A Multiple Access Technique for Differential Chaos Shift Keying

Vijay Prakash Singh, Anubhuti Khare

Abstract- Various chaos-based digital communications techniques have been proposed recently. Among them, differential chaos shift keying (DCSK) allows the receiving end to decode factors. In this paper we also use AWGN channel and see how it effects the BER, the signal using non coherent detection. This paper proposes and analyses a multiple access scheme for DCSK. A simple 1-dimensional iterative map has been used to generate the chaotic signals for all users. Bit error probabilities have been derived numerically for different number of users and computer simulations have been performed to verify the results and also compare the BEP for different spreading factors.

Index Terms- Chaos-based communications, exact bit error rate (BER), multiple access.

I. INTRODUCTION

Chaotic signals are characterised by their sensitive dependence on initial conditions as well as random-like behaviour. Moreover, their continuous broadband power spectrum feature renders them useful in encoding information in communications. However, the optimal decision level of the threshold detector will depend on the signal-to-noise ratio. To overcome the threshold level shift problem, differential CSK (DCSK) is proposed [1],[2]. The advantage of DCSK over CSK is that the threshold level is always set at zero and is independent of the noise effect. Since CSK/DCSK spreads the spectrum of the data signal over a much larger bandwidth, multiple access becomes an essential feature for practical implementation of the system. Furthermore, it is imperative that more users are included in the same bandwidth without causing excessive interference to one another. In [3], a two-user DCSK system was first proposed. In this paper, a generalized multiple access technique for use with DCSK (MADCSK) is proposed and analysed. The proposed scheme is simple and is in theory scalable to any number of users, provided the low-correlation property is maintained among the chaotic signal segments representing the different users.

II. SYSTEM MODEL AND MULTIPLE ACCESS TECHNIQUE

Suppose there are N users within the system. The chaotic signals $x_{i,k}$ (i = 1, 2, .., N) of the users are generated by the same map $x_{i,k+1} = g(x_{i,k})$. On the other hand, all users are assigned different initial conditions such that different chaotic samples are generated.

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Vijay Prakash Singh, Department of Electronics and Communication Engineering, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India.
Dr. Anubhuti Khare, Department of Electronics and Communication Engineering, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India.

Assume the system starts at t = 0 and the binary data to be transmitted has a period of Tb. Let 2α be the spreading factor, defined as Tb/Tc, where α is an integer. Here we propose a multiple access scheme where the separation between the reference and data samples differs for different users, as illustrated in Fig. 1. For user i, each data frame will consist of 2i half-bit slots. The first i half-bit slots in each frame (slots 1 to i) will be used to transmit the i reference samples while the remaining i half-bit slots (slots i+1 to 2i) are used to transmit the data samples. If a "+1" is to be transmitted in slot i+1, the sample in slot 1 is repeated in slot i+1, otherwise, an inverted copy is sent. Similarly, in slot i+2, the same or inverted copy of the sample in slot 2 is sent, and so on. As a result, the reference and data samples of user i will be separated by i half-bit periods. Fig. 2 shows a typical transmitted waveform for user 3.

Let $y_{i,m,f}(t)$ be the reference sample at the mth half-bit slot ($1 \le m \le i$) of the fth data frame for the ith user, i.e., the reference sample at the [2i(f – 1)+m]th half-bit slot for the ith user. Thus we have

$$y_{i,m,f}(t)\ \sum_{k=0}^{\alpha-1} x_{i,k+\alpha[(m-1)+(f-1)i]}\, r\left[t-\left(kT_c+(m-1)\frac{T_b}{2}+(f-1)iT_b\right)\right] \quad \text{where}$$

$r(t)$ is a rectangular pulse of unit amplitude and width Tc.

The overall transmitted signal of the whole system is derived by summing the signals of all individual users, i.e.,

$$s(t)=\sum_{i=1}^{N} s_i(t) \qquad (1)$$

At the receiving end, the half-bit slots in the first half of each frame will correlate with those in the second half. During the same time, the correlator output is sampled every Tb/2 before the correlator is reset. The output is then compared with the threshold zero to determine whether a "+1" or "–1" has been received. Fig. 4 depicts the correlator output and the decoded symbols of user 3 in a 5-user system, assuming a spreading factor of 2000. If the correlation between different samples from the same user or samples from different users is low, a low bit error probability (BEP) is expected.

A standard segmented decoding method is used to interpret the incoming signals, via correlation integrals over each signal section, and then a decision process assigns the correct symbol to the signal message sequence with both $Psnr$ values, when the time delay is accounted for. The first m signals are always in error. as the persistent matrices are not fully populated until four message sequences have been transmitted. Based on the exact analytical expression, it is found that to optimize the BER, the chaotic sequences for different users should have very low correlations even for a finite length.

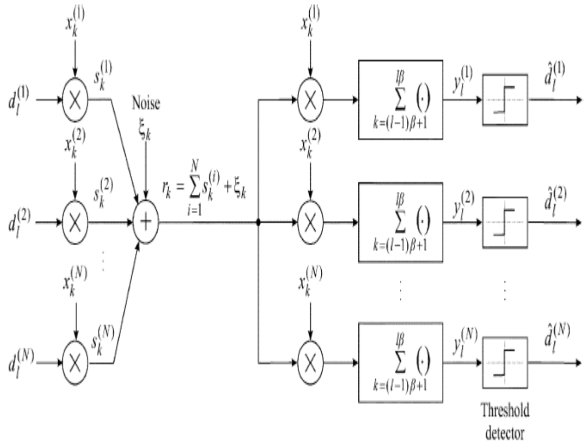

Fig.1 Multiple access chaos based communication system

III. NUMERICAL ANALYSIS

As derived in the previous section, the overall transmitted signal is given by $s(t)$. Ignoring the effect of noise and filters, the same signal will arrive at the receiver input. Consider the *mi*th half-bit slot in the *fi*th data frame of the *i*th user, i.e., the [2(*fi*–1)*i*+*mi*]th half-bit, where$1 \leq mi \leq i$. At the receiving end, the signal in this half-bit slot will correlate with that in the [2(*fi*–1)*i*+*i*+*mi*]th half-bit slot. The output of the correlator is given by

$$O_i = \sum_{u=1}^{N}\sum_{V=1}^{N} x_{u,v,i} \qquad (2)$$

where the conditioning is only on and not the others. With a Gaussian distribution assumed for the Investigation into the "optimal" dimensionality of the new method has shown that, the optimal value for the scheme's dimension is approximately seven. This is for the given set of assumptions. For dimensions greater than seven, the improvement decreases, but the new scheme always performs better than any two dimensional quadrature schemes.

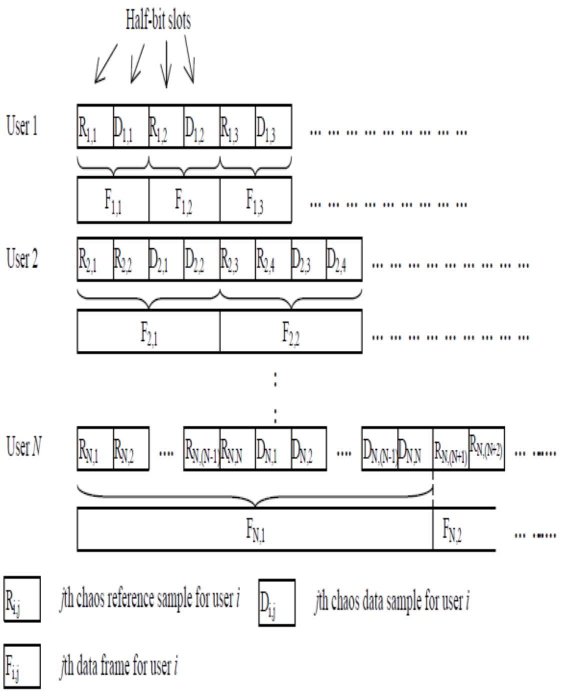

Fig-2 Transmission scheme in a multiple access differential chaos shift keying (MA-DCSK) system (1)

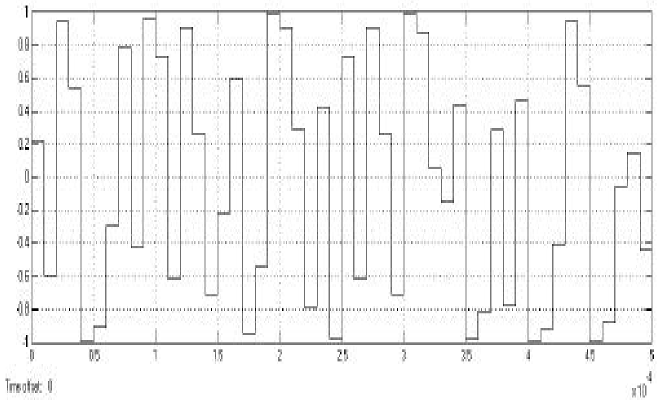

Figure 3 A typical transmitted signal for user 3 in a multiple access DCSK system (spreading factor = 10)

The improvement decrease varies as a function of the relationship between the volume of the communication space and the surface area of the hypersphere, where the symbolic constellations lie. In addition, with higher dimensions, the computational complexity increases approximately as the third order of the dimension An attractor is an infinite collection of points in some dimensional space and one of its basic properties is its dimension. If a simple stable linear system is considered then its attractor is a singular point, which is the steady state of the trajectory in the state space, and clearly this has a dimension of zero. Similarly, a non-linear two dimensional system with a limit cycle settles to a curve in the state space and has an understandable dimension of one. However, chaotic attractors do not have such obvious dimensions, and one of the properties of a chaotic or strange attractor, is that it has a fractional dimension termed a fractal dimension.

	Spreading factor=100		Spreading factor=500	
No. of users	Average BEP among all users by simulation	BEP by numerical calculation	Average BEP among all users by simulation	BEP by numerical calculation
1	0.0000	0.0000	0.0000	0.0000
5	0.0015	0.0019	0.0000	0.0000
9	0.0190	0.0207	0.0007	0.0008
15	0.2560	0.5670	0.0056	0.0890
20	0.3450	0.4569	0.0567	0.3450
30	0.3675	0.3643	0.1230	0.1023
50	0.4098	0.4035	0.2098	0.2098
80	0.4231	0.4231	0.2561	0.2513
100	0.4567	0.4532	0.2673	0.2647

Table 1 Comparison of BEPs from numerical calculation and by simulation

A standard segmented decoding method is used to interpret the incoming signals, via correlation integrals over each

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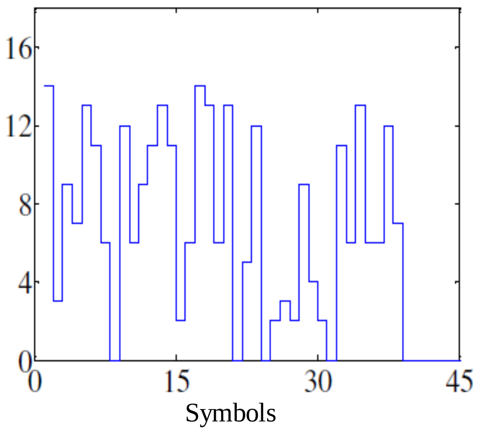
signal section, and then a decision process assigns the correct symbol to the signal. By using this technique, the multilevel and dimensionality problems have been addressed at the cost of less security, in that, this is a scheme of signal sequences which is easily detectable as combinations of the references are constantly repeated within each symbol frame. The method now described in section (2.5.3) is the first step to a truly multidimensional and multilevel orthogonal chaotic communication scheme.

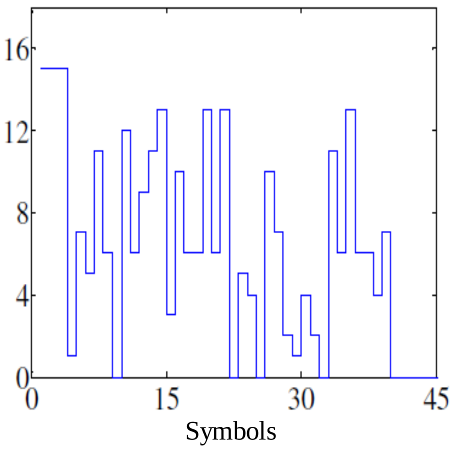
IV. SIMULATION AND RESULTS

Simulations have been carried out to confirm the feasibility of the proposed multiple access scheme and to verify the foregoing numerical analysis. Spreading factors 200 and 2000 are used and the bit duration *Tb* is taken as 10–4s. The number of users in the system is assigned up to 50 and different initial conditions are assigned to different users to generate the chaotic signals. 10,000 bits are first sent from each user. Then, the number of errors received by each user and the average number of errors among all users are noted. Table 1 compares the numerical BEPs with the simulation results. It can be observed that the simulation results match very closely with the numerical ones. As mentioned in the previous section, *s* increases with *N*2. Hence, the BEP becomes high when the number of users is large. On the other hand, by using a higher spreading factor and hence lower autocorrelation and cross corrrelation values, the system performance can be drastically improved.

The same set of transmitted and received 'four' bit messages are shown in figures (4.2.3.3) and (4.2.3.4) graphs (a) and (b). Demonstrates that, there are errors between the transmitted and the received



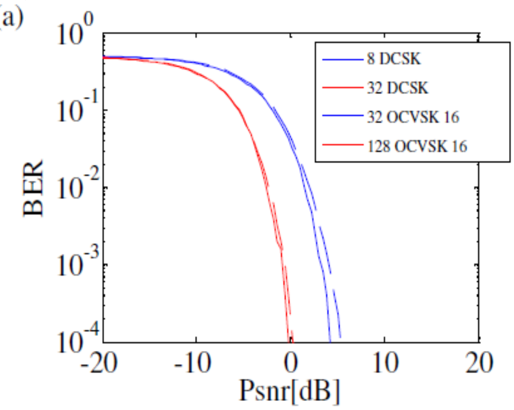
(a)Transmitted 4 bit message for encoding



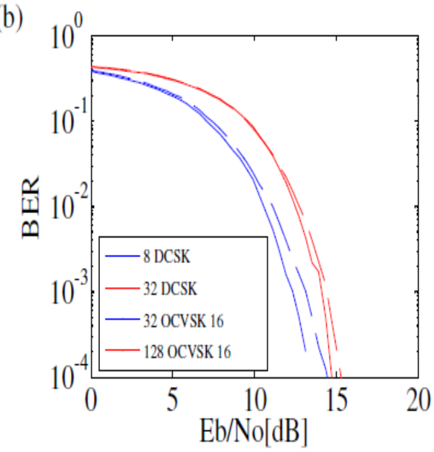
(b) Received decoded 4 bit message

message sequence with both *Psnr* values, when the time delay is accounted for. The first *m* signals are always in error. as the persistent matrices are not fully populated until four message sequences have been transmitted. This illustrates, as with all communication schemes, a need for some form of preamble before real information can be transmitted. The noise rejection can again be increased by the careful selection of the chaotic sequences outlined in section (3.5). The limits of this scheme are the clearly the noise rejection due to the sequence length *n*, the chaotic sequence conditional selection and the dimension chosen for *m*, which is investigated and optimally selected in chapter5.

(a)



(b)



The DCSK BER of figure (4.3.2.1) (a) show better rates than the QCSK 16 examples of graphs (b) . The OCVSK 16 example in graphs (a) and (b) clearly out perform the QCSK 16 scheme and as figure (4.3.2.2) demonstrates it has an equivalent BER to the DCSK example when the data rate is taken into account.

It clearly shows that as the dimension *m* moves through the *m* = 7 value, the improvement in BER Ratio stops and a subsequent increase in the dimension, increases the BER Ratio at higher *Psnr* values. It is also clear, that the benefit of using the higher dimensional architectures is always an improvement over two dimensional quadrature type schemes, as the fall off in the comparative function demonstrates. This simulation is evaluated, with the estimate vector bounded between a magnitude of 0.4 and 1.6 for a nominal value of 1.0. This is a wideband but clearly shows the dimensional effect. This simulation run took several hours to complete, and finer bounding of the solutions requires an exponential increase in computation time,

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to achieve reasonably smooth curves.

V. CONCLUSION

In this paper, we have proposed a simple multiple access scheme for use with differential chaos shift keying (MA-DCSK). The access scheme of different users is described and the corresponding noncoherent receiver is also designed to decode the signals. The scheme can theoretically be scaled to any number of users, provided the low-correlation property is maintained among the chaotic signal samples representing the different users. As would be expected, the proposed scheme achieves unbiased error probabilities for all users and the error performance degrades as the number of users increases. However, the spreading factor can be increased to improve performance.

Based on the exact analytical expression, it is found that to optimize the BER, the chaotic sequences for different users should have very low correlations even for a finite length, and the bit energy should be kept constant for each user. Because the analytical expression makes no approximating assumption on the distribution of the decision parameter, but note that it is conditionally exactly Gaussian, the exact approach gives totally accurate results compared to the conventional approach of performance evaluation which assumes a Gaussian distributed decision parameter. The exact method will therefore be useful to engineers or researchers, especially those who may not be too familiar with computer simulations, to evaluate and compare the performance of chaos-based communication systems

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