Analysis of Multipath and Fading Effects on Direct Sequencing CDMA Transmit/Receive Chain

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Abstract— **This paper presents an analysis of multipath and fading effects on a DS-CDMA system (Direct Sequence-Code Division Multiple Access) system. The bit error rate on a DS-CDMA as a function of signal to noise ratio is investigated. In a typical DS-CDMA system design, about 75% of the mobiles experience multipath and fading effects. The performance of DS-CDMA over the frequency selective fading channel is examined by varying the signal to noise ratio of the input signal. A study of the bit error rate (BER) performance of DS-CDMA system over a frequency selective multipath Rayleigh fading channel is also presented. The system is simulated with the chip rate of 1.2288Mcps. The rake error rate performance under various situations such as, two paths, multipath, with and without fading are investigated. Interesting insights into the DS-CDMA are obtained.**

Index Terms— **PN sequences, multipath, fading, bit error rate, Rayleigh fading, spreading, despreading.**

I. INTRODUCTION

Many CDMA mobiles are affected by distortion in the signal, which they receive. The signal is mainly affected by two factors, one is due to the different paths taken by the signal called the multipath and the other is when the channel becomes faded. When the distance between the mobile and the base-station increases, the signal is distorted by many objects in its path and hence the path taken by the signal get split. These two factors are the main causes for distortion in the cellular signals. During 1998, Esmael and Bijan [1] designed the spreading codes for the DS-CDMA system. The second generation DS-CDMA standard IS-95 is being used as a basis for a third generation system with wider bandwidth [2]. In Japan and Europe, a third generation CDMA is also being developed[3].Gregory et al[4] designed the generalized RAKE RECEIVER for the DS-CDMA system. Currently, there are significant efforts taken to harmonize and merge these systems into a common global third generation CDMA standard.

This paper aims to resolve the multipath and fading problem which generally affects the above developed systems. To resolve this problem the DS-CDMA system with the multipath channel is developed and the multipath delay spread channel is also designed. Initially, the channel is considered as a perfect channel with addictive white gaussian noise. Then the channel is modeled as a fading channel with Gaussian random variates. Further, the channel is designed to be a fading channel with correlated Rayleigh variates. Initially, the change in the BER(bit error rate) and degradation in the performance of the DS-CDMA system is obtained for a two path channel and then the results are obtained for a four-path channel(multipath). The spreading codes are used to identify the channel paths. The simple model of rake receiver is used here. The BER performance for different SNR's in the DS-CDMA system is investigated. This helps in understanding the performance of the DS-CDMA system in comparing with various types of transmit receive schemes.

The delay spread of the channel may cause interference at the receiver, but there is also some diversity available as the same signal appears at the receiver with different delays. When combined properly using the RAKE receiver, helps in averaging out the interference and strengthening the signal. Also, the diversity due to the delay spread of the channel can be exploited only if the channel coefficients are independent. In this paper four paths of the channel are taken and each one differ by a delay of one bit duration. The first path is the line of sight path and the second to the fourth are the delayed paths.

II. SYSTEM MODEL

1. TRANSMITTER

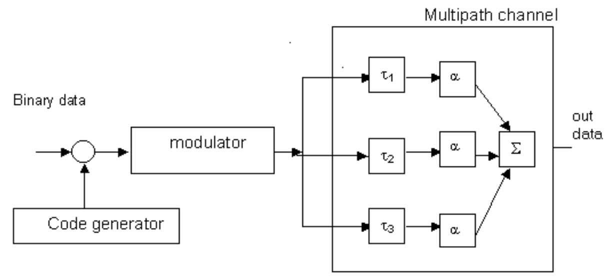

Fig.1 Transmitter for the DS-CDMA system.

Figure 1 shows the system model for the DS-CDMA with the multipath channel. The message bits are taken as the input to the transmitter, which is the digital signal of the users speech. The number of user taken is one. The message bits are spreaded using the spreading codes. The codes generated are PN sequence codes. The IS-95 or CDMA use only one PN sequence code generator, but each base station is assigned a unique shift on the code circle of the PN sequence In this model, the short PN sequence code is used. The codes are generated in the order of 1023.The chip duration is taken to be 64 chips per bit. Using linear feed back shift register technique the PN sequence is generated and tested for their auto-correlation property, if the sequence is orthogonal. The data is modulated using the BPSK modulation and then transmitted through the channel. The multipath channel is of four paths and the data is transmitted through individual paths. τ_1, τ_2 and τ_3 are the delays of the path1, path2 and path3, respectively and α is the gain of the path. The data is received, and analyzed by the rake receiver. The rake receiver has four fingers each one correlates the individual paths with the PN sequences. In the receiver, the data is despreaded using the appropriate code for each path. The de spreaded samples are summed and a threshold is fixed to obtain the data again.. The rake threshold is chosen such that the combined data maximally coincides with the original one. The interesting insights into the CDMA system are obtained through our simulations. The line of sight component of the multipath channel is the dominant factor in determining the BER at distances near the base station.

III. CODE GENERATOR

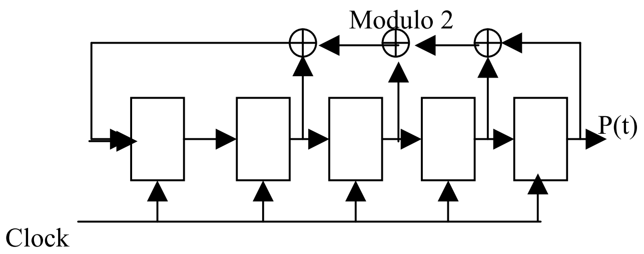

Fig. 2 PN sequence generator

Figure 2 illustrates the block diagram of the code generator. The order of PN sequence generated is 2^M-1, where M is the number of flip-flops. The name pseudorandom noise (PN) means the bits are generated in random for the length of 2^M-1 and then the same bits are repeated periodically. The spreading codes are used to differentiate the users. P (t) is the generated PN sequence. The output of the last flip-flops forms the fist bit of the sequence. The successive bits of the other flip-flops are swapped to the next one and finally when all the bits are swapped the first flip-flop will be empty. The outputs from the second, third and fourth flip-flop are Xored and that bit is given as an input to the first flip-flop. In this way the PN sequence is generated. From the generated PN sequence the data is spreaded and when dispreaded the signal is reconstructed by multiplying with the same PN code that is exactly synchronised to the to the transmitted PN code. This ensures each spread spectrum signal should behave as if it were uncorrelated with every other spread signal using the same band. Therefore, CDMA codes are designed to have very low cross-correlation. These sequences are generated by using an M-bit shift register with the appropriate feedback taps, e.g. as shown in Fig.2 for $M = 5$. With the appropriate taps, the length (N) of the serial bit stream at the output will be a maximum $(L\ max)$:

$$N = L_{max} = 2^M - 1 \qquad (1)$$

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. In the third generation partnership program 3GPP2[7] Wideband CDMA standard, they define Gold Code with periodicity 2^{18}-1 using the following generator equations:

$$x(i+18) = x(i+7) \oplus x(i) \qquad (2)$$

and

$$y(i+18) = y(i+10) \oplus y(i+7) \oplus y(i+5) \oplus y(i) \qquad (3)$$

for i= 0,1……….2^{18}-20 where both x(i) and y(i) are binary numbers and the symbol $\oplus$ signifies the exclusive-Or operation. The initial values for the two linear feed back shift registers are as follows

$x(0)=1$ and $x(1) = x(2) = x(17) = 0$

$y(0) = y(1) = y(2) = y(17) = 1$

Finally the actual Pseudo-Noise (PN) is generated from

$$z(i+18) = y(i+18) \oplus x(I+18) \qquad (4)$$

$$\text{for } i=0,1\ldots\ldots\ldots\ldots 2^{18}-20. \qquad (5)$$

To check the accuracy of the sequence the autocorrelation of the PN sequence is calculated. For this it is desired to convert the data to bipolar representation which is given by

$$w(i) = 2z(i)-1 \qquad (6)$$

For a given a sub-sequence of length L (i.,e L consecutive chips of w(i)) the kth auto-correlation value (ACV)

$$R_w(k) = (1/L) \sum_{j=0}^{L-1} w(j+k)\, w(j) \qquad (7)$$

Using M=20, the ACV (for k=0,1……….M-1) is plotted for L=124.

IV. CONSTRUCTION OF FADING CHANNEL WITH GAUSSIAN RANDOM VARIATES

The channel with gaussian random variates coefficients is generated as follows;

For a two-path channel, first path is the line of sight path without any delay and the second path is the delayed path with one bit duration.

At time instant t, for the line of sight path, and h0 = random number with mean zero and variance 1.

At time instant t+1

$$h1 = \rho\,(h0) + (1- \rho)\,\sigma_n^2 \qquad (8)$$

where σ_n^2 is a random number with mean zero and variance 0.1.

For the delayed path at time t,

h2 = random number with mean zero and variance 1

At time instant t+1

$$h3 = \rho\,(h2) + (1- \rho)\,\sigma_n^2 \qquad (9)$$

Where σ_n^2 is a random number with mean zero and variance 0.1.ρ varies from 0.95 to 0.99. σ_n^2 varies from 0 to 1.

h0, h1,h2 and h3, are the channel coefficients.

For the multipath channel the same process is repeated for all the paths.

V. Noise Addition at the Receiver

The noise is added at the receiver as no system can be fully implemented without noise. A random variable is generated with mean zero, and the variance of the random number is calculated as a function of the signal to noise ratio.

$$E_b/N_0 = \text{SNR per bit} \quad (10)$$

The energy per bit (E_b) is 1.The noise variance is N_0

$$1/N_0 = \text{SNR per bit} \quad (11)$$

When the SNR per bit is taken in db

$$10 \log (1/N_0) = (\text{SNR per bit}) \quad (12)$$

$$\log (1/N_0) = (\text{SNR per bit})/10 \quad (13)$$

Let, SNR per bit = γ

$$\log (1/N_0) = \gamma/10 \quad (14)$$

$$(1/N_0) = 10^{-\gamma/10} \quad (15)$$

$$N_0 = 10^{-\gamma/10} \quad (16)$$

The standard deviation of the above variance is multiplied with a random number and the result gives the noise generation of the corresponding data.

VI. RAYLEIGH FADING MODEL

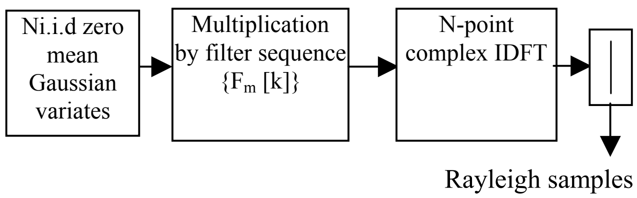

Fig.3. Rayleigh fading simulator

Figure 3 shows the simulation model for the Rayleigh fading. In the present the algorithm of Smith [5] is modified. First N number of Gaussian random variates are taken. The real and imaginary parts of the complex Gaussian sequence are used to form the Rayleigh process. The filter sequence is generated and multiplied with the Gaussian random variates. The N-point complex IDFT (Inverse discrete fourier transform) of the output of the filter sequence gives the Rayleigh samples as shown in Fig.3. The modified simulator consists of one branch only. The output of a single IDFT operation has independent real and imaginary parts and hence it can be used directly for generating the required Rayleigh sequence without the need of second IDFT operation. The sequence at the output of the algorithm has statistical properties, which closely match the theory. The independence between the real and imaginary parts means that the complex output from a single IDFT operation has been eliminated. This has two principal benefits. First, the time to execute the procedure is reduced by almost one-half. Second, the memory use for the new routine is one half to two third of the original. To perform the complex IDFT 2N real storage locations are required.

VII. RAKE RECEIVER

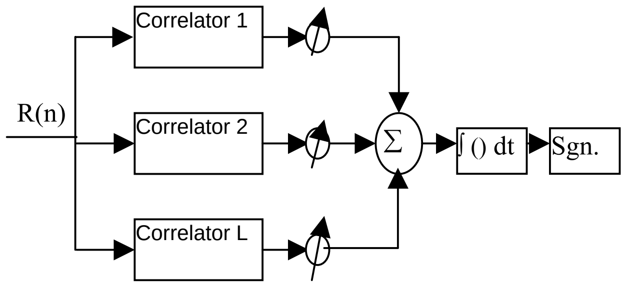

Fig. 4 RAKE receiver with L fingers

Figure 4 shows the Rake receiver with L fingers and each correlating to a different delay of the received signal. The combined outputs result to decision statistic. This structure is equivalent to more practical forms, in which the received signal is first filtered out with the chip pulse shaping matched filter and then despreading is performed using received chip samples and the spreading code sequence. The rake receiver is based on the principle of Maximal Ratio Combining. It is optimal for a multipath channel where the receiver encounters time-shifted versions of the original signal. If those multipath components are delayed in time by more than a chip duration, they appear like uncorrelated noise at a CDMA receiver.

Since there is useful information in the multipath components, the Rake receiver attempts to collect the time-shifted versions of the original signal by providing a separate correlation receiver for each of the multipath components. The Rake receiver can also pick up diversity from other base stations in case of soft hand-off. Although the Rake receiver attempts to gain diversity by combining signals from various paths, it also combines more interference. However, in the presence of good spreading codes, the Rake receiver performs better for multipath channel.

The operation done in the receiver is correlation. The data in the finger one is segmented into seveal parts and each length is equal to the length of PN sequence. The PN sequence is multiplied individually with the parts and they are multiplied separately and summed up. This gives the original sample. A threshold is fixed and decided if the data is one or zero and hence all the bits transmitted are retrieved. The same procedure is followed for all the paths including the delay. The Rake receiver is capable of reconstructing the original data in mid of the multipath problem. The simulation parameters are taken from the specifications of the IS-95 CDMA system and used in various modules of the program. The number of users can vary from one to till 3 lakhs. Here the number of user is assumed as one.

Table 1 Simulation parameters

Parameters	Values
Number of bits used for simulation	10^4
Speed of the mobile	100 km/hr
Carrier frequency	192 khz
Chip rate	1.2288 Mcps
Spreading factor	64
Transmit signal to noise ratio	-6 db
Number of channel taps	5
Received signal to noise ratio	6 db
Threshold acceptance for rake fingers	-3 db /-6 db w.r.t strongest tap

VIII. Results and Discussions

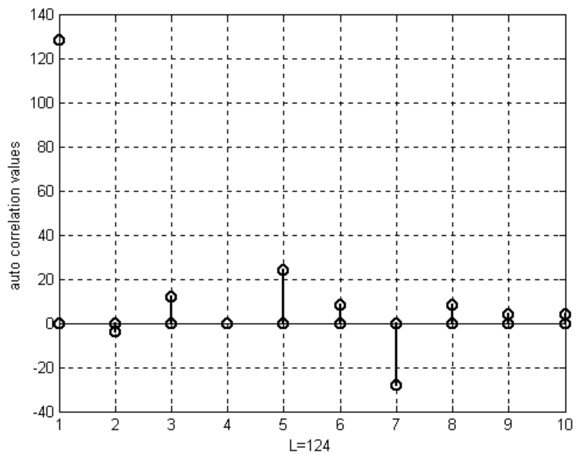

Fig 7.1. Auto correlation values of L=124

Figure 7.1 ensures the auto correlation property of the PN sequence generated. It shows that the autocorrelation value is maximum for the zero shift in the PN sequence. When the shift increases from zero there is a significant decrease in the autocorrelation value of the PN sequence generated. The PN sequence has a very unique feature of orthogonal. Even when there is one shift, the sequences will not correlate or they will give very less amount of correlation. The PN sequence is generated in the form of a code circle of the order of 2^{18}-1, using 18 flip-flops. Hence there are approximately two lakh bits generated as a PN sequence. Each segment or a sub sequence of the code circle can be used for each user. In the receiver the users data are detected using the same PN sequence.

Figure 7.2 shows the variation of bit error rate for the given signal to noise ratio. The SNR varies from –6 db to 6 db. The channel coefficients are independent. The BER is found for the individual fingers and then the combined result is found out. The BER for the finger 1 is found to be better than for finger 2. But both the results combined together

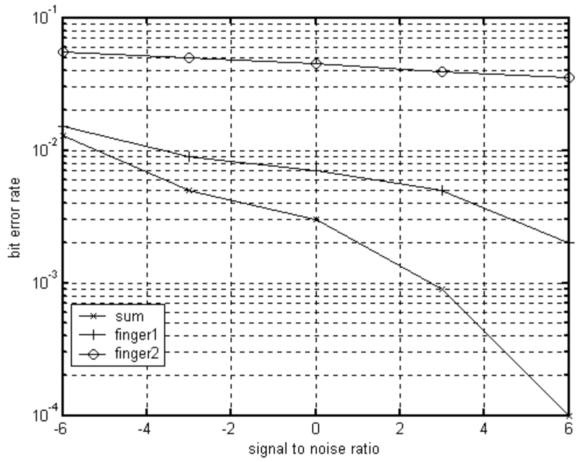

Fig 7.2 SNR Vs BER. (Independent channel taps, without fading rake acceptance threshold –0.0 db. For a two-path channel).

gives a result. The BER finally goes to zero, which means there is no error for the SNR of 6 db. The rake acceptance threshold is taken to be –0.0 db.

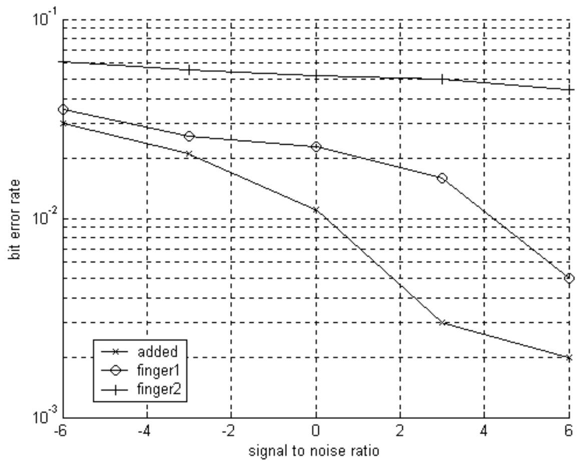

Fig 7.3. SNR Vs BER (fading results for the two path channel for σ=0.1 and ρ = 0.99)

When fading is applied in the channel the BER decreases to a certain extent as shown in Fig.7.3. All the bits cannot be reconstructed. When the channel is fading channel, some loss of data may occur. The channel coefficients are taken to be Gaussian variates. They have a mean of zero and variance of one for first time instant and mean zero and variance 0.1 for second time instant. But the finger1 has better results than that of finger2 and the combined result is better which shows that the rake receiver has solved the multipath fading effect.

Figure 7.4 illustrates the performance of the multipath channel. Four paths are having independent channel taps and the BER is decreasing according to the delay in the path. The paths are having increasing delays and they are increasing by one bit duration. Hence the BER keeps decreasing for the individual paths depending upon the amount of delay in each path.

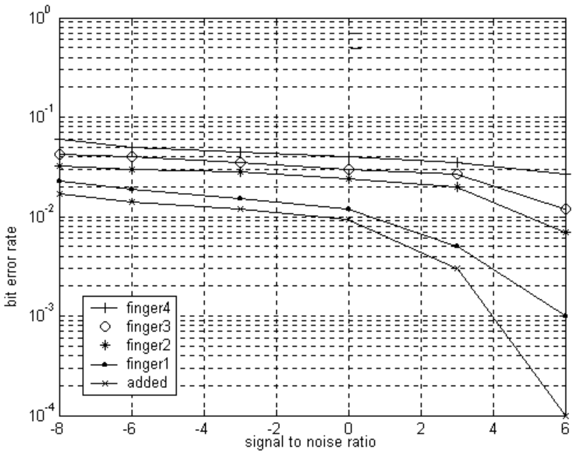

Fig.7.4 SNR Vs BER (for the multipath channel with four paths and without fading).

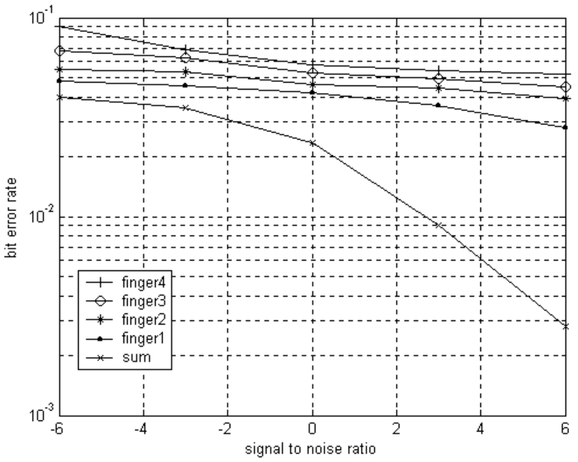

Fig.7.5 SNR Vs BER (for the multipath channel with four paths and with fading with σ =0.1 and ρ =0.95)

The fading in multipath channel is shown in Fig.7.5. The channel is constructed with the specific values of σ =0.1 and ρ =0.95. Four paths are having independent channel taps and the BER is decreasing according to the amount of fading in each paths. Since the channel is fading the BER has been decreased considerably. The zero BER cannot be achieved or all the bits transmitted could not be retrieved There are some errors in all the paths due to fading. The delays are increasing by one bit duration for each path, which also affects the BER. Hence the BER keeps decreasing for the individual paths depending upon the amount of delay.

Figure 7.6 shows the implementation of Rayleigh fading which has been discussed previously. The BER is found to be very worse than other cases. The fading is very high when compared to the fading with Gaussian variates. The line of sight path is also having very high bit error rate because of Rayleigh fading. When the speed of the mobile is increased the fading is more. The speed of the mobile considered here is 100 km/hr, which is considered to be the normal speed for which the graph is drawn above.

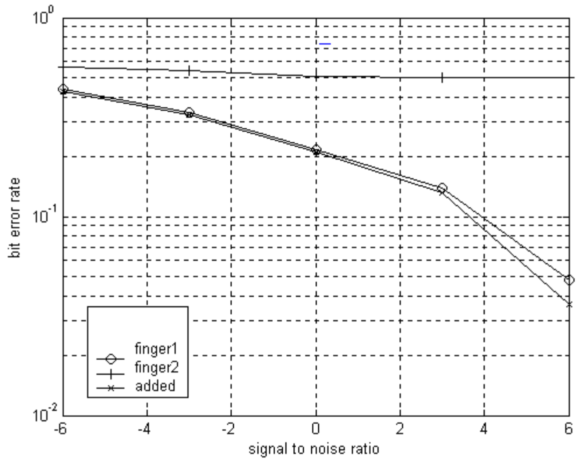

Fig 7.6. SNR Vs BER(for a two path channel with Rayleigh fading and the channel taps are independent).

IX. CONCLUSION

We implemented the simulator for the DS-CDMA system, and investigated the BER performance of the RAKE receiver as a function of the signal to noise ratio. Various modules were proposed to model the delay spread in the channel. The presence of a line of sight(LOS) component in the multipath channel helps tremendously in improving the BER performance especially at distances close to the base station where the LOS component has sufficient strength as compared to the NLOS components. In fact this LOS component can overcome the lack of time diversity due to correlated fading. The bit error rate decreases gradually from zero to powers of 3 or 2 when fading is applied. However, the combined path gives good result than the individual paths. This shows that the RAKE receiver employs the maximal ratio combining. Gaussian fadings are gives better than that of the rayleigh fading. The PN sequence generated is completely orthogonal. The codes show their individuality and they are distinct for individual user data.

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