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BER Improvement of DS-CDMA with Rake Receiver Using Multipath Fading Channel

Mr. Bhalerao G. A. **Prof. Zope R. G.**

Abstract — **Analyze the performance of a CDMA system by varying the system parameters. CDMA is a popular technology in cellular system due to its greater capacity and performance. To obtained better Signal to Noise Ratio (SNR) using matched filter in conventional CDMA rake receiver is used. Rake receiver is one of the receiver technique, consists of multiple correlators, in which the receive signal is multiplied by time-shifted versions of a locally generated code sequence. To maximize the SNR and minimize the Bit Error Rate (BER) the CDMA Rake receiver is used. The aim is to compare the receiver data in CDMA based with and without Rake receiver for different attenuation factor. One of the biggest drawbacks of wireless environment is the limited bandwidth. However, the users sharing this limited bandwidth have been increase considerably by using Direct Sequence Code Division Multiplexing technique (DS-CDMA) that can enhance the capacity of communication system. A Fading Channel is known as communications channel which has to face different fading phenomenon's, during signal transmission. In real world environment, the radio propagation effects combine together and multipath is generated by these fading channels. Due to multiple signal propagation paths, multiple signals will be received by receiver and the actual received signal level is the vector sum of the all signals.**

Key Words — **BER (Bit Error Rate), DS-CDMA (Direct Sequence-CDMA), Error Control Coding, Fading, Multipath Fading Channels, Rake Receiver.**

I. INTRODUCTION

Code Division Multiple Access (CDMA) is a popular technology in cellular system due to its greater capacity and performance. Rake receiver is one of the receiver technique, consists of multiple correlators, in which the receive signal is multiplied by time-shifted versions of a locally generated code sequence. To maximize the SNR and minimize the BER the CDMA Rake receiver is used. In a wireless mobile communication system, a signal can travel from transmitter to receiver over multiple reflective paths; this phenomenon is referred to as multipath propagation. There are many models that describe the phenomenon of small scale fading. Out of these models, Rayleigh fading, Rician fading and Nakagami fading models are most widely used. It is important to evaluate the performance of wireless devices by considering the transmission characteristics, wireless channel parameters and device structure. The performance of data transmission over wireless channels is well captured by observing their BER, which is a function of SNR [3] at the receiver. In wireless channels, several models have been proposed and investigated to calculate SNR. All the models are a function of the distance between the sender and the receiver, the path loss exponent and the channel gain. Several probability distributed functions are available to model a time-variant parameter i.e. channel gain. We describe the three important and frequently used distributions. Those are Additive White Gaussian Noise (AWGN), Rayleigh and Rician models. The signal is detected and decoded by employing several replicas of the received signal. So, we consider multilink receiver structure. The physical layer transmission mode consists of a specific set of modulation, binary convolution coding and data rate.

BER is used to measure the end to end performance of wireless communication system which quantifies the reliability of communication system [4].

Error Control coding is a technique where redundancy is added to the original bit sequence to increase the reliability of the communication [4].

Rake Receiver is used in cellular systems can combine multipath components, which are time delayed versions of the original signal transmission. This combining is done to improve SNR at receiver [1], [2].

Multipath Rayleigh Fading In a wireless mobile communication system, a signal can travel from transmitter to receiver over multiple reflective paths; this phenomenon is referred to as multipath propagation. The effect can cause fluctuations in the received signal's amplitude, phase, and angle of arrival, giving rise to the terminology multipath fading [1].

II. WIRELESS CHANNEL MODELING

Wireless communication is one of the most active areas of technology development and has become an ever-more important and prominent part of everyday life. Simulation of wireless channels accurately is very important for the design and performance evaluation of wireless communication systems and components. Fading or loss of signals is a very important phenomenon that related to the Wireless Communications Field. That leads us to the fading models which try to describe the fading patterns in different environments and conditions. Although no model can 'perfectly' describe an environment, they strive to obtain

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as much precision as possible. The better a model can describe a fading environment, the better can it be compensated with other signals, so that, on the receiving end, the signal is error free or at least close to being error free. This would mean higher clarity of voice and higher accuracy of data transmitted over wireless medium.

III. Fading And Multipath

Fading refers to the distortion that a carrier-modulated telecommunication signal experiences over certain propagation media. In wireless systems, fading is due to multipath propagation and is sometimes referred to as multipath induced fading. To understand fading, it is essential to understand multipath. In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals' reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This distortion of signals caused by multipath is known as fading. In other words it can be said that in the real world, multipath occurs when there is more than one path available for radio signal propagation. The phenomenon of reflection, diffraction and scattering all give rise to additional radio propagation paths beyond the direct optical Line Of Sight (LOS) path between the radio transmitter and receiver [14].

IV. Fading Channels

A Fading Channel is known as communications channel which has to face different fading phenomenon' s, during signal transmission. In real world environment, the radio propagation effects combine together and multipath is generated by these fading channels. Due to multiple signal propagation paths, multiple signals will be received by receiver and the actual received signal level is the vector sum of the all signals. These signals incident from any direction or angle of arrival. In multipath, some signals aid the direct path and some others subtract it.

Causes Of Fading

Fading is caused by different physical phenomenon:

1. Doppler Shift

When a mobile is moving at a constant velocity v along a path, vs is the velocity of the source, f' is the observed frequency and f is the emitted frequency. All these terms will be related by the equation = (v/v ± vs) *f. From the equation, that the detected frequency increases for objects moving towards the observer and decreases when the source moves away. This phenomenon is known as the Doppler Effect [16].

2. Reflection

When a propagating electromagnetic wave impinges on object which has generated large dimensions wave length, when compared to wavelength of the propagating wave, then Reflection will occurred. Actually we know that if the plane wave is incident on a perfect dielectric, part of the energy is transmitted and part of the energy is reflected back into the medium. If the medium is a perfect conductor, all the energy is reflected back. Reflections occur from the surface of the earth and from buildings and walls. In practice, not only metallic materials cause reflections, but dielectrics also cause this phenomenon [17].

3. Diffraction

The sharp irregularities (edges) of a surface between transmitter and receiver and obstructs the radio path then diffraction will occurred. The bending waves around the obstacle, even when a Line of Sight does not exist between transmitter and receiver the secondary waves will be spread over the space. Diffraction looks like a reflection at high frequencies depends on the amplitude, phase and polarization of the incident wave and geometry of the object at the point of diffraction.

4. Scattering

The wave travels through the medium consists of smaller dimension objects compared to the wavelength and having larger volumes of obstacles per unit volume, then scattering will occurred. Due to rough surfaces, small objects and irregularities in the channel scattered waves are produced. In practice, in mobile communications, electrical poles and street signs etc. induces scattering [18] in communication.

V. Types Of Fading

According to the effect of multipath, there are two types of fading

a). **Large Scale Fading**:

In this type of fading, the received signal power varies gradually due to signal attenuation determined by the geometry of the path profile.

b). **Small Scale Fading:**

If the signal moves over a distance in the order of wavelength, in small scale fading leads to rapid fluctuation of the phase and amplitude of the signal.

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1. Flat Fading:

If the bandwidth of the mobile channel is greater than the bandwidth of the transmitted channel, it causes flat fading. Flat fading is one in which all frequency components of a received radio signal vary in the same proportion simultaneously.

There are two types of fading according to the effect of Doppler Spread.

***a).* Slow fading:**

When the coherence time of the channel is large relative to the delay constraint of the channel then slow fading will occurred. The amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. The events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver, causes the slow fading.

***b).* Fast fading:**

When the coherence time of the channel is small relative to the delay constraint of the channel causes the fast fading. The amplitude and phase change imposed by the channel varies considerably over the period of use.

2. Types of small scale fading

There are many models that describe the phenomenon of small scale fading. Out of these models, Rayleigh fading, Rician fading and Nakagami fading models are most widely used.

a). Rayleigh fading model:

The Rayleigh fading is primarily caused by multipath reception [18]. Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal. It is a reasonable model for troposphere and ionospheres' signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading [19] is most applicable when there is no line of sight between the transmitter and receiver.

***b).* Rician fading model:**

The Rician fading model [18] is similar to the Rayleigh fading model, except that in Ricean fading, a strong dominant component is present. This dominant component is a stationary (non fading) signal and is commonly known as the LOS (Line of Sight Component).

c).* Additive White Gaussian Noise Model*:

The simplest radio environment in which a wireless communications system or a local positioning system or proximity detector based on Time of- flight will have to operate is the AWGN [16] environment. AWGN is the commonly used to transmit signal while signals travel from the channel and simulate background noise of channel. The mathematical expression in received signal r(t) = s(t) + n(t) that passed through the AWGN channel where s(t) is transmitted signal and n(t) is background noise.

VI. RAKE RECEIVER

The block diagram of DS-CDMA with Rake Receiver is as shown in figure 1. In multipath channel, delayed reflections interference with the direct signal in a DS-CDMA can be detected by rake receiver, a RAKE receiver technique which uses several baseband correlators to individual process several signal multipath components. The correlators are combined to achieve improved communications reliability and performance. RAKE receiver, used specially in CDMA cellular systems, can combine multipath components, which are time-delayed versions of the original signal transmission. Due to reflections from obstacles a radio channel can consist of many copies of originally transmitted signals having different amplitudes, phases, and delays, a RAKE receiver can be used to resolve and combine them. This combining is done in order to improve the signal to noise ratio (SNR) at the receiver. RAKE receiver attempts to collect the time shifted versions of the original signal by providing a separate correlation receiver for each of the multipath signals. The RAKE receiver uses a multipath diversity principle. It is like a rake that rakes the energy from the multipath propagated signal components. The RAKE receiver consists of multiple correlators in which received signals are multiplied by time shifted versions of a locally generated code sequence. The intension is to separate signals such that each finger only attain signals coming in over a resolvable path. The spreading code is chosen to have a very small autocorrelation value for any non-zero time offset that avoids crosstalk between fingers. It is not a full periodic autocorrelation that determines the crosstalk between signals in different fingers, but rather two partial correlations with contributions from two consecutive bits or symbols. It has been attempted to find sequences that have satisfactory partial correlation values, but the cross talk due to non periodic correlations remains substantially more difficult to reduce than the effects of periodic correlations the rake receiver is designed to optimally detect as DS-CDMA signal transmitted over dispersive multipath channel.

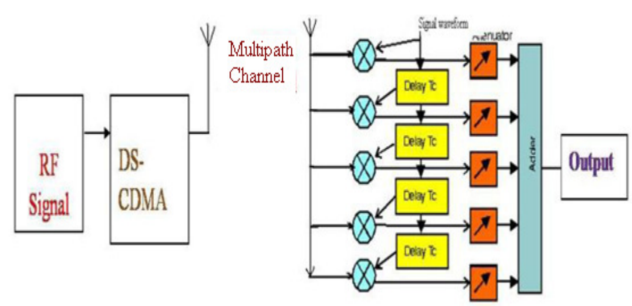

Figure. 1. Simple Block Diagram of DS-CDMA with RAKE Receiver

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Like a garden rake, the rake receiver gathers the energy received over the various delayed propagation paths. According to the maximum ratio combining principle, the SNR at the output is the sum of SNR's in the individual branches, provided that, We assume that only AWGN channel is present and codes with time offset are truly orthogonal.

1. RAKE Receiver Requirements:

RAKE receiver has to know

- Multipath delays: Time delay synchronization
- Phases of the multipath components: carrier phase synchronization
- Amplitudes of the multipath components: Amplitude tracking
- Number of multi-path components: RAKE allocation Time delay synchronization is based on correlation measurements
- Delay acquisition
- Delay tracking by feedback loops (delay-locked loops)

2. Multipath Reception

Experiments with mobile communication were done at VHF frequencies, near 50 MHz, already in the 1920s. Results of these tests revealed a very hostile propagation environment, particularly in urban centers. The signal quality varied from "excellent" to "no signal". Moving the vehicle over a few meters resulted in dramatic changes of the received field strength The bit error in multipath fading is as shown in figure 2.

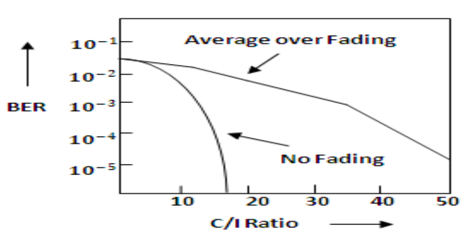

Figure. 2. Bit Error in Multipath Fading

3. Multipath channel

The figure 3 explains principle of Rake Receiver. Due to reflections from obstacles a radio channel can consist of many copies of originally transmitted signals having different amplitudes, phases, and delays Multipath can occur in radio channel in various ways Reflection, diffraction, scattering. The RAKE receiver uses a multipath diversity principle – It rakes the energy from the multipath propagated signal components. A rake receiver is a radio receiver designed to counter the effects of multipath fading. It does this by using several "sub-receivers" each delayed slightly in order to tune in to the individual multipath components. Each component is decoded independently, but at a later stage combined in order to make the most use of the different transmission characteristics of each transmission path. This could very well result in higher SNR (or Eb/No) in a multipath environment than in a "clean" environ. The main challenges for RAKE receivers operating in fading channels are in receiver synchronization de called Short Code and then with one called Long code. Direct Sequence Spread Spectrum uses a rake receiver which is a radio receiver designed to counter the effects of multipath fading. It does this by using several "sub-receivers" called **fingers**, that is, several correlators each assigned to a different multipath component. Each finger independently decodes a single multipath component; at a later stage the contribution of all fingers are combined in order to make the most use of the different transmission characteristics of each transmission path i.e., rake receiver combines the information from several correlators, each one tuned to a different path delay, producing a stronger version of the signal than a simple receiver with a single correlator tuned to the path delay of the strongest signal.

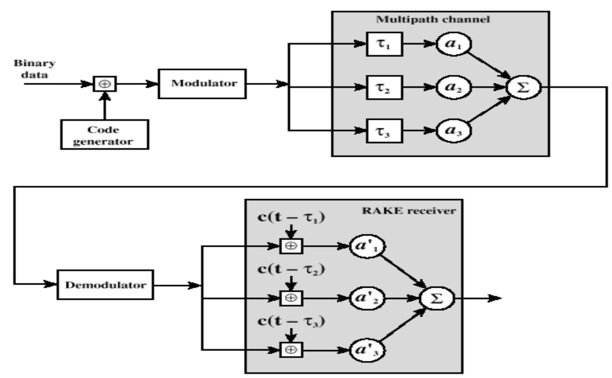

Figure 3. Principle of Rake Receiver.

VII. Error Control Coding

In case of uncoded transmission, the output from the binary source could be applied directly to the modulator, spreader and transmitted as a channel waveform. At the receiver side we detect the signal and find the Bit Error Probability (*BEP u).* In the case of uncoded transmission, the output BER*u is* equal to the BEP*u* .The subscript 'u' is used for the uncoded quantities. Figure 4 shows the Uncoded Transmission System.

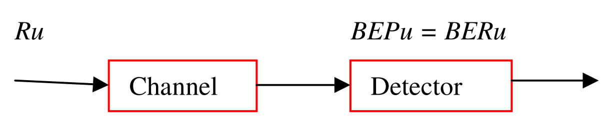

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Figure 4. Uncoded Transmission System

Where,
R*u* = *is* the uncoded input bit rate to the channel.

The Bit Error Probability (BEP*u)* for this system using SGA is given as

$$BEP_u' = \frac{1}{2} - \frac{1}{2\sqrt{1 + \frac{N_0}{2E_b} + \frac{2}{3N_c}\left[\left(1 + \frac{M_c}{5}\right)LK - 1\right]}} \quad \text{-- (1)}$$

Where,
M*c* = is the number of interfering cells
L = *is* the multipath per user, each of them independently faded with Rayleigh statistics. *K* = is the number of users.
N*C* = is the spreading factor.
In the case of uncoded transmission, the output Bit Error Rate (*BERu')* is equal to the *BEPu'*. Thus above equation gives the Bit Error Rate *(BERu')* under perfect power control. Fiure 5 shows the Coded Transmission System. In this new bit rate denoted by R*c*, is generated by encoder which is transmitted along the channel. At the receiver the bit error probability following detection is denoted by BEP*c* and the Bit Error Rate at the output of decoder is given by BER*c*.

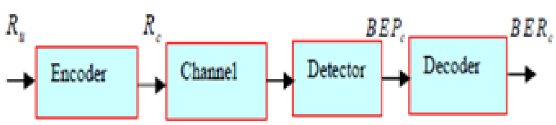

Figure 5 Coded Transmission System

In this we use convolutional coding scheme at the transmitter and associated viterbi decoding scheme at the receiver. There are three parameters which define the convolutional code; these are Code Rate, Constraint length and Generator polynomial. In this the code rate r is 1/2, Constraint length C_L *is* 3 and Generator polynomial is $[7, 5]_8 = [111,101]_2$. The Transfer Function of a this convolutional code is given by

$$T(D;J;N) = \frac{D^5 J^3}{1 - DNJ(1+J)} \quad \text{----- (2)}$$

Here,
The Exponent of D on a branch describe the Hamming weight of encoder output corresponding to that branch,
Exponent of J is the length of each branch and Exponent of N denotes the number of 1's in the information sequence for that path. The free distance d_{free} of a convolutional code is the minimum Hamming distance between any two code sequences. In this the free distance $d_{free} = 5$. The coded *BEPc* is given by

$$BEP_c' = \frac{1}{2} - \frac{1}{2\sqrt{1 + \frac{N_0}{2_r E_b} + \frac{2}{3N_c}\left[\left(1 + \frac{M_c}{5}\right)LK - 1\right]}} \quad \text{---- (3)}$$

Now the Coded *BERc is* given as

$$BER_c' \le \frac{d}{dN} T(D;J;N)\Big|_{J=1;N=1;D=2\sqrt{BEP_c(1-BEP_c)}} \quad \text{- (4)}$$

CONCLUSIONS

Rake receiver is used for CDMA technique rather than using conventional CDMA with matched filter. Rake receiver is used to minimize the BER and obtain maximum SNR. The rake receiver is used in CDMA to decrease BER due to multipath interference.
The BER performance will also increase, if increase the number of fingers in Rake Receiver. Compared the BER of the system for different path numbers over Rake.

APPENDIX

Few results that has been observed are shown below.

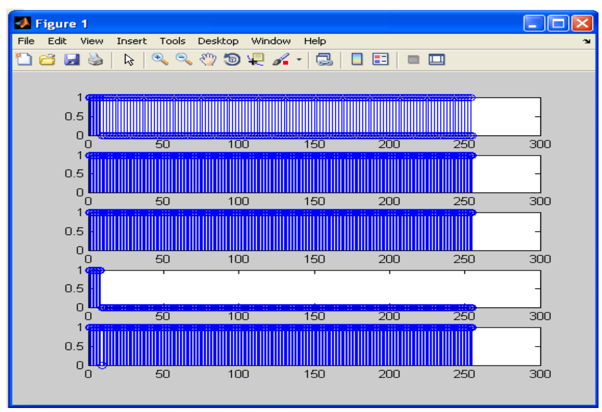

Figure A.1. PN Sequence Code.

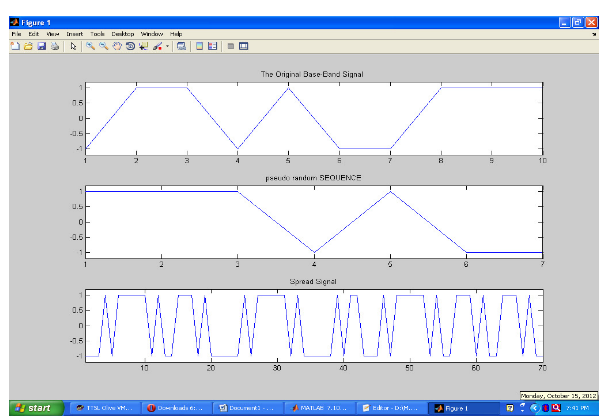

Figure A.2. DSSS Transmitter.

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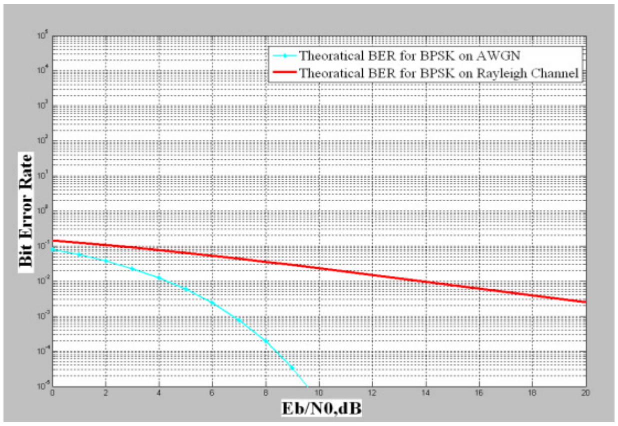

Figure A.3. Theoretical BER for AWGN and Rayleigh channel

CAPACITY AS A FUNCTION OF RAKE FINGERS

In figure A.3, at BER value of 10^{-2}, there are 6 users with using 2 Rake fingers, 9 users with 3 Rake fingers and 19 users with 5 Rake fingers. Thus capacity of communication system will increase with increasing the value of Rake finger

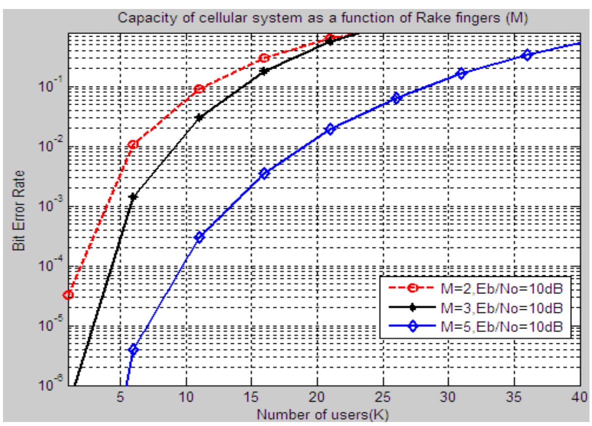

Figure A.4 Capacity as a function of Rake Fingers (M)

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AUTHOR'S PROFILE

Mr. Bhalerao G.A.

He has obtained his B.E. Degree in Electronics & Telecommunication Engineering from Amravati University & pursuing his M.E. Degree from Pune University. He has published 3 papers in various national level conferences.

Prof. Zope R.G.

He has obtained his B.E. degree in Electronics Engineering from Amaravati University in 1989 and M. Tech. degree in Electronics Design and Technology from CEDT Aurangabad, affiliated to Dr. BAM University Aurangabad in 1995. He is presently working professor in E and TC department, SRES' College of Engineering Kopargaon, Maharashtra. His total experience in teaching is 22 years. His areas of interest are analog and digital circuit design, computer networks, and wireless communication. He has published 35 papers in various conferences and journals. He is a Fellow of Institution of Engineers (India), Fellow of IETE New Delhi and Life member of ISTE New Delhi

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