Performance Analysis of DS-CDM(12)A via Waveform Shaping Methods

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Abstract: - This paper examines the performance of Direct-Sequence Spread-Spectrum Multiple-Access (DS/SSMA) communication systems under the influence of Multiple Access Interference (MAI). The study investigates how spreading code type, chip waveform selection, and code length collectively affect the Bit Error Rate (BER) in synchronous DS-CDMA networks through a MATLAB-based simulation framework. Experimental findings reveal that Gold spreading codes yield superior BER performance compared to aperiodic random codes in synchronous configurations. Furthermore, alternative chip pulse shaping techniques—specifically Blackman and Lanczos waveforms—offer negligible performance gain in synchronous network settings.

Key-Words: - Direct-sequence spread spectrum, multiple access interference, bit error rate, spreading codes, wireless communication.

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1 Introduction

The surge in global wireless connectivity demands has intensified the requirement for robust multiple-access schemes capable of accommodating an ever-growing user base. Among current approaches, Direct-Sequence Spread Spectrum (DSSS) techniques have proven effective in supporting concurrent data transmissions across shared spectral resources. However, as the active user population scales up, system capacity becomes increasingly constrained by accumulated inter-user interference, commonly termed Multiple Access Interference (MAI) [1], [2], [3]. A thorough understanding of MAI propagation and its effect on the system is therefore indispensable for advancing spectral efficiency and expanding network capacity in both legacy and emerging communication infrastructures [4], [5].

A substantial body of prior research has addressed MAI characterization in DS/SSMA systems, primarily through theoretical analysis and closed-form approximation methods. Despite providing valuable insights, these analytical frameworks tend to rely on idealized assumptions and capture only a subset of real-world parameters. Relevant factors such as active user count, spreading code structure, and code length all interact in complex ways to shape the overall interference profile. Extending analytical models to incorporate these additional variables often requires considerable mathematical re-derivation, significantly limiting practical adaptability [6], [7], [8].

To overcome these constraints, this work adopts a simulation-driven methodology for characterizing MAI in DS/SSMA systems. A simulation-based approach affords flexible exploration across a broad parameter space and provides a practical mechanism for validating theoretical predictions using scenarios that more faithfully represent operational wireless environments [9], [10].

2 Signal and System Model

The baseband data waveform $b_i(t)$ for each user in the DS/SSMA system is expressed as:

$$b_t(t) = \sum_{n=-\infty}^{\infty} b_{i,n} P_{T_s}(t - nT_s) \quad (1)$$

where $b_{i,n}$ is a sequence of elements, and $P_T(*)$ is a unity-amplitude rectangular pulse spanning one symbol period T_s. The spreading code waveform for the kth user, a_k(t), is defined as:

$$a_k(t) = \sum_{j=-\infty}^{\infty} a_j^{(k)} P_{T_C}(t - jT_C) \quad (2)$$

Each chip value a_j^(k) ∈ [−1, 1] belongs to the k^{th} user's spreading sequence, T_c is the chip duration, and the code period spans N chips. The transmitted signal for user k is:

$$S_k(t)=\sqrt{2P}a_k(t)b_k(t)\ cos\ cos\ (\omega_c t+\theta_k) \quad (3)$$

For balanced power across all users, √(2P) is the uniform signal amplitude, ω_c denotes the carrier angular frequency, and θ_k is user k's initial phase offset. The composite received signal incorporating all K users, multipath delays, and thermal noise is:

$$S_k(t)= S_k(t)=\sum_{k=1}^{K}\ \sqrt{2P}a_k(t-\tau_k)b_k(t-\tau_k)\ cos\ cos\ (\omega_c t+\emptyset_k)+n(t)\ \sum_{k=1}^{K}\ \sqrt{2P}a_k(t-\tau_k)b_k(t-\tau_k)\ cos\ cos\ (\omega_c t+\emptyset_k)+n(t)\ \sum_{k=1}^{K}\ \sqrt{2P}a_k(t-\tau_k)b_k(t-\tau_k)\ cos\ cos\ (\omega_c t+\emptyset_k)+n(t)\ \sum_{k=1}^{K}\ \sqrt{2P}a_k(t-\tau_k)b_k(t-\tau_k)\ cos\ cos\ (\omega_c t+\emptyset_k)+n(t) \quad (4)$$

The parameters τ_k and φ_k represent the propagation delay and received phase for user k, respectively. The thermal noise n(t) is modeled as AWGN with two-sided power spectral density N_0/2. The desired user is assumed to have zero delay and zero received phase; interfering users have delays uniformly distributed over [0, T_s] and phases over [0, 2π]. In a synchronous network, all user delays are identically zero.

The correlator output Z_i for the desired user over one symbol interval is:

$$Z_i=\int_0^T\ r(t)a_i(t)\ cos\ cos\ (\omega_c t)dt. \quad (5)$$

Since ω_c >> T_s^(−1), the double-frequency terms are negligible and Z_i simplifies to:

$$Z_i=\sqrt{\frac{P}{2}}.\Big\{b_{t,0}T+\sum_{k=1\ k\neq i}^{K}\ \big[b_{k,-1}R_{k,i}(\tau_k)+b_{k,0}\hat{R}_{k,i}(\tau_k)\big].cos\ cos\ \emptyset_k\Big\}+\int_0^T\ n(t)a_i(t)\ cos\ cos\ (\omega_c t)dt \quad (6)$$

The partial cross-correlation functions R_{ki}(τ) and Ħ_{ki}(τ) are continuous-time integrals that quantify the temporal overlap between user k and the desired user i due to their relative delay:

$$R_{ki}(\tau)=\int_0^T\ a_k(t-\tau)a_i(t)dt$$

$$\hat{R}_{k,i}(\tau)=\int_\tau^T\ a_k(t-\tau)a_i(t)dt \quad (7)$$

These integrals capture the symbol-boundary misalignment between user k and the desired user. R_{ki}(τ) accounts for the tail of user k's preceding symbol, while Ħ_{ki}(τ) accounts for the head of the ensuing symbol. Both may be reformulated using the discrete aperiodic cross-correlation function C_{k,i}(l):

$$C_{k,i}(l)=\{\sum_{j=0}^{N-1-l}\ a_j^{(k)}a_{j+1}^{i}\quad 0\le l\le N-1\ \sum_{j=0}^{N-1+l}\ a_{j-1}^{(k)}a_j^{i}\quad 1-N\le l\le 0\ 0\quad |l|\ge N. \quad (8)$$

Substituting Eq. (8) into Eq. (7) provides the alternate correlation expression:

$$R_{ki}(\tau)\ and\ \hat{R}_{k,i}(\tau):\hat{R}_{k,i}(\tau)=C_{k,i}(l)T_c+\big[C_{k,i}(l+1)-C_{k,i}(l)\big].(\tau-lT_c) \quad (9)$$

To evaluate the received SINR, the total interference-plus-noise power is computed as the variance of Z_i over one symbol period: $=\left(\frac{P}{4T}\right)\sum_{k=1\ k\neq i}^{K}\ \sum_{l=0}^{N-1}\ \int_{lT_c}^{(l+1)T_c}\ \left(R_{k,i}^2(\tau)+\hat{R}_{k,i}^2(\tau)\right)d\tau+\frac{N_oT}{4}$ (10)

In this case, the statistical expectation is taken with respect to variable $\emptyset_{k,}\tau_k$ and b_k. Given the desired user's data remains constant over the symbol interval under considerations, (10) only contains contributions from channel noise and MAI. The expectation is computed with respect to φ_k, τ_k, and b_k. Since the desired user's symbol is constant within the integration window, only MAI and noise contribute to the variance. Substituting Eq. (9) into Eq. (10) yields:

$$Var\{Z_i\}=\left(\frac{PT^2}{12N^3}\right)\left(\sum_{k=1\ k\neq i}^{K}\ r_{k,i}\right)+\frac{N_oT}{4} \quad (11)$$

where

$$r_{k,i}=\sum_{k=1}^{N-1}\ \{C_{k,i}^2(I-N)+C_{k,i}(I-N)C_{k,i}(I-N+1)+C_{k,i}^2(I-N+1)+C_{k,i}^2(I)+C_{k,i}(I+1)+C_{k,i}^2(I+1)\} \quad (12)$$

The SINR is obtained by dividing the desired signal power by the rms noise:

$$SINR = \left[(6N^3)^{-1} \sum_{k=1}^{K} \quad r_{k,i} + \frac{N_0}{2E_b}\right]^{-1/2} \quad (13)$$

For preliminary design using random spreading sequences, Eq. (13) simplifies to:

$$SINR = \left\{\frac{N_0}{2E_b}\right\}^{-1/2} \quad (14)$$

The term (K−1)/(3N) arises from taking the expected value over random sequences. The BER for a single-user BPSK system under AWGN alone is:

$$P_B = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad (15)$$

Using the SINR approximation from Eq. (14) in place of the single-user SNR, an approximate multi-user BER is:

$$P_B = Q(SINR). \quad (16)$$

When only one user is active (K = 1), Eq. (14) reduces identically to the Q-function argument in Eq. (15), confirming the single-user consistency of the model.

2.1 BER for Synchronous Systems

It should be noted that Eq. (14) is specifically derived for asynchronous transmissions with rectangular chip shaping. For the synchronous case with rectangular pulses, the SINR simplifies to:

systems using rectangular shaped chip waveforms

$$???? = \left\{\frac{N_0}{2E_b}\right\}^{-1/2} \quad (17)$$

2.2 Chip Waveform Shaping

One approach to suppressing MAI in DS-CDMA systems involves substituting the conventional rectangular chip pulse with alternative waveforms. This technique operates by modifying the cross-correlation profile of the spreading codes through changes in chip pulse shape, potentially lowering the interference floor. The following pulse shapes are evaluated in this study: rectangular (baseline), half-sine, raised-cosine, Blackman, Kaiser, and Lanczos—each analytically defined below:

a) **Blackman**:
$\psi(t) = k\,[0.42 - 0.5\cos(2\pi t/T_c)]\,u(t)$
b) **Half-sine**:
$\psi(t) = \sqrt{2}\sin(\pi t/T_c)\,u(t)$
c) **Kaiser**:
$\psi(t) = k \cdot I_0\,(\beta\pi\sqrt{(1-((t-T_c/2)/T_c)^2)}) / I_o(\beta\pi) \cdot u(t)$
d) **Lanczos**:
$\psi(t) = k\,[\sin(2\pi t)/(2\pi t)]^2\,u(t)$
e) **Raised-cosine**:
$\psi(t) = \sqrt{(2/3)}\,[1 - \cos(2\pi t/T_c)]\,u(t)$

3 Results and Analysis

Simulation experiments were conducted to assess how chip waveform selection affects BER in synchronous DS-CDMA networks. Each scenario employed K = 9 simultaneous users with spreading codes of length N = 31, enabling controlled and consistent cross-scenario comparisons. Performance was evaluated for aperiodic random sequences, best-case Gold codes, and worst-case Gold codes, each paired with rectangular, Blackman, and Lanczos chip waveforms.

Figure 1 displays BER curves for the synchronous system under best-case and worst-case Gold code selections relative to the random code baseline. The best-case Gold code configuration achieves substantially lower BER than the random code system, while the worst-case Gold code results in somewhat elevated BER by comparison. Error bars in Figure 1 confirm that these performance differences are statistically significant across all tested E_b/N_0 levels.

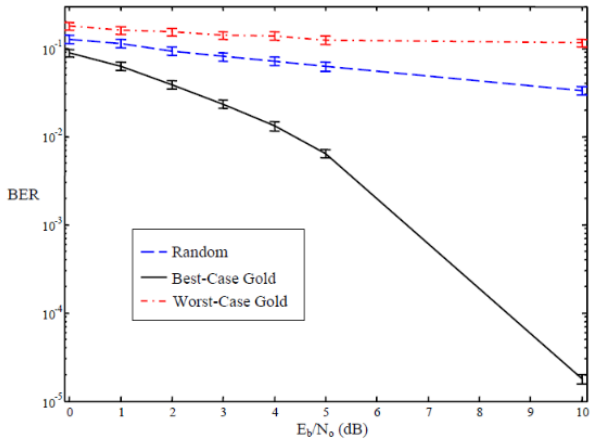


Fig. 1: Synchronous Network: Gold vs. Randomly Coded System
Source: created by the authors

3.1 Synchronous System Performance

Simulation outcomes shown in Figure 2, Figure 3, and Figure 4 demonstrate that chip waveform shaping produces negligible improvement in BER for synchronous DS/SSMA systems. In all tested configurations, the error bars associated with different pulse shapes overlap substantially, confirming that the observed BER differences are

not statistically significant and do not constitute a genuine performance advantage.

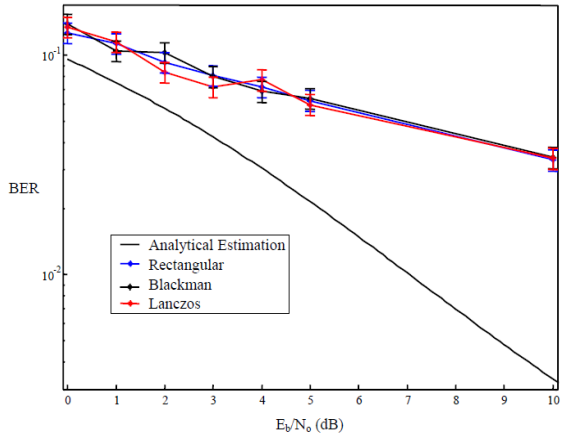


Fig. 2: BER for Synchronous Randomly Coded DS/SSMA System with K = 9 Users, N = 31 Length Codes and Chip Waveform Shaping
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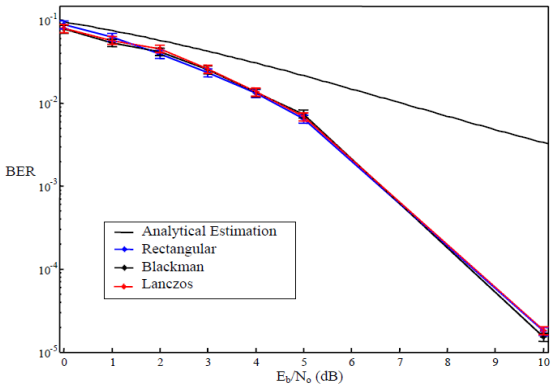


Fig. 3: BER for Synchronous Best-Case Gold Coded DS/SSMA System with K = 9 Users, N = 31-Length Codes and Chip Waveform Shaping
Source: created by the authors

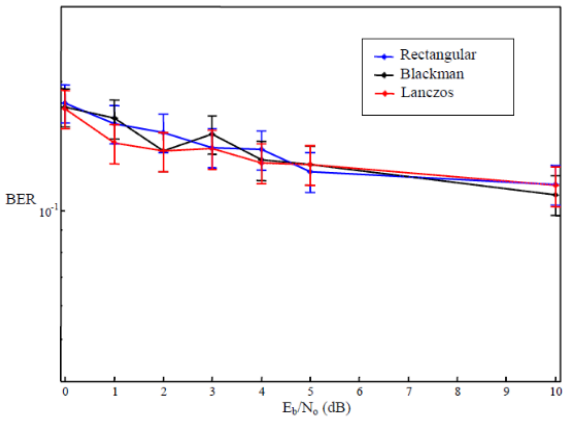


Fig. 4: BER for Synchronous Worst-Case Gold Coded DS/SSMA System with K = 9 Users, N = 31 Length Codes and Chip Waveform Shaping
Source: created by the authors

4 Conclusions

4.1 Research Contributions

This work presents a comprehensive characterization of MAI in DS/SSMA systems by systematically varying three core parameters: spreading code type (random versus Gold), chip waveform shape, and code length. The analysis provides insight into the practical applicability of BER approximation models and quantifies the relative contribution of each system factor to overall communication performance.

4.2 Random versus Gold Spreading Codes

Across all tested scenarios, DS/SSMA systems employing Gold spreading codes consistently outperform those relying on random sequences. The advantage of Gold codes becomes especially evident at E_b/N_0 levels beyond 1.0 dB—the point at which MAI emerges as the dominant impairment over AWGN. The benefit is further amplified in synchronous configurations, reflecting the fact that Gold code families are designed with synchronous cross-correlation properties that minimize mutual interference.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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J. Ravindrababu, Problem identification
P Sushma, Algorithm implementation
P L S Sandeep, Carried out the simulation with Matlab
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