Multiple Access Communication Based on Control of Special Chaotic Trajectories

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1. Introduction

The necessity of simultaneous access to one communication channel by many users, e.g., in satellite communication systems or cellular telephony, has led to the development of the corresponding standards: FDMA (Frequency Division Multiple Access) and TDMA (Frequency Division Multiple Access). Increasing requirements to the communication channel transmission rates gave rise to the appearance of CDMA (Code Division Multiple Access) using code division of information channels. Use of individual code sequences for communications has forced the search for potential efficient code sources. And dynamic, or deterministic, chaos gives an attractive opportunity for realization of such sources.

There is a number of ideas for chaotic signal applications in multiple-access systems [1-4], but as a rule, chaotic signals are used there only as efficient and versatile means of quasi-noise signal formation. In such applications, important and attractive features, such as multitude of chaotic modes, flexible control of their dynamics, chaotic self-synchronization phenomena, and potential communication confidence due to the very dynamic properties of chaotic nonlinear systems, are neglected.

Here we discuss another principle of multiple access, based on fine strucure of chaotic attractor, using conrol of special chaotic trajectories and also demonstrate the experimental verification of the proposed approach for asynchronous packet data transmission.

2. Principle of multiple access communication

The strange attractor, an image of deterministic chaos can be treated as a number of countable sets of special trajectories - unstable periodic orbits (UPO) and transitions between these orbits [5-6]. Instability of the periodic orbits and transient trajectories between them gives rise to irregular chaotic behavior. One can try to use the set of the unstable "skeleton" periodic trajectories, constituting the structure of the strange attractor (or a part of this set), as a "reservoir" of potential codes for multi-user communication systems [7-8]. The multitude of the codes from a certain "reservoir" for communications is practically infinite, i.e., the number of users provided with individual code sets is unlimited.

The principle of communication using unstable periodic orbits (UPO) of a chaotic attractor can be represented as follows. The initial information carrier (in the absence of the transmitted message) is chaotic oscillations produced by the dynamic system. The "user" codes are the fragments of the entire complex motion, so the use of the "own" codes does not disturb the system behavior, and alternating of the "own" (for a certain user) and others' orbits does not change the structure of the total signal in the channel. The signal in the channel is the "information for everybody", containing pieces of chaotic trajectory, "own" unstable cycles (orbits) and "others'" codes. This means that the proposed method for the transmitted message formation has an additional useful property of confidentiality. Both position and duration of the code packages in the channel can be arbitrary, thus sequential asynchronous stream of cycle-codes is realized. The example of *asynchronous stream*, containing the information fragments ("own" cycles for two different pairs of user) is presented in the Fig.1.

Here, first pair of users is provided with "own" cycles -**X**, **Y**, **Z**. The second pair of users is provided with another cycle- codes – **A** and **B**. Total message **AXZABZYXB** contains two individual message – **XZZYX** (first pair) and **AABB** (the second pair). The absence of any information corresponds to the non informational (chaotic) fragments of the stream. If we supply each user with selective choice of only the "own" codes from the common asynchronous stream, then we create the system having the properties of the multi-user access. As the number of skeleton unstable periodic cycles of the chaotic attractor is countable, the

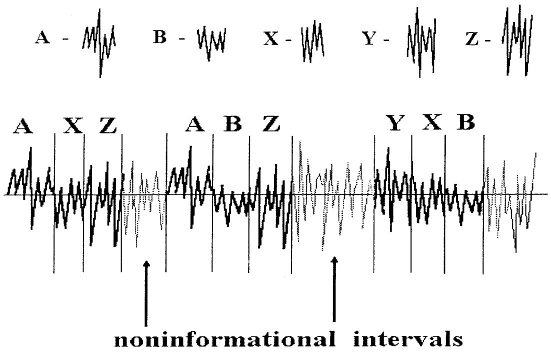

Fig. 1. The asynchronous sequence corresponding to the symbol sequences for two pairs of users

potential number of different messages (number of the individual virtual channel) may be also very large. It is only necessary to provide all the users with their individual systems of cycle-codes (individual alphabets).

So the proposed scheme of multi-user access must be equip with the set of the individual systems of codes, the unit of forming the total chaotic asynchronous data stream and the selecting unit at the receiver, extracting the "own" codes from the stream. Considering that skeleton of UPO is proposed for choice of cycle-codes, it necessary to obtain the catalogues of these unstable orbits. Multitude of UPO consists of cycles with different ordit's lengths. The total number of the orbits of certain period increases with the period length. Fig. 2 illustrates this dependence for chaotic attractors, produced by Lozi map [9]:

$$x_{n+1} = a - 1 - a\,|x_n| + y_n$$
$$y_{n+1} = b\,x_n \qquad (1)$$

The number of orbits N exponentially increases from N=6÷10 for period-7 to thousands for period T>15.

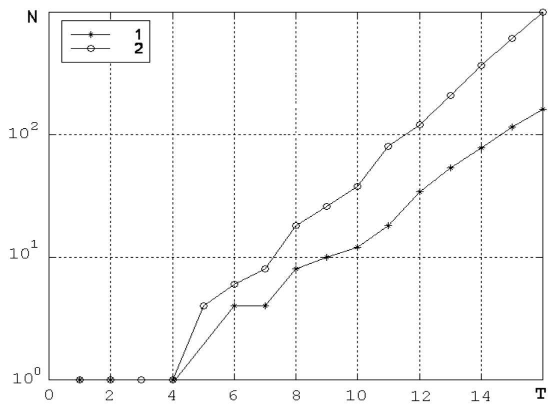

Fig. 2. Number of UPO vs orbits'period for various parameters of Lozi map: 1- (α,β) = (1.7, 0.5); 2- (α,β) = (1.1, 0.85).

Lozi attractor (1.7, 0.5) and skeleton period-16 orbit are presented in Fig. 3.

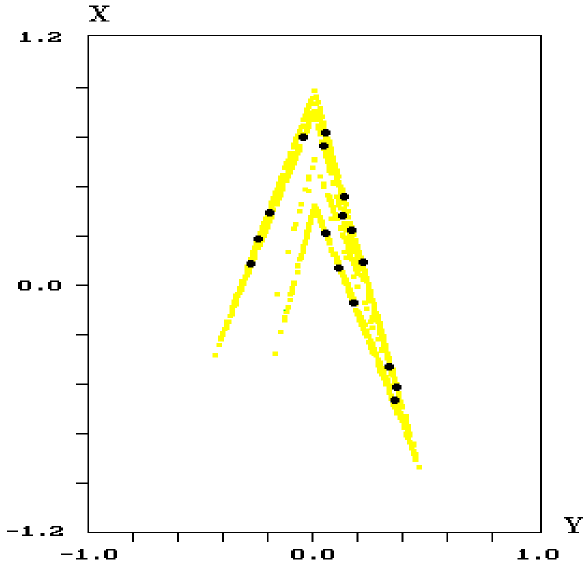

Fig. 3. Lozi attractor with period-16 unstable periodic orbit.

The choice of certain chaotic attractor is determined by preliminary requirements for communication system (number of virtual channels, the lengths of individual alphabets, principles of codes controlling, selection and so on

3. Processing of the unstable orbits

Forming of asynchronous data stream. Once each symbol in each alphabet is matched with unstable periodic orbit from catalogue, the asynchronous data stream in the multiple-access communication system is formed as follows. In accordance with an input asynchronous information sequence the transmitting chaotic dynamic system successively reproduces the appropriate orbits (see Fig. 1). The step of tuning the dynamic chaotic system to generate a required signal (the stabilization of the corresponding unstable periodic orbit) can be performed in different ways. For example it may be realized by so-called OGY controlling [10]. The control procedure consists of three phases. A first phase is a system transition from chaotic motion to the required unstable periodic orbit. A second phase is holding the chaotic system on the required unstable periodic orbit. A third phase is an aftereffect, i.e. a switching off and relaxation of the dynamical system to the chaotic state. From the viewpoint of the information rate, it is necessary to minimize the first phase duration. The second phase is the operation. Its duration is determined by the reception conditions. Instead of the third phase a control action for the next information symbol may be performed

In order to increase the transmission rate some modification of the controlling procedure was proposed. The switching between twenty period-16 unstable orbits for Lozi map is presented in the Fig. 2. As it can be seen from this diagram the forming of all successive cycles (10-times repeating) is practically instantaneous.

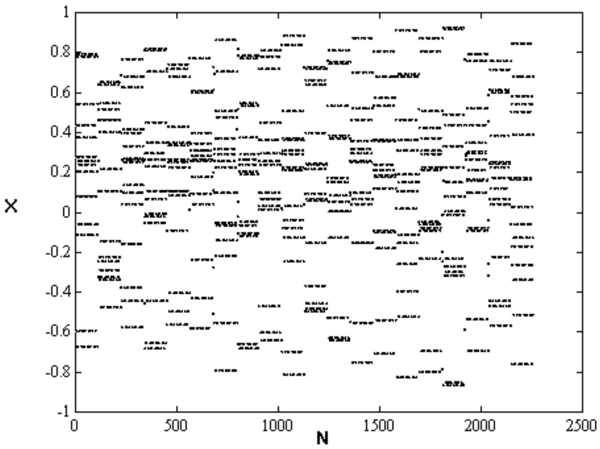

Fig. 3. The switching between 20 period-16 unstable cycles of Lozi map.

Selection of cycle-codes from the stream The main task of the receiver in the proposed multiple access technique is the selection of the "own" unstable cycles from common asynchronous data stream. For example from the common data stream **AXZABZYXB** in the Fig.1 the receiver of the second pair of users must extract only **AABB**. Another words, the receiver must ilter the input stream of chaotic signals, and only the signal on which this receiver is tuned passes without distortions.

One possible structure of such matched filter is presented in Fig. 4. A current sample *Z* comes to the input of this circuit, which sample belongs to the received asynchronous data stream. Preliminary, the receiver evaluates the metric proximity of a point corresponding to the received asynchronous data stream sample, to points corresponding to each orbit of the unstable periodic orbit set belonging to the strange attractor of this selecting dynamic chaotic system F. A norm of the distance between the points in the corresponding phase space may be used as the proximity measure. If the obtained estimate of the metric proximity for the point corresponding to the received sample to the point of some unstable periodic orbit exceeds predetermined limits, the step of estimating the metric proximity continues for other points of this orbit or for points of other orbits. If the obtained estimate fits the predetermined limits, the current sample passes through the switch to the selecting dynamic chaotic system with the parameter control. Since the coming sample is close to one of points of one of own unstable periodic orbit of the selecting dynamic chaotic system F, its iterative process starts from the point to which the received sample occurs to be close. In so doing, the cycle control unit stabilizes the iterated unstable periodic orbit. The output signal X is compared with the next sample of the received asynchronous data stream. If the difference between the compared values is within predetermined limits, i.e. the point corresponding to the new received sample is close to the point of the generated orbit, then the iterative process of the dynamical system F for the stabilization of the selected orbit is continued. But if the new incoming sample Z is «far» from the corresponding sample of the stabilized orbit, then the control unit moves the switch from the feedback loop to the forward circuit. The difference value is accumulated during the stabilized orbit period and compared with the threshold value to decide that an «own» chaotic signal has come.

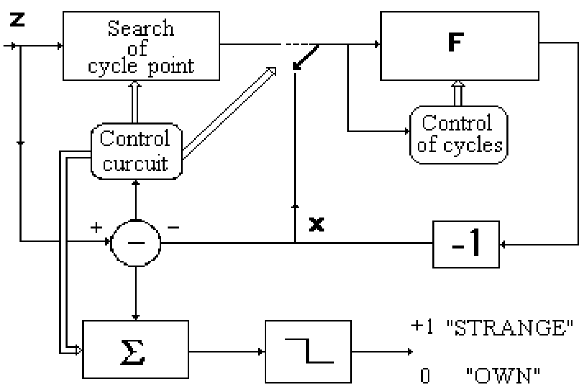

Fig. 4. Selective unit

4. Asynchronous packet data transmission

Unstable periodic orbits can be utilized for not only encoding the entire transmitted information, but also for attributing it to this or that group of users, i.e., they play the role of “chaotic markers”.

The idea to use the system of unstable periodic orbits as markers was applied to the problem of asynchronous packet transmission of data from several users through a single common communication channel.

Let there be a transmitter and a receiver catering to *N* information senders and *N* destinees, respectively. The capacity of the channel between the transmitter and the receiver is sufficient to carry all the information from the senders to the destinees. The task is to organize the operation in such a way as to allow each pair of senders and destinees to transmit information without essential delays. The transmission rates of different pairs of users may considerably vary.

To comply these requirements, in the transmitter each sender's message is cu into fragments (information packets) whose length depends on the transmission rate required by the particular user and by the other senders. In order to let the receiver to sort out the packets devoted to different destinees and to restore the initial messages, each pair of users is given a pair of unstable periodic trajectories — "chaotic" markers. This pair of markers is used to wrap each message fragment of those users, so that one marker is opening the packet (it is the packet "head"), and the other is closing it (the packet "tail"). Both the sender and the destinee of the pair have the same markers, which are formed by means of iterating the same chaotic dynamic systems in the transmitter and the receiver.

Thus, asynchronous sequence of information packets wrapped with individual markers is sent through the channel. The packets from different users follow each other in a random order in the common stream. There may be pauses of a random duration between them, e.g., corresponding to the absence of information at the transmitter input. Typical structure of the asynchronous data stream for two pairs of users is shown in Fig. 5.

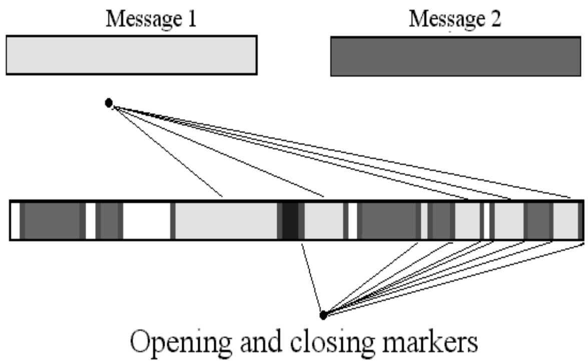

Fig. 5. The structure of an asynchronous packet data stream.

In the receiver, markers are used to identify the beginning and the end of each information packet and to determine the destinee. This is made in two stages. At the first stage the entire information stream is passed through a special nonlinear filter incorporating the chaotic dynamic system as a base element. The filter determines the subsequences of the data stream corresponding to markers, identifies information packets, sorts them out and sends them to concrete destinees. At the second stage the users restore the messages out of the received information packets.

To test the described circuit for asynchronous information transmission we carried out experiments with two pairs of users with two different music signals transmitted to them simultaneously through a single channel.

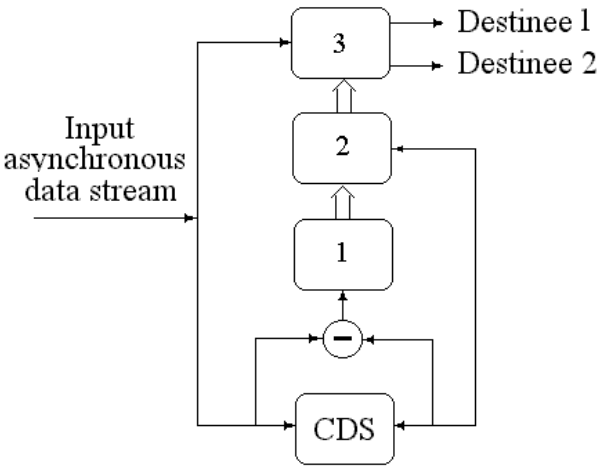

Fig. 6. Nonlinear filter, selecting the asynchronous packet data stream: CDS - Chaotic Dynamical System; 1 - comparator, 2 - indentificator of markers, 3 - packet distributer.

The transmitter and the receiver were accomplished on with signal processors AD2181. The signals from two analog audio sources, a cassette player and a CD-player, were fed to two inputs of the transmitter. The analog audio signals were sampled with 16-bit 6-kHz ADCs. Then the digital signals the cut in the transmitter into fragments, wrapped with corresponding chaotic markers, and the common data stream was formed with these fragments. The length of each fragment, set by a random number generator, was varied in the range 30 to 300 16-bit samples. The markers were unstable period-5 trajectories of the chaotic attractor of Lozi map (1) with parameters set at $\alpha = 1.1$ and $\beta = 0.85$.

In order to transmit through the channel, which was a wire line, each 16-bit sample of markers or digital audio signal was transformed into a sequence of sixteen binary pulses.

The receiver solved the following tasks:

– synchronization of incoming binary pulses,

– transformation of the binary input stream into 16-bit samples and self-synchronization on chaotic marker samples,

– location of all opening and closing packet markers,

– distribution of packets between the users, according to the markers, formation of original messages, conversion to analog form, and feeding the signals to corresponding acoustic systems.

The experiments demonstrated high quality of the data transmission and applicability of the chaotic markers to identification of information in multiple access systems.

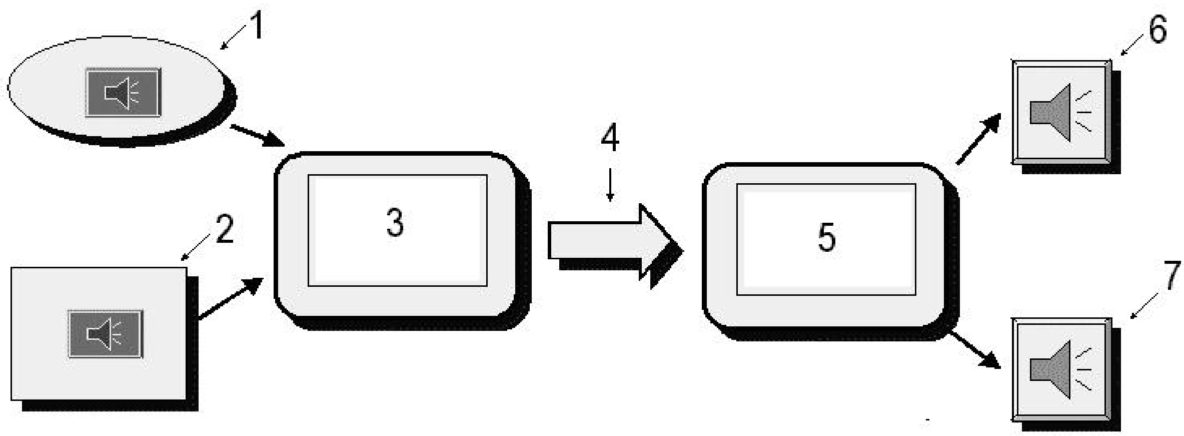

Fig. 7. The scheme of the experiments: 1,2 - music sources; 3 - transmitter (realized on Digital Signal Processor AD2189); 4- channel; 5 - receiver (realized on Digital Signal Processor AD 2189); 6,7 - acoustic systems.

5. Conclusion

The use of unstable skeleton periodic orbits allows to form the large number of individual alphabets for mutliple access.

The set of these orbits is the rough inherent property of given dynamical system and depends only on the system parametes. The same orbit set may be obtained at any place and by any procedures.

There are wide possibilties for the choice of the orbit's system depending of thier unstability, legnth, mertric properties and so on and one could easly organize the controlling procedure and switching of the unstable orbits.

The selection of "own" orbits in the receiver is provided dynamically, by special matched filter, using the same chaotic system as in the transmitter.

Multitude of UPO's may be also used for identification of certain information data packets as a system of special markers. So one can form asynchronous channels for simultaneous data transmission assigned to various destinees.

Finally, the generating and controlling of UPO may be realized in rather high frequecy band, provided in by modern digital methods.

6. Acknowledgements

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