Performance analysis of Matched filter using Multiuser detection in CDMA

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Abstract: **Performance analysis of matched filter using mud algorithm in code division multiple access (CDMA). The design is based on the step by step practical implementation of matched filter (MF) detection. A model of matched filter is created and the simulated results are compared with the previous results and verified against theoretical predictions.**

Keywords—MATLAB simulation, CDMA, multiuser detection

I. INTRODUCTION

The performance of a detection technique, which is usually expressed in terms of bit error rate (BER), may be evaluated via three options. The first one entails a mathematical formulation of the process, while the second course is based on computer simulation. The final method is the physical act of measuring BER . Code division multiple access (CDMA) works on the principle of code multiplexing and its advanced version, named as W-CDMA. *Code-division multiple access* (CDMA) is one such technique that allows multiple users to share a common channel, and it finds applications in a number of communication systems, such as mobile radio, satellite, and wireless LAN systems . The possibility of efficient bandwidth utilization, asynchronous access, graceful degradation, and secure communication offered by CDMA, together with its success in other applications, has led to various studies on the design of optical CDMA (OCDMA) communication systems . In direct-sequence (DS) CDMA systems, each user is assigned a signature sequence for spreading and identification purposes [4]. These signature codes should possess some nice cross correlation and autocorrelation properties. Signature codes (sequences of 1's and -1's) designed for the radio systems are no longer suitable when they are used in optical systems because of the unipolarity of the incoherently detected signals. Special types of signature codes consisting of pulses and spaces corresponding to 1's and 0's have been developed for these system In an OCDMA multiuser system, the received signal is just the superposition of light waves from individual users. Since there are many non coordinating users, there may be collision of pulses from two of more signature codes that leads to interference. It has been shown that the performance of the conventional CDMA correlation receiver deteriorates rapidly with an increasing number of users. Such performance degradation is mainly due to the effect of *multiuser interference* (MUI). The joint demodulation of all the users by taking advantage of the structure of MUI is known as multiuser detection. In particular, several multiuser receiver structures capable of reducing the effect of MUI have been proposed for DS OCDMA systems. The optimal receiver has an exponential complexity with the number of users and is too complicated for practical realization. The optimum coding-spreading tradeoff is well understood for single-user, or matched filter (MF), detection systems spreading is favored if the users are synchronous, and coding is favored if the users are asynchronous. In this paper, we examine the role of coding in CDMA systems that employ multiuser detection to calculate how much bit error rate (BER) has reduced and maximizes signal to noise ratio(SNR) so that number of users can be increased to allocate the channel[8].

II. CONSTRUCTION OF INITIAL MODEL

To ensure the reliability of our design and also to aid apprehension of the matter, we initially attempted to construct a model whose end results can easily be compared to those readily available in the literature. For this purpose, the selected platform was phase shift keying (PSK) detection in an additive WGN environment, where the degrading effects of the channel are completely ignored. Under such circumstances, the theoretical probability of error, which is essentially the quantification of BER, for antipodal and orthogonal binary PSK signals are respectively defined as

$$P_{BPSKap} = Q[2(SNR)^{0.5}], P_{BPSKorg} = Q[(SNR)^{0.5}] \quad (1)$$

where Q is the complimentary error function, $SNR = E_b / N_o$ is the signal to noise obtained by dividing the energy of one bit E_b, by two sided noise power spectral density N_o. Probability of error can also be computed by creating the message signal, $s(t)$, the noise signal, $n(t)$, and the matched detection (MF) process in MATLAB. To this end, the intrinsic MATLAB functions of *randint* is used for message signal, $s(t)$, and *wgn* for noise signal, $n(t)$. For detection process, we have employed the correlation metrics, $C(r, s_m)$ given in [12]

$$C(r, s_m) = 2rs_m - [s_m]^2 \quad (2)$$

where ***r*** is the vector obtained from the samples of MF detector after multiplying the incoming signal, $r(t) = s(t) + n(t)$ by orthogonal basis functions, integrating the result over the bit period, *T*, and sampling it at the end of *T*. Similarly s_m is the vectorial representation of $s_m(t)$, where the index *m*, refers to which message signal was sent. In binary PSK, *m* = 1, 2. The operation of 2 $[s_m]^2$ gives the square of the length for vector s_m or the energy in $s_m(t)$. During detection process, $C(r, s_m)$ is evaluated by sequentially substituting s_1 and s_2 in (2). Then a decision is made in favor of that message signal $s_1(t)$ or $s_2(t)$, yielding the greatest numerical value when substituted in (2).

Finally, this experimental probability of error is to be calculated from simply dividing accumulated number of errors by the total number of received bits, *n*, expressed formally as

$$P_{BPSK\,exper} = \sum_{i=1}^{n} d_e / n \quad (3)$$

where $d_e = 1$ if an error has occurred, and $d_e = 0$ otherwise. Establishing the BER via the course of (3). But, the number of samples (*n*) to be used in the simulation is inversely proportional to BER figures achievable

III. CDMA MODEL FORMULTIUSER DETECTION

Using the experience of the initial model, we have constructed a simulation model for CDMA detection using matched filter for 10 users. In CDMA, there is a similar correlation metrics, $c(r_k, b_k)$

$$c[r_k, b_k] = 2b_k r_k^t - b_k r_s b_k^t \quad (4)$$

Here, r_k is the MF processed row vector of received signals (message signal plus noise) from *K* number of users, b_k is the row vector of possible transmitted sequence multiplied by the received amplitude levels of the users in question, R_s is the correlation matrix containing the cross correlation of then spreading codes and the letter *t*, as a superscript indicates the transpose operation. Analogous to the procedure outlined in the previous section, the detection of CDMA signals may be carried out via testing all likely sequences of b_k in (4) and deciding on the b_k sequence that maximizes the numeric value of $c(r_k, b_k)$. This detection mechanism yields the best i.e. the optimum detection, but its complexity grows in the order of 2^k. As an alternative, sub optimum methods have been developed, some of which are decorrelating detector, minimum mean square error (MMSE) detector and blind force detector. For our application, we have the adopted decorrelating detector where the detection process suitably takes into account the interference from other users, hence it has multiuser capability. In the case of decorrelating detector, the received bits are resolved as $b_k^{'}$, by computing the sign (denoted by the operator sgn) of the product $R_s^{-1} r_k$, i.e.,

$$b_k^{'} = \text{sgn}(R_s^{-1} r_k) \quad (5)$$

Compared with (3), this treatment is much simpler and only involves taking the inverse of the correlation matrix R_s and multiplying it by the MF processed received signals r_k. Experimental probability of error for CDMA will be

$$P_{CDMA} = \sum_{i=1}^{n} d_e / n \quad (6)$$

The theoretical probability of error, BER, for CDMA applications may be stated as follows

$$P_{CDMA} = Q[(2SNR)^{0.5}]/(1 + SNR\{\sum_{K=2}^{K} P_K [2M_K(0) + M_{K,1}(1)]/(3P_1 N^3)\})^{0.5}] \quad (7)$$

where *N* is the period of the spreading code, *SNR* is defined with respect to the intended user, in our case we have selected the first user as the intended user, therefore $SNR = E_1 / N_o$, P_k with *k* = 1…*K* indicates the received power level of the signal belonging to *K*th user, the terms $m_{k,1}(0) + m_{k,1}(1)$ are related to the interference arising from the nonzero cross correlation coefficients of the spreading codes and are the same as those defined in [1]. It is easy to conclude that when only one user is active, i.e., *K* = 1, then the interference terms, subsequently the sum in the denominator of (7) collapse to zero. This way, (7) becomes identical to first equation of (1). In the literature, there exists a number of different versions of the theoretical probability of error for CDMA, including those independent of the characteristics of spreading code and the one named as improved Gaussian approximation. Another version is possible for P_{CDMA}, if all the received power level of all users are equal and *SNR* >> 1. For this specific case, (7) will reduce to [16]

$$P_{CDMA} \approx Q[(\frac{3N}{K-1})^{0.5}] \quad (8)$$

IV. RESULTS AND DISCUSSIONS

In the construction of our simulation model for CDMA detection, we have used the *mdl* file utility of MATLAB to generate the GOLD spreading sequences. To the same file, a scope and signal from workspace blocks were added to Visualize waveforms of message signal, gold sequences, transmitted signal as a sum of signals belonging to all active users and received signal. In our simulation runs, we observed that from the viewpoint of computation time and memory, it is impossible to go beyond $K = 10$, $n = 1000$, and $N = 31$ using the optimum detection technique supplied by (4). Up to these limits, the produced BER results conformed perfectly to the theoretical predictions of (7) in the range, BER = 10^{-1} to 10^{-2}. Secondly, the detection mechanism based on (5) was tried. In this particular case, $n = 10000$ was achievable provided that $K < 10$ and $N = 31$. To proceed further and reach lower BER figures, it was decided to introduce importance sampling (IS) at this stage. The theory behind IS is that the probability density function governing the noise samples is artificially biased in such a way that more errors are produced with lesser n values. Assume that the initial noise pdf is to be biased by increasing its variance, hence noise power spectral density, N_o. Then we may introduce a weight function, *wi*, in the following Manner

$$w_i = f_{phy}(ni) / f_{bias}(ni) \qquad (9)$$

where $f_{phy}(ni)$ and $f_{bias}(ni)$ are respectively the pdf of noise source before and after biasing. Now the new BER estimator for probability of error, P_{bias} , will be in the form of

$$P_{bias} = \sum_{i=1}^{n} W_i d_e / n \qquad (10)$$

The above equation differs from (3) and (6) in the sense that the error counting includes its associated weighting factor. This action is necessary to offset the original biasing applied. By carefully adjusting *wi*, it is possible to attain really low BER figures with a much smaller number of samples than actually required. This process is known as the classical importance sampling (CIS). Altering the noise distribution by a shift in the mean value is named as improved importance sampling (IIS). It is the former that is used in our graphs.[9]

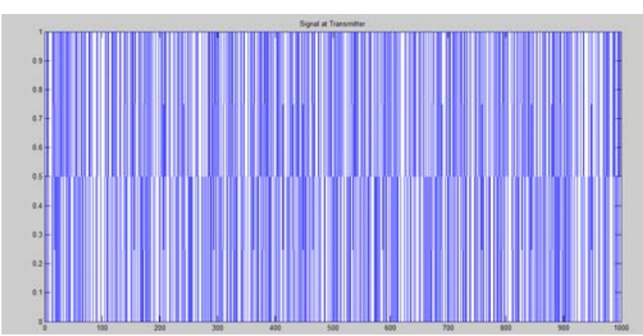

Figure1. Signal at transmitter

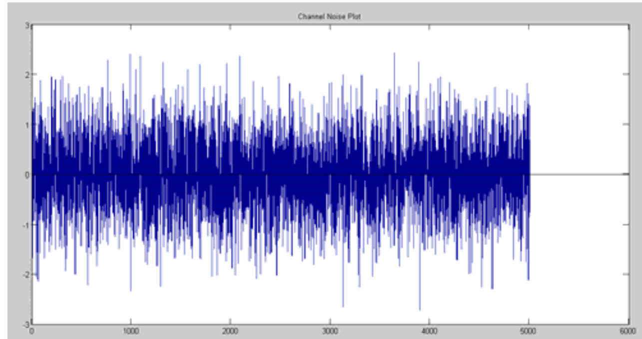

Figure2. Channel noise plot

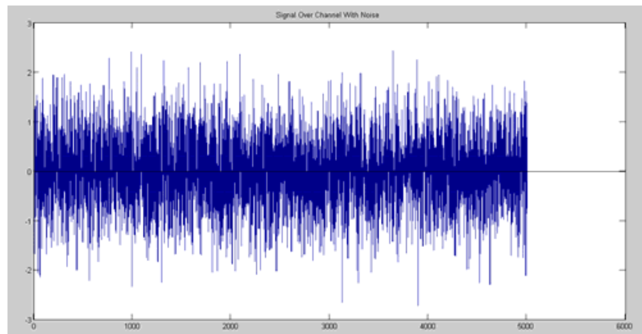

Figure3. Signal over channel with noise

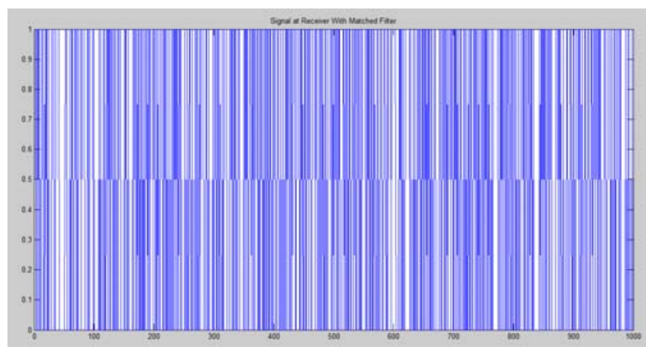

Figure4. Signal at receiver with matched filter

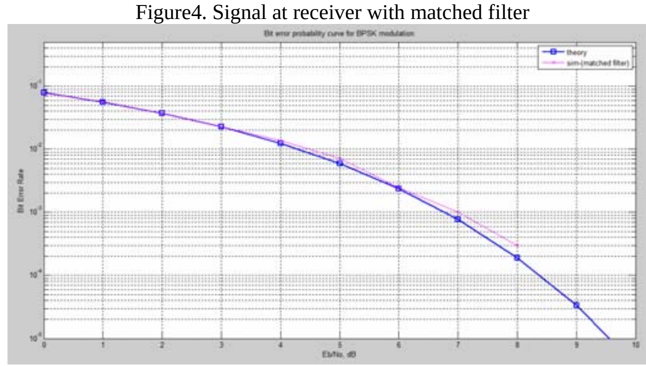

Figure5. Average bit error rate with matched filter

V. CONCLUSION AND SUGGESTION FOR FURTHER STUDIES

In this study, starting with a simple initial model of BPSK, we have demonstrated the feasibility of constructing a CDMA multiuser detection process in a MATLAB environment. In our terminology theoretical results are those obtained from the available analytic formulation, where as the experimental results are computed from the model constructed in the MATLAB environment. To reach low BER figures, we have resorted to importance sampling. We note that our present experimental results cover only the fundamental detection strategy in CDMA. By incorporating other features such as synchronization, the characteristics of the communication channel, it will be possible to set up a simulation environment much closer to practical situations. This way, we will also be able observe the effects of parameters that may not be accounted for theoretically. Presently, we are engaged in this direction.

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