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Performance Evaluation of a Multiple Access DCSK System under a Noisy Multiuser Environment

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Abstract - In this paper a multiple-access technique for use with DCSK (MA-DCSK) under a noisy condition is proposed and analyzed. In order to evaluate the performance of the system, a simple one dimensional iterative map is used to generate the chaotic signals for all users. As would be expected, the proposed scheme achieves similar error probabilities for all users and the error performance degrades as the number of users increases. Bit-error rates for different number of users and computer simulations are performed to verify the results.

I. INTRODUCTION

Chaotic signals are characterized by their sensitive dependence on initial conditions as well as random-like behavior. Moreover, their continuous broadband power spectrum feature renders them useful in encoding information in communications. Typically, in a chaos-based digital communication system, digital symbols are mapped to nonperiodic chaotic basis functions. For instance, in chaos-shift-keying (CSK), different symbols are mapped to different chaotic attractors which are produced either by a dynamical system for different values of a bifurcation parameter or by a set of completely different dynamical systems [1]. A coherent correlation CSK receiver is then required at the receiving end to decode the signals. Noncoherent detection is also possible provided the signals generated by the different attractors have different attributes, such as mean of the absolute value, variance and standard deviation.

The optimal decision level of the threshold detector will depend on the signal-to-noise ratio in general, although specific examples with noise-invariant threshold can be designed for CSK. As in other communication systems, its performance increases with the symbol energy or the signal-to-noise ratio. To overcome the threshold level shift problem, differential CSK (DCSK) is proposed. The advantage of the DCSK over CSK is that the threshold is always set at zero and is independent of the noise effect.

In conventional communication systems, the allocated spectrum is shared by a number of users. Multiple-access techniques such as frequency-division multiple access (FDMA), time-division multiple access (TDMA) and code-division multiple access (CDMA) are commonly used. Similar to CDMA, CSK/DCSK spreads the spectrum of the data signal over a much larger bandwidth as compared to FDMA and TDMA. As a result, multiple access becomes an essential feature for practical implementation of the system.

In this paper, a multiple-access technique for use with DCSK (MA-DCSK) under a noisy condition is proposed and analyzed. The proposed scheme gives equal average data rates of all users. As in a single-user DCSK system, each bit duration is always divided into two time slots for all users. To minimize the correlation between signals, the frame periods and the arrangements of the reference and sample waveforms of all users are different. In order to evaluate the performance of the system, a simple one-dimensional iterative map is used to generate the chaotic signals for all users. As would be expected, the proposed scheme achieves similar error probabilities for all users and the error performance degrades as the number of users increases. However, we show that when the correlation between samples of the same/different chaotic signals is low, achieved by using a large spreading factor, a low bit-error rate (BER) can be achieved. Section 2 describes the DCSK modulation method. The multiple-access technique is discussed in Section 3. Results found by the analytical method are compared with simulation in Section 4.

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. REVIEW OF

DCSK was first proposed by Kolumban et al. [1]. By using a chaotic carrier to spread the digital signal over a large bandwidth, the spread signal possesses some of the advantages of spread spectrum communications such as mitigation of multipath fading and low probability of detection.

In DCSK, each bit duration is first divided into two equal time slots and every transmitted symbol is represented by a pair of chaotic signal samples ..... T... ...s. s...ple se..es .s ..e reference (reference sample) while the second one carries the data (data sample). If a "+1" is to be transmitted, the data sample will be identical to the reference sample, and if a "-1" is to be transmitted, an inverted version of the reference sample will be used as the data sample. Assume the system is discrete and starts at $k=0$. Let 2α be the spreading factor, defined as the number of time units occupied by a binary symbol, where α is an integer. Fig. 1 shows a typical transmitted waveform, for a spreading factor of 10. At the receiving end, the reference sample and the corresponding data sample are correlated. Depending on whether the output is larger or smaller than the threshold zero, a "+1" or "-1" is decoded. Fig. 2 shows the output waveform of the correlator, which is sampled at multiples of 2α time units and Fig.3 shows the performance of the DCSK in the presence of the noise.

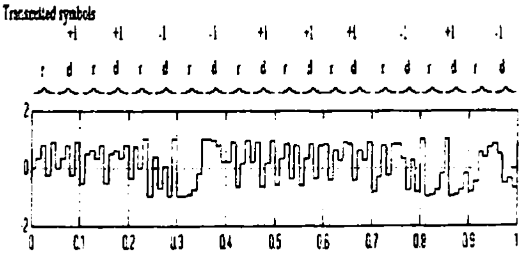

Fig.1. A typical DCSK signal (spreading factor = 10)

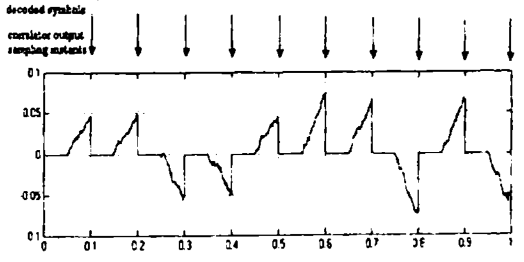

Fig.2. Output of the correlator and the decoded symbols

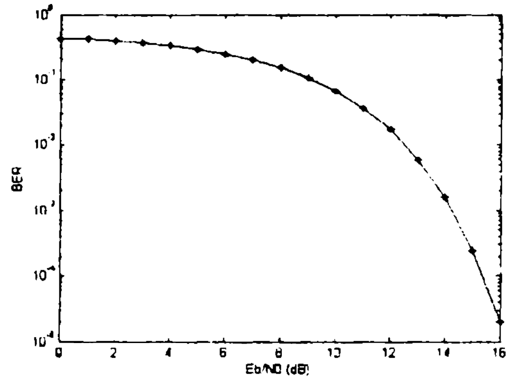

Fig 3. BER versus E_b/N_0 in a DCSK system (spreading factor = 100)

III. ANALYSIS OF MA-DCSK SYSTEM

In a MA-DCSK system, to avoid excessive interference, and hence, misdetection, the separation between the reference and data samples must be different for different users. A multiple access scheme has been proposed by Lau et al [2,3] where the separation between the reference and data samples differs for different users, as illustrated in Fig. 4. For all users, each bit duration is first divided into 2 slots. For user i, $2i$ consecutive slots are collected to form a frame. Hence, the slot duration (half of bit duration) is the same for all users but the frame periods are different for different users. In each frame of user i, the first i slots (slots 1 to i) will be used to transmit i sets of reference samples while the remaining i slots (slots $i+1$ to $2i$) are used to transmit i sets of data samples. If a binary symbol "+1" is to be transmitted in slot $i+1$, the samples in slot 1 are repeated in slot $i+1$. If a "-1" is to be sent, an inverted version of the samples in slot 1 will be transmitted in slot $i+1$. Similarly, in slot $i+2$, the same or inverted copy of the samples in slot 2 is sent, and so on. As a result, the reference and data samples of user i will be separated by i slots. Therefore, within a frame of length i bit periods (or $2i$ time slots), i bits of information will be sent. The data rates of all users are the same.

Fig. 5 shows a multiple access DCSK communication system in a discrete-time mode. In the transmitter of the i th user, a chaotic map is used to generate a chaotic signal $\{x_k^{(i)}\}$ with zero mean. The chaotic maps for different users are different in general. Assume that α chaotic samples are sent in each slot (spreading factor$=2\alpha$). Consider the transmitted signal of user i during the m th time slot, i.e., for time $k=(m-1)\alpha+1,(m-1)\alpha+2,\ldots,m\alpha$. Denote the output of the transmitter by $y_k^{(i)}$. If the slot is a reference sample slot, $y_k^{(i)}=x_k^{(i)}$. If the slot corresponds to a data sample slot sending a binary symbol "+1", $y_k^{(i)}=x_{k-i\alpha}^{(i)}$. Otherwise, if the slot

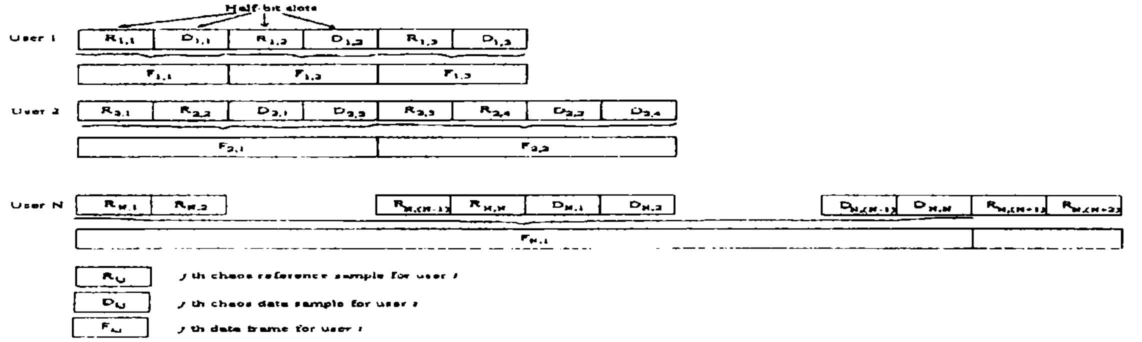

Fig.4. Transmission scheme for the MA-DCSK communication system

corresponds to a data sample slot sending a binary symbol "-1", $y_k^{(i)} = -x_{k-i\alpha}^{(i)}$. Thus, for the mth time slot of user i, we define $a_m^{(i)}$ as

$$a_m^{(i)} = \begin{cases} +1 & if \quad y_k^{(i)} = x_{k-l}^{(i)} \\ -1 & if \quad y_k^{(i)} = -x_{k-l}^{(i)} \end{cases} \qquad (1)$$

where $l = 0$ for reference samples and $l = i\alpha$ for data samples. Therefore, the transmitted signal of user i during the mth time slot can be represented by

$$y_k^{(i)} = a_m^{(i)} x_{k-l}^{(i)};$$
$$k = (m-1)\alpha+1, (m-1)\alpha+2, \dots, m\alpha \qquad (2)$$

The overall transmitted signal at time k, denoted by y_k, equals

$$y_k = \sum_{i=1}^{N} y_k^{(i)}. \qquad (3)$$

Assuming the channel is AWGN, the received signal at time k, denoted by r_k, is simply given by

$$r_k = y_k + \xi_k \qquad (4)$$

where ξ denotes the AWGN with zero mean and variance $N_0/2$. For each user, the signal received during a reference sample slot will correlate with the signal at the corresponding data sample slot. Depending on whether the output is larger or smaller than the threshold, a "+1"or "-1" is decoded. Such a correlator-based DCSK receiver is shown, also, in Fig. 5. Note that the sampling switch only operates during the second half of each frame and the threshold detector produces a decoded symbol after each slot during that period of time.

Consider the jth user and the received signal during the lth time slot. Suppose the slot corresponds to a reference-sample slot for the jth user, i.e., $a_l^{(j)} = +1$. The reference samples in this slot will then correlate with the received samples j slots later, i.e., in the $(l+j)$th slot. The output of the correlator is

$$y_l^{(j)} = \sum_{k=(l-1)\alpha+1}^{l\alpha} \left(\sum_{u=1}^{N} s_k^{(u)} + \xi_k\right)\left(\sum_{v=1}^{N} s_{k+\alpha j}^{(v)} + \xi_{k+\alpha j}\right)$$

$$= \sum_{k=(l-1)\alpha+1}^{l\alpha} \left(\sum_{u=1}^{N} a_l^{(u)} x_{k-\eta_u}^{(u)} + \xi_k\right)\left(\sum_{v=1}^{N} a_{l+j}^{(v)} x_{k+\alpha j-\eta_v}^{(v)} + \xi_{k+\alpha j}\right) \qquad (5)$$

where $\eta_i = 0\ (i = 1,2,\dots,N)$ for reference samples, and $\eta_i = i\alpha$ for data samples. The decoding of the symbol corresponding to this pair of time slots, denoted by $\delta_l^{(j)}$, can be done according to the following simple rule

$$\delta_l^{(j)} = \begin{cases} +1 & if \quad y_l^{(j)} > 0 \\ -1 & if \quad y_l^{(j)} < 0 \end{cases}. \qquad (6)$$

In [2] several assumptions are made for derivation of BER. With these assumptions (chaotic sequences from different generators are independent of one another, all chaotic sequences have zero mean) and if is assumed that all users transmit with equal average power, the BER for the jth user can be written as [2,3]

$$BER_{DCSK}^{(j)} = \frac{1}{2} erfc\left(\left[\frac{2\Psi^{(j)}}{\alpha} + \frac{2(N^2-1)}{\alpha} + 4N\left(\frac{E_b}{N_0}\right)^{-1} + 2\alpha\left(\frac{E_b}{N_0}\right)^{-2}\right]^{-\frac{1}{2}}\right) \qquad (7)$$

where E_b denotes the average bit energy, $E_b = 2\alpha P_s$, $P_s = E\left[(x_k)^2\right]$ and

$$\Psi^{(j)} = \frac{\operatorname{var}\left[\left(x_k^{(j)}\right)^2\right]}{P_s^2} \qquad (8)$$

Clearly, the performance of the MA-DCSK system is affected by

1. spreading factor 2α;
2. variance of $\left\{\left(x_k^{(j)}\right)^2\right\}$ for a given P_s;
3. number of users N;
4. noise power.

Thus, for a fixed E_b/N_0, we may improve the BER for the jth user by making one or more of the following adjustments.

1. C ange t e spreading actor 2α until he optimal BER is obtained;
2. Minimize the variance of $\left(x_k^{(j)}\right)^2$ for a fixed P_s;
3. Reduce the number of users N.

IV. S.MULATIONS, RESULTS AND DISCUSSIONS

The quadratic map $\left(x_{k+1} = 1 - 2x_k^2\right.$ and cubic map $\left(x_{k+1} = 4x_k^3 - 3x_k\right)$ are used in our simulations. The number of users in the system is assigned up to 5 and different initial conditions are assigned to different users to generate the chaotic signals.

In Fig. 6 are shown the results for a 3-user and a 5-user MA-DCSK system in which all chaotic sequences are generated from the cubic map and a spreading factor of 200 $(\alpha = 100)$ is used. It is observed that BERs increase (degrade) as the number of users increases for a given E_b / N_0. This is apparently due to the increasing inter-user interference.

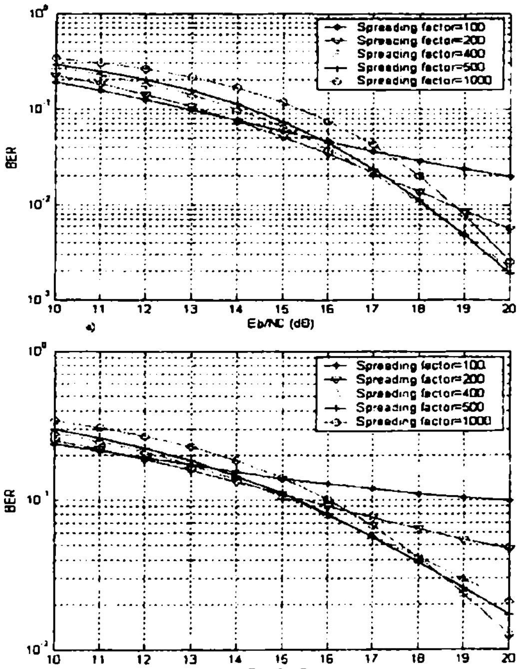

Fig. 6. BER versus E_b / N_0 under different spreading factor
a) 3-user system; b) 5-user system

Finally, assuming the quadratic map is used, we plot the BER against the spreading factor under different E_b / N_0 for a 3-user and a 5 user system. Fig. 7 shows that when the spreading factor increases initially, the BER improves. After the spreading factor has reached an optimum value, increasing the spreading factor further will deteriorate the BER.

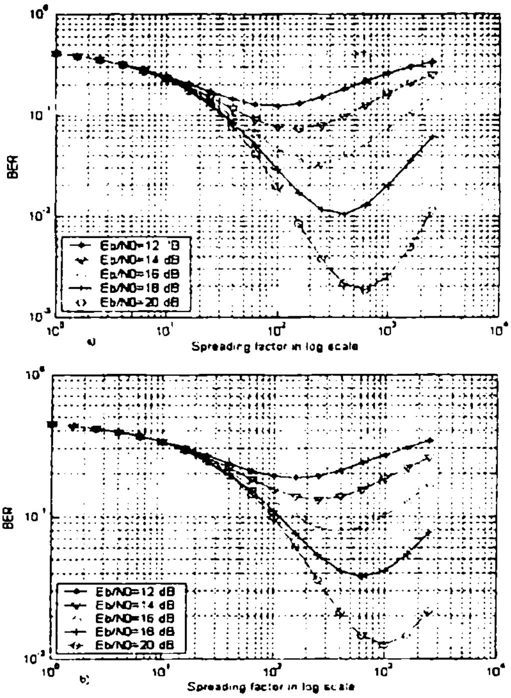

Fig. 7. BER versus spreading factor under different E_b / N_0
a) 3-user system; b) 5-user system

V. CONCLUSIONS

In this paper, a multiple-access technique for use with DCSK under a noisy condition is analyzed. The access scheme of different users has been described and the corresponding noncoherent receiver has also been designed to decode the signals.

The MA-DCSK system has been studied with the assumption that the time slots are synchronized among all participating users. We expect that the interference between users will not vary too much even when the time slots are not synchronized.

Finally, the performance of the system should be further investigated over a multipath and fading channel. These will be left to future publications.

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