KING FAHAD UNIVERSITY OF PETROLEUM AND MINERALS

Computer Engineering Department

COE 543 (Mobile and Wireless Networks)

"Final Report"

Capacity Evaluation for cdma2000 Integrated – Service Network

Instructor

Dr. Ashraf S. Hasan Mahmoud

By

Naser S. AL-Ubaidi

ID # 925469

Tuesday, May 20, 2003

ABSTRACT

CDMA2000 is an IS-95 based third generation standard that will provide high data rate services through packet data connection. The promise of the third generation (3G) mobile communication systems is to provide the subscriber a wide variety of services such as access to Internet over the packet data connections. In this paper a brief description about cdma2000 and other technologies, like, W-cdma will be given. In addition, aspects of cdma2000 will be exposed. These include: protocol stack of cdma2000, channel characteristics for both forward and reverse links. Simulation example of channel capacity of the reverse was discussed and results have been stated. A small case has been implemented and discussed. The paper is ended with a mathematical model of reverse channel capacity

CONTENT

FIGURES

TABELS

1 INTRODUCTION

CDMA2000 is an IS-95 based third generation standard that will provide high data rate services through packet data connection. The promise of the third generation (3G) mobile communication systems is to provide the subscriber a wide variety of services such as access to Internet over the packet data connections at the data rate of 144 kbps for high mobility, 384 kbps with restricted mobility and 2.4Mbps in an indoor office environment [1]. The International Telecommunication Union (ITU) has set forth the requirement that the candidate 3G standards should provide variable bit rate, asymmetric transmission, packet data and multimedia services while meeting the minimum Quality of Service (QoS) requirements. Cdma2000 is an IS-95 based 3G standard that has targeted to meet all the ITU performance requirements.

Feature	IS-95	Cdma2000
RF channel	1.25	1.25/5/10/15/20
User data rate	9.6-115.2kbps	9.6k-2.4Mbps
Supplemental Ch. Modulation	0-7 at 9.6k, 14.4k BPSK-Quad	0-1 @9.6k-2.4M Quad-Quad
Pilot coherent det.	Fw Link Yes Rv Link No	Fw Link Yes Rv Link Yes
Fw Power control	No	Yes
Fw trans. Diversity	No	Yes
Turbo Code	No	Yes

Table 1: cdma2000 vs. IS-95.

CDMA2000 is a follow-on development of the established TIA / EIA 95 A/B standard for second-generation mobile radio Table 1 [2] summarizes the main differences between cdma2000 and IS-95. The extensive backward compatibility of signaling and network characteristics considerably simplifies introduction. For instance, CDMA2000 islands can be implemented in the overlay of an existing cdmaOne network during a transition period. Basically, two introductory phases are distinguished for CDMA2000. In the first step, CDMA2000 1X (1xRTT) is implemented with a signal bandwidth of 1.25 MHz and a spreading rate (SR) of 1 (i. e. 1.2288 Mchip/s). This corresponds to the physical characteristics of cdmaOne. CDMA2000 1X offers more code channels (128 Walsh codes) on the forward link, the connection from the base station to the mobile station. In addition, fast power control is introduced also on the forward link. Packet data rates of up to 307.2 kbit/s for stationary and mobile applications can be handled; voice quality and capacity are almost doubled. CDMA2000 1X supports new antenna techniques such as spot beams for covering limited areas with high traffic volume for short periods. In the subsequent phase, CDMA2000 3X (3 x RTT) with an SR of 3 (3.6864 Mchip/s) offers three times the bandwidth of cdmaOne. Peak data rates of up to 2.4 Mbit/s allow true multimedia applications. Table 2 shows cdma2000 parameters.

Item	Parameter
Bandwidth	1.25/5/10/20 MHz
Chip rate	1.2288/3.6864/7.3728/11.0592/18.432 Mcps
Duplex scheme	FDD & TDD
Synchronization	Synchronous
Frame length	20ms
Modulation	Forward - QPSK, Reverse – BPSK
Spreading	Forward - QPSK, Reverse – OQPSK
Multi-rate	Variable rate
Detection	Pilot based coherent detection (Forward and Reverse link)
Power Control	Closed loop 800 bps

Table 2: Key Parameters of cdma2000

1.1 3G Technologies

1.1.1 CDMA2000 EV

CDMA2000 EV stands for CDMA2000 Evolution. Currently there is a Data Optimized or EV-DO version being deployed throughout the world. EV-DO is a CDMA2000 carrier dedicated to only data traffic. The EV-DO carrier has been further multiplexed via time to create efficient varying time slots for bursting packet transmissions. EV-DO has also been enhanced by using 8-PSK and 16 QAM modulation (3 bits per symbol and 4 bits per symbol respectively) in addition to the standard QPSK (2 bits per symbol) modulation used CDMA2000. With these enhancements, EV-DO can transmit data in burst as high as 2.4 Mbps with a 1.25 Mbps sustained rate [3].

Recently, EV-DV (Evolution-Data Voice) has been finalized and commercial equipment is currently being developed for deployment. EV-DV can transmit both voice and data traffic on the same carrier. Recently, peak data throughput for EV-DV has been confirmed at 3.09 Mbps.

1.1.2 WCDMA or UMTS

Universal Mobile Telecommunication System (UMTS) is a marketing name for Wideband CDMA or WCDMA [4]. The wideband description is added due to the large 5 MHz carrier it uses as apposed to the 1.25 MHz carriers of a narrower band CDMA technology like IS-95. As for modulation, UMTS uses QPSK for the uplink and the downlink.

UMTS uses a spreading factor of 256 for the uplink, which could mean up to 256 different users. Due to overhead, the theoretical max number of simultaneous voice users is reduced to 196. However, due to harsh channel conditions, data needs to be redundant to insure the Quality of Service (QOS) need for voice traffic. Thus, in realistic conditions Ericsson has only been able to accommodate 57 simultaneous voice users. As codecs, antennas and overall technology improves, this number could move closer to the theoretical limit. For data transmission, the total aggregate bandwidth available for downlink is 2 Mbps. However, this is a theoretical limit and typical peak downlink transmission speeds are around 384 kbps.

UMTS has plagued by three main issues; bandwidth requirements, backwards compatibility and certification. Again UMTS uses 5 MHz carriers per link. This means to deploy just one channel of UMTS, 10 MHz of bandwidth must be available to a carrier. Most operators that will eventually migrate to UMTS currently use GSM. Due to GSM reuse pattern of 3 or 4 and the popularity of mobile phones, operators due not have 10 MHz open. So operators had to purchase extra spectrum for UMTS. Auctions made the price of spectrum so high, that no body could afford to pay for the spectrum they won. Bottom line is, even though UMTS equipment has been available for some time, only one operator, NTT DoMoCo has had the means to deploy it. However, the cost of their deployment was so high, the end users cost became practically unaffordable.

Also, WCDMA is not backwards compatible with the standards it replaces. This means one of two things must happen; either operators will need to upgrade its entire network and all their roaming networks at the same time or dual-mode handsets need to be produced. Since neither of these scenarios are happening, migrating customers effectively loose coverage, which slows down adoption and negatively impacts ROI.

Another hindrance to UMTS is slow certification approval. Version 99 of UMTS was approved in 1999 and the next revision was not due for a while. NTT DoMoCo choose not to wait for a better revision and is currently deploying version 99. Since then version 4 was approved and it is supposedly not compatible with version 99, which will create roaming and unification issues in the future. Also, many carriers are choosing to deploy UMTS when Version 6 is approved in 2004. Version 5, which is compatible with version 4 is due out soon and it will optimized downlink data transmission

Table 3 compares the prominent 3G technologies and their aggregate number of users and mean data throughput. Table 4 shows the comparisons between cdma2000 and W-cdma.

Total users & Aggregate Throughput per Cell using 3-Sectored Cells & 10 Mhz of Spectrum									
Technology	*Spectrum (MHz per link)*	*RF carrier bandwidth (MHz)*	*Sector Reuse*	*RF carriers per cell*	*Voice Users per Carrier (est.)*	*Max DL Carrier Throughput (Mbps)*	*Avg. DL Estimated throughput (Mbps)*	*Total voice users per cell (est.)*	*Mean DL Cell Throughput (Mbps)*
WCDMA	5	5	1	3.0	57.0	1.920	1.000	171	3.00
CDMA2000	5	1.25	1	12.0	29.0	0.307	0.288	348	3.46
CDMA2000 EV ?DO	5	1.25	1	12.0	0.0	2.543	1.100	0	13.20
CDMA2000 EV DV	5	1.25	1	12.0	29.0	3.090	1.400	348	16.80

Table 3. 3G Comparison

Feature	Cdma2000	W-cdma
Chip rate	3.6864 Mcps	4.096 Mcps (Docomo) 3.84 Mcps (UMTS)
Synchronized BS	Yes	No/ Yes (optional)
Frame length	20 ms	10ms
Multicarrier spreading options	Yes	No
Over head	Low (because of shared pilot code channel)	High (because of nonshared pilot code channel)

Table 4: Cdma2000 vs. W-cdma

2 BACKGROUND

2.1 The Protocol Stack Of Cdma2000

Protocol stack can bee seen in Figure 1 [ ].CDMA2000 takes the information – user data and signaling – from the high layers and adds two lower-layer protocols before transferring the data over the air interface. The link layer consists of the link access control (LAC) and media access control (MAC) layers.

Each traffic type coming from the higher layer has a different QoS requirement in terms of delay, delay variations, and error rates. The function of the LAC is to ensure that various types of traffic are transferred over the air interface according to their QoS requirements. The MAC layer also provides a certain degree of transmission reliability.

CDMA2000 physical channels are classified into two groups: *Dedicated* and *Common* channels. Dedicated Physical Channels (DPCH) offer a point-to-point connection while Common Physical Channels (CPCH) offer a point to multi-point access.

A. Dedicated Physical Channel (DPHCH):

Fundamental Channel (*FCH*): Designed to transport dedicated data.

Supplemental Channel Type (SCHT): Allocated dynamically to meet a required data rate.

Dedicated Control Channel (DCCH): Transports mobile-specific control information.

Pilot Channel (R-PICH): Provides the capabilities for coherent detection.

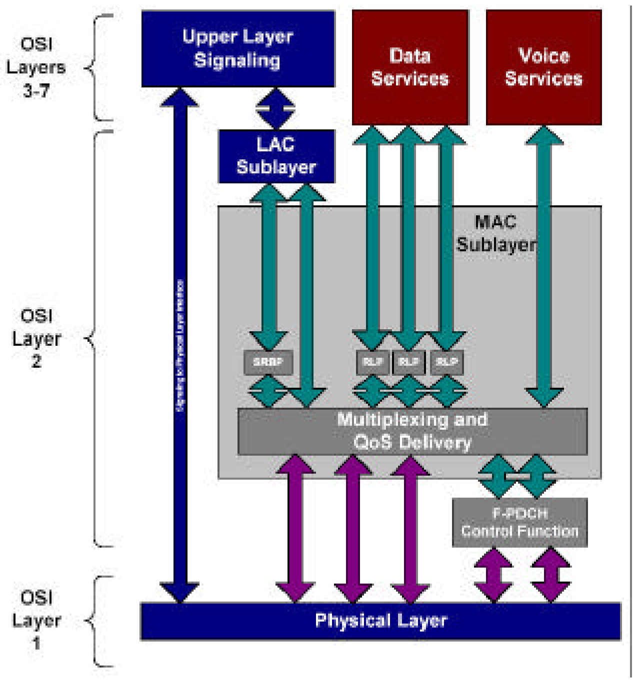


Figure 1: Cdma2000 protocol stack

Dedicated Auxiliary Pilot Channel (F-DAPICH) (optional): Used with antenna beam-forming and beam-steering techniques to increase the coverage or data rate towards a particular user.

B. Common Physical Channel (CPHCH):

Pilot Channel (F-PICH): Provide capabilities for soft handoff and coherent detection.

Common Auxiliary Pilot Channel (F-CAPICH): Provides capabilities for soft handoff and coherent detection.

Common Channel Type (F-CCHT):

- Paging Channel (F-PCH)
- Common Control Channel (CCCH)
- Sync Channel (F-SYNC)

Access Channel (R-ACH): Multiple access channel where mobiles station communicates message with the base station.

2.2 CDMA2000 Process Gain

One of the most important concepts required in order to understand spread spectrum techniques is the idea of process gain. The process gain of a system indicates the gain or signal to noise improvement exhibited by a spread spectrum system by the nature of the spreading and despreading process. The process gain of a system is equal to the ratio of the spread spectrum bandwidth used, to the original information bandwidth. Thus, the process gain can be written as:

$$Gp = \frac{BW_{RF}}{BW_{info}}$$

Where BW_{RF} is the transmitted bandwidth after the data is spread, and BW_{info} is the bandwidth of the information data being sent.

Figure 2 shows the process of a CDMA transmission. The data to be transmitted (a) is spread before transmission by modulating the data using a PN code. This broadens the spectrum as shown in (b). In this example the process gain is 125 as the spread spectrum bandwidth is 125 times greater the data bandwidth. Part (c) shows the received signal. This consists of the required signal, plus background noise, and any interference from other CDMA users or radio sources. The received signal is recovered by multiplying the signal by the original spreading code. This process causes the wanted received signal to be despread back to the original transmitted data. However, all other signals that are uncorrelated to the PN spreading code become more spread. The wanted signal in (d) is then filtered removing the wide spread interference and noise signals.

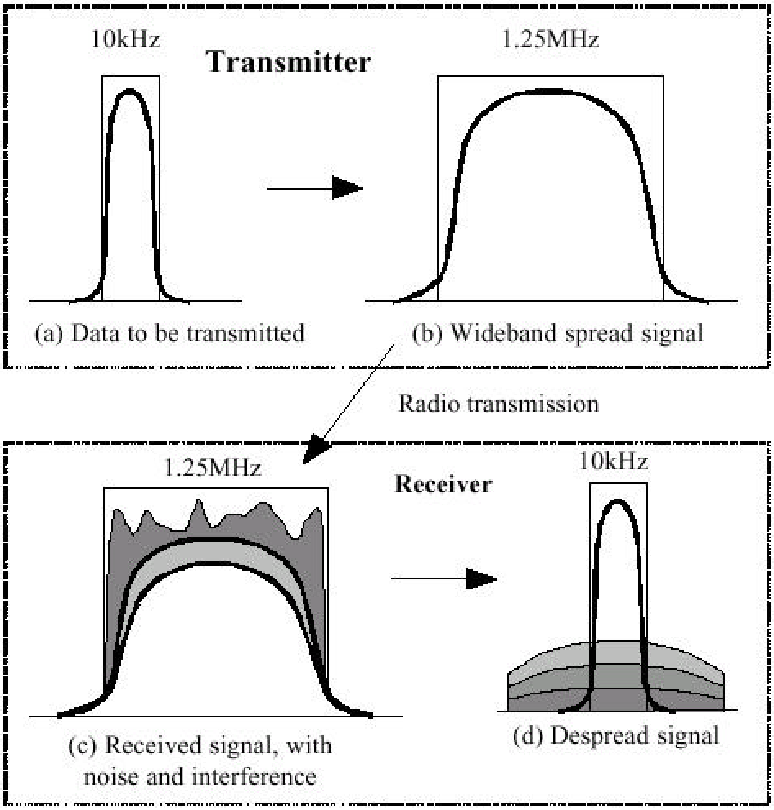


Figure 2 Basic CDMA transmission[7]

2.3 CDMA2000 Generation

CDMA is achieved by modulating the data signal by a pseudo random noise sequence (PN code), which has a chip rate higher then the bit rate of the data. The PN code sequence is a sequence of ones and zeros (called chips), which alternate in a random fashion. Modulating the data with this PN sequence generates the CDMA signal. The CDMA signal is generated by modulating the data by the PN sequence. The modulation is performed by multiplying the data (XOR operator for binary signals) with the PN sequence. Figure 3 shows a basic CDMA transmitter. The PN code used to spread the data can be of two main types. A short PN code (typically 10-128 chips in length) can be used to modulate each data bit. The short PN code is then repeated for every data bit allowing for quick and simple synchronization of the receiver. Figure 4 shows the generation of a CDMA signal using a 10-chip length short code. Alternatively a long PN code can be used. Long codes are generally thousands to millions of chips in length, thus are only repeated infrequently. Because of this they are useful for added security as they are more difficult to decode.

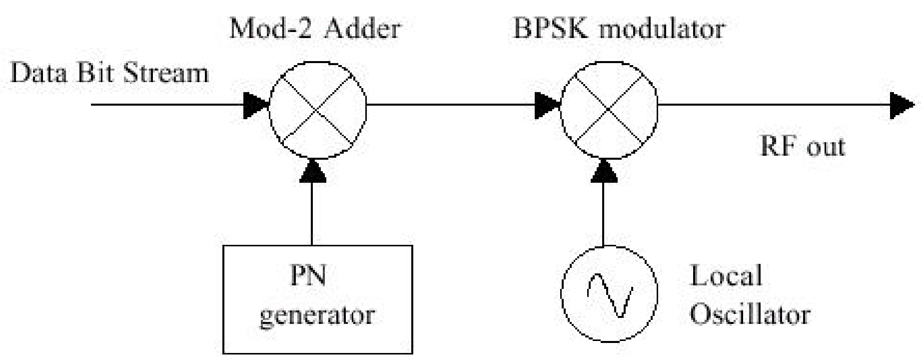


Figure 3 Simple direct sequence modulator

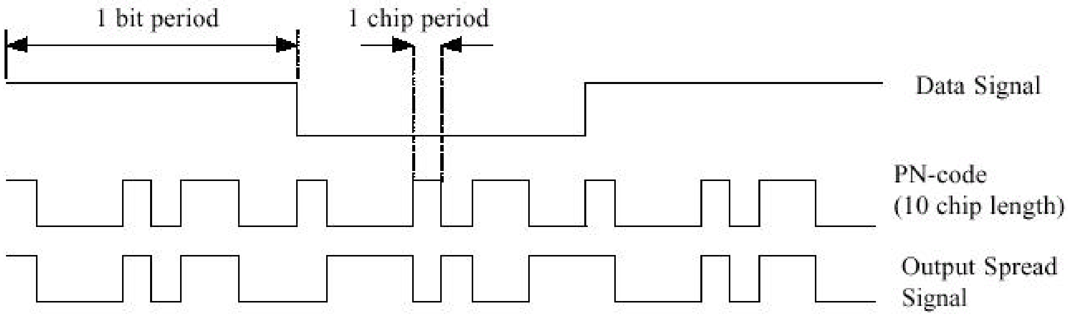


Figure 4 Direct sequence signals

2.4 Forward Link Characteristics

The individual physical channels are distinguished by means of orthogonal Walsh codes. Walsh codes is used to separate the multiple users on the same channel. Codes of different length are used to obtain different data rates from a constant chip rate for the actual information bits. Convolutional coders are used for conventional voice and data services, and turbo coders for the high data rates of the supplemental channels. If the number of Walsh codes is no longer sufficient because the orthogonal vector space is exhausted, channel separation can be continued with the aid of non-orthogonal functions. Quasi-orthogonal functions (QOFs) are created by masking existing Walsh codes. The frame lengths for signaling and user information vary between 5 ms, 20 ms, 40ms and 80 ms. Another specified possibility is that under certain conditions system capacity can be increased by splitting up the forward link signal to several transmit antennas (transmit diversity).

Walsh codes are based on a Walsh matrix, which is a square matrix with binary elements and dimensions that are a power of two. It is generated from the basis that Walsh(1) = W_1 = 0 and that:

$$W_{2n} = \begin{bmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{bmatrix}$$

Where W_n is the Walsh matrix of dimension n. For example:

$$W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

Walsh codes are orthogonal, which means that the dot product of any two rows is zero. This is due to the fact that for any two rows exactly half the number of bits match and half do not.

Each row of a Walsh matrix can be used as the PN code of a user in a CDMA2000 system. By doing this the signals from each user is orthogonal to every other user, resulting in no interference between the signals. However, in order for Walsh codes to work the transmitted chips from all users must be synchronized. If the Walsh code used by one user is shifted in time by more than about 1/10 of chip period, with respect to all the other Walsh codes, it looses its orthogonal nature resulting in inter-user interference. This is not a problem for the forward link as signals for all the users originate from the base station, ensuring that all the signal remain synchronized.

2.5 Reverse Link Characteristics

The reverse link is different to the forward link because the signals from each user do not originate from a same source as in the forward link. The transmission from each user will arrive at a different time, due to propagation delay, and synchronization errors. Due to the unavoidable timing errors between the users, there is little point in using Walsh codes as they will no longer be orthogonal. For this reason, simple pseudo random sequences are typically used. These sequences are chosen to have a low cross correlation to minimize interference between users.

Different channels can be used depending on the quality of service (QoS) and physical channel characteristics (Figure 5). On the reverse link, a continuous pilot simplifies synchronization to the base station. Traffic data is transmitted in an independent fundamental channel (FCH) and in supplemental channels (SCFs) with separate power and targets for frame error rate (FER). As on the forward link, convolutional coders are used for low-rate voice and data transmissions and turbo coders for the new, high data rates of the supplemental channels. A new feature is fast control of base station power by the mobile station (forward link power control). Nine different radio configurations (RCs) on the forward link and six on the reverse link determine the different connection modes defined by the IS 2000 standard:

RC1 and RC2 define cdmaOne connections for rate sets 1 and 2.

RC3 to RC5 on the forward link (RC3 and RC4 on the reverse link) define CDMA2000 connections for spreading rate 1 (CDMA2000 1X)

RC6 to RC9 on the forward link (RC5 and RC6 on the reverse link) are reserved for CDMA2000 connections for spreading rate 3 (CDMA2000 3X)

Service options define possible connection modes and their parameters, e. g. the different speech modes (depending on the voice coder used), SMS, fax and other data links, or especially test loopbacks. CDMA2000 operates worldwide in different frequency bands.

The capacity is different for the forward and the reverse links because of the differences in modulation. The reverse link is not orthogonal, resulting in significant inter-user interference. For this reason the reverse channel sets the capacity of the system.

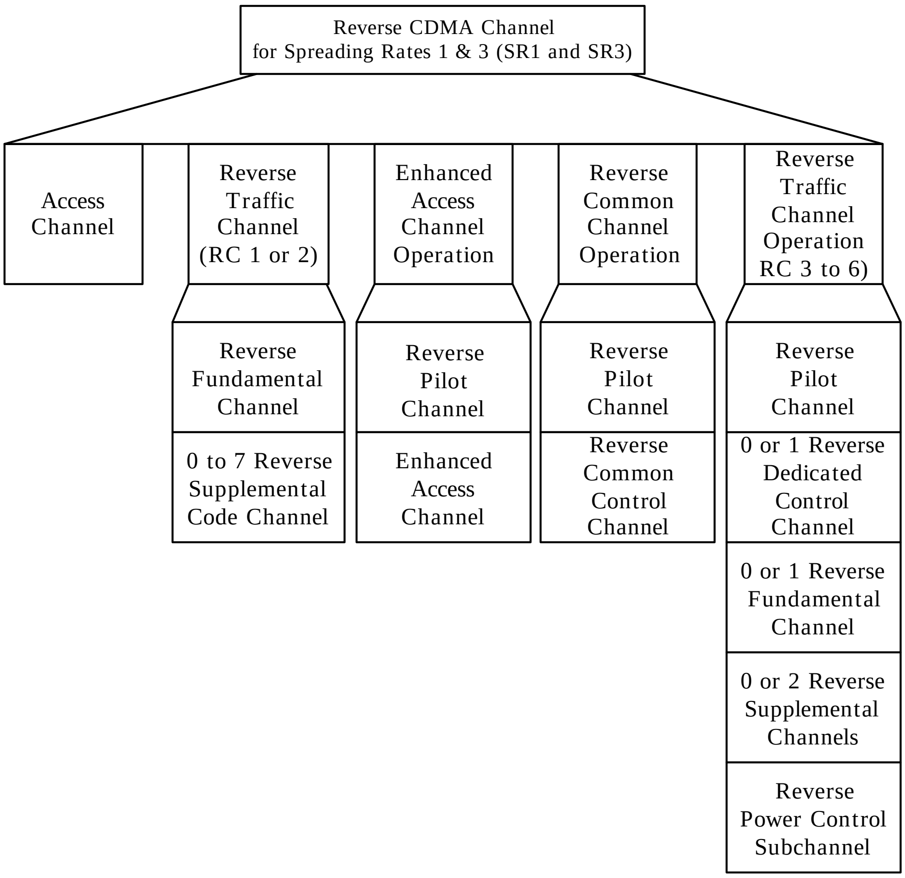
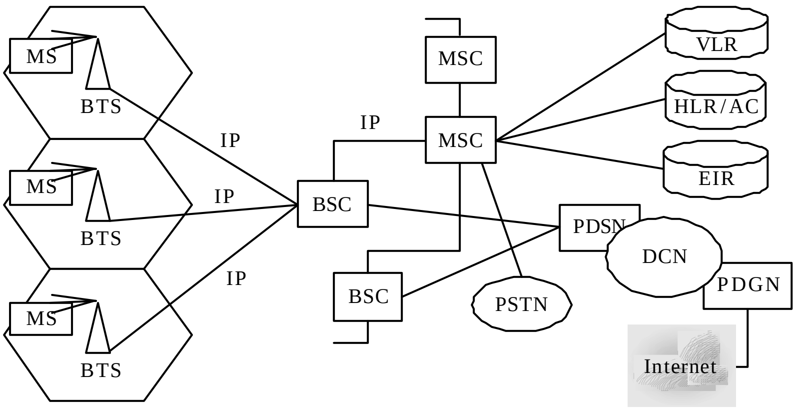


Figure 5: Depending on the operating mode, different physical channels are used on the reverse link of cdma2000[1]

3 CDMA2000 NETWORK ARCHITECTURE

Although the specific operations and components of a cellular telephone system depend on the specific technology employed (FDMA, TDMA, CDMA) the basic architecture of a cellular network is essentially common across standards (Figure 6 provides a basic network depiction)[5].



IP: The entire internal network becomes packet-based, an IP-based "core network" PDSN Packet Data Service Node
DCN: Core Network Backbone PDGN Packet Data Gateway Node

Figure 6: CDMA2000 (1xRTT) Network Architecture.

3.1 The Cell and BTS

Within the cell, the user communicates with the system via the Base Transceiver Station (BTS). Each cell has one BTS, a tower which contains radio transceivers and antenna, a processor, channel cards, and other equipment necessary for providing service in the cell. The capacity of a BTS/cell is determined by the number of available channels, cell sectorization, and caller demand (typically measured in Erlangs).

3.2 The Base Station Controller (BSC)

Each BTS is controlled by a base station controller (BSC); one BSC typically manages several BTSs. A BSC contains a high capacity packet data switch router, and provides crucial services required for controlling the BTSs, including managing call handoffs from one cell to the next and administering radio resource. The capacity of a BSC is limited by the number of transmission ports they have to communicate with the transceivers from the BTSs. BSCs are typically loaded at 80% of capacity. The BSC has a direct trunk link to the BTS, typically via a T-1 line. have a direct link to the core data network via the packet data switch node (PDSN). The core data network then links to the public data network (Internet) via a packet data gateway node (PDGN).

3.3 The Mobile Switching Center (MSC)

The mobile switching center (MSC) serves a similar role to the switch in a local phone central office (CO). The MSC switch (such as a 5eSS) provides connections to the PSTN as well as the data network via an internetworking function (IWF). It also must support all the functions required to manage the mobile user, including device registration, location updating, and call handoff (from one cell to another). Additional tasks of the MSC include call setup & supervision, routing, billing information collection, managing connections to BSCs and other MSCs. The MSC typically manages a number of BSC/BTS subsystems (typically via a T-1 connection), with its capacity measured by the number of Erlangs that its switch can handle.

3.4 The Operations Support System (OSS)

We have termed the Operations Support System (OSS) the subsystem of components and functionality that enables management of the mobile cellular system. Each of these components is described below.

3.4.1 The Home Location Register (HLR)/Authentication Center (AC)

The home location register (HLR) is a database of information on all subscribers (service restrictions and supplementary services, billing information, etc.) within the entire network, including a subscriber's current location. Typically, there is one HLR per cellular network, though it might be deployed in a decentralized manner. The authentication center (AC) is often directly associated with the HLR. The AC contains the key parameters used to ensure authenticity in initial location registration, location updates, and call setup.

3.4.2 The Visitor Location Register (VLR)

The visitor location register (VLR) is a temporary database that contains information about the mobile users who are currently in the service area controlled by the MSC/VLR. There is typically one VLR per MSC.

3.4.3 Equipment Identity Register (EIR)

The equipment identity register (EIR) is a database which maintains the information needed to validate mobile devices in order to identify and deny service to stolen or fraudulent devices.

4 SIMULATION

In this section an approach to simulate and evaluate channel capacity of cdma2000 for the reverse channel link will be described briefly, followed by a small example that I tried to simulate.

4.1 Capacity Simulation by Lin & Zhigang

Lin and Zhigang [7] carried out a capacity simulation for cdma2000. Their approach is to provide the performance information to include two major steps, the link level simulation and the system level simulation. In the first step the link level simulation is performed to determine the energy requirement to achieve a performance criterion. In the link level simulation, the single radio link performance is evaluated. The radio link consists of channel coding, interleaving, modulation, spreading, pulse shaping, multipath propagation, additive noise or interference, receiver filtering, demodulation, and decoding, etc. The output of the link level simulation is represented in the form of Frame/Bit Error Rate (FER/BER) vs. Signal to Interference Ratio (SIR) or required energy vs. geometry to achieve a target FER/BER.

After the link level simulation, the system level simulation is performed to determine the system capacity by using the link level simulation output as a lookup table. In the system level simulation, a number of cells are generated in the network, and mobile users are uniformly distributed within the cells. For each user, the received SIR value is measured. An outage occurs when the average SIR is less than the one required to achieve the target FER/BER, or the user gets blocked when arriving at the system. Capacity is then derived from the amount of traffic load at the maximum allowed outage level.

4.1.1 Traffic Modeling and Packet Scheduling

In the system level simulation, packet traffic models are implemented and packet scheduling schemes are applied to control the traffic. A simplified model emulating the web browsing traffic is used in the simulation, where Poisson arrivals of packets with exponential packet lengths (calls) are simulated. The mean packet length in the forward link is 12 kB and 2250 bytes in the reverse link. These numbers are derived from aggregate web traffic behavior typically observed over the Internet.

In the simulation, the newly arrived packets are put in a queue. The users from the queue are admitted one by one through a packet scheduling scheme. The packet scheduling scheme is used by the network in making rate assignment and QoS decisions. The packet scheduling schemes in either the forward link or the reverse link is handled by examining the power and interference constraints and through the use of interference measurements gathered from the distributed mobiles and neighbor base stations.

In the reverse link, the packet scheduling scheme employs the interference power budget technique. It always requires the base station to estimate that after granting a specific data rate to the requesting packet data user, the interference levels at own cell and neighboring cells are below the budget level. Thus the qualities of the existing users can still be satisfied.

4.1.2 Simulation Parameters

The simulation parameters used in their simulations are listed in Table 5. The reverse link specific parameters are listed in Table 6.

Parameters	Value	Comments
Chip rate	1.2288	Mcps
Carrier frequency	2000	MHz
Power control frequency	800	Hz
Power control step size	0.5	Db
Power control delay	1	PCG
Power control BER	4	%
Log-nor mal Shadowing Std	10	Db
Site-to-site correlation	0.5	
Maximum Active Set size	2	
Soft handoff threshold Antenna Pattern	3 db Omni-direction	e.g, secondary pilot must be within 3 db of the strongest pilot
Maximum data rate	76.8	Kbps
Target physical layer FER	10	%
Maximum number of retransmission	3	
Maximum outage	5	%
Number of cells	19	

Table 5. Simulation Parameters

Parameters	Value	Comments
MS Maximum transmission power	24	dBm
Coding scheme	Convolutional Turbo	
Coding rate	¼	
Channel model	ITU Vehicular ITU Pedestrian 1 path Rayleigh	
Mobile speed	120 km/h	ITU Vehicular

	3 km/h 30 km/h	ITU Pedestrian 1 path Rayleigh

Table 6 Reverse Link specific Parameters

4.1.3 Results

The link level performance for data rate of 76.8 kbps in vehicular B and Pedestrian B channels with convolutional code are illustrated in Figure 3. The system simulation results are presented in Table 7.

The performance for 1 path Rayleigh fading channel with mobile speed of 30 km/h and Turbo code are also evaluated. The link and system results are shown in Figure 7 and Table 8, respectively.

The packet scheduling scheme is applied to control the packet traffic in order to maximize the system throughput. The results show that the rate ¼ code always performs better than rate ½ code and the Turbo code can achieve better spectrum efficiency than convolutional code

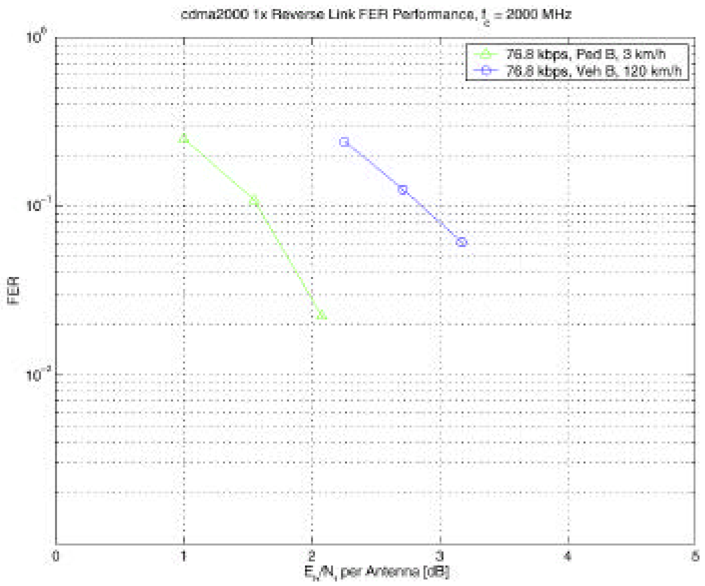


Figure 7. Link Level Performance of Vehicular B and Pedestrian B Channel, Reverse Link, CC

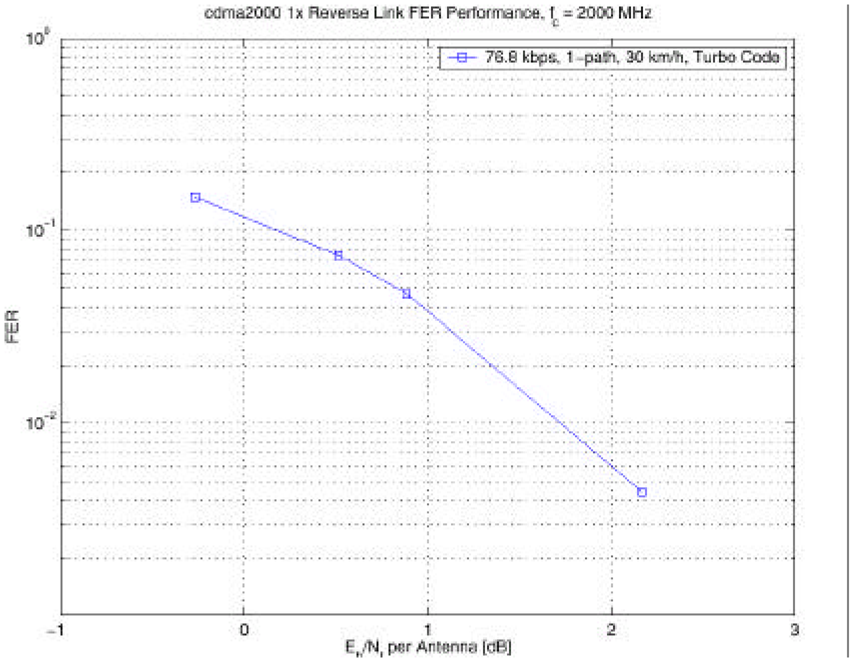


Figure 8. Link Level Performance of 1 Path Rayleigh Fading, 30 km/h, Reverse Link, TC

Environment	Throughput (kbps/MHz/cell)	Mean delay (s)
Vehicular B	133.8	0.25
Pedestrian B	134.2	0.24

Table 7. Reverse Link System Simulation Results, Convolutional Code

Environment	Throughput (kbps/MHz/cell)	Mean delay (s)
1 path Rayleigh Fading, 30 km/h, Turbo code	217.7	0.25

Table 8. Reverse Link System Simulation Results, Turbo Code

4.2 Simulation Model for the Reverse Channel

The reverse CDMA2000 Channels are made up of access channels and reverse traffic channels. Both share the same frequency assignment, and each Traffic/Access channel is identified by a distinct user long code. The reverse channel modulation process for single user is described in Figure 9.

The information bits are 172 bits for 9600 bps. The CRC will be calculated on information bits within the frame, except the CRC itself and the encoder tail bits. The generator polynomial for 9600 bps is given as $g(x) = 1 + x + x^4 + x^8 + x^9 + x^{10} + x^{11} + x^{12}$. CRC will add 8 bits to the end of each frame. 8 bit Encoder Tail add 8 zero bits to the end of each frame to set the convolutional encoder back to zero state.

In reverse channel, (3, 1, 8) Convolutional Encoder is used (R=1/3, K=9). The generator sequences for this encoder are g_0=(10110111), g_1=(1100110011), g_2=(111001001). The initial state of the convolutional encoder is assumed to be all zeros.

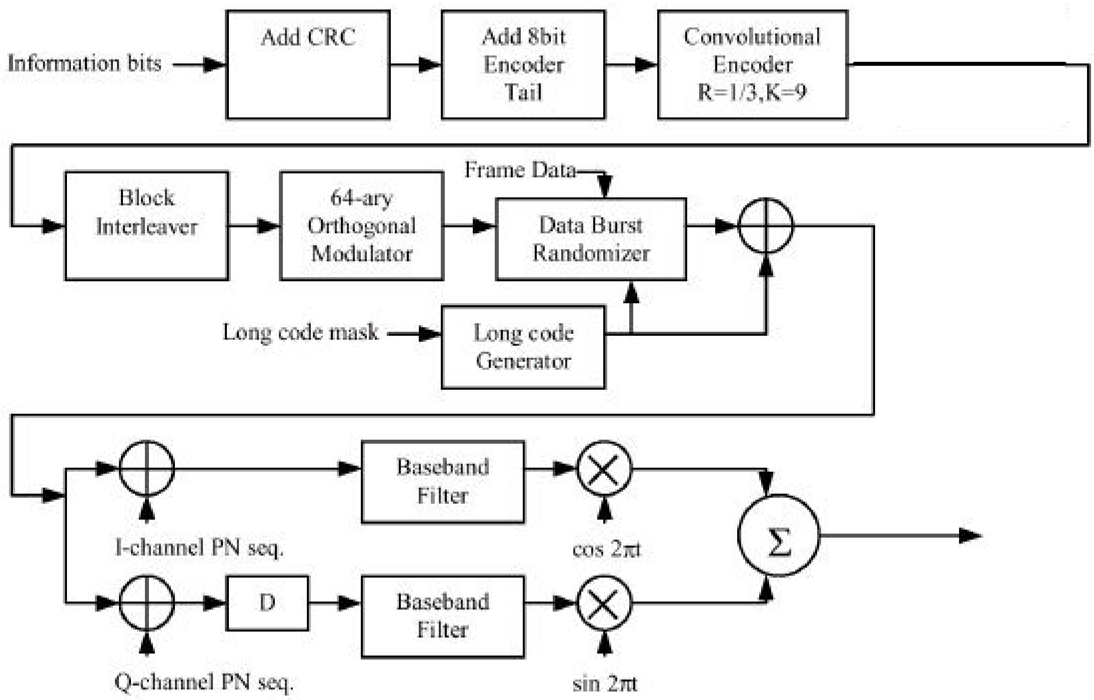


Figure 9: Reverse channel structure [3)]

The Block interleaver spanning 20 ms interleaves all code symbols on the reverse channel prior to orthogonal modulation. The interleaver forms a 576-cell array with 32 rows and 18 columns. Code symbols will be output from the interleaver by rows.

Modulation for reverse channel is 64-ary orthogonal modulation. One of 64 possible modulation symbols generated by Walsh functions is transmitted for each six symbols. Modulation symbols are selected according to the modulation symbol index (MSI). MSI = $c_0 + 2c_1 + 4c_2 + 8c_3 + 16c_4 + 32c_5$ where each c_i represents the binary valued code symbol.

The Data Burst Randomizer ensures that every code symbol input to the repetition process is transmitted exactly once. Long code generator generates long code to perform direct sequence spreading

(DSS). In reverse channel, spreading operation involves modulo-2 addition of the data burst randomizer output stream and the long code. The long code is periodic with period 2^{42}-1 chips. Long code generator polynomial is $P(x) = 1 + x + x^2 + x^3 + x^5 + x^6 + x^7 + x^{10} + x^{16} + x^{17} + x^{18} + x^{19} + x^{21} + x^{22} + x^{25} + x^{26} + x^{27} + x^{31} + x^{33} + x^{35} + x^{42}$. Each PN chip of the long code is generated by the modulo-2 sum of the results through the AND gates inputting a 42-bit mask with the 42-stage LFSR of the sequence generator. The long code provides limited privacy. The long code mask varies depending on the channel type on which the mobile station is transmitting. The long code mask consists of a 42-bit binary sequence that creates the unique identity of the long code. There are two types of long code mask such as public long code mask and private long code mask.

Direct sequence spreading is done by EX-ORing the orthogonal modulation symbols and the long code PN chips (PN chips/Walsh chip is 4).

After the direct sequence spreading, the reverse channel is subject to spread the stream in quadrature. The I and Q pilot PN sequences are generated based on the each generating polynomial ($P_I(x) = 1 + x^5 + x^7 + x^8 + x^9 + x^{13} + x^{15}$, $P_Q(x) = 1 + x^3 + x^4 + x^5 + x^6 + x^{10} + x^{11} + x^{12} + x^{15}$). Then the Q-data stream obtained after spreading delayed by half a chip time.

4.2.1 Results

Table 9 shows the simulation results of the reverse channel model.

Trial Number	Interference (number of users)					
	10	20	30	35	40	45

1	0	0	3	6	9	24
2	0	0	0	3	12	27
3	0	0	0	6	9	21
4	0	3	3	9	14	21
5	0	0	0	3	12	24
6	0	0	0	3	11	21
7	0	0	0	3	15	30
8	0	0	3	6	9	24
9	0	0	3	6	12	27
10	0	0	3	4	12	19
Total error	0	3	15	49	115	238
Average		0.3	1.5	4.9	11.5	23.8
% of error per frame (184 bits)	0	0.16	0.82	2.7	6.25	12.9

Table 9. Results of Reverse traffic channel simulation

The percentage of error is calculated from dividing average error by 184 bit of one user frame length (184 = 192 – 8 encoder tail).

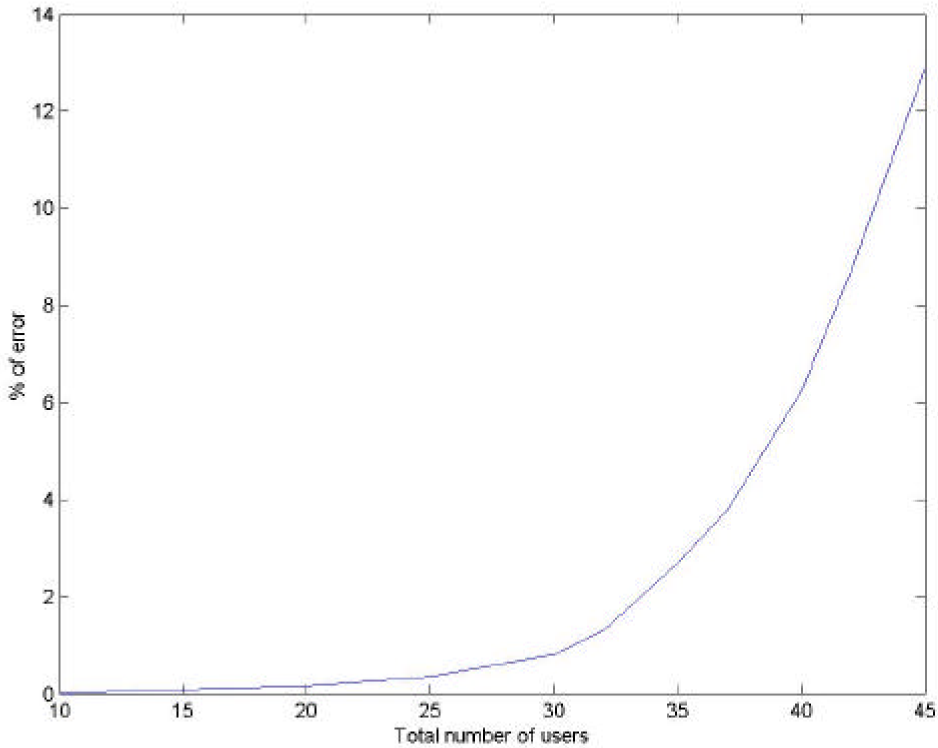


Figure 10: The % of error in one frame vs. Total number of user

The percentage of error in one frame of one particular user is increased exponentially as the total number of user is in increased. The simulation shows great results less than 20 users. The increasing percentage of error will cause a limitation of total number of users.

4.3 Mathematical Model for Reverse Link

The capacity of a CDMA system is limited by the reverse link. The reverse link uses uncorrelated, non-orthogonal PN codes, which makes it limited by interference from other users. Each other user appears as noise as additional noise to the cell. If we initially assume a single cell then the noise in the system will be determined by the number of users in the cell. If we let the number of users be N, and the transmitted 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: $SNR = \frac{S}{(N-1)S} = \frac{1}{N-1}$

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. The process gain is the ratio of the total bandwidth (W) to the base band information bit rate (R). Thus the received energy per bit to noise ratio (Eb/No) is $\frac{E_b}{N_o} = \frac{W}{R(N-1)}$

The above equation does not take into account thermal noise. The thermal noise simply increased the effective amount of noise. Let the thermal noise be $\boldsymbol{n}$. Thus, the Eb/No becomes $\frac{E_b}{N_o} = \frac{W}{R(N-1) + n/S}$

In order to achieve an increased capacity, the interference from users needs to be reduced. This can be achieved by monitoring the voice activity so that the transmitter is switched off during periods of no voice activity. This reduces the effective interference level by the reduced duty cycle of the transmitted signal. Using antenna sectorization can also reduce the interference. If for example the cell was sub divided using three antennas, each having a beam width of 120°, then the interference seen by each antenna is one third that of an omni-direction antenna. If we let $\boldsymbol{d}$ be the duty cycle of the voice activity, and $\boldsymbol{G}$ be the cell sectorization then equation becomes

$$\frac{E_b}{N_o} = \frac{W}{R\left[(N-1)\frac{d}{G} + n/S\right]}$$

Thus the capacity of a single cell CDMA system would be

$$N = \frac{G}{d}\left[\frac{N_o}{E_b}\frac{W}{R} - \frac{n}{S}\right] + 1 \qquad \text{Eq.(2)}$$

Where:

G is the antenna sectorization,

d is the voice duty cycle,

Eb/No is the energy per bit to noise ratio,

W is the total transmission bandwidth,

R is the base band bit rate,

n/S is the ratio of received thermal noise to user signal power.

4.3.1 Example to calculate a capacity of a single CDMA cell

The cell capacity of a CDMA2000 system is dependent on the bandwidth used the process gain and the allowable error rate. For this discussion we will consider a system with a bandwidth of 1.25MHz. If we use a process gain of 64, this will give each user a data rate capacity of 19.5kbps. Since the capacity of a CDMA2000 system is dependent on the noise tolerance of data if we assume an Eb/No of 8dB this will give a BER of ~0.006 which is acceptable for voice communications. For a the CDMA2000 link that has no voice detection activity and no cell sectorization then cell capacity can be calculated using Equation 2 as follows:

G = 1, **d** = 1, **Eb/No** = 8dB = 6.31, **W** = 1.25MHz, **R** = 19.5kHz and **n/S** = 0 (Assume no thermal noise) From Equation 2

$$N = 1\left[\frac{1.25 \times 10^6 / 19530}{6.31}\right] + 1 = 10.1 + 1 = 11.1$$

This gives a spectral efficiency of only: $= \frac{11.1/19530}{1.25 \times 10^6} = 0.173 bits/Hz$

The efficiency of CDMA can be improved by using voice detection to reduce the duty cycle of each user, and by using cell sectorization. Note however, that voice activity detection can only be used for voice communications and not for general data transfer. Thus all it is effectively doing is reducing the data throughput allowed for each user.

Appling both voice duty cycle detection and cell sectorization the effective capacity is increased. If we assume that the cell is split three ways then the ideal cell sectorization factor will be 3. However, side-lobes of the antennas used will always reduce this, there reducing the factor to about 2.55. Using **G** = 2.55, **d** = 0.4 (i.e. 40%) the cell capacity becomes: $N = \frac{2.55}{0.4}\left[\frac{1.25 \times 10^6 / 19530}{6.31}\right] + 1 = 65.7$

The spectral efficiency is thus: $= \frac{65.7/19530}{1.25 \times 10^6} = 1.026 bits/Hz$ 1.02/0.173 $\approx$6 times increase in the efficiency.

Table 10 shows how the over capacity of the CDMA system changes depending on what BER is allowed.

Eb/No (db)	Expected bit error rate (BER)	Max No. users (no voice detection, no cell sectorization)	Spectral efficiency (bits/hz)	Max No. users (voice detection, cell sectorization	Spectral efficiency (bits/hz)
6	0.023007	17.1	0.267	103.6	1.62
8	0.006004	11.1	0.173	65.7	1.03
10	0.000783	7.4	0.116	41.8	0.65
12	3.43E-05	5.0	0.078	26.5	0.41

Table 10 Predicted cell capacity with process gain of 64, depending on the tolerable Eb/No

5 CONCLUSION

In this paper a brief description about cdma2000 and other technologies, like, W-cdma have been given. Also, aspects of cdma2000 have been exposed. These include: protocol stack of cdma2000, channel characteristics for both forward and reverse links. Simulation example of channel capacity of the reverse was discussed and results have been stated. A small case has been implemented and discussed. The paper is ended with a mathematical model of reverse channel capacity.

The area of cdma2000 is attractive especially in how to increase the channel capacity of the system. Approaches, like using adaptive antenna, using adaptive arrays in smart antenna and using Polarization and Spatial Diversity can increase the channel capacity, which one can try to do a research on them.

6 REFERENCES

[1] CDMA2000 – a new challenge for 3G mobile radio testers News from Rohde & Schwarz Number 173 (2002/I)

[2] "IMT-2000: Standards Efforts of the ITU", *IEEE Personal Communications*, vol. 4, No 4, August, 1997.

3] Black Peter J., et. al., "Capacity Simulation of cdma2000 1xEV Wireless Internet Access System." IEEE Mobile Wireless Communications Networks 2001 August, 2001.

[4] E. Dahlman, B. Gudmumdson, M. Nilsson, and J. Skold, "UMTS/IMT-2000 Based on Wideband CDMA," IEEE Communications Magazine, September 1998.

[5] Jonathan Liew et al "3G WIRELESS IN THE US: CDMAONE TO CDMA2000" May 8, 2000

[6] Rappaport, T., *Wireless Communications: Principles and Practic*e, Prentice Hall, 1996.

[7] Lin Ma and Zhigang Rong Capacity Simulations and Analysis for cdma2000 Packet Data Services" Nokia Research Center

[8] "Wireless Access Frequently Asked Questions," http://www.telecomresearch.com/wirelessfaq.html.

[9] CDMA Development Group White Paper, "Third Generation Systems," http://www.cdg.org/3Gpavillion/Detailed_Info/3Gwhitepaper1.html, November 1998.