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Abstract— **The small yet non-zero cross-correlation between chaotic spreading sequences in multi user chaotic communication system leads to MAI. The effect of MAI increases as the number of users increases. In order to eliminate the effect of MAI we propose the use of Orthogonal Chaotic Vectors (OCV) as spreading sequences to modulate the message data. At the receiver a simple correlator type detector is used. Analytical expressions for BER are derived for both AWGN and fading channels are compared with that of simulation results.**

Keywords-orthogonal chaotic vector (OCV),orthogonal chaotic vector shift keying(OCVSK), chaos,gram-schimdt orthonormalisation, AWGN, fading channels.

I. INTRODUCTION

In wireless communication multiple accesses to the same communication channel is vital, spread spectrum communication is one of the popular techniques which provides this capability. Digital communication using chaotic waveform has been extensively studied for about two decades [1]-[2]. Properties of chaotic waveforms such as sensitive to initial conditions, wide spectrum, very low cross correlation and impulse like auto correlation function makes it very attractive to use as an alternate to conventional spreading sequences in spread spectrum communication.

The Quasi-orthogonal nature of the chaotic sequence results in cross correlation estimation problem [5], which causes co-channel interference in multi user communication systems. This co-channel interference due to non zero cross correlation of chaotic spreading sequences is termed as Multiple Access Interference (MAI).

The application of orthogonal chaotic vector for multi level chaotic communication has been previously discussed in [3] and [4]. Based on the ideas presented in [3], we present a new improved multiple access chaotic communication system in which orthogonal chaotic vector is used as spreading sequence.

This paper is organized as follows: Section II describes the system architecture of the proposed system. Performance of the proposed system over AWGN and fading channels are dealt in Section III and Section IV respectively. Finally, we present the simulation and conclusion in Section V and VI respectively.

II. SYSTEM ARCHITECTURE

The transmitter and receiver structure of the proposed system is as shown in Fig. 1 which is similar to MA-ACSK scheme [8] except the spreading sequence used are orthogonal chaotic vectors. The transmitter contains *Nu* number of chaotic signal generators, where *Nu* is the number of users. The chaotic generators used to generate sequences can be from different chaotic maps or from the same map with different initial conditions. If $x(k)^{(i)}$ is the chaotic carrier for i^{th} user and defining the number of chaotic samples used to transmit single binary bit as the spreading factor, β. Gram-Schmidt ortho-normalization process [6] is used to generate orthogonal chaotic vectors,$\hat{x}(k)^{(i)}$. The mean value of chaotic carrier is made equal to zero, in order to avoid unwanted dc power transmission. It is then modulated by data sequence $d_l \in \{-1\ +1\}$, assuming that transmitted symbols "+1"(for 1) and "-1"(for 0) are generated with equal probability to obtain modulated vector $v(k)^{(i)}$.The transmitted signal $s(k)$ is the sum of modulated orthogonal chaotic vectors of each user. At receiver simple correlator type detection is used.

III. PERFORMANCE ANALYSIS OVER AWGN CHANNEL

Assuming that the signal is corrupted only due to AWGN, received signal r(k) can be represented as

$$r(k) = \sum_{i=1}^{N_u} v(k)^{(i)} + \xi(k) \tag{1}$$

Where $\xi(k)$ represents the additive white Gaussian noise with zero mean and variance *No/2*. At receiver it is assumed that exact replica of spreading sequence is available and it is exactly synchronized with the transmitter then, the m^{th} decoded symbol for the j^{th} user, denoted by $\tilde{d}_m^{(j)}$, is determined according to the rule:

$$\tilde{d}_m^{(j)} = \begin{cases} +1 \text{ if } \tilde{z}_m^{(j)} = \sum_{k=1}^{\beta} r(k)\hat{x}(k)^{(j)} > 0 \\ -1 \text{ if } \tilde{z}_m^{(j)} = \sum_{k=1}^{\beta} r(k)\hat{x}(k)^{(j)} \le 0 \end{cases} \tag{2}$$

A. Derivation of BER:

Consider the j^{th} user. Without the loss of generality, we consider the probability of error for the first symbol. For brevity, the subscripts of the variables $\tilde{d}_m^{(j)}$and $z_m^{(j)}$are omitted.

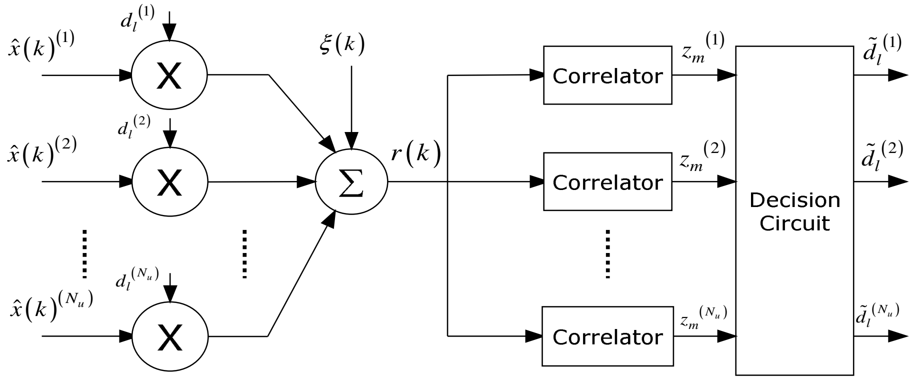

Fig. 1. Transmitter and Receiver structure

The decision parameter of the j^{th} user is given by

$$z^{(j)} = d^{(j)} \sum_{k=1}^{\beta} \left[\hat{x}(k)^{(j)}\right]^2 + d^{(j)} \sum_{i=1,i\neq j}^{N_u} \sum_{k=1}^{\beta} \left(\hat{x}(k)^{(i)} \hat{x}(k)^{(j)}\right)^2 + \sum_{k=1}^{\beta} \xi(k)\, \hat{x}(k)^{(j)} \qquad (3)$$

Since, chaotic vectors used for each user is ortho-normal to each other, the second term in eq. (3) causing MAI will be equal to zero. Assuming, that $z^{(j)}$ has a Gaussian distribution, the BER for j^{th} user can be written as

$$\mathrm{BER}^{(j)} = \frac{1}{2}\, \mathrm{erfc}\left(\frac{E\left(z^{(j)} \middle| d^{(j)}=+1\right)}{\sqrt{\left(2\, \mathrm{var}\left(z^{(j)} \middle| d^{(j)}=+1\right)\right)}}\right) \qquad (4)$$

Where, mean value of $\left(z^{(j)} \middle| d^{(j)} = +1\right)$ is given by

$$E\left(z^{(j)} \middle| d^{(j)} = +1\right) = \beta\, E\left[\left(\hat{x}(k)^{(j)}\right)^2\right] = E_b \qquad (5)$$

Where, E_b is energy per bit. And variance is given by

$$\mathrm{Var}\left(z^{(j)} \middle| d^{(j)} = +1\right) = \mathrm{var}\left[\sum_{k=1}^{\beta} \left[\hat{x}(k)^{(j)}\right]^2\right] + \beta \frac{N_o}{2}\, E\left[\left(\hat{x}(k)^{(j)}\right)^2\right] = \frac{E_b N_o}{2} \qquad (6)$$

Using equation 5 & 6 in equation 4, we get

$$\mathrm{BER}^{(j)} = \frac{1}{2}\, \mathrm{erfc}\left(\sqrt{\frac{E_b}{N_o}}\right) \qquad (7)$$

From equation (7) it is clear that BER performance of the proposed system is independent of number of users and spread factor.

From Fig. 2 we see that for small values of spread factor the BER performance of the proposed system is better than multiple access antipodal chaos shift keying (MA-ACSK),[8] system in which non orthogonal chaotic vectors are used. For larger values of spread factor both have same BER performance.

IV. Performance Analysis Over Fading Channels

In this Section we will analyze the BER performance of the proposed system over fading channels assuming that the channel is slow fading.

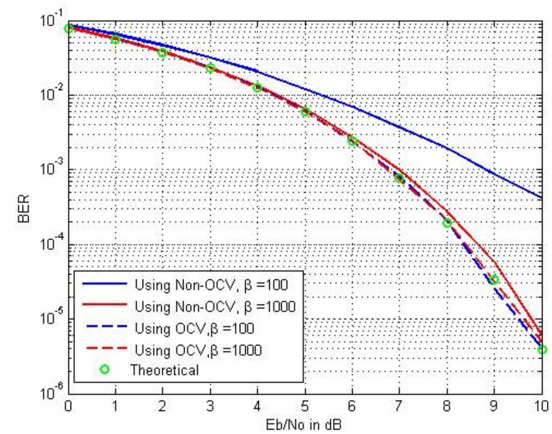

Fig. 2. Comparison of BERs v/s Eb/No plots for number of users = 5

A. Rayleigh fading channel

Let α be the Rayleigh distributed random variable denoting fading gain. Then it can be shown that the BER of j^{th} user in symbol duration will be

$$\mathrm{BER}_{\alpha}^{(j)} = \frac{1}{2} \mathrm{erfc}(\gamma) \qquad (8)$$

Where, $\gamma = \frac{\alpha E_b}{N_o}$

Since, α is Rayleigh-distributed γ (the received instantaneous signal to noise ratio per bit) will be chi-square distributed and has the form,

$$f_{\mathrm{Rayleigh}} = \frac{1}{\bar{\gamma}} e^{-\frac{\gamma}{\bar{\gamma}}}, \gamma \geq 0 \qquad (9)$$

Where, $\bar{\gamma} = E[\gamma] = E[\alpha] \cdot \frac{E_b}{N_o}$

Therefore, the average BER for j^{th} user is

$$\mathrm{BER}_{\mathrm{Rayleigh}} = \int_0^{\infty} \mathrm{BER}_{\alpha}(\gamma) f_{\mathrm{Rayleigh}}(\gamma)\, d\gamma \qquad (10)$$

In Fig. 3 a plot of both simulated and theoretical BER are given. We see that the theoretical result closely matches with that of simulation result.

B. Ricean fading channel

If the received signal has a dominant line of sight component then channel is considered to be ricean fading channel. The conventional single user DCSK BER performance over multipath ricean fading channel has been investigated in [7], where the ricean distribution with a PDF is derived as

$$f_{Ricean} = \frac{(1+K)e^{-K}}{\bar{\gamma}} \exp\left(-(1+K)\frac{\gamma}{\bar{\gamma}}\right) G(\gamma) \quad (11)$$

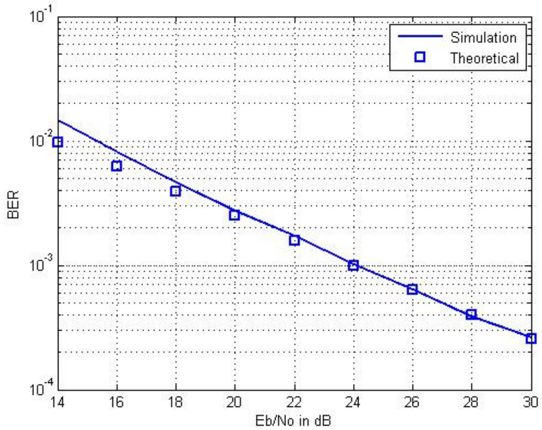

Fig. 3. Simulated and theoretical BERs versus Eb/No, Over Rayleigh fading channel for β = 100 and $N_u = 5$

Where $G(\gamma) = I_o\left[\sqrt{\frac{4K(1+K)\gamma}{\bar{\gamma}}}\right]$ and $I_o = \frac{1}{2\pi}\int_{-\pi}^{\pi} e^{x\cos\theta}\, d\theta$ is the modified Bessel function of the modified Bessel function of the first kind and zero order, $K = \frac{A^2}{2\sigma^2}$is the ricean factor, *A* denotes the amplitude of the dominant stationary signal,σ^2 is the average power of the scattered signals. Therefore, the average BER for j^{th} user is

$$BER_{Ricean} = \int_0^{\infty} BER_{\alpha}(\gamma) f_{Ricean}(\gamma)\, d\gamma \quad (12)$$

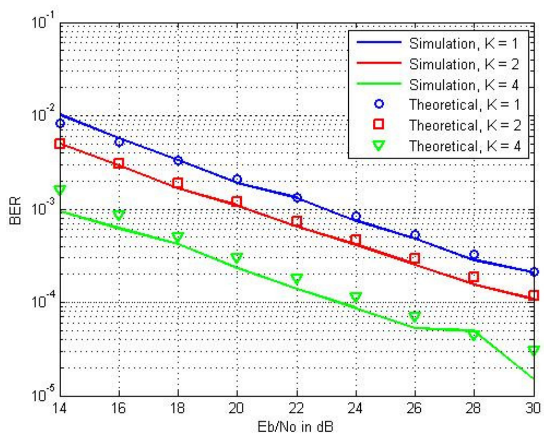

Fig. 4. Simulated and theoretical BERs versus Eb/No, Over Ricean fading channel for different values of K with β = 100 & N_u=5

In Fig. 4 we present the comparison of theoretical and simulated BER's over ricean fading channel for different values of ricean factor, K.

V. Simulation

For generating chaotic sequence chebyshev map of order three is used, which is given by,

$$x(k+1) = 4x^3(k) - 3x(k) \quad (13)$$

To test the performance of the system we ran a Monte-Carlo simulation by transmitting 1,000,000 bits and the number of bits in error is found to compute BER. The initial condition for chaotic sequence generator is chosen such that the map operates in chaotic regime. For the simulations to test the performance over fading channels the average power gain of the fading channel,$E[\alpha]$is taken as unity.

VI. Conclusion

In this paper, an improved multiple access chaotic communication system using orthogonal chaotic vectors as spreading sequence has been tested and analysed. We also compared the results of the proposed system with that of MA-ACSK system and found that the proposed system gives better performance for small values of spread factor, β. Theoretical expression for BER is derived for both AWGN and fading channels. It is found that theoretical result matches with simulated results thus validating the analysis carried out.

The use of the orthogonal chaotic vectors as spreading sequences and with the receivers being coherent the system performance will be equal to the theoretical bound (Single user BPSK system with coherent receiver). So, the results obtained can be used as benchmark to evaluate the non coherent multiple access chaotic communication systems.

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