Performance Improvement of DS-CDMA Wireless Communication Network with Convolutionally Encoded OQPSK Modulation Scheme

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Abstract:

This paper considers the bit error probability analysis of Direct-Sequence Code-Division Multiple Access (DS-CDMA) system. A statistical characterization of the decision variable at transmitter and receiver is obtained. System is simulated with OQPSK modulation scheme which when compared with conventional Binary Phase Shift Keying (BPSK) gives improved performance in terms of Probability of Error (Pe). Convolution coding is further incorporated with both of the modulations schemes and results show that this coding further improves the system when compared without coding. However, mathematical analysis includes exact bit error calculation as well as various approximation methods based on Gaussian modeling of the Multiple-Access Interference (MAI) terms.

Keywords: *Direct-sequence code-division multiple access, multiple-access interference, Offset QPSK, BPSK, convolution encoder etc.*

1. INTRODUCTION

CDMA technique for wireless communication networks always gives better performance as far as Probability of Error (Pe) is concerned, when compared to either FDMA or TDMA. CDMA is now a days are widely being used particularly in wireless cellular networks. Several modulation techniques namely bit error efficient techniques, OQPSK, MSK (Minimum Shift keying) etc. can further enhance the performance. Here, bit error probability analysis of DS-CDMA system using offset quadrature phase-shift keying (OQPSK) modulation is done. Offset QPSK is essentially the same as QPSK except that the I- and Q-channel pulse trains are staggered. The modulator and the demodulator of OQPSK differ from the QPSK by an extra delay of half of the bit time $T_b/2$ with T_b as bit duration in the Q-channel. QPSK is also excellent modulation method, when necessary to maximize transmitter output power [1]. For spectrum conservation, band occupancy of the chosen modulation scheme must be small, so that as many channels as possible can be accommodated in a given band. Of all the constant envelope digital modulation schemes considered for radio transmission, OQPSK (offset quadrature phase shift keying) is considered to have good spectral properties.

Here, effect of the Multiple-Access Interference (MAI) on the bit error performance of the single user correlation receiver is considered. The problem is examined in the context of OQPSK spreading, which is more applicable to the recently introduced third-generation CDMA standards. Accurate evaluation of error performance for DS-CDMA with offset quadrature modulation schemes can be simply achieved by applying the Standard Gaussian Approximation (SGA).

2. SYSTEM MODEL

2.1. Transmitter

Analysis of DS-CDMA systems with mixed-data rates is considered for analysis. The data bits for the k_{th} user are transmitted after spreading and OQPSK modulation. [1,2]. For each of in-phase and quadrature component, BPSK spreading is used. Data bits b_k are randomly generated and assumed independent identically distributed(iid). If s_k denotes the transmitted signal of k_{th} user then transmitted stream can be mathematically represented by [6]

$$s_k(t) = \mathrm{Re}[(\sqrt{p_k b_k}(t)\, a_k(t) + j\sqrt{p_k b_k}\left(t - \frac{T}{3}\right) a_k(t))\, e^{-t}\tau^{t-\Delta_k} \quad (1)$$

where $\sqrt{P_k}$ $\sqrt{P_k}$ is the normalized power of k^{th} user and ϕ_k is the phase of carrier signal for k^{th} user. After serial to parallel conversion of the data stream, $b_{kI}(t)$ and $b_{kI}(t)$ are the data signals of in-phase branch and quadrature branch respectively ,expressed as

$$b_{kI}(t) = \sum_i^{\infty} = -\infty\, b_{kI}^{(i)} tp\tau_b(t - iT_b) \quad (2)$$

and

$$b_{kQ}(t) = \sum_i^{\infty} = -\infty\, b_{kQ}^{(i)} tp\tau_b(t - iT_b) \quad (3)$$

where $b_{kI}^{(i)}$ and $b_{kQ}^{(i)} \in \{\pm 1\}$ are the i^{th} bit of the k^{th} user for the in-phase and quadrature branches respectively. The signal pulse $P_{Tb}(t)$ is a unit rectangular pulse defined by

$$p_{Tb} = \begin{Bmatrix} 1 & \text{if } 0 \le t \le T_b \\ 0 & \text{elsewhere} \end{Bmatrix}$$

with T_b *a*s duration of one bit. Bit stream $a_k(t)$ is a spreading waveform, written as [6]

$$a_k(t) = \sum_{j=-\infty}^{\infty} a_k^{(j)} pc(t - jT_c) \quad (4)$$

where $a_k^{(f)} \in \{\pm 1\}$ is the j^{th} chip of the k^{th} user's spreading sequence $\{a_k^{(f)}\}$.

2.2. Multipath Channel

Impulse response of the multi path fading channel can be represented as [6]

$$h(t,\tau) = \mathrm{Re}\{h(t,\tau)e^{j\omega_c t}\} \quad (5)$$

where τ is a multipath delay and ω_c is a carrier angle frequency. The signal h(t,τ) is the complex baseband impulse response, expressed for k_{th} user as

$$h_k(t,\tau) = \sum_{l=1}^{L} \alpha_{k,l} e^{j\phi kl}\delta(t - \tau_{kl}) \quad (6)$$

with L as number of multi path components; a_{kl} :amplitude fading of l^{th} path (Rayleigh distributed random variable); τ_{kl} : delay of l^{th} path; ϕ_{kl} :phase shift of l^{th} path (uniform distributed random variable); $\delta(.)$: Dirac delta function.

2.3. RECEIVER

Received signal is a sum of user signals, their multi path delayed signals, AWGN and can expressed as [6].

$$r_a(t) = n(t) + \frac{1}{2}\sum_{k=1}^{k} \sum_{l=1}^{L} \alpha_{k,l}\, S_k(t - \tau_k - \tau_{k,l})e^{jfk,l} \quad (7)$$

Above equation may be broken in to several individual parts as

$$r_g(t) = n(t) + \frac{1}{2}\sum_k^K \sum_l^Z \alpha_{k,l}\left\{\sqrt{P_k b_{k,l}}(t-\tau_k-\tau_{k,l})\ a_k(t-\tau_k-\tau_{k,l}) + j\sqrt{p_k b_{k,Q}}(t-\tau_k-\tau_{k,l})\ a_k(t-\tau_k-\tau_{k,l})\ \right\}e^{j\theta_{k,l}} \quad (8)$$

However, decision statistic $z_{K,M}$ from the m[th] correlator branch can be written as [4, 5, 7]

$$z_{k,m,\,Re} = \int_{\tau_{k,l^{(m)}}}^{\tau_{k,l^{(m)}}+T_s} r_a^{\sim}(t)\left\{\cos\left[\omega_c t + \theta_{k,l^{(m)}}\right]a_{k(\ )}\left(t - \tau_k - \tau_{k,l^{(m)}}\right)\right\} dt \quad (9)$$

and

$$z_{km,\,lm} = \int_{\tau_{k,l^{(m)}}+T_{s/2}}^{\tau_{kl^{(m)}}+x\,T_{s/2}} r_a^{\sim}(t)\left\{-\sin\left(\omega_c t\right) + \theta_{k,l^{(m)}}\, a_{k(\ )}\left(t - \tau_k - \tau_{k,l^{(m)}}\right)\right\} dt \quad (10)$$

where $Z`_{k,m,Re}$ and $Z`_{k,m,Im}$ are the real and imaginary parts of $Z`_{k,m}$. These parts are further expanded as

$$z_{k,m,Re} = x_l + A_l + \sum_{l=l(m))}^{L} i = 1\ L_{k,\,l,\,Re} + \sum_{\substack{k=1\\k=k}}^{K}\ \sum_{l=1}^{L}\ L_{k,\,l,\,Re} \quad (11)$$

and

$$z_{k,m,l_m} = x_Q + A_Q + \sum_{l=l(m))}^{L} i = 1\ L_{k,\,l,\,l_m} + \sum_{\substack{k=1\\k=k}}^{K}\ \sum_{l=1}^{L}\ L_{k,\,l,\,l_m} \quad (12)$$

Terms A_l and A_Q represent the in-phase and quadrature contribution of the desired component to the overall decision statistic which can be simplified as

$$A_l = \frac{1}{4}\sqrt{P_k}\, a_{k,l^{(m)}}\ b_{kl}^{i} Ts \quad (13)$$

and

$$A_Q = \frac{1}{4}\sqrt{P_k}\, a_{k,l^{(m)}}\ b_{kQ}^{i} Ts \quad (14)$$

ξ_l and ξ_Q are the in-phase and quadrature phase variances due to the noise respectively. Third and fourth terms are interferences due to single and multi paths.

3. BER ANALYSIS

Standard Gaussian Approximation is the most common technique for the evaluation of the bit error probability of DS-CDMA systems. Here central limit theorem to model the MAI as a Gaussian random variable added to the thermal noise is used. Variance due to interference without incorporation of convolution coding is given by [4, 6]

$$VAR[I] = \frac{NT^z}{3}\sum_{k=1}^{z} P_k \quad (15)$$

which is further simplified as

$$\sigma^2_{MAL} = \frac{1}{3}(\kappa-1)\ E_b T_b \tag{16}$$

with $T_b = NT_c$ where T_b and T_c as bit and spreading chip durations respectively, N as spreading factor.
Variance due to noise is given by

$$\text{var}(\eta)\frac{N_b T_b}{4} \tag{17}$$

Average SNR can be calculated as

$$\text{SNR} = \frac{A_1^2}{\text{Var}(1) + \text{Var}(\eta)} \tag{18}$$

which is further simplified as

$$\text{SNR} = \frac{\frac{1}{16} P_k \alpha_{k,l}^{z,m} b_{kl}^2 T_c^2}{\frac{N_b T_b}{4} + \frac{1}{3}(k-1)E_b T_b} \tag{19}$$

Or

$$\text{SNR} = \frac{2N_0}{E_b \alpha_{k,l}^{2(m)} b_{k,l}^2} + \frac{4(\kappa-1)}{3N\alpha_{k,l}^{2(m)} b_{k,l}^2} \tag{20}$$

Now, convolution coding is applied with OQPSK modulation scheme, giving average SNR as [4, 10]

$$\text{SNR} = \frac{\frac{1}{16} P_k \alpha_{k,l}^{z,m} b_{kl}^2 T_b^2}{\frac{N_b T_b}{4}} \tag{21}$$

$$\frac{4}{E_b \alpha_{k,l}^{2(m)} b_{l,k}^2 / NC} \tag{22}$$

or
Finally, BER is calculated as

$$\text{BER} = Q\sqrt{\text{SNR}} \tag{23}$$

Where Q(.) as standard Gaussian error function, given by

$$Q(x) = (1/2p)\int_x^{\infty} e^{-\frac{t^2}{2}} dt \tag{25}$$

For simulation purpose, different values taken are as follows:

$$N = 63 \text{ and } \frac{E_b}{N_0} = 50\text{db} \tag{26}$$

4. RESULTS AND DISCUSSIONS

Now, system is simulated for OQPSK and BPSK modulation schemes with and without incorporation of convolution coding as shown in Fig (1) and fig (2) respectively. From both of the diagrams, it is clear that OQPSK modulation scheme outperformed the BPSK technique in terms of probability of error. Hence, system performance can be improved using this particular modulation over conventional BPSK scheme. However, incorporation of convolution coding can further improve the performance as can be observed from both of the figures. Taking numerical value of SNR e.g. 10, it is OQPSK gives Pe of 10^{-9} with coding whereas it gives Pe of 10^{-7} without applying coding, hence an improvement of almost 90% is achieved in this case which is clear from the respective figures. Similar conclusions can be drawn for BPSK modulation scheme which gives Pe of 10^{-7} with coding and Pe of 10^{-6} without coding almost 80% improvement as can be observed from simulated Fig (1) and Fig (2) respectively.

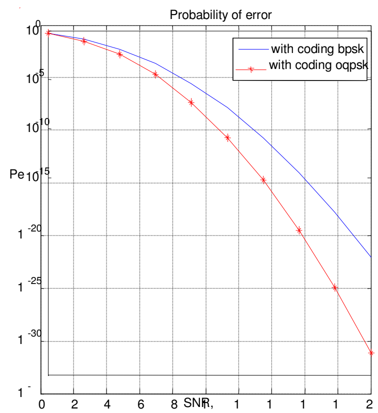
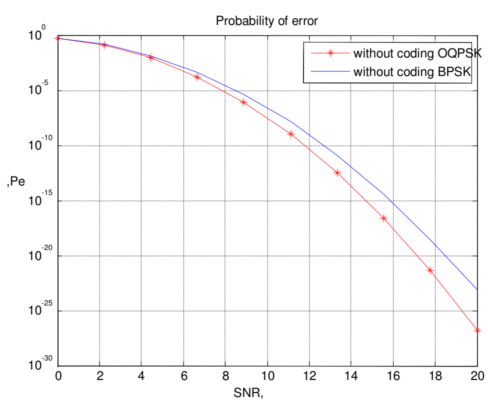


Fig.(1). Comparison between Probabilities of error P_b versus Signal to Noise ratio Eb/N_0 in the case of OQPSK modulation in DS-CDMA network with convolution coding.



Fig(2). Comparison between Probabilities of error P_b versus Signal to Noise ratio Eb/N_0 in the case of OQPSK modulation in DS-CDMA network without convolution coding.

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