Design and Analysis of an Orthogonal Chaotic Vectors based Differential Chaos Shift Keying Communication System

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Abstract
An orthogonal chaotic vectors based differential chaos shift keying (OCV-DCSK) digital communication system is presented. In this system the data transmission rates are increased by sending M bits in the same frame without needing for synchronization and channel state information since it use the benefit of non-coherent modulation of the DCSK and the orthogonality of chaotic vectors in the same scenario as QCSK system but instead of using Hilbert transform to create two orthogonal signals in QCSK, Gram Schmidt process is used to create M orthogonal chaotic signals from the M non-orthogonal chaotic signal. In the proposed system the analytical expression for OCV-DCSK are derived in AWGN and multipath fading channels. The simulation results show that the derived analytical expression have matched the Monte-Carlo simulation of the proposed system. Furthermore, comparison between orthogonal chaotic vectors and non-orthogonal, that are generated either as different initial conditions with the same chaotic generator or as different types of chaotic maps, reveals its superior BER performance in multipath fading channel.
Keywords: Non-coherent chaos based communication system, Orthogonal Chaotic Vectors, DCSK, Multipath Rayleigh fading channel, Performance analysis.

1. Introduction
The characteristics of chaotic signals such as wideband spectrum, good randomness behavior [1], easy to generate [2]and perfect correlation properties [3] making it suitable used for digital communication and spread spectrum systems. Furthermore, it has strong immunity to multipath fading channel [4] and jamming with low probability of interception [5]. Among all types of chaos based digital communication system, the differential chaos shift keying (DCSK) system [6] represents the most famous study due to it is a non-coherent detection where the transmitted signal is detected without channel state information (CSI) and has good bit error rate (BER) performance in multipath fading channel [4].In DCSK systems two slots are used for transmitted signal one for the reference chaotic signal and the other for the information-bearing chaotic signal. When bit '1' is sent, the information-bearing chaotic signals are transmitted with the same value of the reference chaotic signal. While for bit '0' is sent, the information-bearing chaotic signal is transmitted with the negative value of reference chaotic signal [4].

Since half of the bit duration is wasted on reference chaotic signal, the information rate of DCSK system is not high. There are several studies for increasing the information rate in DCSK [7-14]. In [7] a quadrature chaos-shift keying (QCSK) is proposed to double the information rate of the conventional DCSK with the same frame time. In QCSK system the information-bearing signal carries two bits by using linear combination of two orthogonal chaotic signals. The orthogonal signal is obtained by applied Hilbert transform to the reference chaotic signal. Hilbert transform will add complexity at transmitter and receiver sides. In [8] orthogonal chaotic vector shift keying (OCVSK) is proposed in the same idea as QCSK system but instead of Hilbert transform, Gram Schmidt method is used to generate an orthogonal chaotic signals from the originally generated signals. In [9] high efficiency DCSK (HE-DCSK) is proposed to double bandwidth efficiency by carry two bits in one information modulated sequence. This occurs by recycling each reference sequence in DCSK system. In [10] high-data-rate code-shifted DCSK (HCS-DCSK) is designed to increase information rate by letting the transmitted bits to share the same reference chaotic slot. The orthogonal chaotic signals are designed from one reference chaotic signal and multiplied by other appropriate chaotic signals. This system required time synchronization between the transmitter and receiver sides. In [11] quadrature amplitude modulation DCSK (QAM-DCSK) is designed to combine QAM modulation with DCSK system where the information bits are transmitted in two orthogonal channels. The analytical performance of QAM-DCSK system is analyzed under additive white Gaussian noise (AWGN) channel. A new multi resolution M-ary DCSK modulation with circular constellation is studied in [12] to enhance the data rate. The operation of M-ary DCSK is similar to QCSK where Hilbert transform is used to generate the orthogonal chaotic signal with only difference it can carry m bits instead of two bits.

Furthermore, the orthogonal Walsh code is used with reference chaotic signal to generate independent orthogonal chaotic signal as in M-ary DCSK with Walsh code [13] where each symbol is mapped into corresponding Walsh code signal and multiplied by the same reference chaotic signal. While in [14] a multilevel code shifted DCSK (MCS-DCSK) is used where the reference and information-bearing chaotic signals are orthogonalized by using Walsh codes and transmitted in the same time slot. The last two types of modulation solved the problem of delay line but instead synchronization is needed at receiver side. To avoid the needs for synchronization and RF delay lines at the receiver, both Hilbert transforms and Walsh codes techniques are combined to produce orthogonal multi-level differential chaos shift keying (OM-DCSK) system [15]. It based on both the transmitted-reference technique and M-ary orthogonal modulation. This system used Inphase and Quadrature (I/Q) channels to send the reference signal via an Inphase channel and send the information-bearing signal via a Quadrature channel in simultaneously.

In this paper, an orthogonal chaotic vector based DCSK (OCV-DCSK) is introduced. In which multi-bits are transmitted in the same frame using orthogonal chaotic signals to separate between each bits. The reference signal contains M chaotic signals each with β samples that transmitted in M slots therefore, the reference signal has $M\beta$ samples. The information-bearing signal consists of combination M orthogonal chaotic signals where each one is multiplied by the corresponding data transmitted bits to become the total frame length ($(M+1)\beta$). OCV-DCSK is different from [8] in which Gram Schmidt process is used only at transmitter side and also is different from other high data rates that used either Hilbert transform to generate orthogonality between two chaotic signals like QCSK system or using Walsh codes to create orthogonality between multi-signals, where the last systems required synchronization at receiver side like HCS-DCSK. In this system the following points are contributed,

- Design and analysis of an OCV_DCSK system.
- The analytical BER performance is derived in AWGN and multipath Rayleigh fading channels.
- The orthogonal chaotic vectors are compared with non-orthogonal chaotic vectors in multipath fading channel.

The rest of this paper is organized as follows: In section II, the architecture of OCV-DCSK system is presented. Performance analysis of OCV-DCSK system is explained in section III. In section IV, simulation results under AWGN and multipath fading channels are presented and the conclusions are drawn in section V.

2. Orthogonal Chaotic Vector based DCSK (OCV-DCSK) Communication System

In DCSK modulation one bit is transmitted for each frame. To transmit M bits in a frame, orthogonal chaotic vector is proposed to combine with DCSK modulation. The theory of using orthogonal chaotic vector in digital communication is studied in [8] where M orthogonal sequences are generated from M chaotic sequences using Gram-Schmidt algorithm. The proposed OCV-DCSK modulator is illustrated in Fig. 1. In the first, the M chaotic sequences each with length β are generated from the same chaotic generator using tap delay of β samples. The M chaotic sequences of the jth frame are symbolized by $c_{j,k}^1, c_{j,k}^2, .., c_{j,k}^M$ that are generated using a second order Chebyshev polynomial function (CPF) with unity variance and zero mean [16]

$$c_{k+1} = 1 - 2c_k^2 \quad (1)$$

These sequences are non-orthogonal in perfectly with each other. The mth orthogonal chaotic vectors of the jth frame, $x_{j,k}^m$, can be extracted from these source signals using Gram-Schmidt process by using the following expression [17]

$$x_{j,k}^m = \frac{c_{j,k}^m - \sum_{q=1}^{m-1}\left[\sum_{k=1}^{\beta} c_{j,k}^m x_{j,k}^q\right] x_{j,k}^q}{\sqrt{\sum_{k=1}^{\beta}\left[c_{j,k}^m - \sum_{q}^{m-1}\left(\sum_{k=1}^{\beta} c_{j,k}^m x_{j,k}^q\right) x_{j,k}^q\right]^2}} \quad (2)$$

where m=2,3,….,M. The orthogonal chaotic vector for m=1 is given by

$$x_{j,k}^1 = \frac{c_{j,k}^1}{\sqrt{\sum_{k=1}^{\beta}\left[c_{j,k}^1\right]^2}} \quad (3)$$

These M orthogonal chaotic vectors are used as reference chaotic signal with total length M β. For each jth frame, the data stream $d_{j,m} \in \{1,-1\}$ is converted into blocks of M bits $\{d_{j,1}, .., d_{j,M}\}$ using serial to parallel converter. The information-bearing sequence of length β is calculated by combination of mth data ($d_{j,m}$) multiplied by mth orthogonal chaotic vector ($x_{j,k}^m$) where each data bit has its own reference chaotic sequence. Therefore, the total frame consists of concatenation of reference and information-bearing sequences with a total length (M+1) β. Fig. 2 shows the OCV-DCSK frame where the first M slots are used as reference chaotic sequences and the last slot used as information-bearing sequence. The discrete baseband OCV-DCSK signal of the jth frame and kth spreading sequence $s_{j,k}$ is written as

$$s_{j,k} = \begin{cases} x^1_{j,k} & for\ \ 0 < k \le \beta \\ x^2_{j,k} & for\ \ \beta < k \le 2\beta \\ \vdots & \\ x^M_{j,k} & for\ \ (M-1)\beta < k \le M\beta \\ \frac{1}{\sqrt{M}} \sum_{m=1}^{M} d_{j,m} x^m_{j,k} & for\ \ M\beta < k \le (M+1)\beta \end{cases} \quad (4)$$

Fig. 3 illustrates block diagram of OCV-DCSK demodulator. The received sequence $r_{j,k}$ represents the received of the first reference sequence, while $r_{j,k+\beta}$ represents the received of the second reference sequence and so on until to $r_{j,k+(M-1)\beta}$ that represents the received of the Mth reference sequence. Also, the received of information-bearing sequence is represented by $r_{j,k+M\beta}$. There are M correlations functions that used to detect the M transmitted bits. The mth correlation of the jth frame is written as

$$Z_{j,m} = T_c \sum_{k=0}^{\beta-1} r^*_{j,(k+(m-1)\beta)}\, r_{j,(k+M\beta)} \quad ,m = 1,2,\dots,M \quad (5)$$

where T_c is the chip time and $(.)^*$ is the conjugate operator. The mth transmitted bits of the jth frame is then detected by applying decision threshold to the real components of $Z_{j,m}$ and then converted into stream bits using parallel to serial converter. As can be seen from transmitter and receiver system only need to transmit and receive multi-bits in the same frame is Gram-Schmidt process at transmitter side with simple mathematical expression using (1) and (2) comparing to other methods that are used Hilbert transform as in QCSK or using Walsh code as in MCS-DCSK system. In other words, there are some limitations for using the OCV-DCSK system represented by the long reference sequence and hence long frame duration is produced. To study the effect of transmitted bit numbers on the bit duration and the transmitted bit energy of OCV-DCSK let define the bit duration of OCV-DCSK as $T_{b,OCV-DCSK} = (M+1)\beta T_c/M$ and the transmitted bit energy for jth frame is calculated as

$$E_{j,b,OCV-DCSK} = \frac{T_c}{M}\left(\sum_{m=1}^{M}\sum_{k=0}^{\beta-1}(x^m_{j,k})^2 + \frac{1}{M}\sum_{m=1}^{M}\sum_{k=0}^{\beta-1}(x^m_{j,k})^2\right) = T_c\left(\frac{M+1}{M^2}\right)\sum_{m=1}^{M}\sum_{k=0}^{\beta-1}(x^m_{j,k})^2 \approx T_c\frac{(M+1)}{M}\beta\, E\left[\left(x^1_{j,k}\right)^2\right] \quad (6)$$

where E[.] is the expectation function. For large M, $T_{b,OCV-DCSK} \approx \beta T_c$ and $E_{j,b,OCV-DCSK} \approx T_c\beta\, E\left[\left(x^1_{j,k}\right)^2\right]$. Therefore, the bit duration and the bit energy of OCV-DCSK is less than the bit duration and the bit energy of DCSK by a factor of two ($T_{b,DCSK} = 2\beta T_c$ and $E_{b,DCSK} = 2T_c\beta\, E[x_k^2]$) while they are similar to the bit duration and the bit energy of QCSK ($T_{b,QCSK} = \beta T_c$ and $E_{b,QCSK} = T_c\beta\, E[x_k^2]$).

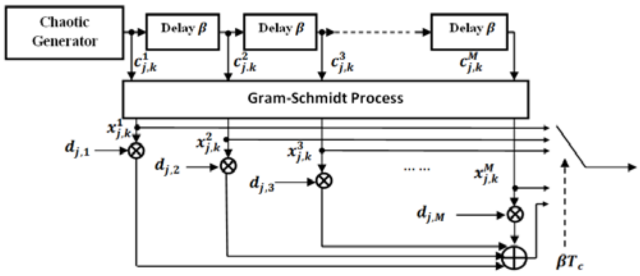

Figure 1: OCV-DCSK transmitter

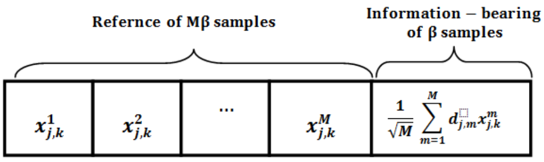

Figure 2: OCV-DCSK frame

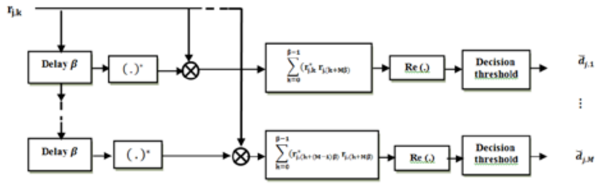

Figure 3: OCV-DCSK receiver

3. Performance Analysis of OCV-DCSK System

In this section, bit error rate (BER) performance of OCV-DCSK is analytically derived over multipath Rayleigh fading channel and AWGN. Define τ_ℓ and α_ℓ as ℓ^{th} path time delay and complex channel coefficients respectively for L tapped delay Rayleigh fading channel. The channel coefficients α_ℓ are independent and identical Rayleigh distribution with slow fading that have probability density function (PDF) given by [16]

$$f(\alpha) = \frac{\alpha}{\sigma^2} e^{-\frac{\alpha^2}{2\sigma^2}} \quad (7)$$

where σ is the root mean square value of the received voltage sequence. The baseband discrete received signal of the jth frame is written as

$$r_k = \sum_{\ell=1}^{L} \alpha_\ell\ s_{j,k-\tau_\ell} + n_k \quad (8)$$

where n_k is the additive white Gaussian noise with zero mean and variance $N_0/2$ and $s_{j,k-\tau_\ell}$ is the channel delay version of the transmitted sequence $s_{j,k}$. In order to derive BER of a OCV-DCSK system the following assumption is considered: the maximum channel delay τ_{max} is less than the reference sequence to reduce the intersymbol interference (ISI), the chip duration T_c=1 and the sub-index j is omitted from all equations for simplicity. Since all the data detection is identical, only the first detection is analyzed. By substituted (4) and (8) into (5), the output of the first correlator is given by

$$Z_1 = \sum_{k=0}^{\beta-1}\left[\sum_{\ell=1}^{L}\left(\left(\frac{1}{\sqrt{M}}d_1\,\alpha_\ell x_{1,k-\tau_\ell} + \frac{1}{\sqrt{M}}d_2\,\alpha_\ell x_{2,k-\tau_\ell} + \ldots + \frac{1}{\sqrt{M}}d_M\,\alpha_\ell x_{M,k-\tau_\ell}\right) + n_{k+\beta}\right)\left(\sum_{\ell=1}^{L}\alpha_\ell x_{1,k-\tau_\ell} + n_k\right)^*\right] \quad (9)$$

Where $x_{m,k-\tau_\ell}$ is the delay version of the m[th] orthogonal chaotic vector and $(.)^*$ is the conjugate operator. Since all reference chaotic vectors are orthogonal to each other and for large reference length, the following expressions are used [16]

$\sum_{k=0}^{\beta} x_{m,k-\tau_\ell}\, x_{m,k-\tau_\mathcal{V}} \approx 0, \ell \neq \mathcal{V}$ and

$$\sum_{k=0}^{\beta-1} x_{m,k-\tau_\ell}\, x_{n,k-\tau_\ell} \approx 0, m \neq n \quad (10)$$

From above equations and assumptions the first decision variable D_1=Real (Z_1) represents the input to the decision threshold block that is expressed as

$$D_1 = \text{Real}\left(\frac{d_1}{\sqrt{M}}\sum_{\ell=1}^{L}|\alpha_\ell|^2\sum_{k=0}^{\beta-1}x_{1,k-\tau_\ell}^2 + \frac{d_1}{\sqrt{M}}\sum_{\ell=1}^{L}\alpha_\ell\sum_{k=0}^{\beta-1}x_{1,k-\tau_\ell}n_k^* + \cdots + \frac{d_M}{\sqrt{M}}\sum_{\ell=1}^{L}\alpha_\ell\sum_{k=0}^{\beta-1}x_{M,k-\tau_\ell}n_k^* + \sum_{\ell=1}^{L}\alpha_\ell\sum_{k=0}^{\beta-1}x_{1,k-\tau_\ell}n_{k+\beta} + \sum_{k=0}^{\beta-1}n_{k+M\beta}\,n_k^*\right) \quad (11)$$

where Real (.) is the real part of the complex sequence and n_k^* is the conjugate of n_k that is also AWGN [7]. The first term of (11) represents the desired information sequence of transmitted bit $d_1$while all the remaining terms in the same equation represent the interference and noise sequence. By applying the central limit theorem, the decision variable D_1 is treated as Gaussian distribution with variance σ_D^2 and expectation μ_D. Therefore, BER of OCV-DCSK is expressed in terms the complementary error function (erfc) as

$$\text{BER} = \frac{1}{2}\,\text{erfc}\left(\left[\frac{2\sigma_D^2}{\mu_D^2}\right]^{-\frac{1}{2}}\right) \quad (12)$$

where erfc (t)= $\frac{2}{\sqrt{\pi}}\int_t^\infty e^{-\mu^2}d\mu$. The mean of the decision variable D_1 (μ_D) is the average of the first term only in (11) since the remaining terms are considered as AWGN with zero mean. Therefore, after consider d_m=+1 for m=1,2,.., M, μ_D is given by

$$\mu_D = \frac{\beta}{\sqrt{M}}\sum_{\ell=1}^{L}|\alpha_\ell|^2\; E\left[x_{1,k}^2\right] \quad (13)$$

The transmitted bit energy $E_{j,b,OCV-DCSK} \approx E_b$ is assumed constant for all frames for long reference length (M β).Write $E\left[x_{1,k}^2\right]$ in terms E_b, $E\left[x_{1,k}^2\right]$=$\frac{M}{\beta(M+1)}\,E_b$ and substitute d_1=+1 (13) becomes

$$\mu_D = \frac{\sqrt{M}}{M+1}\sum_{\ell=1}^{L}|\alpha_\ell|^2\,E_b \quad (14)$$

The variance of D_1 is calculated by combination the variances of each terms in separately since all terms are assumes independent random variable. Also, it is assumed that all mean square value of m[th] OCVs, $E\left[x_{m,k}^2\right]$, are equals ($E\left[x_{1,k}^2\right]$ = $E\left[x_{2,k}^2\right]$=…= $E\left[x_{M,k}^2\right]$) then σ_D^2 is given by

$$\sigma_D^2 = \frac{\beta}{M}\left(\sum_{\ell=1}^{L}|\alpha_\ell|^2\right)^2\left(E\left[x_{1,k}^2\right]\right)^2 + \beta\frac{N_0}{2}\sum_{\ell=1}^{L}|\alpha_\ell|^2\;E\left[x_{1,k}^2\right] + \beta\frac{N_0}{2}\sum_{\ell=1}^{L}|\alpha_\ell|^2\;E\left[x_{1,k}^2\right] + \beta\frac{N_0^2}{4} \quad (15)$$

Rewrite (15) in terms of E_b and rearranged to get

$$\sigma_D^2 = \frac{M}{\beta\ \ (M+1)^2}\left(\sum_{\ell=1}^{L}|\alpha_\ell|^2\right)^2\;E_b^2 + N_0\,\frac{M}{(M+1)}\sum_{\ell=1}^{L}|\alpha_\ell|^2\;\;E_b + \beta\frac{N_0^2}{4} \quad (16)$$

Substituted (14) and (16) into (12) and rearranged to become

$$\text{BER} = \frac{1}{2}\,\text{erfc}\left(\left[\frac{2}{\beta} + \frac{N_0}{E_b}\frac{2(M+1)}{\sum_{\ell=1}^{L}|\alpha_\ell|^2} + \frac{\beta(M+1)^2}{2M\left(\sum_{\ell=1}^{L}|\alpha_\ell|^2\right)^2}\frac{N_0^2}{E_b^2}\right]^{-\frac{1}{2}}\right) \quad (17)$$

For large β , the term 2/ β is approached to zero, then (17) becomes

$$\text{BER} = \frac{1}{2}\,\text{erfc}\left(\left[\frac{N_0}{E_b}\frac{2(M+1)}{\sum_{\ell=1}^{L}|\alpha_\ell|^2} + \frac{\beta(M+1)^2}{2M\left(\sum_{\ell=1}^{L}|\alpha_\ell|^2\right)^2}\frac{N_0^2}{E_b^2}\right]^{-\frac{1}{2}}\right) \quad (18)$$

Define $\lambda = \sum_{\ell=1}^{L}|\alpha_\ell|^2\,E_b/N_0$ then the conditional BER for OCV-DCSK becomes

$$\text{BER} = \frac{1}{2}\,\text{erfc}\left(\left[\frac{2(M+1)}{\lambda} + \frac{\beta(M+1)^2}{2M\lambda^2}\right]^{-\frac{1}{2}}\right) \quad (19)$$

The average BER, $\overline{BER}$, over the probability density function (pdf) of λ is given by

$$\overline{BER} = \frac{1}{2}\int_0^\infty \text{erfc}\left(\left[\frac{2(M+1)}{\lambda} + \frac{\beta(M+1)^2}{2M\lambda^2}\right]^{-\frac{1}{2}}\right)\;f(\lambda)\;d\lambda \quad (20)$$

where $f(\gamma)$ is the pdf of λ that is given as [16]

$$f(\lambda) = \sum_{\ell}^{L}\frac{1}{\bar{\lambda}_\ell}\left(\prod_{j=1,j\neq\ell}^{\ell}\frac{\bar{\lambda}_\ell}{\bar{\lambda}_\ell-\bar{\lambda}_j}\right)e^{-\frac{\lambda}{\bar{\lambda}_\ell}} \quad (21)$$

where $\bar{\lambda}_\ell$ is the mean value of $\lambda_\ell = |\alpha_\ell|^2\,E_b/N_0$ which is the instantaneous signal to noise ratio for ℓ^{th} path. The integral in (20) is not easy to calculate, Therefore the numerical integration is used as in [16] to approximate $\overline{BER}$ as

$$\overline{BER} = \frac{1}{2}\sum_{c=1}^{C}\text{erfc}\left(\left[\frac{2(M+1)}{\lambda} + \frac{\beta(M+1)^2}{2M\lambda^2}\right]^{-\frac{1}{2}}\right)\;f(\lambda_c) \quad (22)$$

where C is the number of classes (here C=100 [16]) with a unite step size of integration and $f(\lambda_c)$ is the pdf of having the energy in intervals centered at λ_c.

In other words, BER of OCV-DCSK over AWGN channel can be founded from (18) by putting $\alpha_1 = 1$ and the remaining path gains $\alpha_\ell = 0,$ for $\ell = 2,..,L$ to become

$$\text{BER}_{OCV-DCSK} = \frac{1}{2}\,\text{erfc}\left(\left[\frac{2(M+1)N_0}{E_b} + \frac{\beta(M+1)^2}{2M}\frac{N_0^2}{E_b^2}\right]^{-\frac{1}{2}}\right) \quad (23)$$

4. Simulation Results

In order to validate the analytic performance of OCV-DCSK system, the system is simulated and the simulation results are compared with those of the analytical expressions in (21) and (22) under multipath Rayleigh fading and AWGN channels.

4.1 AWGN Channel Results

Fig. 4 shows BER performance of OCV-DCSK in AWGN channel for β=50 and M=2, 4 and 8. In this figure the BER performance comparison between the simulation and analytical are considered the results show the analytical and simulation analysis are approximately matched to each other. It is clearly that for M is large, the analytic and the simulation results are more matching together than when M is small because the length of reference signal is proportional to M value. Also, increase M will enhance multilevel technique but degrade the BER performance. Furthermore, OCV-DCSK is compared with DCSK and QCSK systems where can see that OCV-DCSK with M=2 is degraded in SNR compared to DCSK and QCSK by 1 dB and 2 dB respectively at BER=10^{-3}. This degradation due to the length of reference sequence in OCV-DCSK is greater than both DCSK and QCSK and hence noise power is increased for the corresponding frame. Fig. 5 shows BER performance of OCV-DCSK in AWGN channel for M=4 and β =50, 100 and 200. It is clearly that increase β will degrade the performance for the same reason when M is increased, where any increased in β by a factor of two (50, 100, 200) will SNR losing gain by about 1 dB in each case. Also here, the analytic and the simulation results are both approximately matching.

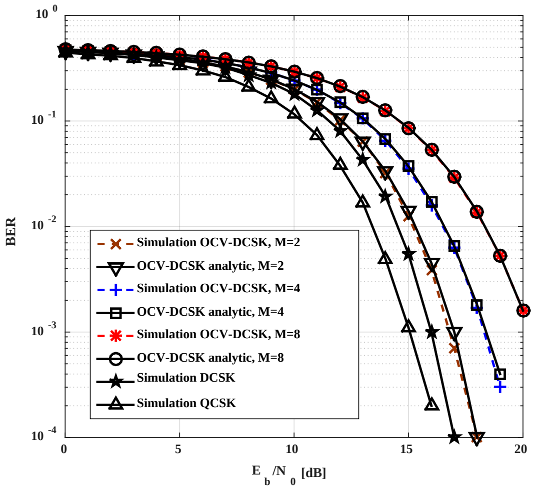

Figure 4: BER performance of OCV-DCSK in AWGN channel for β=50 and M=2, 4 and 8.

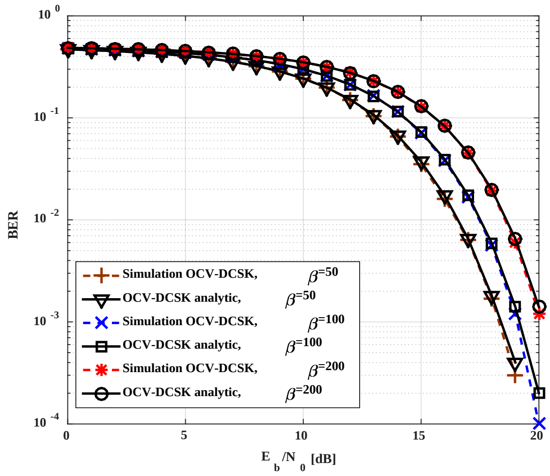

Figure 5: BER performance of OCV-DCSK in AWGN channel for M=4 and β=50, 100 and 200.

4.2 Multipath Rayleigh Fading Channel Results

In this simulation, multipath Rayleigh fading channel with two paths are considered with an average powers are $E(\alpha_1^2) = 2/3$ and $E(\alpha_2^2) = 1/3$ and the corresponding delays for each path are τ_1=0 and τ_2=2T_c respectively. Fig. 6 shows BER performance of OCV-DCSK in multipath fading channel for β=50 and M=2, 4 and 8. It can be seen that the simulation results are approximately matching the BER analytic. Any increase in M will enhance the multi-bit transmitted but instead will decrease the SNR gain where it is required SNR about 23.5, 24.5 and 27 dB for M=2,4 and M respectively to reach BER about 10^{-3}. Furthermore, OCV-DCSK with M=2 will degrade SNR gain about 1 and 2 dB at BER=10^{-3} comparing to DCSK and QPSK respectively. Therefore, orthogonal chaotic vectors enhance multi-bits transmitted technique with low complexity comparing to QCSK but instead will affect the BER performance. Also the bandwidth efficiency is decreased, where the length of reference signal is increased by β to become (3β) for M=2 comparing to 2β for QCSK system. The limitation of QCSK comparing to OCV_DCSK is capability to bear two information signals only in the same frame and use Hilbert transform in the transmitter and receiver side, while the capability of the OCV-DCSK is extended to M signals in the same frame and use Gram Schmidt process only at transmitter side with delay components.

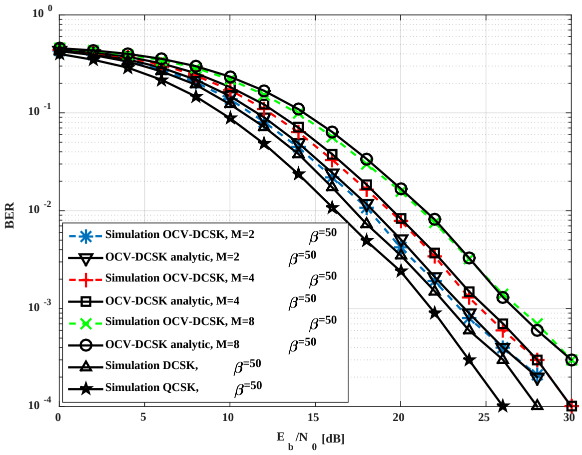

Figure 6: BER performance of OCV-DCSK in multipath fading channel for β=50 and M=2, 4 and 8. Also the performance are compared with DCSK and QCSK system

Fig. 7 shows the BER performance of OCV-DCSK that used orthogonal chaotic signals comparing with those for non-orthogonal chaotic signals generated either as different initial condition for CPF chaotic map or using different types of chaotic maps including CPF, Tent, Henon and Gauss iterated map [18], where the comparison is made for M=2 and 4. It can be noticed that for M=2, approximately all have the same performance and OCV-DCSK becomes best at SNR greater than 25 dB but for M=4, OCV-DCSK has SNR gain about 2 and 3 dB comparing for those using different chaotic maps or different initial conditions respectively. Therefore, using Gram Schmidt to generate orthogonal vectors gives boost enhancement for the orthogonality between the chaotic signals.

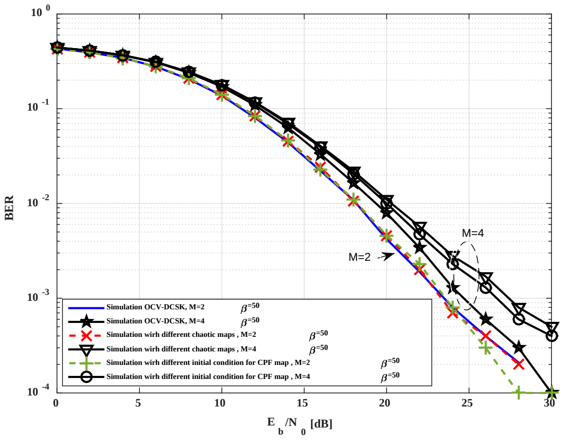

Figure 7: BER performance comparison between orthogonal chaotic vectors and those generator either using different initial condition with the CPF chaotic maps or using different chaotic maps including CPF, Tent, Henon and Gauss iterated map for β=50 and M=2 and 4 in multipath fading channel.

V. Conclusion

In this paper, an OCV-DCSK system is presented to carry M bits on the same frame in the same scenario of QCSK system but the last system can carry only two bits on the same frame. Therefore, OCV-DCSK used Gram Schmidt process to allow M bits to transmit in the same frame and received it in correct way without using CSI and the complexity that founds in the systems that used either Walsh codes or Hilbert transforms. The only limitation with this system is required long reference length and this will decrease the bandwidth efficiency (this problem will solve in the next paper). The analytic BER for OCV-DCSK is derived for both AWGN and multipath fading channels and compare to Monte-Carlo simulation. The results demonstrate that both the analytical and empirical performances are approximately matching. The results show that the BER performance of OCV-DCSK depends on M and β values where increased M with degrade the performance by about 1, 1.5 and 4.5 dB for M=2, 4 and 8 respectively comparing to DCSK system in AWGN and multipath fading channel. Also any increased in β by a factor of two (50, 100, 200) will decrease SNR gain by about 1 dB. Furthermore, OCV-DCSK is compared with those using non-orthogonal chaotic signals that generated either as with different initial conditions for CPF map or with different types of chaotic maps where the results show that the proposed orthogonal technique has superior BER performance.

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تصميم وتحليل منظومة المفتاح المزاحة الفوضوية التفاضلية بالاعتماد عل المتجهات الفوضوية المتعامدة

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الخلاصة

تم اعتماد المتجهات الفوضوية المتعامدة في بناء منظومةالاتصالات الرقمية ذات المفتاح المزاحةالفوضوية التفاضلية (OCV-DCSK). في هذا النظام تم زيادة معدل نقل البيانات بارسال M من البتات في نفس الاطار من دون الحاجة الى استخدام التزامن ومعلومات حالة القناة وذلك عن طريق استخام الخاصية المتبعة لمنظومة DCSK وخاصية المتجهات الفوضوية المتعامدة بنفس الطريقة المتبعة في انظمة QCSK ولكن بدل من استخدام متحولة هلبرت لإنشاء إشارتين متعامدتين في منظومة QCSK فانه يستخدم عملية غرام شميت لانشاء M من الإشارات الفوضوية المتعامدة منM من الإشارات الفوضوية غير المتعامدة . تم اشتقاق التعبير التحليلي للمنظومة المقترحة في قناة AWGN وقناة التوهين المتعددة. نتائج المحاكاة اثبتت ان التعبير التحليلي المشتق يطابق النتائج المحصلة من المحاكاة . بالاضافة الى ذلك تم مقارنة المتجاهات الفوضوية المتعامدة مع تلك الغير المتعامدة والتي تم توليدها اما من استخدام الشروط الابتدائية المختلفة لنفس المصدر الفوضوي او باستخدام انواع مختلفة من المصادر للخرائط الفوضوية, حيث كشفت النتائج ان المنظومة المقترحة تمتلك اداء BER افضل في قناة التوهين المتعددة.