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Effect of Multi-Rate on the Performance of WCDMA Downlink FDD Mode at Bandwidth 5 MHz

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Abstract: Third Generation (3G) systems are intended to provide a global mobility with wide range of services including telephony, paging, messaging, internet and broadband data. Wideband code division multiple Accesses is the system favored by most operators able to obtain new spectrum. In WCDMA, each user transmits a data sequences spread by a code commonly called spreading code. This code is unique to the Mobile Station (MS) to Base Station (BS) connection on both uplink and downlink. This study deals with analytical treatment and computer aided performance analysis of downlink FDD mode of WCDMA under the variable strategic conditions of processing gain, signal to noise as well as number of interference.

Key words: Mobility, windoband

INTRODUCTION

WCDMA has an edge over the existing techniques in terms of capacity, voice quality, coverage area, power requirement, security and bandwidth etc. Algorithm for computer aided simulation has been developed. The study is useful in the Link level simulation of WCDMA for mobile communication. Computer Aided system level simulation of WCDMA FDD mode has been attempted which is useful in the following Scenario.

- In order to increase the accuracy and performance of WCDMA network capacity.
- In the planning of WCDMA network.
- To achieve the flexibility in use data rates in different environment.
- In the reduction of Multiple Access Interference (MAI) which is the dominate factor in system capacity and quality of communication at minimum power level.
- Better use of available radio frequency bandwidth.
- Design of future cellular mobile communication network.
- Useful to enhance voice quality, coverage area, security etc.

Emerging requirements for higher rate data services and better spectrum efficiency are the drivers for the third generation mobile radio system. ITU third generation network (IMT 2000) and Europe (UMTS) have proposed main objectives for the third generation as follows:

- Full coverage and mobility for 144 Kbps, Preferably 384 Kbps,
- Limited coverage and mobility for 2 Mbps,
- High spectrum efficiency compared to existing system,
- High flexibility to introduce new services.

The current WCDMA specification fully satisfies the IMT-2000 requirements, including support of data rates up to 2 Mbit/s in indoor/small-cell-outdoor environments and up 384 kbit/s with wide-area coverage, as well as support for both high-rate packet data and high-rate circuit-switched data. These data rates are acceptable for many internet based applications. However, several applications, for example file download and streaming, are able to benefit from higher data rates and lower delays. For other more interactive applications the quality perceived by the end-user is largely determined by the latency (or delay) of the system. Thus, to benefit most services, an evolution of WCDMA should both enhance data rates as well as reduce delays, different scheduling algorithms, the operators can tailor the behavior of the system to suit their needs[1]. Wideband CDMA is designed to flexibly offer support for higher bit rates, higher spectrum efficiency, higher quality of services wideband services, such as wireless Internet services (i.e.

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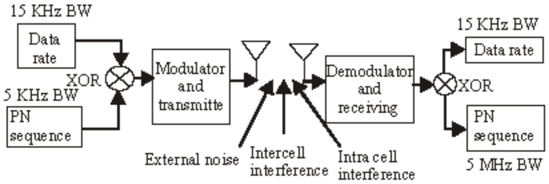


Fig. 1: Spreading process

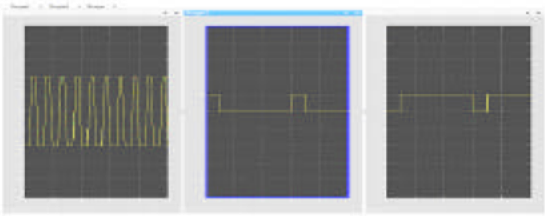


Fig. 2: Waveforms of data signal, PN code and spreaded data signal

peak rate of 384 kb/s to download information web) and video transmission (data rate up to 2Mb/s). Wideband is essential about the data rate. The physical limitations and impairments to radio channels such as bandwidth constraints, multipath fading, noise and interference present fundamental technical challenges to the goal of reliable high data rate communications[2].

In WCDMA system, the access scheme is Direct Sequence Code Division Multiple Access (DS-CDMA). The Direct Spectrum is the most commonly used technique among the different Spectrum techniques. In this technique the transmission system that combines the sending data signals with Pseudo-noise code (PN code), independent of the information data is employed as a modulation waveform to spread the signal energy over a bandwidth much higher than the signal information bandwidth (5 MHz). At the receiver the signal is despread using a synchronized replica of the PN code. FDD WCDMA uses spreading factors 4 - 512 to spread the base band data over ~5MHz band[3]. Fig. 1 and 2 shows the spreading process and spreaded waveform for WCDMA at bandwidth 5 MHz. Transmitter converts an incoming data (bit) stream into a symbol stream where each symbol represents a group of one or more bits This technique is reliable and highly resistance to interference and give the opportunity to multiple users can communicate through one channel[4].

There are two different modes of operation namely:

- Frequency Division Duplex (FDD): - The uplink and downlink transmission employ two separated frequency bands for this duplex method (transmitter/receiving). A pair of frequency bands with specified separation for a connection.

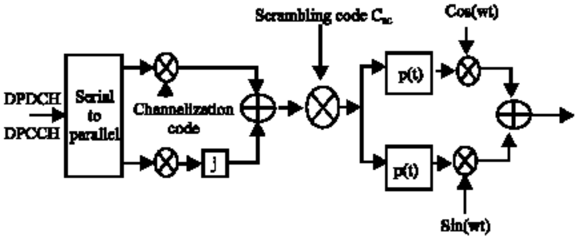


Fig. 3: Spreading and modulation

- Time Division Duplex (TDD):- uplink and downlink transmissions are carried over the same frequency band by using synchronized time intervals thus time slots in a physical channel are divided into transmission and reception part[5,6].

DESCRIPTION OF RADIO ACCESS NETWORK OF WCDMA

A brief description of the radio access network of a WCDMA system operating in the FDD mode. The spreading and modulation operation for the Dedicated Physical Channels (DPCH) at downlink are described here. Quaternary Phase Shift Keying (QPSK) is applied for data modulation in the downlink. Each pair of two bits is serial to parallel converted and mapped to the I and Q branches respectively. The data at I and Q branches are spread to the chip rate by the same chanalization code. The channelization code is the same Orthogonal Variable Spreading Factor (OVSF) codes. This spread signal is then scrambled by a cell specific scrambling code. The scrambling code is than is pulse shaped p(t), square root raised cosine filter with roll-off factor of 0.22 are employed at the transmitter. The receiver at the base station has a filter matched to the pulse-shaping filter at the transmitter. The data rate in the I and Q channels are the same in the downlink whereas data rate in uplink may be different.

DOWNLINK SPREADING AND MODULATION

Quaternary Phase Shift Keying (QPSK) is applied for data modulation in the downlink. Each pair of two bits are serial-to-parallel converted and mapped to the I and Q branches respectively. The data in the I and Q branches are spread to the chip rate by the same channelization code. The channelization codes are known as Orthogonal Variable Spreading Factor (OVSF) codes. This spread signal is then scrambled by a cell specific scrambling code. Fig. 3 shows the spreading and modulation for a downlink user. The downlink user has a DPDCH and a DPCCH. Additional DPDCHs are QPSK modulated and spread with different channelization codes. OVSF codes

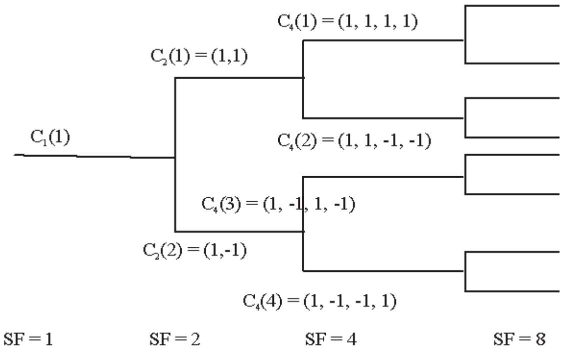


Fig. 4: Code tree for OVSF codes

and scrambling code are discussed next in section. We can observe some differences between the spreading and modulation in the downlink and that in the uplink. The data modulation is QPSK in downlink whereas it is BPSK for the uplink. The data rates in the I and Q-channels are the same in the downlink whereas data rates in the I and Q-channel of the uplink may be different. The scrambling code is cell specific in the downlink, whereas it is mobile station specific in the uplink. Square-Root Raised Cosine filters with roll-off factor of 0.22 are employed for pulse shaping, more description in[7].

Spreading code for downlink: The spreading code, as the name suggests, spreads the data to the chip rate of 3.84 Mega Chips Per Second (Mcps). The most important purpose of the spreading codes is to help preserve Orthogonality among different physical channels. OVSF codes can be explained using the code tree discussed in Fig. 4. The subscript here gives the spreading factor and the argument within the parenthesis provides the code number for that particular spreading factor. Each level in the code tree defines spreading codes of length SF, corresponding to a particular spreading factor of SF. The number of codes for a particular spreading factor is equal to the spreading factor itself. All the codes of the same level constitute a set and they are orthogonal to each other. Any two codes of different levels are orthogonal to each other as long as one of them is not the mother of the other code. The spreading code for the first DPDCH is always a repetition of {1, 1, -1, -1}. Subsequently added DPDCHs for multi-code transmission are spread by codes in ascending order starting from code number 2 excepting the code used for the first DPDCH. Code selection in this orderly manner along with the proper choice of scrambling code increases the spectral efficiency by limiting the diagonal transitions in the signal constellation.

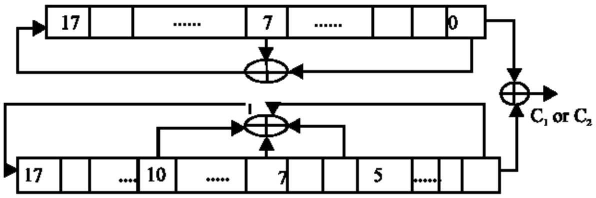


Fig. 5: Generation of downlink scrambling codes

Downlink scrambling codes: The downlink scrambling codes are used to maintain cell or sector separation. The total number of available scrambling codes is 512. These codes are divided into 32 code groups with 16 codes in each group. The grouping is done to facilitate fast cell search by the mobile. The downlink scrambling codes are generated by the two different generator polynomials. The X sequence sis constructed using primitive polynomial 1+X7+X 18 and the Y sequence is constructed from 1+X5+X7+X10+X18. Fig. 5 shows downlink spreading modulation[8-10].

SYSTEM MODEL

In Cellular Mobile Communication systems, base station transmit signal to all the users present in a cell independently, since their relative time delays are randomly distributed. K independent user use the same carrier frequency and may transmit simultaneously. The kth binary source generates a binary sequence $b_k(m)$, where m is the time instant. The spreaded data is given by $X_k(t)$.

$$\begin{aligned} X_k(t) = \sum_{m=-M}^{M} \sqrt{E_{ck}}\, b_{kI}(m) C_{kI}(t - mT - \tau_k) \\ + j\sqrt{E_{ck}}\, b_{kQ}(m) C_{kQ}(t - mT - \tau_k) \end{aligned} \quad (1)$$

E_{ck} = Kth transmitted energy per chip.
T_k = Time shift of the Kth User.
C_{kI} = Pseudorandom Code Sequence of I channel
C_{kQ} = Pseudorandom Code Sequence of Q channel.

In an asynchronous system, transmitted signals have different time shift but the symbol interval (T) for the transmitters are assumed to be equal and C_{kI}, C_{kQ} is the PN codes assigned to I and Q channel. Suppose the data at the I channel is represented by the signal $d_I(t)$, while the data at Q channel is $d_Q(t)$ in Equation 1,

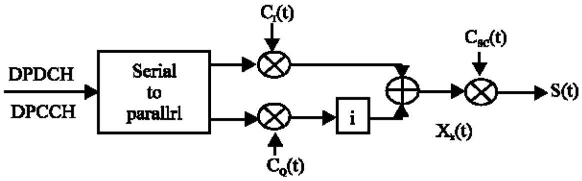


Fig. 6: Signal transmitter

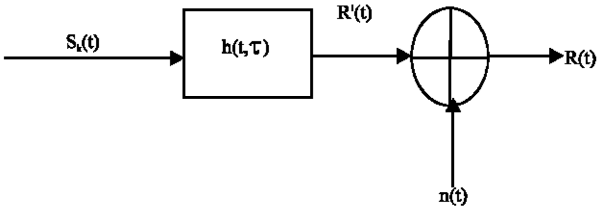


Fig. 7: Transmission through channel and reception at the rake front end

$$C_I(t) = C_{KI}(t - mT - \tau_k)$$
$$C_Q(t) = C_{KQ}(t - mT - \tau_k)$$
$$d_I(t) = \sqrt{E_{ck}}\, b_{kI}(m)$$
$$d_Q(t) = \sqrt{E_{ck}}\, b_{kQ}(m)$$

The Fig. 6 shows the transmitter and signals at different points

$$X_k(t) = d_I(t)C_I(t) + jd_Q(t)C_Q(t). \quad (2)$$

The spreaded data is than coded with complex downlink scrambling code.

$$S_k(t) = X_k(t).C_{sc}(t) \quad (3)$$

where C_{SC} is the complex Downlink scrambling code.

Each transmitted signal is passed through a multipath channel[11]. The channel is modeled by the zero mean Additive White Gaussian Noise (AWGN) n(t) with variance σ_n^2 and there is no other distortion in the channel apart from constant linear scaling of signal amplitudes and multiple access interference caused by the presence of other active users as shown in Fig. 7. R(t) is the received signal, h(t, σ_k) is the complex channel response due to multipath, n(t) is the complex Gaussian noise at the front end of the receiver, than

$$R'(t) = \sum_{k=1}^{K} h(t,\tau_k) S_k(t - \tau_k) A_k \quad (4)$$

A_k is the attenuation of the kth signal, due to propagation; we assume that we have N multipath

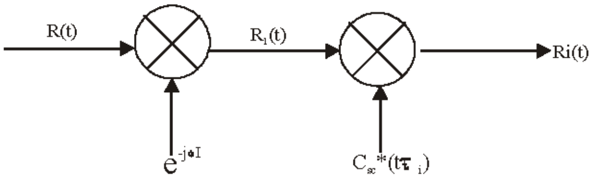


Fig. 8: Descrambling at rake finger

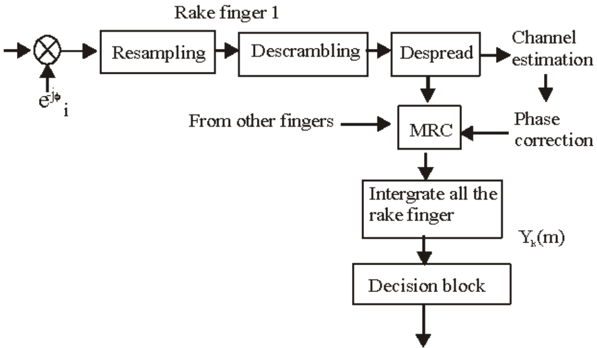


Fig. 9: Rake receiver

component in the channel. Each of these $h_i(t, \tau_k)$ is complex i.e.

$$h_i(t) = |h_i(t, \tau_k)|.e^{j\phi_i(t, \tau_k)}$$

The received signal is given by,

$$R(t) = R'(t) + n(t)$$

The Fig. 8 represents the signals at the ith finger of the rake receiver. τ_k is the time shift of the kth user.

$$R_1(t) = R(t)\, e^{-j\Phi_i(t)} = \{R'(t) + n(t)\}\, e^{-j\Phi_i(t)}$$
$$= R'(t)\, e^{-j\Phi_i(t)} + n(t)\, e^{-j\Phi_i(t)} \text{ Suppose } ni'(t) = n(t)\, e^{-j\Phi_i(t)}$$
$$R1(t) = R'(t)\, e^{-j\Phi_i(t)} + n_i'(t)$$
$$R_1(t) = \sum_{k=1}^{K} |h_i(t-\tau_k)| S(t-\tau_k)\, e^{j\Phi_i(t)} e^{-j\Phi_i(t)} A_k + n_i'(t) \quad (5)$$

scrambling

$$R'_1(t) = R_1(t)\, C^*_{SC}(t-\tau_k) + n_i'(t)\, C^*_{SC}(t-\tau_k)$$
$$= \sum_{k=1}^{K} |h_i(t-\tau_k)| S(t-\tau_k)\, C^*_{sc}(t-\tau_k)\, A_k + n_i''(t)$$
$$= \sum_{k=1}^{K} |h_i(t-\tau_i)| X_k(t-\tau_i)\, C_{sc}(t-\tau_i)\, C^*_{sc}(t-\tau_i)\, A_k + n_i''(t)$$
$$R'_1(t) \sum_{k=1}^{K} = |h_i(t-\tau_i)| X_k(t-\tau_i) A_k + n_i''(t) \quad (6)$$

The receiver consists of number of rake finger for simultaneous demodulation of K user signals followed by

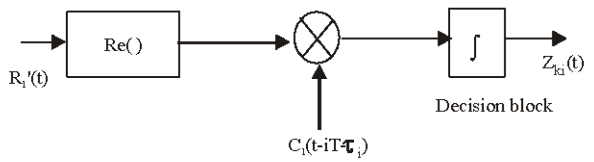


Fig. 10: Despreading in rake finger

a decision block as shown in Fig. 9. The out put of integrate rake finger block is sampled at the of the math. symbol interval. It is represented by

$$Y_k(m)=\frac{1}{T}\int_{\tau_k+mT}^{\tau+(m+1)T} R'_1(t)C_k(t-mT-\tau_k)dt \quad -M\le m\le M \qquad (7)$$

The final processing operation in the demodulator adds the received samples $Y_k(m)$ for all sampling instants within one bit and forms the decision variable $[Z_k(m)]$ represented as

$$Z_k=\sum_{m=1}^{Gp} Y_k(m)$$

where Gp is the number of chips per bit, which is assumed to be equal to the code sequence length (N). The kth decision device estimates the mth symbol of the kth user by examining the sign of the decision variable (Z_k)[12].

$$b_k(m)=\mathrm{sgn}[Z_k]=\begin{cases}+1 & \text{if} Z_k\ge 0\\ -1 & \text{if} Z_k\langle 0\end{cases}$$

where m is the sampling instant, $--M \le m \le M$,
Substituting $R'_1(t)$ in Eq. 7

$$Y_k(m)=\frac{1}{T}\int_{\tau_k+mT}^{\tau_k+(m+1)T}\sum_{k=1}^{K} h_i\left(t-\tau_i\right)X_k(t-\tau_k)$$
$$A_kC_k(t-mT-\tau_k)dt+n_i''(t) \qquad (8)$$

X_k (t) contain the two channel parts (I and Q). But here we take only real parts at the front end of the receiver as shown in Fig. 10.

$$Y_k(m)=h_i(t)\sqrt{E_{ck}}b_k(m)A_k+\frac{1}{T}$$
$$\int_{\tau_k+mT}^{\tau_k+(m+1)T}\sum_{\substack{i=1\\ i\ne k}}^{K} h_i(t-\tau_i)A_i\sqrt{E_{ci}}\sum_{i=-M}^{M} b_i(i)C_i \qquad (9)$$
$$(t-iT-\tau_i)C_k(t-mT-\tau_k)dt+n_k(m)$$

$n_k(m)$ is the Gaussian noise sample at the sampling instant m. The first term represents the desired signal, while the second term represents multiple Access interference. The Eq. 9 is further written as

$$Y_k(m)=h_i(t)\sqrt{E_{ck}}b_k(m)A_k+$$
$$\sum_{i=-M}^{M}\sum_{j\ne k}^{K} h_i(i)\sqrt{E_{ci}}A_ib_i(i)E_{ik}(l)+n_k(m) \qquad (10)$$
$$E_{ik}(l)=\frac{1}{T}\int_{\tau_k+mT}^{\tau_k+(m+1)T} C_i(t-iT-\tau_i)C_k(t-mT-\tau_k)dt$$

E_{ik} (l) is the cross correlation of code sequences in which l = (i-m). The Eq. 10 shows, the interference term is linear in amplitude of the interfering users.

$$Y_k(m)=\underbrace{h_i(t)\sqrt{E_{ck}}b_k(m)A_k}_{Y_{k1}(m)}$$
$$\underbrace{+\sum_{i=-M}^{M}\sum_{j\ne k}^{K} h_i(i)\sqrt{E_{ci}}A_ib_i(i)E_{ik}(l)}_{Y_{k2}(m)}\underbrace{+n_k(m)}_{Y_{k3}(m)}$$

The first term in above equation is the desired signal $Y_{k1}(m)$. The Second term is multiple access interference due to other user (MAI) denoted by $Y_{k2}(m)$. The last term is noise factor $Y_{k3}(m)$.

$$Y_k(m)=Y_{k1}(m)+Y_{k2}(m)+Y_{k3}(m)$$

The decision Variable, Z_k can be than represent as,

$$Z_k(t)=\sum_{m=1}^{Gp}\left[Y_{k1}(m)+Y_{k2}(m)+Y_{k3}(m)\right]$$

The average Probability of Bit Error, P_b can be expressed as

$$P_b=½\,P_r\{Z_k>0, b_k=-1\}+½\,P_r\{Z_k<0 \text{ when } b_k=+1\}$$

Assuming that the probabilities of transmitting symbols -1 and +1 are equal. The Bit Probability can then be written as

$$P_b=P_r\{Z_k>0, b_k=-1\} = P_r\{Z_k<0 \text{ when } b_k=+1\}$$

Assuming that the number of chips per bit, G_p is large, the decision variable Z_k can be approximated according to the Central limit theorem by a Gaussian random variable. The Bit Error probability is given by

$$P_b=Q\sqrt{\frac{[E(Z_k)]^2}{Var(Z_k)}}$$

E[Z_k] is the mean and Var[Z $]_k$is the variance of the decision variable Z_k. The mean value of Z_k is given by

$$E[Z_k]=E\left[\sum_{m=1}^{Gp} Y_{k1}(m)b_k = 1+Y_{k2}(m)+Y_{k3}(m)\right]$$

$$E[Z_k]=E\left\langle\left[\begin{array}{l}\sum_{m=1}^{Gp} Y_{k1}(m)b_k = 1+E \\ \left[\sum_{m=1}^{Gp} Y_{k2}(m)\right]+E\left[\sum_{m=1}^{Gp} Y_{k3}(m)\right]\end{array}\right]\right\rangle$$

$$\text{Since } E\left[\sum_{m=1}^{Gp} Y_{k2}(m)\right]=0 \text{ and } E\left[\sum_{m=1}^{Gp} Y_{k3}(m)\right]=0$$

$$E[Z_k]=E\left[\sum_{m=1}^{Gp} Y_{k1}(m)b_k = 1\right]=Gp\sqrt{E_{ck}}$$

the variance var(Z_k) is given by

$$\text{var}(Z_k) = Gp\ \text{var}[\ Y_{k1}(m)]+\text{var}[Y_{k2}(m)]+\text{var}[Y_{k3}(m)]$$

The desired signal variance is

$$\text{var}[Y_{k1}(m)] = 0$$

The variance due to thermal Gaussian noise is

$$\text{var}[Y_{k1}(m)] = No/2$$

Where No is the one sided thermal noise power spectral density. The variance of the interfering signals can be computed assuming that the interfering signal is modeled as white noise with the two sided power spectral density of Ec/Tc. Taking into account the relative phase difference between the desired signal and interfering g signals and averaging over them[13].

$$\text{var}[Y_{k3}(m)] = \sum_{\substack{i=1\\ i\neq k}}^{K}\frac{E_{ck}(i)}{2}$$

Then the bit Error Probability is lower bounded by

$$P_b \geq Q\left[\sqrt{\frac{2E_{ck}Gp}{No+\sum_{\substack{i=1\\ i\neq k}}^{k}E_{ci}}}\right]$$

The term $2E_{ck}Gp$ is the double bit energy $2E_b$ and the denominator represents the total power spectral density coming for the thermal noise and multiple access interference. If we denote by I_o, than

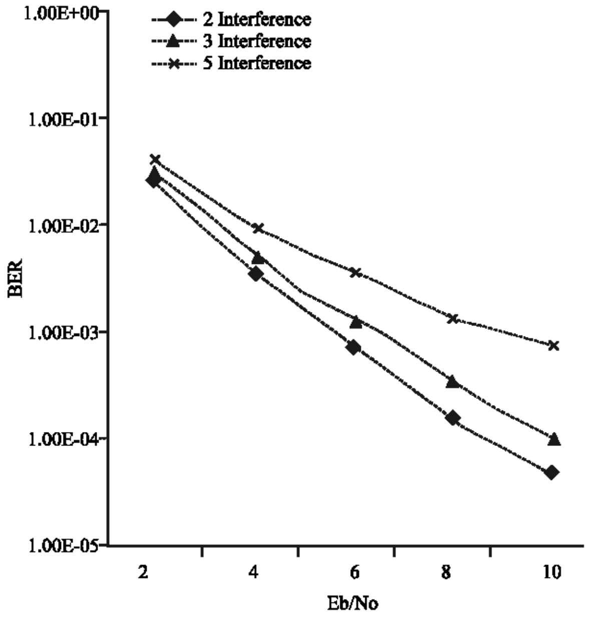


Fig. 11: BER vs Eb/No at 5 MHz bandwith with bite rate is 12.2 kbps

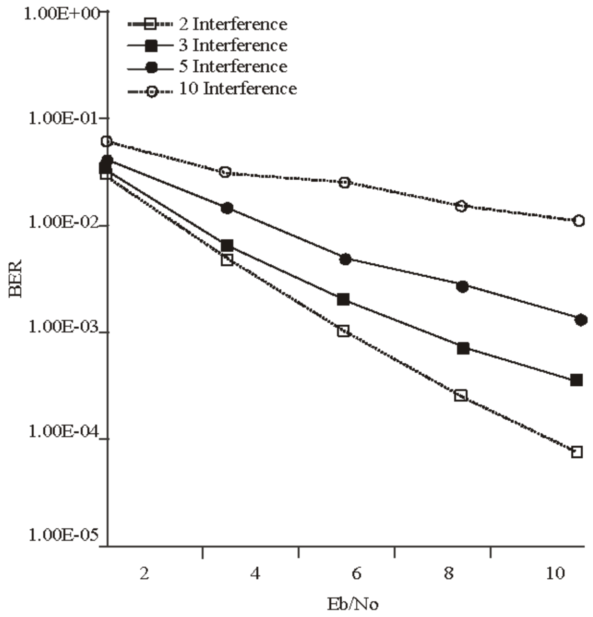


Fig. 12: BER vs Eb/No at 5 MHz bandwith with 64 kbps bite rate, variation of interference from 2 to 10 12.2 kbps

$$I_o = N_o + \sum_{\substack{j=1\\ j\neq k}}^{k} E_{cj}$$

The bit error Probability lower bound can be written as

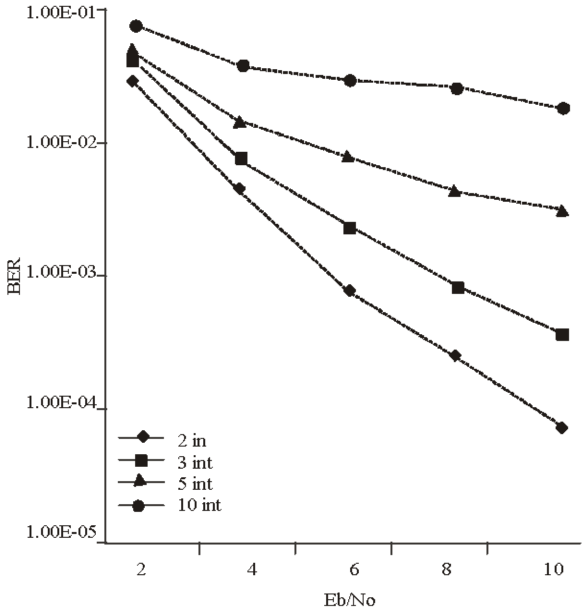


Fig. 13: BER vs Eb/No at 5 MHz bandwith with 144 kbps bite rate, variation of interference from 2 to 10

$$P_b \geq Q\left[\sqrt{\frac{2E_b}{I_o}}\right]$$

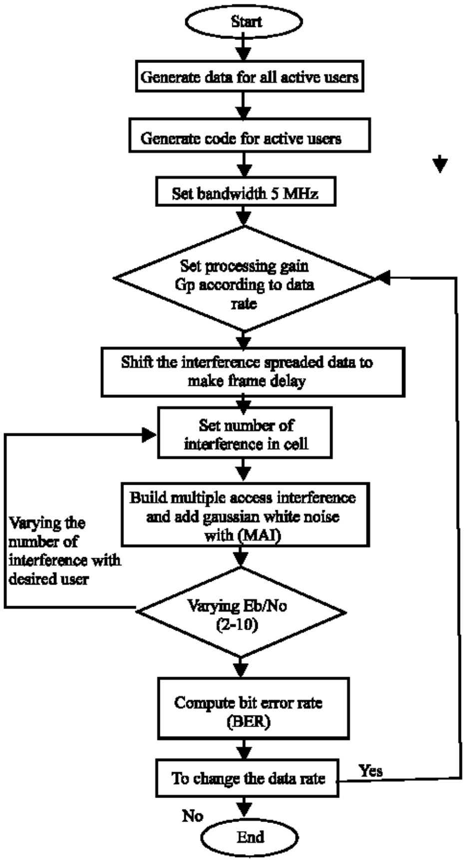
The bit error probability P_b on a Gaussian Channel can be approximated by

$$P_b = Q\left\{\frac{[K-1]}{3G_p} + \frac{No}{2E_b}\right\}^{\frac{-1}{2}}$$

where No is the Gaussian noise one–sided power spectral density. This expression for the Bit Error Probability is obtained assuming Perfect power Control[14]. The degradation depends on operating Eb/No, the number of User (k) and the spreading factor. More users imply greater degradation, as one might expect.

Performance evaluation: The Flow chart for Downlink FDD mode of WCDMA for computing BER was developed for computer aided performance analysis under following varying condition. The flow chart for above computation is given in Appendix 1.

Figure 11, 12 and 13 shows the variation of Bit Error Rate at different data rates, when Eb/No is changed from (2-10). It can be observed from the Fig. 11 that system becomes interference limited. As the Number of interference is increased at the fixed value of processing gain with the bit rate is 12.2 kbps with the varying of Signal to noise ratio (Eb/No), the required quality of service (BER) is decreased. It should be noted that the processing gain of the desired user remains constant and all users transmit at the same power. The effective value of BER is 10^{-3} is achieved at Eb/No is 6 only when one interference with the desired user is present. But as the interference users are increased from 2 to 5 the achievable target i.e BER 10^{-3} is achieved at Eb/No is 10. The same study was carried out at different data rates 64 kbps and 144 kbps. The Fig. 12 and 13 clearly shows that there is degradation of Bit Error rate at fixed bandwidth 5 MHz as well as data rates of 64 kbps and 144 kbps, respectively, when Eb/No changed from 2 to 5.



Appendix 1: Computational flow chart of BER with number of interferende in cell for performance evaluation

At data rate 12.2 kbps, more energy is required to get the achievable target. The other users are not aligned in time therefore the code do not align in an orthogonality way that is retain in the receiver. So these users causes the multiple access interference to be non-zero and the performance of the system is deteriorates as the number of users is increased.

CONCLUSION

In this Study the performance of the FDD downlink of WCDMA is analyzed in term of BER and Number of interference with desired user in the varying conditions for the WCDMA system. In WCDMA interface different users can simultaneously transmit at different data rates and data rates can vary in time. The processing gain, together with the wideband nature, suggests a frequency reuse between different cells of a wireless system (i.e. a frequency is reused in every cell/sector). This feature can be used to obtain high spectral efficiency.

REFERENCES

1. Dungan, R. Frank, 1998. Electronic Communication: Third Edn, Dalmar Publishers, London.
2. Samuel, C. Yung, 1997. Cdma RF system Engineering: Artech House, Boston.
3. Prasad Ramjee, 1998. CDMA for wireless personal communication: Artech House, New York.
4. Umts-3G WCDMA link budget.htm.
5. Prasad Ramjee, Tero Ojenpera.: Wideband CDMA for third generation Mobile Communication.: Artech House, Boston London.
6. Shanmugan, K. Sam, 2000. Digital and Analog Communication Systems. John Willey and Sons, USA.
7. Third Generation Partnership Project Technical Specification Group Radio access Network Working Group 1.:Multiplexing and Channel Coding (FDD), TS 25.212 V2.0.1.
8. Lee and A. Edward, Messer Schmitt.; David, G.: Digital Communication: Kluwer Publisher, Boston.
9. Third Generation Partnership Project Technical Specification Group Radio Access Network Group 1.: Spreading and Modulation. TS 25. 213V2.1.2.
10. Sarkar, N., Digital Communication.: Khanna Publication, New Delhi.
11. Vijay K. Garg, Kenneth F. Smolik and Joseph E. Wilkes: Application of CDMA in Wireless/Personal Communications.: Prentice Hall PTR, NJ.
12. Third Generation Partnership Project Technical Specification Group Radio Access Network Working Group 1.: Physical Channels and Mapping of transport Channels on to physical Channels (FDD): TS 25.211 V 2.2.1.
13. Savo Glisic, 1997. Spread Spectrum CDMA Systems for Wireless Communications.: Artech House, Inc, Norwood, MA.
14. Haykin, S. and M. Mohar, 2005. Modern Wireless Communications: Pearson Education New Delhi.