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BER analysis of DSSS-CDMA using MATLAB

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Abstract**—** This article gives the details about the modulation and detection of DSSS-CDMA system in a gaussian channel having additive Gaussian noise.Implementation of DSSS transmitter and receiver with two users is done using MATLAB. Finally the bit error rate (BER) of the two detected users is calculated and compared and analysed as the noise power increases.

Keywords—*DSSS, CDMA, BER, Additive Gaussian noise.*

1.Introduction

Because of the difficulty to jam or detect spread spectrum signals, the first applications were in the military field. However nowadays spread spectrum systems are gaining popularity also in commercial applications. The main parameter in spread spectrum systems is the processing gain: the ratio of transmission and information bandwidth. which is basically the "spreading factor". The processing gain determines the number of users that can be allowed in a system, the amount of multi-path effect reduction, the difficulty to jam or detect a signal etc. For spread spectrum systems it is advantageous to have a processing gain as high as possible. There exist different techniques to spread a signal: Direct-Sequence (DS), Frequency-Hopping (FH), Time-Hopping (TH) and Multi-Carrier CDMA (MC-CDMA). It is also possible to make use of combinations of them. We will now concentrate on the most popular technique: Direct-Sequence.

A number of advantages are:

1. Low power spectral density: As the signal is spread over a large frequency-band, the Power Spectral Density is getting very small, so other communications systems do not suffer from this kind of communications. However the Gaussian Noise level is increasing.
2. Interference limited operation: In all situations the whole frequency-spectrum is used.
3. Privacy due to unknown random codes: The applied codes are - in principle - unknown to a hostile user. This means that it is hardly possible to detect the message of another user.
4. Applying spread spectrum implies the reduction of multi-path effects.
5. Random access possibilities. Users can start their transmission at any arbitrary time.
6. Good anti-jam performance.

2. ACCESS SCHEMES

For radio systems there are two resources, frequency and time. Division by frequency, so that each pair of communicators is allocated part of the spectrum for all of the time, results in Frequency Division Multiple Access (FDMA). Division by time, so that each pair of communicators is allocated all (or at least a large part) of the spectrum for part of the time results in Time Division Multiple Access (TDMA). In Code Division Multiple Access (CDMA), every communicator will be allocated the entire spectrum all of the time. CDMA uses codes to identify connections. Multiple Access refers to the sharing of a common channel by multiple nodes to allow them to communicate with each other simultaneously. The multiple access techniques greatly used in wireless communication can be categorized into three basic techniques.

1. Frequency Division Multiple Access (FDMA)
2. Time Division Multiple Access (TDMA)
3. Code Division Multiple Access (CDMA)

These three basic techniques can be combined to obtain various hybrids of channel access schemes like the frequency division and time division (FD/TD), frequency division and Code division (FD/CDMA) and so on. All these techniques aim at distributing signal energy per access within the constrained time-frequency plane resource available.

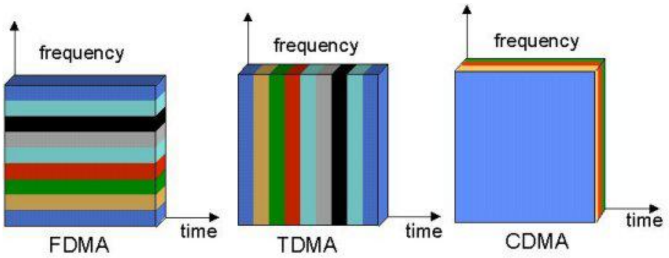

Figure 1 various multiple access schemes

3. DSSS

In DSSS-CDMA multiple users share the same bandwidth, without significantly interfering with each other. The spreading waveform is controlled by a Pseudo-Noise (PN) sequence, which is a binary random sequence. This PN is then multiplied with the original baseband signal, which has a lower frequency, which yields a spread waveform that has a noise like properties. In the receiver, the opposite happens, when the pass band signal is first demodulated, and then dispreads using the same PN waveform. An important factor here is the synchronization between the two generated sequences. In Code Division Multiple Access (CDMA) systems all users transmit in the same bandwidth simultaneously. Communication systems following this concept are "spread spectrum systems". In this transmission technique, the frequency spectrum of a data-signal is spread using a code uncorrelated with that signal. As a result the bandwidth occupancy is much higher than required. The codes used for spreading have low cross-correlation values and are unique to every user. This is the reason that a receiver which has knowledge about the code of the intended transmitter is capable of selecting the desired signal.

4. PN- SEQUENCE

PN is the key factor in DSSS systems. A Pseudo Noise or Pseudorandom sequence is a binary sequence with an autocorrelation that resembles, over a period, the autocorrelation of a random binary sequence .It is generated using a shift register, and a combinational logic circuit as its feedback. The logic circuit determines the PN words. The unique characteristics of PN sequences make them useful in spectral whitening, random test-data generation, data scrambling and spectral expansion (as in SS). It is their close-to-ideal randomness and ease of generation that makes them so useful. These sequences are easily generated by using an *M*-bit shift register with the appropriate feedback taps.

With the appropriate taps, the length (*N*) of the serial bit stream at the output will be a maximum (*Lmax*):
N = *Lmax* = 2*M* – 1

The meaning of bit-stream length in this context is the maximum length of the bit sequence before it starts repeating itself. PN sequences of maximum length are called maximal linear code sequences. The feedback taps are added modulo-2 (exclusive OR’ed) and fed to the input of the initial shift register. Only particular tap connections will yield a maximum length for a given shift register length.

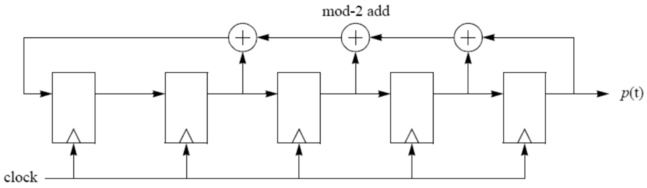

Figure 2 PN sequence generator

These maximal length PN codes have the following properties:

- Code balance: The number of ones and the number of zeros differ by only 1, i.e., there is 1 more one than the number of zeros. This particularly useful when the channel is AC coupled (no DC transmission).
- Run-length distribution: The run-lengths of ones, i.e., the number of ones in a row,and zeros are distributed in a deterministic and somewhat statistically balanced way.
- Autocorrelation: The autocorrelation of a PN sequence has a value of -1 for all phase shifts of more than one bit time. For no phase shift (perfect alignment with itself), the autocorrelation has a value of *N*, thesequence length.
- Modulo-2 addition: Modulo-2 addition of a PN sequence with a shifted version of itself results in a differently-shifted version of itself.
- Shift Register States: The binary number represented by the *M* bits in the shift register randomly cycle through all 2*M* values, except for 0, in successive 2*M*-1 clocks.If the value of 0 (all shift register bits are 0) is ever present in the shift register, it will stay in that state until reloaded with a nonzero value.

The continuous-time (CT) autocorrelation of a PN sequence is defined as

$$C_{CA}(\tau) = \frac{N}{N \cdot T_c} \cdot \int_{N \cdot T_c} p(t) \cdot p(t+\tau)dt$$

$$= \frac{1}{T_c} \cdot \int_{N \cdot T_c} p(t) \cdot p(t+\tau)dt \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

where *p*(t) is the PN sequence as a function of time, *N* is the number of PN sequence bits, *Tc* is a PN bit-time and *N Tc* is its length.

5. DSSS TRANSMITTER

In Direct Sequence-Spread Spectrum the baseband waveform is multiplied by the PN sequence. The PN isproduced using a PN generator. Frequency of the PN is higher than the Data signal. This generator consists of ashift register, and a logic circuit that determines the PN signal. After spreading, the signal is modulated and transmitted. The most widely modulation scheme is BPSK (Binary Phase Shift Keying). The equation that represents this DS-SS signal is :

$$S_{ss}=\sqrt{\frac{2E_s}{T_s}}m(t)p(t)\cos(2\pi f_c t+\theta) \quad \text{…..……(2)}$$

where m(t) is the data sequence, p(t) is the PN spreading sequence, fc is the carrier frequency, and Ө is the carrier phase angle at t=0. Each symbol in m(t) represents a data symbol and has a duration of Ts . Each pulse in p(t) represents a chip, and has a duration of Tc. The transitions of the data symbols and chips coincide such that the ratio Ts to Tc is an integer . Here we notice the higher frequency of the spreading signal p(t). The resulting spread signal is then modulated using the BPSK scheme. The carrier frequency fc should have a frequency at least 5 times the chip frequency p(t).

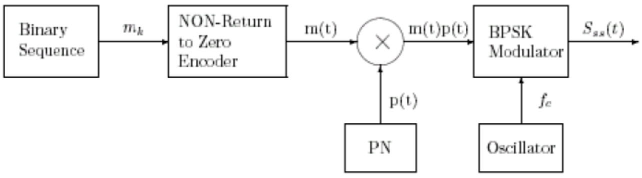

Figure 3 DSSS transmitter

6. DSSS RECIEVER

In the demodulator section, we simply reverse the process. We demodulate the BPSK signal first using low pass filter the signal, and then Dispread the filtered signal, to obtain the original message. The process is described by the following equations

$$\hat{m}(t)=S_{ss}(t)\times\cos(2\pi f_c t+\theta) \quad \text{....................... (3)}$$

$$\cos\alpha\times\cos\alpha=\frac{1}{2}[1+\cos(2\alpha)]$$

$$\hat{m}(t)=\sqrt{\frac{2E_s}{T_s}}m(t)p(t)\frac{1}{2}[1+\cos(4\pi f_c t+\theta)] \quad \text{....... (4)}$$

PN sequence in the receiver it should be an exact replica of the one used in the transmitter, with no delays, cause this might cause severe errors in the incoming message. Again, my design is based on the idea that PN sequences are matched, and actually i am going to use the same generator for both to ease the design.

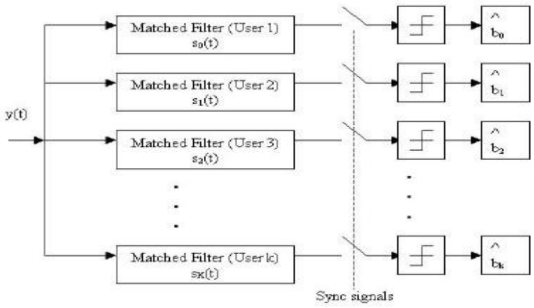

Figure 4 CDMA reciever

The signal at the receiver is given by

$$y(t)=\sum_{k=1}^{K}A_k b_k s_k(t)+n(t) \quad \text{……….. } \mathit{(5)}$$

Where sk is the signature waveform of the kth user (sk is normalized to have unit energy i.e., < sk ,sk > =1). bk is the input bit of the kth user, bk ∈ {-1,1}.Ak is the received amplitude of the kth user. n(t) is additive white gaussian noise with PSD No.

The cross-correlation of the signature sequences are defined as

$$\rho_{ij}=\langle s_i s_j\rangle=\sum_{k=1}^{N}s_i(k)s_j(k) \quad \text{……… } \mathit{(6)}$$

where N is the length of the signature sequence . The cross-correlation matrix is then defined

$$\mathbf{R}=\{\rho_{ij}\}$$

$$\mathbf{R}=\begin{bmatrix}\rho_{11} & \rho_{12} & \cdots & \rho_{1K}\\ \rho_{21} & \rho_{22} & \cdots & \rho_{21K}\\ \vdots & \vdots & \cdots & \vdots\\ \rho_{K1} & \rho_{K2} & \cdots & \rho_{KK}\end{bmatrix} \quad \text{……….} \mathit{(7)}$$

R is a symmetric, non-negative definite, toeplitz matrix.The decision statistic a the output of the Kth matched filter is given by

$$y_k=\int_0^T y(t)s_k(t)dt \quad \text{………..…......... } \mathit{(8)}$$

where y(t) is given by (5). Expanding (8),

$$y_k = \int_0^T \left\{ \sum_{j=1}^{K} A_j b_j s_j(t) + n(t) \right\} s_k(t)dt$$

…………………………….….………… *(9)*

using eq(6), we get

$$y_k = \sum_{j=1}^{K} A_j b_j \rho_{jk} + n_k$$

……………… *(10)*

$$n_k = \int_0^T n(t)s_k(t)dt$$

……………….…... *(11)*

Since ρ11=1, (10) simplifies to

$$y_k = A_k b_k + \sum_{\substack{j=1 \\ j\neq k}}^{K} A_j b_j \rho_{jk} + n_k$$

.... *(12)*

The 2nd term in (12) is the MAI. The matched filter treats the MAI just as
white noise.

Stacking up (12) for all the users we get

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_K \end{bmatrix} = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1K} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{21K} \\ \vdots & \vdots & \cdots & \vdots \\ \rho_{K1} & \rho_{K2} & \cdots & \rho_{KK} \end{bmatrix} \begin{bmatrix} A_1 & 0 & \cdots & 0 \\ 0 & A_2 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & A_K \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_K \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_K \end{bmatrix}$$

.... (13)

7. IMPLEMENTATION

Implementation of simulated CDMA system for two users, including signal generation, detection, decoding, and calculation of error rates in a gaussain channel with noise power p is done using MATLAB. CDMA simulation program generates BA and BB of length k, encodes them with the chip sequences SA and SB, respectively, to obtain EA and EB; adds them together with Gaussian noise of power p to simulate the channel; and then applies a detector to the channel output to guess the values of BA and BB. The function then calculates the number of errors e for each user (e.g.,for user A, the number of times when the detector's guess for BA was incorrect), and returns the estimated probability of error, e/k, for each user.

The system consists of two users, A and B, with 31-bit chip sequences. The chip sequences for users A and B, written CA and CB respectively, are:
CA = [0 0 0 0 1 0 1 0 1 1 1 0 1 1 0 0 0 1 1 1 1 1 0 0 1 1 0 1 0 0 1]
CB = [0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 1 1 0 1 1 0 0 1 1 1]
Modulating a signal.: In class, we created continuous functions sA(t) and sB(t) from the chip sequences CA and CB, respectively. We cannot represent a continuous function in MATLAB, so I simply used the following discrete-time equivalent: replace all zeros in the chip sequence with +1, and all the ones in the chip sequence with -1. These new sequences SA and SB for users A and B,respectively.The bit sequences for users A and B are BA and BB, respectively, while the modulated sequences for users A and B are given by EA and EB, respectively. To generate EA, suppose for example that BA =[0 1 1 0]. Then EA = [SA -1*SA -1*SA SA].EA will have a length of 31 times the length of BA.
I have assume that the users are synchronized. Once I have EA and EB, which ARE of the same length, added them together, and added a vector of Gaussian noise with the same length as EA and EB. To obtain a vector of Gaussian noise of length k with noise power p, and store it in n, I used the command:

```
n = sqrt(p)*randn(1,k);
```

To detecting the signal I multiplied the received signal y(t) by the continuous functions sA(t) and sB(t) to detect the signal for users A and B, respectively; if the result was positive, I decided that the bit is zero, and if the result was negative, the bit is one. Now, for each bit, multiplied the appropriate segments of Y by SA and SB and take the sum of the result. The decision rule is the same as in the continuous case.This function gets a random bit sequence of length k; use it to generate either BA or BB.

8. RESULT

The CDMA transmitter and receiver is simulated for two users using MATLAB for various noise power and various waveforms is obtained. Finally BER(bit error rate) of each user is plotted against the noise power.

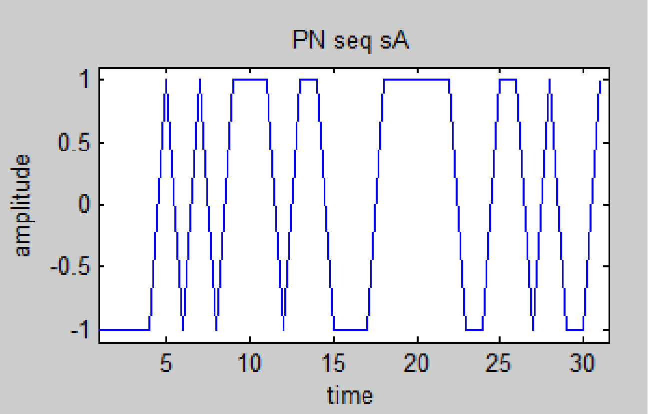

Figure 5 PN sequence of user A

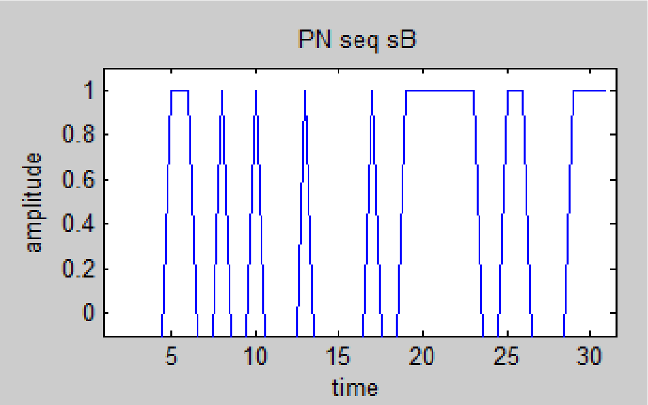

Figure 6 PN sequence of user B

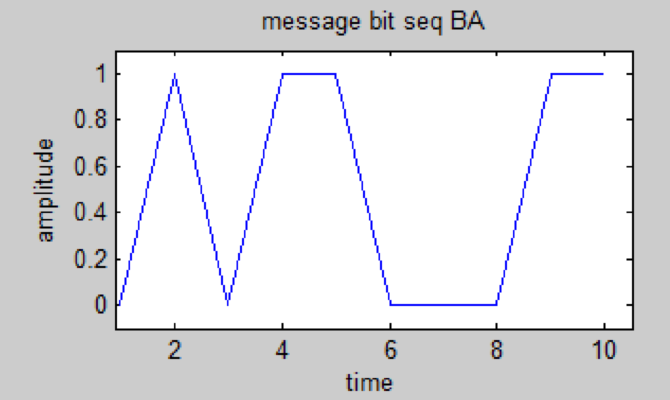

Figure 7 message sequence of user A

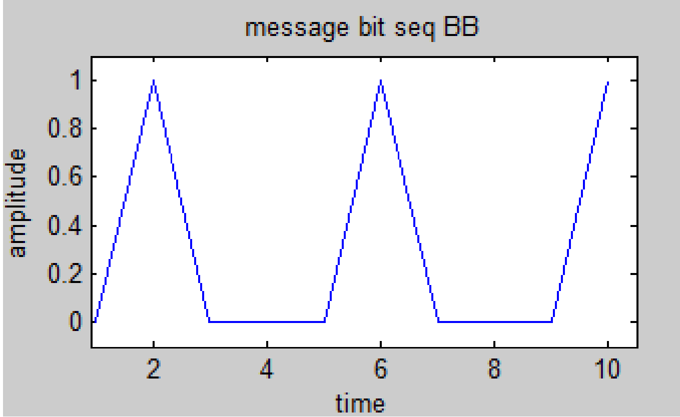

Figure 8 message sequence of user A

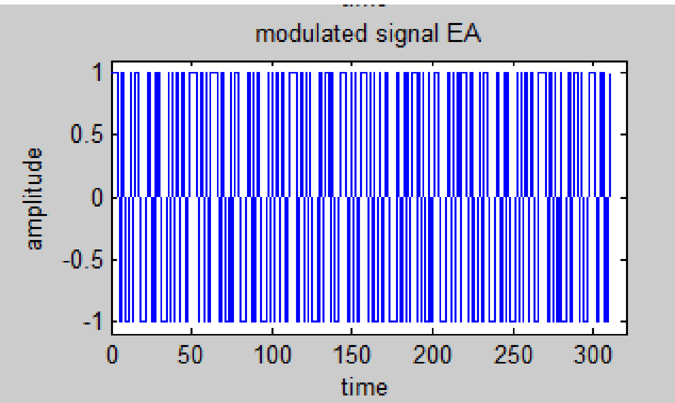

Figure 9 modulated sequence of user A

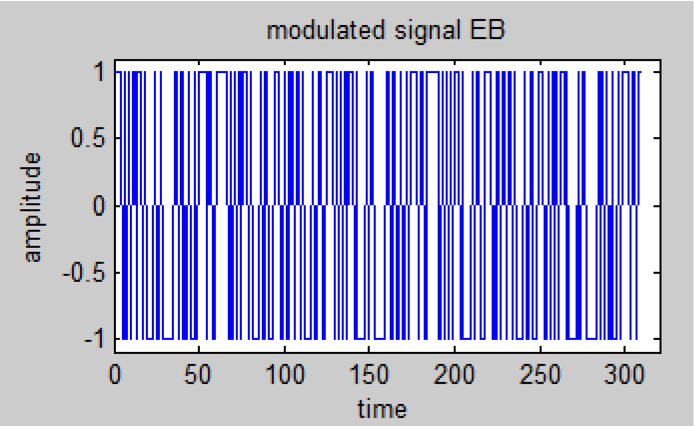

Figure 10 modulated sequence of user B

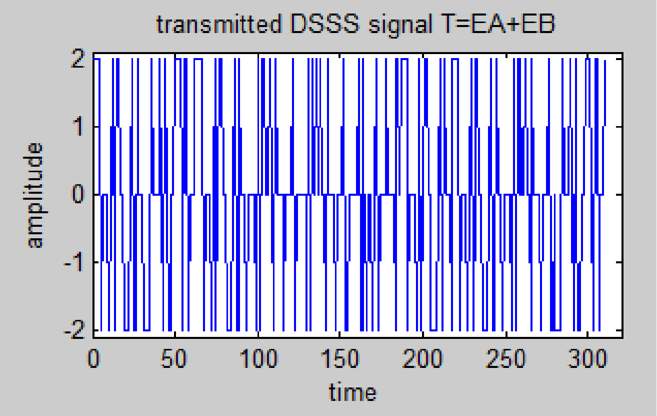

Figure 11 transmitted DSSS signal

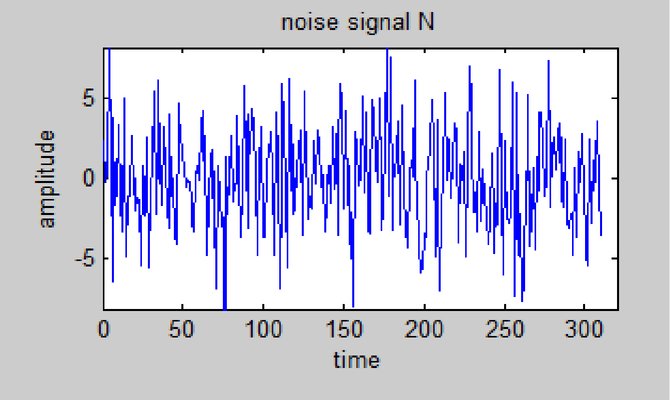

Figure 12 AWGN noise

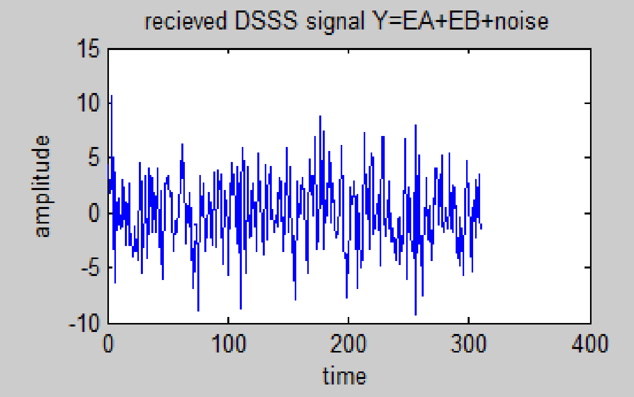

Figure 13 recieved DSSS signal

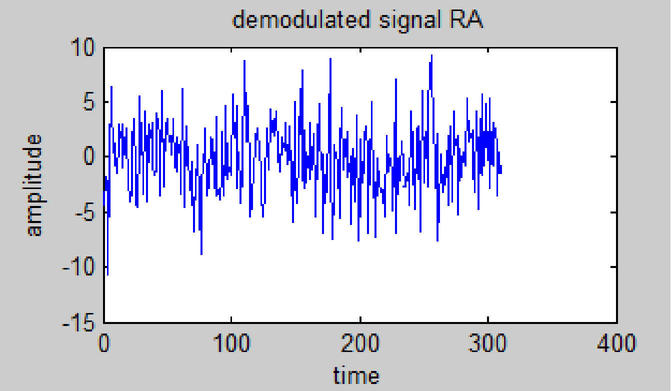

Figure 14 demodulated DSSS signal for user A

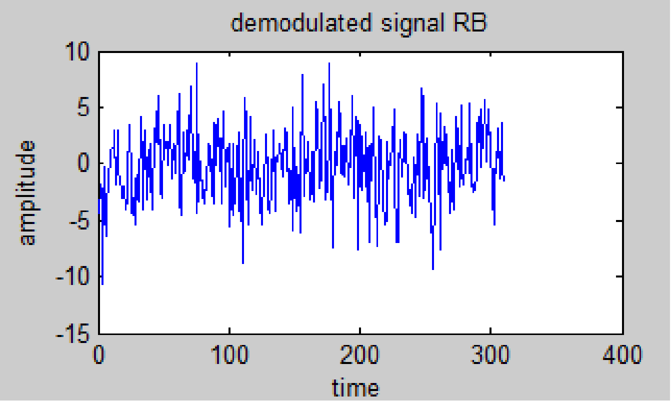

Figure 15 demodulated DSSS signal for user B

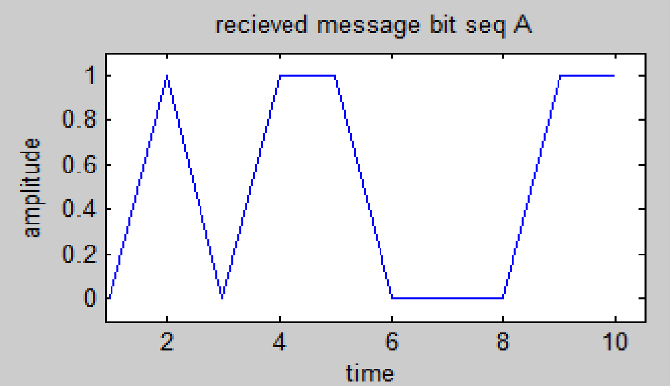

Figure 16 recovered message signal of user A

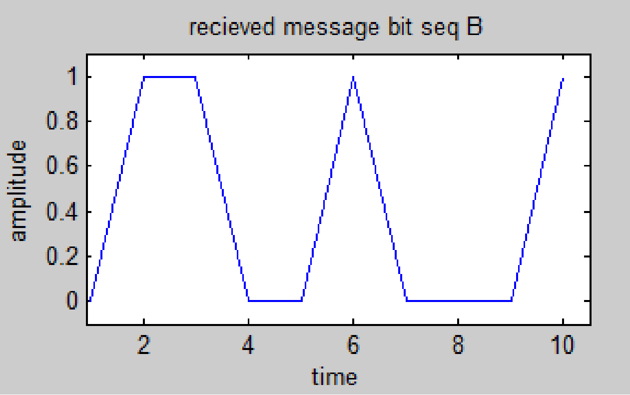

Figure 17 recovered message signal of user B

9. CONCLUSION

The probability of error increases as the noise power increases in a CDMA system. Also BER approaches closer to accuracy as the number of message bits increases. The bit error rate is plotted against noise power. To recieve the message signal with less probability of error, signal to noise ratio should be greater.

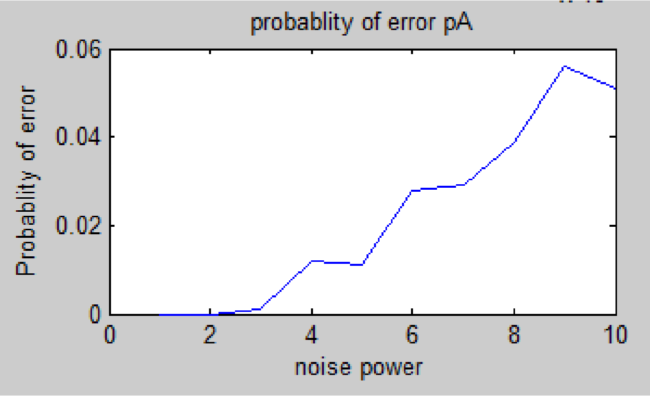

Figure 18 probability of error for user A

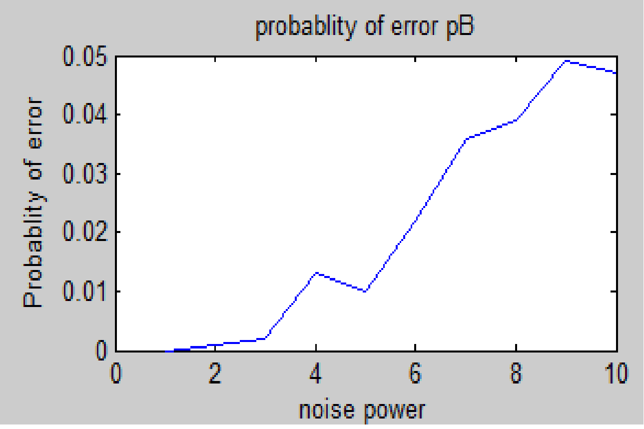

Figure 18 probability of error for user B

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