda_2)^n}{\lambda_1 + \lambda_2}. \quad (8)$$

As a result, the fractal dimension depends on the scale corresponding to the definition of the multifractal, and can be obtained from (1):

$$\begin{cases} n_1 M(n_1) = C \cdot n_1^d \\ n_2 M(n_2) = C \cdot n_2^d \end{cases},\ \frac{n_1 M(n_1)}{n_2 M(n_2)} = \frac{C \cdot n_1^d}{C \cdot n_2^d},\ \ln \frac{n_1 M(n_1)}{n_2 M(n_2)} = d \ln \frac{n_1}{n_2}.$$

$$d(n_1,n_2)=1+\ln(M(n_1)/M(n_2))/\ln(n_1/n_2)\,. \qquad (9)$$

Finally (10):

$$d(n_1,n_2,\lambda_1,\lambda_2)=1+\ln\left(\frac{\lambda_1+\lambda_2-\lambda_2(1-\lambda_1)^{n_1}-\lambda_1(1-\lambda_2)^{n_1}}{\lambda_1+\lambda_2-\lambda_2(1-\lambda_1)^{n_2}-\lambda_1(1-\lambda_2)^{n_2}}\right)/\ln(n_1/n_2) \qquad (10)$$

However, a lot of parameters are used to determine the fractal dimension (10). It is proposed to reduce the dimension of the dimensioning function (11):

$$\lim_{n_1\to n_2} d(n_1,n_2,\lambda_1,\lambda_2)=1+\lim_{n_1\to n_2}\ln\left(\frac{\lambda_1+\lambda_2-\lambda_2(1-\lambda_1)^{n_1}-\lambda_1(1-\lambda_2)^{n_1}}{\lambda_1+\lambda_2-\lambda_2(1-\lambda_1)^{n_2}-\lambda_1(1-\lambda_2)^{n_2}}\right)/\ln(n_1/n_2) \qquad (11)$$

As a result of disclosing the boundary (11), we have the following expression for the search for the fractal dimension, depending on the scale n:

$$d(n,\lambda_1,\lambda_2)=1-\frac{\lambda_2(1-\lambda_1)^n\ln(1-\lambda_1)+\lambda_1(1-\lambda_2)^n\ln(1-\lambda_2)}{\lambda_1+\lambda_2-\lambda_2(1-\lambda_1)^n-\lambda_1(1-\lambda_2)^n}\,. \qquad (12)$$

The next step is to determine the properties of the sequence on individual elements with n → 1, which eliminates the uncertainty of the choice of scaling (13):

$$d(\lambda_1,\lambda_2)=1-\frac{\lambda_2(1-\lambda_1)\ln(1-\lambda_1)+\lambda_1(1-\lambda_2)\ln(1-\lambda_2)}{2\lambda_1\lambda_2}\,. \qquad (13)$$

As a result, for a multifractal traffic generator, the graph of which is shown in Fig. 3, the properties of the sequence are determined by the probabilities of transitions between the states λ1, λ2, and their dimension is expressed by the formula (13).

To simulate a real process with similar properties, for experimental data it is necessary to estimate the probabilities λ1 and λ2. Sometimes real data in the form of the probability of transitions λ1, λ2 to receive on the line is not possible, since the equipment is able to receive only the number of received/transmitted packets per unit time. In this case, it is possible to determine the intensity of traffic relative to the maximum throughput of the channel τ=p1, and the probability of staying in the state of "0" (λ0 – can be expressed in the probability of lack of packet transfer per unit time with the known maximum number of information packets). The graph of the index of the fractal dimension of the generated sequence, depending on the probabilities λ1, λ2, is shown in Fig. 4.

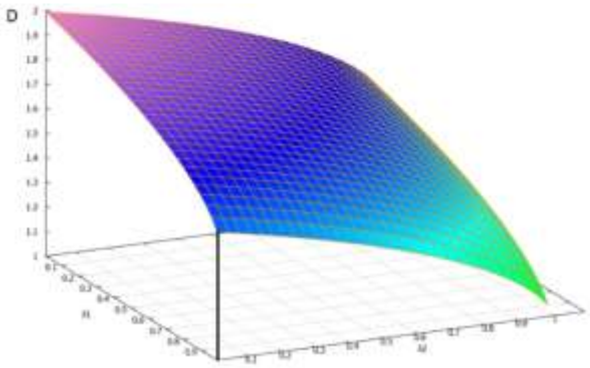


Fig. 4. The fractal dimension of the sequence, depending on the probabilities λ1, λ2

5 Estimation of the fractal properties of the generated binary sequences

In the case of a random process λ=λ1=λ2=0.5, formula (10) is simplified to (14)

$$M(n) = 1 - 0.5^n, \qquad d(n_1, n_2) = 1 + \frac{\ln((1-0.5^{n_1})/(1-0.5^{n_2}))}{\ln(n_1/n_2)}. \qquad (14)$$

However, there is a problem of choice for the values n1, n2. The influence of the selected scaling factors n1, n2 is shown in Fig. 5:

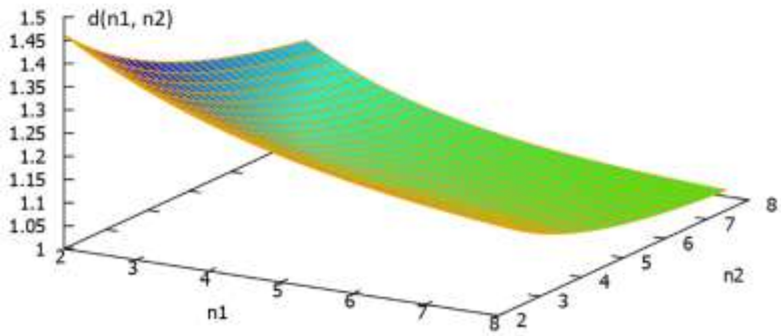
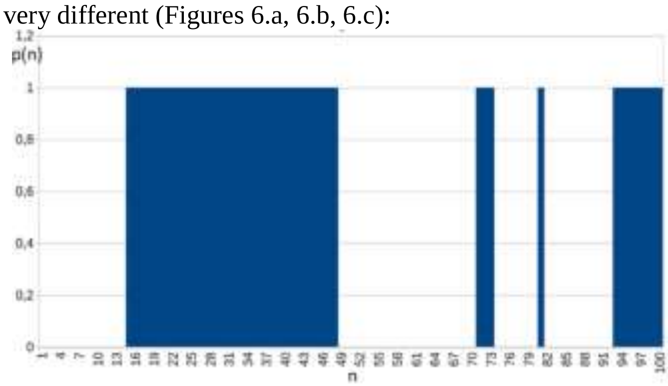
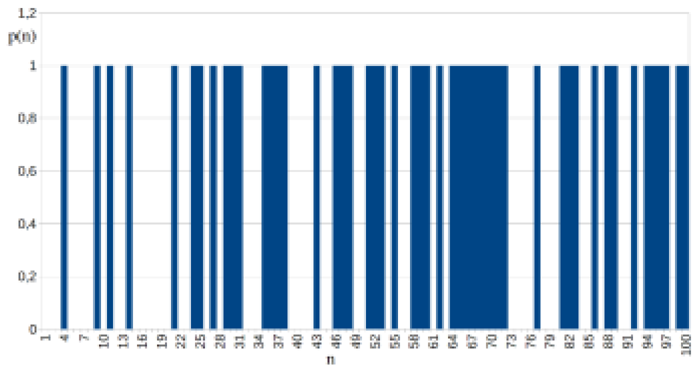


Fig. 5. Dependence of the estimation of the fractal dimension on the length of the samples

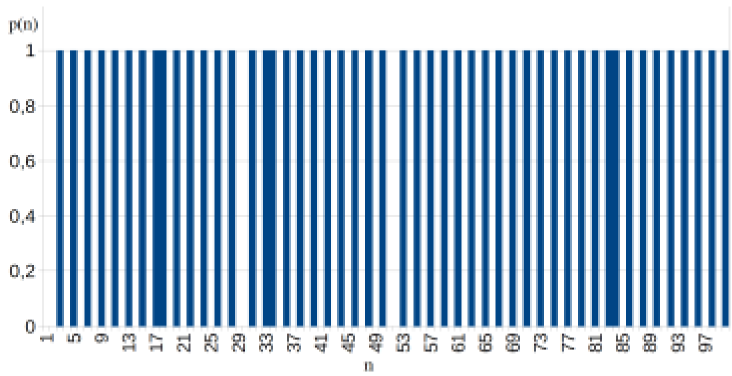
As can be seen from the graph (Fig. 5), with the increase of n1, n2, the calculated fractal dimension falls to a single value corresponding to the transformation of a large scale of a bounded band by a unit amplitude of the binary traffic graph into a one-dimensional line. The minimum values of n1, n2 correspond to the classical representation, which is the logical confirmation of the decisions taken in the previous paragraph. Also, it is important that at λ1=λ2 the intensity of traffic is stored τ=0.5, which corresponds to the mathematical expectation of the received binary sequence. Also, for all λ1=λ2, the process variance is stored, and these values coincide with the random process, for which the «0» and «1» are 0.5. In practice, the appearance of these sequences is very different (Figures 6.a, 6.b, 6.c):



a) λ1=λ2=0.95, a row is persistent



b) λ1=λ2=0.5, a row is random



c) λ1=λ2=0.05, a row is unpersistent

Fig. 6. Examples of statistically identical series with different fractal dimension

Accordingly, the graphs in Fig. 6, we can conclude that the generator, whose graph is shown in Fig. 3, capable of reproducing the fractal properties of the sequence.

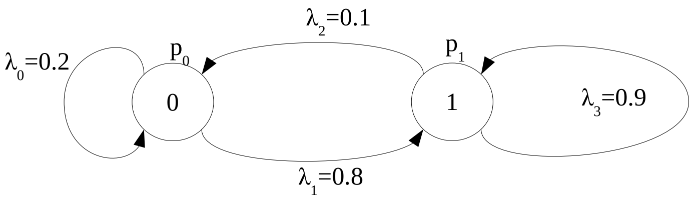
6 Managing the intensity of generated traffic

We use the definition of the intensity of traffic τ, as the probability of packet transfer in a given time slice and is measured from 0 to 1.

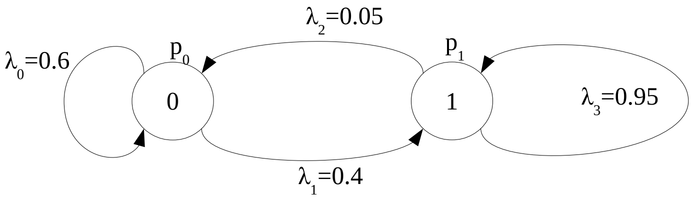
In the previous paragraph, the traffic generator was considered for which the probability of output «0» and «1» were equal, the traffic intensity was τ=0.5. For conducting simulation experiments and theoretical searches it is necessary to be able to control the intensity of the generated packets, that is, the probability of generating «1»: p1. Above was the probability values p1 and p0, which is written by the relations (4). Find the coefficients of the rice generator model (from Fig. 3): λ0, λ1, λ2, λ3. To do this we use the relations (4) and obtain the following system of equations:

$$\begin{cases} 1-\tau = \dfrac{\lambda_2}{\lambda_1+\lambda_2}, \\ \tau = \dfrac{\lambda_1}{\lambda_1+\lambda_2}. \end{cases} \quad (15)$$

However, the system does not have a single solution. For example, consider two realizations of sequence generators (Fig. 7):



a) A variant of the generator with a high probability of changing the state



b) Option of the generator with reduced probability of change of state

Fig. 7. Variants of generators of binary sequences of the same intensity

As can be seen from Fig. 7, the intensity of the flow of single bits τ=0.8/(0.8+0.1)=0.4/(0.4+0.05)=8/9. That is, the implementation of generators have the same values of the probability of staying in a single state. However, the likelihood of staying in the current state and the next step is greater in the implementation of the generator b): 0.6>0.2, 0.95>0.9, respectively. Thanks to this, the generator b) gives out a more persistent series. Compare the work of generators by the results of the constructed sequences (Figs. 8, 9):

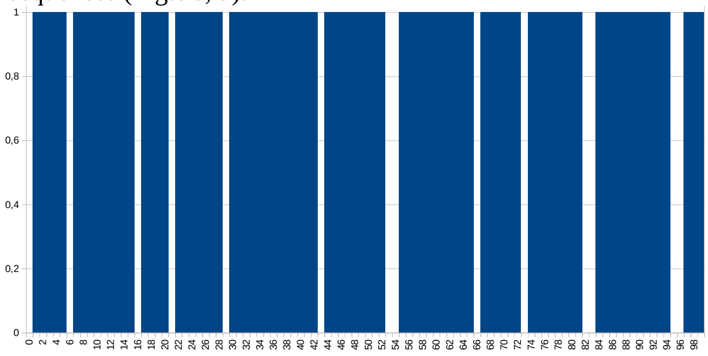


Fig. 8. Generation result of 100 bits generator a), (τ = 8/9)

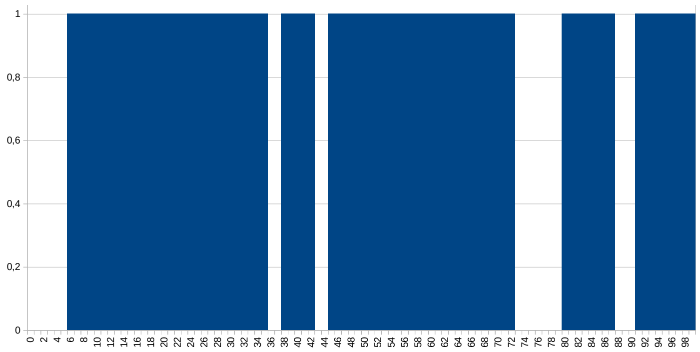


Fig. 9. Generation result of 100 bits, generator b), (τ = 8/9)

According to past examples of generation of sequences with intensity τ=0.5, two consecutive bits depicted in Fig. 8 and 9, have the same traffic intensity, but have a different fractal dimension.

In general, the intensity of traffic, depending on the values of $\lambda 1$, $\lambda 2$ is shown in Fig. 10:

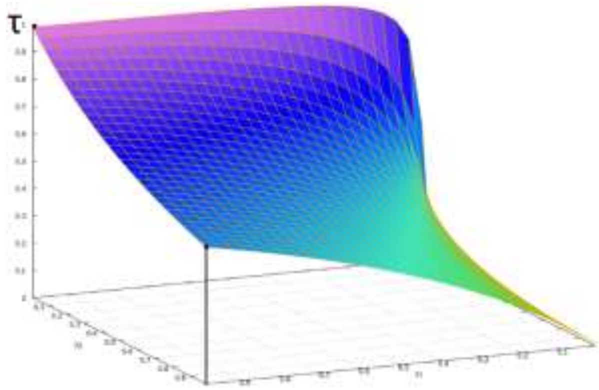


Fig. 10. Intensity of traffic τ depending on probabilities $\lambda 1$, $\lambda 2$

As a result, we can conclude that the generator is suitable for generating traffic of given intensity and different fractal dimensions.

7 Bring the generator to match the sample traffic

Assume that as a result of experiments, we have a sample of sufficient traffic to evaluate its statistical parameters with sufficient accuracy: τ is the traffic intensity (4), and the probability of obtaining a series of n quanta of time without having the packet transfer (6). As a result, we have a system of equations (16):

$$\begin{cases} p_0(n) = \dfrac{\lambda_2(1-\lambda_1)^n + \lambda_1(1-\lambda_2)^n}{\lambda_1 + \lambda_2}, \\ \tau = \dfrac{\lambda_1}{\lambda_1 + \lambda_2}. \end{cases} \tag{16}$$

After moving to the power equation, we have (17):

$$f(\lambda_1) = (1-\tau)(1-\lambda_1)^n + \tau^{1-n}(\tau - \lambda_1(1-\tau))^n - p_0(n);\ f(\lambda_1) = 0\,. \tag{17}$$

Unfortunately, the obtained equation for searching λ1 has no analytical solutions. But on the interval (0; 1) contains a root that can be found by numerical methods, which for almost all polynomials convergence is guaranteed. For example, you can use the tactile method:

1) λ1 = 0.5
2) λ1 := λ1 – f(λ1)/f'(λ1)
To repeat the specified accuracy 2)
3) λ2 = λ1(1-τ)/τ

It is also possible to use other numerical methods:

As an example, in Fig. 11 shows a part of the graph of function (17) for parameters corresponding to the generation of the sequence at λ1=λ2=0.5. From the figure it can be seen that the graphic search for the root in the interval (0; 1) gives a single value λ1=0.5.

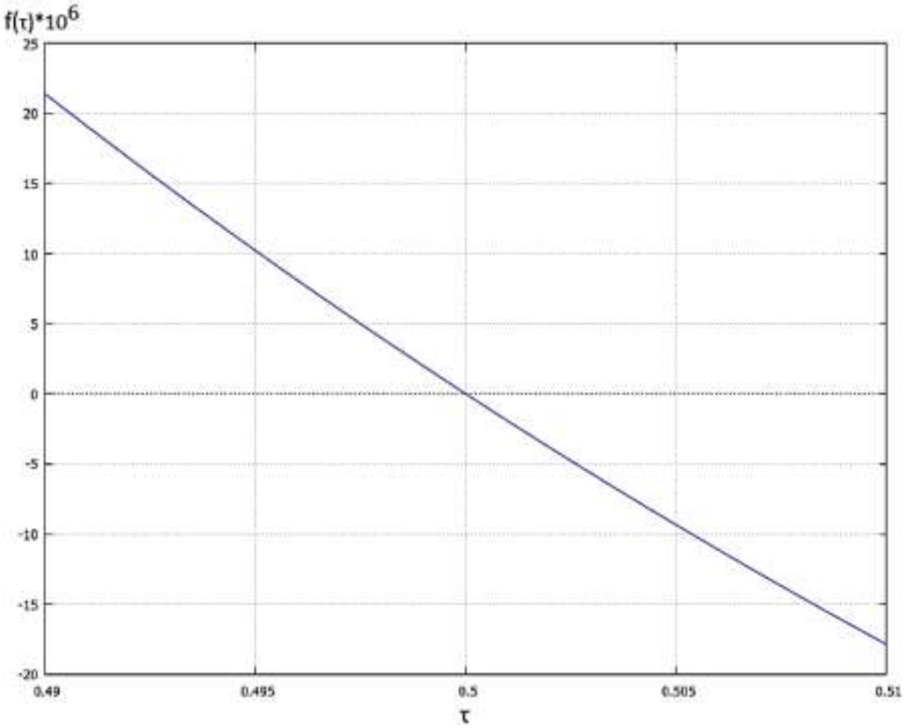


Fig. 11. The graph f(λ1)106 at τ=0.5 and p0(10)=1/210

8 Conclusions

To implement the method of generating fractal traffic using the generator model on the graph, the following tasks were solved:

- the relevance of the problem of generators of fractal binary sequences without the use of infinite distributions is shown.
- it is proposed to use a generator of the fractal binary sequence given by the Markov chain.
- variability of the fractal dimension of the binary sequence and at different intensities τ is shown.
- the analytical expressions are derived for obtaining generator parameters with a given output bits density with control of their fractal dimension.

The work requires continuation, where it is necessary to prove the existence of a single real root of equation (17) at the interval (0; 1) and to determine numerical methods for guaranteed approximation to the desired root. In the case of multiple roots, determine the fundamental difference solutions and develop an algorithm for choosing a solution that meets the needs for generating traffic.

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