# Evaluation of CDMA System Performance in Wireless Telecommunication

Md. Younus Ali, M. M. Ashiqur Rahman, S.M. Shamsul Alam, *and* Rajiv Kumar Mistry

***Abstract*— Code Division multiple Accesses (CDMA) is one of the effective and efficient technologies is used in 2nd generation (2G) and 3rd generation (3G) wireless communication. Multipath delay spread, channel noise, Doppler effects, peak to average power ratio (PAPR) and time synchronization error are ubiquitous problem in wireless communication system. By considering these problems the performances of CDMA system has been analyzed. All the performances are measured on the basis of bit error rate (BER). It is found that CDMA performs slight worse in multipath delay spread and channel noise and offers a very high tolerance to Doppler effects and PAPR.**

***Index Terms*—CDMA, Channel Noise, Doppler Effect, Multipath Delay Spread, PAPR.**

## I. Introduction

Wireless communication is a fastest increasing industry. It is forecasted that in future generation wireless networks (4G and beyond), a convergence of mobile phone technology, computing, internet access, and potentially many other multimedia applications will occur. It is very much required to improve the performances of the existing modulation techniques used in telecommunication to increase the available spectrum and better spectral to fulfill the demand for the new applications and services. CDMA technology is one of potential candidates for the physical layer of 4G mobile systems with the aim of improving cell capacity, multipath immunity, and flexibility. In this work the performance of CDMA system has been analyzed on the basis of Multipath delay spread, channel noise, Doppler effects, peak to average power ratio (PAPR). In the existing analysis and researches, it has been shown that code division multiple access (CDMA) systems support higher information capacity over time division multiple access (TDMA) and frequency division multiple access (FDMA) systems.

In CDMA, all users transmit in the same broad frequency band using specialized codes as a basis of channelization. Both the base station and the mobile station know these codes which are used to modulate the data sent [1].

Moreover, it has been shown that CDMA based communication is more resilient to narrow band interference [2]. For these reasons, over the past decade CDMA has been incorporated in many wireless standards and is considered for future. To realize the efficiency of any system it is required to justify the performance of that system due to different effecting factors.

Md. Younus Ali is with the Electronics and Communication Engineering Discipline, Khulna University (www.ku.ac.bd), Khulna-9208, Bangladesh (e-mail: younus_ece03@yahoo.com).

M. M. Ashiqur Rahman is with the Electronics and Communication Engineering Discipline, Khulna University (www.ku.ac.bd), Khulna-9208, Bangladesh (e-mail: the_jimmyneutron@yahoo.com).

S.M. Shamsul Alam is with the Electronics and Communication Engineering Discipline, Khulna University (www.ku.ac.bd), Khulna-9208, Bangladesh (e-mail: alam_ece@yahoo.com).

Rajiv Kumar Mistry is with the HEQEP URP project, Khulna University (www.ku.ac.bd), Khulna-9208, Bangladesh (e-mail: rajiv03_ece@yahoo.com).

## II. Capacity Of Single Cell CDMA System

In CDMA forward link data transmits by BTS to all active users in the cell at same time. So orthogonality between the PN codes maintained properly. But in the case of reverse link, the active users do not transmit data at same time. So, synchronization is not achieved and orthogonality is damaged. As a result capacity of a CDMA system is limited by the reverse link. In reverse link, uncorrelated PN code used instead of orthogonal codes. Let there are N number of user in the cell. We assume that the system processes perfect power control, which means that the transmitted power of all mobile users are actively controlled such that at the base station receiver, the received power from each users are equal [3]. Consider, the received power from each user to be S. The received signal will consists of the received signal power for the desired user (S) and the interference from (N-1) other users, thus the signal to noise ratio will be

$$SNR = \frac{S}{(N-1)S} \qquad 2.1$$

Since the noise in the channel is reduced by the process gain during demodulation, the noise on each data bit seen after demodulation will be less [3]. The SNR is defined by following way

$$SNR = \frac{E_b}{N_o} \cdot \frac{R}{W} \qquad 2.2$$

Where $E_b/N_o$ = Received energy per bit to noise ratio
$W/R$= Process gain

Using (2.1) and (2.2), $\frac{E_b}{N_o} = \frac{W}{R} \cdot \frac{1}{N-1}$ 2.3

By considering the background thermal noise n, $E_b/N_o$ can be represents as

$$\frac{E_b}{N_o} = \frac{W/R}{(N-1) + n/S} \qquad 2.4$$

In order to achieve an increase in capacity, the interference due to other users should be reduced [3], [4]. This can be done by decreasing the denominator of (3.4). The first technique for reducing interference is antenna sectorization. Instead of having an omni directional antenna, which has an antenna pattern over 360º, cell can be sectorized to three sectors so that each sector is only receiving signal over 120º. This arrangement decreases the effect of loading by a factor of approximately 3. If sectorization gain is *G*, then

$$\frac{E_b}{N_o} = \frac{W/R}{(N-1)\frac{1}{G} + n/S} \qquad 2.5$$

In reality, *G* is typically around 2.5 for three sector configured system and 5 for six sector configured systems [4]. Second technique for reducing interference involves the monitoring of voice activity such that each transmitter is switched off during period of no voice activity. This reduces the effective interference level by the reduced duty cycle of the transmitted signal [3], [4]. If α is voice activity factor, then

$$BER = Q\left(\sqrt{\frac{1}{\frac{K}{3\times 31} + \frac{31}{SNR\times 2\times 31\times 1}}}\right)$$

$$\frac{E_b}{N_o} = \frac{W/R}{(N-1).\frac{\alpha}{G} + \frac{n}{S}} \qquad 2.6$$

Thus the capacity of a single cell CDMA system would be

$$N = \frac{G}{\alpha}\left[\frac{W/R}{E_b/N_0} - \frac{n}{S}\right] + 1 \qquad 2.7$$

The probability of bit error (BER) using QPSK modulation technique is given by [5],

$$BER = \frac{1}{2} erfc\sqrt{E_b/N_0} \qquad 2.8$$

The *erfc(x)* is known as complementary error function.

Varying the number of active user *N*, different values of $E_b/N_o$ can be achieved by (2.6) and corresponding BER is given by (2.8).

*BER* Vs *N* is shown in Fig.1. In the reverse links of CDMA system, from the MS to the BTS, the users do not transmit data at same time as BTS so orthogonal properties are not maintained. As a result orthogonal PN codes are not efficient in this case. Hence non-orthogonal un-correlated PN codes are used. This leads to the signal from each user interfering with each other. The BER for the reverse link of a CDMA system increases as more users use the same cell. From Fig.1 it can be seen that if omni directional antenna (*G*=1) and no voice activities is used then BER becomes significantly large if the number of user is greater than 20. This represents only 31% of the total user capacity of 64.

From Fig.1 it is seen that the multiple access interference limits the performance of CDMA system. As a result 18 to 20 users are survived successfully. To increase the system performance directional antenna and voice activity detection can be used. If three sectored antenna and voice activity is used, then 60 users can easily access the system which is 93% of the total user capacity of 64.

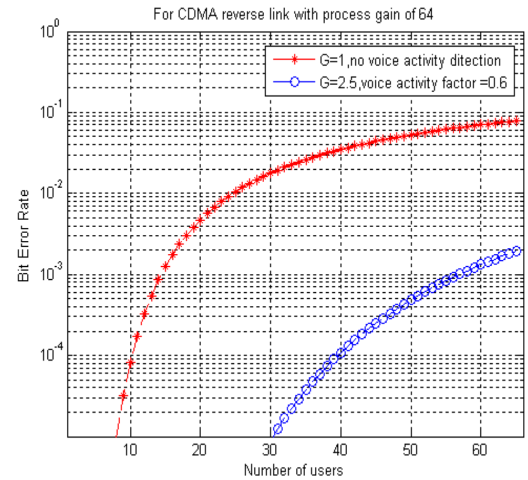


Fig. 1. BER Vs Number of users in single cell CDMA system.

## III. Effect of Channel Noise on CDMA

When A CDMA signal propagates through the air it is suffered by Additive White-Gaussian Noise (AWGN). If we consider that a general asynchronous binary CDMA system supports K active users then the BER of CDMA system due to channel noise in Rayleigh fading using Standard Gaussian Approximation(SGA) is given by [3],

$$BER = Q\left(\sqrt{\frac{1}{\frac{K-1}{3G_P} + \frac{N_o}{2T_b P_1}}}\right) \qquad 3.1$$

Where, $Q(z) = \frac{1}{2} erfc\left(\frac{z}{\sqrt{2}}\right)$, $G_p$= $W/R$ =Process Gain, $T_b$= bit period and $P_1$ = transmitted signal power of user one. Considering chip period $T_c$ = 1, and sequence factor (process gain), $G_p$ = 31 then bit period $T_b = N.T_c$ = 31. For simplicity, using transmitted power $P_1 = P_2 = P_k$=1, the energy per bit becomes, $E_b = P_1.T_b$ = 31.

Now, $SNR = 10^{(SNRdB/10)}$

Noise spectral density, $N_o = E_b/SNR$ =31/*SNR*

So from (3.1) BER becomes,

$$BER = Q\left(\sqrt{\frac{1}{\frac{K-1}{3\times 31} + \frac{31}{SNR\times 2\times 31\times 1}}}\right)$$

$$BER = Q\left(\sqrt{\frac{1}{\frac{K-1}{93} + \frac{1}{2SNR}}}\right) \qquad 3.2$$

The noise performance of CDMA reverse link is shown in Fig. 2. This shows that the BER rises as the SNR of the channel decreases and vice versa. For ten users when the SNR less than 10dB the BER becomes significant. From the Fig. 2, it is seen that BER is unacceptable for 20 and 30 users for any SNR. Here 20 and 30 users become unusable because it provides high multiple access interference.

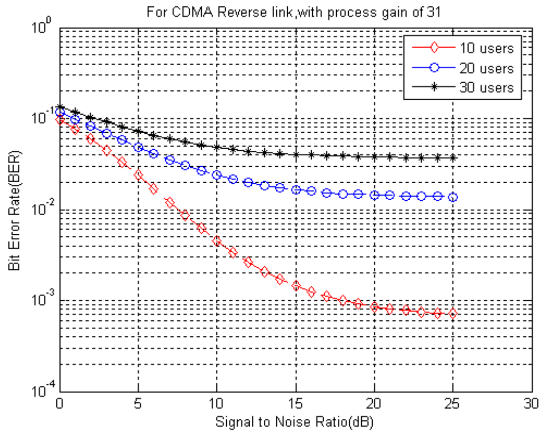


Fig. 2. BER vs. SNR of the radio channel for the reverse link of the CDMA system.

## IV. Effect of Multipath Delay Spread on CDMA

The receiver receives signal from the transmitter not only at line of sight path but also the reflected signal from the obstacles such as mountains, buildings etc. The reflected signals arrive at a later time than the direct signal because of the extra path length giving rise to a different arrival time of the transmitted signal. In a digital system, the delay spread can lead to inter-symbol interference (ISI). This is due to the delayed multipath signal overlapping with the following symbols. This can cause significant errors in high bit rate systems. As the transmitted bit rate is increased the amount of inter-symbol interference also increases. Time dispersion occurs when the reflected signal comes from an object far away from the receiving antenna. The time dispersion causes ISI where consecutive symbols (bits) interfere with each other making it difficult for the receiver to determine which symbol is the correct one [6].

The DS-CDMA use serial data transmission technique. Typical data rate are 9.6kbps, 19.2kbps and 38.4kbps and corresponding process gain 128, 64, 32 respectively (for 1.228MHz). In higher data transmission higher the BER due to multipath delay spread. Considering BER occurs when more than one-fourth of the two different symbols overlap with each other, then allowable extra reflection path length between two symbols

$$S_{CDMA} = \frac{C.T_{symbol}}{4} \qquad 4.1$$

Where, $\boldsymbol{C}$ = velocity of light = $3\times10^5\text{kms}^{-1}$

$$\therefore \quad S_{CDMA} = \frac{3\times10^5\times1.042\times10^{-4}}{4} = 7.812 \quad \text{Km}$$

The simulation model which was designed for showing effects of multipath delay spread on CDMA system shown in Fig. 3.

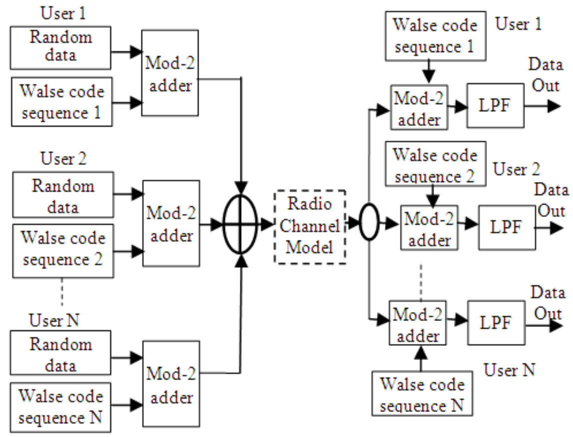


Fig. 3. CDMA model for multipath delay spread.

CDMA results with channel effects for larger multipath delay spread samples are shown in Fig. 4. From this figure, when the delay spread greater than 25 samples high bit error occurs and BER is essentially flat for high delay spreads as shown. CDMA result for 30 users is clearly worse than CDMA result for 10 users under multipath delay spread condition. For delay spread, high BER occur because the PN sequence becomes uncorrelated.

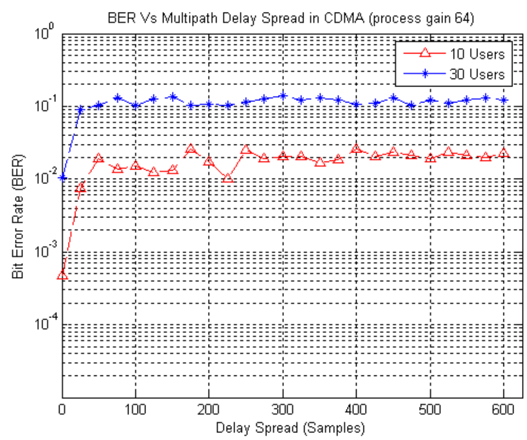


Fig. 4. CDMA multipath delay spread.

It is seen that multipath delay spread is bad side for CDMA. It limits the CDMA system performance because it breaks the orthogonal property.

## V. Doppler Effect

When a receiver and a wave source are moving relative to one another the frequency of the received signal will not be the same as the source. When they are moving away from each other the frequency decreases and when they are moving toward each other the frequency of the received signal is higher than the source. This phenomenon is known as Doppler Effect. The amount the frequency changes due to the Doppler Effect depends on the relative motion between the source and receiver and on the speed of propagation of the wave [7]. If the distance between source and receiver is $R$ and the wavelength of the propagated signal transmit from source is $\lambda$ then total number of wavelength in distance $R$

is $R/\lambda$. Each wavelength corresponds to a phase change of $2\pi$ radians. The total phase change in distance $R$ is then

$$\phi = 2\pi R/\lambda \qquad 5.1$$

Because of relative motion between source and receiver, $R$ is change so will the phase. Differentiating (5.1) with respect to time gives the rate of change of phase, which is the angular frequency

$$\omega_d = \frac{d\phi}{dt} = \frac{2\pi}{\lambda}.\frac{dR}{dt} = \frac{2\pi.v_r}{\lambda}$$
$$= 2\pi.f_d \qquad 5.2$$

Where, $v_r = \frac{dR}{dt}$ is the radial velocity ($ms^{-1}$) and $f_d$ is Doppler frequency shift. Thus from (3.40) it can be written as

$$f_d = \frac{v_r}{\lambda} = \frac{f_0.v_r}{c} \qquad 5.3$$

Where $c$ = velocity of electromagnetic wave = $3\times10^5$ $kms^{-1}$.

To produce Doppler Effect on CDMA system, MATLAB simulation was used. The CDMA simulation model was taken for showing Doppler Effect as Fig.5.

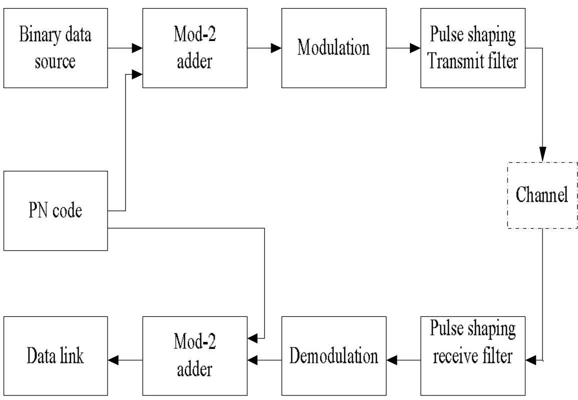


Fig. 5. Block diagram of CDMA model used for Doppler Effect.

Here the binary data speed was taken 19.6 kbps and a Walsh code of 64 lengths taken as PN sequence which has a speed of 1.228Mbps and the modulation scheme taken as QPSK. To consider only the Doppler Effect, noise level amplitude was taken as zero and SNR was taken as 20dB.

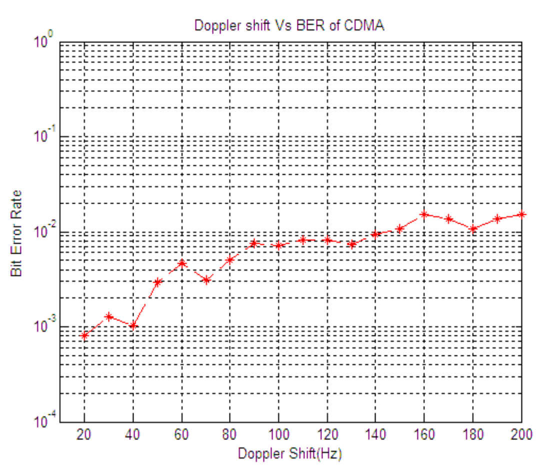


Fig. 6. Doppler Effect Vs BER of CDMA and OFDM.

From Fig. 6, for lower Doppler shift the BER of CDMA is low but when the Doppler shift exit 140 Hz, the BER of CDMA becomes significant. This is corresponding to 1GHz frequency of the source and relative velocity between source and receiver is $42ms^{-1}$ ($151.2Kmhr^{-1}$). Practically Doppler Effect is negligible because most of the traffic moves lower than that 75 $kmh^{-1}$.

## VI. Peak to Average Power Ratio

Communication systems use high power amplifier to transmit the signal which have non-linear transfer function which limits the system performance. Operation in the non-linear region near the peak results in a form of distortion, known as inter-modulation distortion when multiple carriers are present which cause an ISI. The peak to average power ratio is defined as [8],

$$\text{PAPR} = \frac{P_{Max}}{P_{Avg}} \qquad 6.1$$

Where, $P_{Max}$ = Maximum power and
$P_{Avg}$ = Average power

High peak to average power ratio indicate signal peak is high. As a result at peak position power amplifier operated in non-linear region and causes non-linear distortion, inter modulation distortion, fast battery discharging and high temperature producing. To avoid the power amplifier operate non-linear region due to high peak signal must be clipped at suitable level. Because of clipping some bit error introduce.

A challenge for DS-CDMA systems is to support rate adaptation for users who demand widely varying data rates for different applications. For voice applications, a few kbps on both the forward (base station to mobile) and the reverse (mobile to base station) links suffice. But internet access, file transfer, streaming video and multimedia applications will demand much higher rates, of the order of hundreds of kbps and up, in both directions. Multi-carrier CDMA is a system where several PN codes are assigned for each user during data transmission. In effect, the transmitted signal in an MC-CDMA system is a sum of some number n of basic rate signals, where n is the rate multiple required by a user. As a result , the peak signal power in an MC-CDMA system can be as large as n times the average signal power. Typically $n=2^m$ where m lies between 2 and 6. Thus an MC-CDMA signal can have a significantly higher peak-to-average power ratio (PAPR) than a basic rate signal [8]. So signal clipping must be performed to protect inter-modulation distortion due to nonlinearity of power amplifier. If x is the value of modulated signal and clipping threshold is $B$ then x's will be clipped when its amplitude exceed $B$. So probability of clipping = $P(|x| > B)$, gives the probability of bit error due to clipping.

Complementary cumulative distribution function,

$$\text{CCDF} = P(|x| > B) = e^{-\frac{B^2}{2\psi_o}} \qquad 6.2$$

Here, $\Psi_0 = E\left[X^2\right]$ is represent average power.

By simulating a sequence of 64-bit CDMA signal using 16-PSK and 16-QAM modulation techniques were transmitted with and without clipping. Before modulation 64-bit data is divided into 16 data stream by taking 4-bit each. The transmitted signal before clipping is shown in Fig. 7.

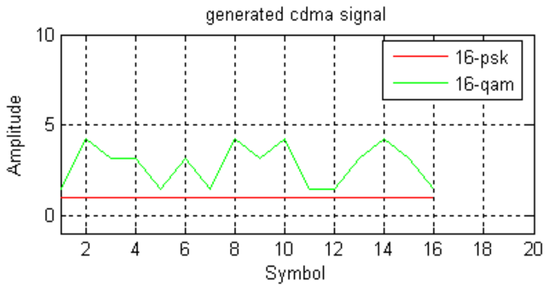


Fig. 7 Generated CDMA signal.

Since in PSK modulation technique the amplitude is constant and its value is 1, from Fig. 7 it's seen that resultant amplitude (absolute value) is 1 which is expected. But amplitudes of QAM modulated signal are varied because QAM used different level of amplitude. The transmitted CDMA signal after clipping is shown in Fig. 8.

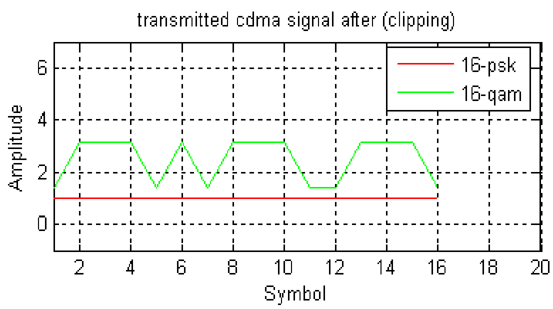


Fig.8 Transmitted CDMA signal after clipping.

The clipping is performed at threshold level = average amplitude + 0.15.

In 16-PSK the average amplitude and the peak are same so it's not clipped, only QAM signal is clipped as shown in Fig.8 when the signal crosses the threshold label. The PAPR before and after clipping is shown in Fig. 9. It's seen from the Fig.9 that PAPR is not large. Hence it is not a problem in CDMA. For16-PSK, PAPR before and after clipping is same because the signal is not clipped. But in QAM, PAPR is high. So, in where the PAPR is a problem there PSK is suitable than QAM.

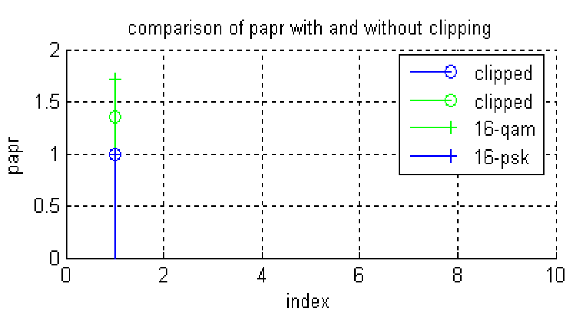


Fig. 9. PAPR with and without clipping (CDMA).

## VII. Conclusion

From this work it is seen that CDMA performs slight worse in multipath delay spread and in channel noise. In CDMA Channel noise effect can be solved in acceptable level by using sectoring antenna and by voice activity detection where multipath delay spread can be solved by frequency hopping. It is found that PAPR is not problem for CDMA because PAPR is small as a result it shows low BER. It is also found that Doppler Effect is negligible for CDMA because most of the traffic moves lower than that 75 $kmh^{-1}$. So CDMA system can be used in next generation i.e. fourth generation (4G) wireless telecommunication.

## References

[1] Saleh Faruque, “Cellular Mobile System Engineering”, *London Edition*, 1996.

[2] Samer L. Hijazi, “Multiuser Detection for Multicarrier Communication Systems”, Thesis, *College of Engineering, Kansas State University, Manhattan, Kansas* 2006.

[3] Theodore S. Rappaport, “Wireless Communications- Principles and practice”, Second Edition, 2006.

[4] Samuel C. Yang, “CDMA RF System Engineering”, *Boston London*, 1998.

[5] Dennis Roddy and John Coolen,”Electronic Communications” Fourth edition- twentieth printing, *Prentice-Hall, Delhi-110 001*, 2006.

[6] Ericsson,”GSM System Survey”, Student text edition, 2006.

[7] Merrill I. Skolnik, “Introduction to Radar Systems” Third edition, *Tata McGraw-Hill, Delhi- 110 053.*

[8] Kenneth G. Paterson,”On codes with low peak to average power ratio for multi code CDMA”, *Member of IEEE.*