OPTIMIZATION OF CDMA NETWORKS FOR CAPACITY ENHANCEMENT IN MOBILE CELLULAR COMMUNICATIONS.

By

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This is to certify that the thesis titled **"Optimization of CDMA Networks for Capacity Enhancement in Mobile Cellular Communications"** is the result of my study for partial fulfillment of the requirement for the degree of Masters of Science under the supervision of Dr. A. B. M. Siddique Hossain, Professor, dept of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, and it has not been submitted elsewhere for award of any other degree or diploma.

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Nomenclature

I_{TOT}	Total interference
I_{own}	Interference from subscribers in the local cell
I_{other}	Interference from subscribers from the neighboring cells
P_N	Background noise of receiver
I_{ext}	External interference
K	Boltzmann constant
T	Kelvin temperature
W	Signal bandwidth
NF	Noise figure of receiver
P_j	Power received by jth user
$(Eb/N_t)_j$	Demodulation threshold for the jth user
$\frac{W}{R_j}$	Processing gain for the jth user.
v_j	Voice activity factor
f	Interference factor
n_{ul}	Uplink load factor
B_{cdma}	Soft Blocking probability
W/R	Processing gain
$\overline{\alpha}$、$\overline{\alpha^2}$	1st and 2nd order voice activity factor
ε、ε'	1st and 2nd order Interference factor
α	Demodulation threshold standard deviation (power control variance)
ρ	Mean demodulation value
X_0	Blocking load of system

$\overline{M}$	Erl of the cell.
P_{total}	Transmit power of BTS
P_{pil}	Power of synchronous channel
P_{pag}	Power of paging channel
P_{traf}	Power of traffic channel
N_p	Number of paging channels
K_{traf}	Coefficient of subscriber distribution
M	Activated subscribers of system
Kf	Coefficient of system interference
ρ_{pil}	Demodulation threshold of pilot channel
ρ_{sync}	Demodulation threshold of synchronous channel
ρ_{pag}	Demodulation threshold of paging channel
ρ_{traf}	Demodulation threshold of traffic channel
G_{pil}	Spreading gain of pilot channel
G_{sync}	Spreading gain of synchronous channel
G_{pag}	Spreading gain of paging channel
Gtraf	Spreading gain of traffic channel
Ts	Capacity of a site without sector to sector interference
T_b	Capacity of a BTS considering sector to sector interference
m	Sectorization gain
N	No of carriers
T_{3S1}	Capacity of a 3 sector single carrier BTS
T_{3S2}	Capacity of a 3 sector dual carrier BTS
T_{6S1}	Capacity of a 6 sector single carrier BTS
Ec/Io	Ratio of pilot channel energy per chip to interference spectral density

List of Abbreviations

1G	First Generation Wireless technology
2G	Second Generation Wireless technology
3G	Third Generation Wireless technology
3GPP	Third Generation Partnership Project
8-PSK	Eight-phase shift keying
ACTS	Advanced Communication Technologies and Services
ADSL	Asymmetric Digital Subscriber Line
AMPS	Advanced Mobile Phone Service
ARIB	Association of Radio Industries and Businesses
BSC	Base station controller
BTS	Base Transmitter Station
C/I	Carrier-to-interference ratio
CATT	China Academy of Telecommunications Technology
CDMA	Code division multiple access
CTS	Cordless Telephone System
CWTS	China Wireless Telecommunications Standard
D-AMPS	Digital Advanced Mobile Phone Service
DAB	Digital audio broadcasting
DCS-1800	Digital Cellular System 1800
DECT	Digital Enhanced Cordless Telecommunications
DS	Direct Spread
DS-SS	Direct-sequence spread spectrum
DTC	Digital traffic channel
DVB	Digital video broadcasting
EDGE	Enhanced Data Rates for Global Evolution
EHDM	Extended handoff direction message
ETSI	European Telecommunications Standards Institute

EVDO	Evolved Data Optimized
FDD	Frequency division duplex
FDMA	Frequency-division multiple access
FER	Frame Error rate
FH-SS	Frequency-hopping spread spectrum
FSK	Frequency shift keying
FT	Frequency Time
GHDM	Global handoff direction message
GMSK	Gaussian minimum shift keying
GPS	Global Positioning System
GPRS	General Packet Radio Services
GSM	Global System for Mobile communications
HCR	High chip rate
HDR	High Data Rate
HHO	Hard handoff
HSCSD	High-speed circuit-switched data
IS-95	Interim Standard 95
ISI	Intersymbol interference
ITU	International Telecommunication Union
JDC	Japanese Digital Cellular
MAC	Medium access control
MAP	Mobile Application Part
MC	Multicarrier
MS	Mobile station
NMT	Nordic Mobile Telephone
OFDM	Orthogonal frequency division multiplexing
OHG	Operators' Harmonization Group
PDC	Personal digital cellular
PHS	Personal Handyphone System
PN	Pseudo Noise

RACE	Research on Advanced Communication Technologies in Europe
RLC	Radio link control
RR	Radio resources
SC	Single Carrier
SDMA	Space-division multiple access
SF	Spreading factor
SHO	Soft handoff
SMG	Special Mobile Group
TACS	Total Access Communications System
TC	Time code
TDD	Time division duplex
TDMA	Time division multiple access
TD-SCDMA	Time-division synchronous CDMA
TH-SS	Time-hopping spread spectrum
TSM	System for Mobile Communication
TTA	Telecommunication Technology Association
TTC	Telecommunication Technology Committee
UHDM	Universal handoff direction message
UMTS	Universal Mobile Telecommunications System
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
WAP	Wireless Application Protocol
WCDMA	Wideband Code division multiple access

ABSTRACT

Code division multiple access (CDMA) has become a main stream technology in future mobile cellular systems. This is due to its attractive features, such as universal frequency reuse, soft handoff, fast power control, and thus providing high and soft capacity [1]. The second generation (2G) CDMA IS-95A has evolved to third generation (3G) CDMA20001x and Evolution Data Optimized (EV-DO). CDMA 20001x provides twice the voice capacity gain of IS-95A, while the highest data rate achieved by CDMA 2000 EV-DO is 2.4Mb/s [2],[13]. W-CDMA (Wideband CDMA) bas been adopted by the European Telecommunications Standards Institute (ETSI) for frequency-division duplex (FDD) bands in January 1998 [2-4]. WCDMA systems support multiple services with different data rates and different quality requirements, and are compatible with second generation GSM system. Although cellular technology continues to advance itself, the fundamental bottleneck –shortage of frequency spectrum -remains the same.

In Bangladesh, the major part of spectrum resource is occupied by 5 GSM operators of which 25 MHz under 900 and 38 MHz under 1800 band. Only one CDMA mobile operator consume 7.5 MHz and part of the rest are allocated for CDMA WLL services where they can occupy only 1/2 carriers. Still the bandwidth is not enough for any. The GSM operators need to integrate UMTS/WCDMA network to provide high speed data service. Hence, even if only one carrier (5 MHz) is allocated per GSM operator for WCDMA services, it will occupy 25 MHz in total. Again for the CDMA operator, need one additional carrier for EVDO services. Under such circumstance, it has become very challenging for all the operators to reach millions of subscriber with such a limited bandwidth. Larger capacity per cell per frequency has been the most crucial demand for all the cellular service providers worldwide.

The objective of the thesis is to provide alternatives to enhance system capacity in times using same spectrum resource and with minimum investment cost. For this, 6 sector configuration BTS is proposed to deploy rather than conventional 3 sector and interference cancellation technique is implemented on the MSs to maximize the system capacity both forward and reverse link. Soft handoff thresholds are also proposed to optimize since MSs with interference cancellation capability may have a wider soft handoff region than that of regular MSs [13].Though soft handoff always combats interference, it introduces overhead limitation on the forward link. Intelligent admission control algorithm should be implemented as well so that MSs that are interference capable have a better chance of being admitted and hence occupy less resource than a regular MS thereby increasing network capacity.

CHAPTER 1

Introduction

1.1 Background and Previous work

Code division multiple access (CDMA) has received a great deal of attention as one of the most promising access techniques for the third-generation mobile and personal communication systems [1]. This is due to its attractive features, such as universal frequency reuse, soft handoff, anti-multipath fading, macro diversity, thus providing high and soft capacity. The second generation (2G) CDMA IS-95A cellular network has been deployed for almost ten years. The IS-95A has evolved to third generation (3G) CDMA20001x and Evolution Data Optimized (EV-DO) [2]. CDMA 20001x provides twice the voice capacity gain of IS-95A, while the highest data rate achieved by CDMA 2000 EV-DO is 2.4Mb/s [2],[13]. W-CDMA (Wideband CDMA) bas been adopted by the European Telecommunications Standards Institute (ETSI) for frequency-division duplex (FDD) bands in January 1998 [2-4]. WCDMA systems support multiple services with different data rates and different quality requirements, and are compatible with second generation GSM system. Therefore, CDMA technology has become a main stream technology in future mobile cellular systems. Although cellular technology continues to advance itself, the fundamental bottleneck –shortage of frequency spectrum- remains the same.

1.2 Motivation and Objectives

In Bangladesh, under 800-900MHz band, two GSM and one CDMA mobile operator consume 7.5MHz each. Another two GSM operators occupy 5 MHz each. The rest is distributed among the CDMA WLL operators where they can occupy only 1.23-2.46

MHz (maximum 1/2 carrier). Under 1800-1900 MHz band 13 MHz is occupied by one GSM operator and part of the rest is reserved for WLL services.

The GSM operators are currently using GPRS and EDGE technologies to provide data service but their performance is not enough to satisfy current market demand of higher speed and multiple services. So the GSM operators need to integrate 3rd generation technologies like UMTS/WCDMA for which they require at least 5 MHz each. Hence, even if only one carrier is allocated per GSM operator for WCDMA services, it will occupy 25 MHz in total. Under such circumstance, it will become very difficult for the GSM operator to provide 3G services to a massive level.

Again for the CDMA operators, one carrier has to be reserved if they want to deploy EVDO service and hence only one carrier is dedicated for voice and data. Hence more and more sites need to be added to reach millions of subscribers. But in that case, network deployment cost will become too high and network quality will degrade abruptly.

Scarcity of spectrum resource has been the major limitation in telecommunication sector worldwide. So the most crucial demand now for all the cellular service providers is to find out some solutions to ensure higher capacity within same spectrum resource. The technology has to be simple enough to be quickly and easily integrated to existing system and requires minimum deployment cost as well. The objective of the thesis is to provide alternatives to enhance system capacity in times using same spectrum resource and with minimum investment cost.

1.3 Summary and Contributions

So far all the capacity analysis of CDMA system is done in the cell level. But we know sectorization provides increment of capacity in times based on the no of sectors. So if we can increase the no of sectors instead of increasing the carrier, we can increase the capacity to almost same level. But this requires narrow beam pattern antenna rather than conventional 65° beam pattern antenna to limit sectorization interference. 33° narrow beam pattern antenna and cell split cross polarized antennas are now commercially available which can be used for this purpose. Moreover, three other key issues closely related to capacity improvement, handoff, power control and interference cancellation are also studied in details in this thesis. The thesis represents the performance report of several techniques to improve network capacity within same spectrum resource.

In chapter 1, a review of the related research on the capacity of CDMA systems is provided, and the motivation and objectives of this thesis are also described. Chapter 2 briefly reviews all the access techniques introduced in telecom system so far. Chapter 3 focuses on fundamental techniques of CDMA system and their contribution to network quality and capacity. Chapter 4 describes capacity analysis for both forward and reverse link. In chapter 5, all the performance report of different techniques of capacity improvement is given from simulation analysis. Finally chapter 6 highlights the achievements of this thesis work and some suggestions for future work.

CHAPTER 2

Overview on Wireless communication

2.1 History of Mobile Cellular Systems

2.1.1 First Generation

The first generation of mobile cellular telecommunications systems appeared in the 1980s. The first generation was not the beginning of mobile communications, as there were several mobile radio networks in existence before then, but they were not cellular systems either. The capacity of these early networks was much lower than that of cellular networks, and the support for mobility was weaker [3].

In mobile cellular networks the coverage area is divided into small cells, and thus the same frequencies can be used several times in the network without disruptive interference. This increases the system capacity. The first generation used analog transmission techniques, for traffic, which was almost entirely voice. There was no dominant standard but several competing ones [20].

The most successful standards were *Nordic Mobile Telephone* (NMT), *Total Access Communications System* (TACS), and *Advanced Mobile Phone Service* (AMPS). Other standards were often developed and used only in one country, such as C-Netz in West Germany and Radiocomm 2000 in France. NMT was initially used in Scandinavia and adopted in some countries in central and southern Europe. It comes in two variations: NMT-450 and NMT-900. NMT-450 was the older system, using the 450-MHz frequency band. NMT-900 was launched later and it used the 900-MHz band. NMT offered the possibility of international roaming. Even as late as the latter half of the 1990s, NMT-450 networks were launched in several Eastern European countries. TACS is a U.K. standard and was adopted by some Middle Eastern countries and southern Europe. It is actually based on the AMPS protocol, but it uses the 900-MHz band. AMPS is a U.S. standard that uses the 800-MHz radio band. In addition to North America, it is used in some countries in South America and the Far East, including Australia and New Zealand. NTT's MCS was the first commercial cellular network in Japan. Note that although the world is now busy moving into 3G networks, these first-generation networks are still in use. Some countries are even launching new first-generation networks, and many existing networks are growing. However, in countries with more advanced telecommunications infrastructures, these first-generation systems will soon be, or already have been, closed, as they waste valuable frequency spectrum that could be used in a more effective way for newer digital networks (e.g., the NMT-900 networks were closed at the end of 2000 in Finland) [21].

2.1.2 Second Generation

The *second-generation* (2G) mobile cellular systems use digital radio transmission for traffic. Thus, the boundary line between first- and second generation systems is obvious: It is the analog/digital split. The 2G networks have much higher capacity than the first-generation systems. One frequency channel is simultaneously divided among several users (either by code or time division). Hierarchical cell structures—in which the service area is covered by macrocells, microcells, and picocells—enhance the system capacity even further.

There are four main standards for 2G systems: *Global System for Mobile* (GSM) communications and its derivatives; *digital AMPS* (D-AMPS); *codedivision multiple access* (CDMA) IS-95; and *personal digital cellular* (PDC). GSM is by far the most successful and widely used 2G system. Originally designed as a pan-European standard, it was quickly adopted all over the world. Only in the Americas has GSM not reached a dominant position yet. In North America, Personal Communication System-1900 (PCS-1900; a GSM derivative, also called GSM-1900) has gained some ground, and in South

America, Chile has a wide-coverage GSM system. However, in 2001 the North American *time-division multiple access* (TDMA) community decided to adopt the *Third Generation Partnership Project* (3GPP)-defined *wideband CDMA* (WCDMA) system as its 3G technology, and as an intermediate solution in preparation for WCDMA many IS-136 systems did convert to GSM/GPRS.

The basic GSM uses the 900-MHz band, but there are also several derivatives, of which the two most important are Digital Cellular System 1800 (DCS-1800; also known as GSM-1800) and PCS-1900 (or GSM-1900). The latter is used only in North America and Chile, and DCS-1800 is seen in other areas of the world. The prime reason for the new frequency band was the lack of capacity in the 900-MHz band. The 1,800- MHz band can accommodate a far greater user population, and thus it has become quite popular, especially in densely populated areas. The coverage area is, however, often smaller than in 900-MHz networks, and thus dualband mobiles are used, where the phone uses a 1,800-MHz network when such is available and otherwise roams onto a 900-MHz network. Lately the *European Telecommunications Standards Institute* (ETSI) has also developed GSM-400 and GSM-800 specifications. The 400-MHz band is especially well suited for large-area coverage, where it can be used to complement the higher-frequency-band GSM networks in sparsely populated areas and coastal regions. However, the enthusiasm towards GSM-400 seems to have cooled down, and there were no operational GSM-400 networks by the end of 2002. GSM-800 is to be used in North America.

Note that GSM-400 uses the same frequency bands as NMT-450.
GSM-400: 450.4–457.6 [uplink (UL)] 0/460.4–467.6 [downlink (DL)]
MHz and 478.8–486.0 (UL)/488.8–496.0 (DL) MHz;
NMT-450: 453–457.5 (UL)/463–467.5 (DL) MHz.

Therefore, countries using NMT-450 have to shut down their systems before GSM-400 can be brought into use.

D-AMPS (also known as US-TDMA, IS-136, or just TDMA) is used in the Americas, Israel, and in some countries in Asia. It is backward compatible with AMPS. AMPS, as explained earlier, is an all-analog system. D-AMPS, as defined in standard IS-54, still uses an analog control channel, but the voice channel is digital. Both of these control channels are relatively simple *frequency shift keying* (FSK) resources, while the D-AMPS version has some additional signaling to support the *digital traffic channel* (DTC). D-AMPS was first introduced in 1990. The next step in the evolution was an all-digital system in 1994. That was defined in standard IS-136. AMPS and D-AMPS are operating in the 850-MHz band, but the all-digital IS-136 protocol can also operate in the 1,900-MHz band. US-TDMA and GSM do not have common roots, although both are based on the TDMA technology. Note that the term TDMA may cause some misunderstanding, as sometimes it may be used to refer to all time division multiple access systems, including GSM, and sometimes it is used to refer to a particular TDMA system in the United States, either IS-54 or IS-136.

CDMA, and here we mean the IS-95 standard developed by Qualcomm, uses a different approach to air interface design. Instead of dividing a frequency carrier into short time slots as in TDMA, CDMA uses different codes to separate transmissions on the same frequency. The principles of CDMA are well explained later on, as the 3G *Universal Terrestrial Radio Access Network* (UTRAN) uses wideband CDMA technology. IS-95 is the only 2G CDMA standard so far to be operated commercially [23],[26]. It is used in the United States, South Korea, Hong Kong, Japan, Singapore, and many other east Asian countries. In South Korea especially this standard is widely used. IS-95 networks are also known by the brand name cdmaOne.

PDC is the Japanese 2G standard. Originally it was known as *Japanese Digital Cellular* (JDC), but the name was changed to *Personal Digital Cellular* (PDC) to make the system more attractive outside Japan. However, this renaming did not bring about the desired result, and this standard is commercially used only in Japan. The specification is known as RCR STD-27, and the system operates in two frequency bands: 800 MHz and 1,500 MHz. It has both analog and digital modes. Its physical layer parameters are quite similar to D-AMPS, but its protocol stack resembles GSM. The lack of success of PDC abroad has certainly added to the determination of the big Japanese telecommunications equipment manufacturers to succeed globally with 3G. Indeed, they have been pioneers in many areas of the 3G development work. PDC has been a very popular system in Japan. This success has also been one of the reasons that the Japanese have been so eager to develop 3G systems as soon as possible, as the PDC system capacity is quickly running out.

There are three well-known examples of digital cordless systems: CT2, *Digital Enhanced Cordless Telecommunications* (DECT), and *Personal Handyphone System* (PHS). These systems do not have a network component; a typical system configuration includes a base station and a group of handsets. The base station is attached to some other network, which can be either a fixed or mobile network. The coverage area is often quite limited, consisting of town centers or office buildings. Simpler systems do not support any handover (HO) techniques, but PHS is an advanced system and can do many things usually associated with mobile cellular systems. However, these systems are not further discussed here, as they are not mobile cellular systems as such. Recently there has been an attempt in the GSM community to enhance GSM to meet the requirements of cordless markets. *Cordless Telephone System* (CTS) is a scheme in which GSM mobiles can be used at home via a special home base station, in a manner similar to the present-day cordless phones. This scheme can be seen as an attempt of the GSM phone vendors to get into the cordless market.

2.1.3 Generation 2.5

"Generation 2.5" is a designation that broadly includes all advanced upgrades for the 2G networks. These upgrades may in fact sometimes provide almost the same capabilities as the planned 3G systems. The boundary line between 2G and 2.5G is a hazy one. It is difficult to say when a 2G becomes a 2.5G system in a technical sense.

Generally, a 2.5G GSM system includes at least one of the following technologies: *high-speed circuit-switched data* (HSCSD), *General Packet Radio Services* (GPRS), and *Enhanced Data Rates for Global Evolution* (EDGE). An IS-136 system becomes 2.5G with the introduction of GPRS and EDGE, and an IS-95 system is called 2.5G when it implements IS-95B, or CDMA2000 1xRTT upgrades.

The biggest problem with plain GSM is its low air interface data rates. The basic GSM could originally provide only a 9.6-Kbps user data rate. Later, 14.4-Kbps data rate was specified, although it is not commonly used. Anyone who has tried to Web surf with these rates knows that it can be a rather desperate task. HSCSD is the easiest way to speed things up. This means that instead of one time slot, a mobile station can use several time slots for a data connection. In current commercial implementations, the maximum is usually four time slots. One time slot can use either 9.6-Kbps or 14.4-Kbps speeds. The total rate is simply the number of time slots times the data rate of one slot. This is a relatively inexpensive way to upgrade the data capabilities, as it requires only software upgrades to the network (plus, of course, new HSCSD-capable phones), but it has drawbacks. The biggest problem is the usage of scarce radio resources. Because it is circuit switched, HSCSD allocates the used time slots constantly, even when nothing is being transmitted. In contrast, this same feature makes HSCSD a good choice for real-time applications, which allow for only short delays. The high-end users, which would be the most probable HSCSD users, typically employ these services in areas where mobile networks are already congested. Adding HSCSD capability to these networks certainly will not make the situation any better. An additional problem with HSCSD is that handset manufacturers do not seem very interested in implementing HSCSD. Most of them are going to move directly to GPRS handsets, even though HSCSD and GPRS are actually quite different services. A GPRS system cannot do all the things HSCSD can do. For example, GPRS is weak with respect to real-time services. It can be seen that HSCSD will be only a temporary solution for mobile data transmission needs. It will only be used in those networks where there is already a high demand for quick data transfer and something is needed to ease the situation and keep the customers happy while waiting for 3G to arrive.

The next solution is GPRS. With this technology, the data rates can be pushed up to 115 Kbps, or even higher if one can forget error correction. However, with adequate data protection, the widely quoted 115 Kbps is the theoretical maximum in optimal radio conditions with eight downlink time slots. A good approximation for throughput in "average" conditions is 10 Kbps per time slot. What is even more important than the increased throughput is that GPRS is packet switched, and thus it does not allocate the radio resources continuously but only when there is something to be sent. The maximum theoretical data rate is achieved when eight time slots are used continuously. The first commercial launches for GPRS took place in 2001. GPRS is especially suitable for non-real-time applications, such as e-mail and Web surfing. Also, bursty data is well handled with GPRS, as it can adjust the assigned resources according to current needs. It is not well suited for real-time applications, as the resource allocation in GPRS is contention based; thus, it cannot guarantee an absolute maximum delay.

The implementation of a GPRS system is much more expensive than that of an HSCSD system. The network needs new components as well as modifications to the existing ones. However, it is seen as a necessary step toward better data capabilities. A GSM network without GPRS will not survive long into the future, as traffic increasingly becomes data instead of voice. For those operators that will also operate 3G networks in the future, a GPRS system is an important step toward a 3G system, as 3GPP core networks are based on combined GSM and GPRS core networks [22].

The third 2.5G improvement to GSM is EDGE. Originally this acronym stood for Enhanced Data rates for GSM Evolution, but now it translates into Enhanced Data rates for Global Evolution, as the EDGE idea can also be used in systems other than GSM. The idea behind EDGE is a new modulation scheme called *eight-phase shift keying* (8PSK). It increases the data rates of standard GSM by up to threefold. EDGE is an attractive upgrade for GSM networks, as it only requires a software upgrade to base stations if the RF amplifiers can handle the nonconstant envelope modulation with EDGE's relatively high peak-to-average power ratio. It does not replace but rather coexists with the old *Gaussian minimum shift keying* (GMSK) modulation, so mobile users can continue using their old phones if they do not immediately need the better service quality provided by the higher data rates of EDGE. It is also necessary to keep the old GMSK because 8PSK can only be used effectively over a short distance. For wide area coverage, GMSK is still needed. If EDGE is used with GPRS, then the combination is known as *enhanced GPRS* (EGPRS). The maximum data rate of EGPRS using eight time slots (and adequate error protection) is 384 Kbps. Note that the much-advertised 384 Kbps is thus only achieved by using all radio resources of a frequency carrier, and even then only when the mobile station is close to the base station. ECSD is the combination of EDGE and HSCSD and it also provides data rates three times the standard HSCSD. A combination of these three methods provides a powerful system, and it can well match the competition by early 3G networks.

The IS-95 (CDMA) standard currently provides 14.4-Kbps data rates. It can be upgraded to IS-95B, which is able to transfer 64 Kbps with the use of multiple code channels. However, many IS-95 operators have decided to move straight into a CDMA2000 1xRTT system. 1xRTT is one of several types of radio access techniques included in the CDMA2000 initiative. The North American version of 3G, CDMA2000, is in a way just an upgrade of the IS-95 system, although a large one. The IS-95 and CDMA2000 air interfaces can coexist, so in that sense the transition to 3G will be quite smooth for the IS-95 community. There are several evolution phases in CDMA2000 networks, and the first phase, CDMA2000 1xRTT, is widely regarded to be still a 2.5G system.

Qualcomm has its own proprietary high-speed standard, called *High Data Rate* (HDR), to be used in IS-95 networks. It will provide a 2.4-Mbps data rate. A standard for HDR has been formulated in IS-856. The *1x Evolved Data Optimized* (1xEV-DO) term is used when referring to the nonproprietary form of this advanced CDMA radio interface. The 1xEV-DO adds a TDMA component beneath the code components to support highly asymmetric, high-speed data applications.

PDC in Japan has also evolved to provide faster data connections. NTT DoCoMo has developed a proprietary service called *i-mode*. It uses a packet data network (PDC-P) behind the PDC radio interface. Customers are charged based on the amount of data retrieved and not on the amount of time spent retrieving the data, as in typical circuit-switched networks. The i-mode service can be used to access wireless Internet services. In addition to Web surfing, i-mode provides a good platform for wireless e-mail service. In a packet-switched network the delivery of e-mails over the radio interface is both economical and quick. The i-mode Internet Web pages are implemented using a language based on standard HTML. So in that sense, the idea behind i-mode is similar to the *Wireless Application Protocol* (WAP) [18]. This similarity becomes even more evident once GPRS networks are used and WAP can be used over packet connections. Indeed, NTT DoCoMo's competitor in Japan, KDDI, is offering a WAP-based Internet service.

The i-mode has been a true success story. The system was launched in February 1999, and in June 2002, it already had more than 33 million subscribers. In fact, the demand for i-mode has been so overwhelming that DoCoMo has had to curb new subscriptions at times. This proves that there is a market for WAP-like services, but they will require a packet-based network, like GPRS, to be feasible and affordable for users.

It seems that NTT DoCoMo has made a conscious decision to introduce new services as early as possible, even if that may require proprietary solutions. The i-mode is one example, and WCDMA is another. NTT DoCoMo was first to start 3G services before other operators, using a proprietary version of 3GPP WCDMA specifications. This gave them a few months' head start, even though the launch was a bit rocky, as a new complex system always includes new problems.

2.2 Overview of 3G

The rapid development of mobile telecommunications was one of the most notable success stories of the 1990s. The 2G networks began their operation at the beginning of the decade (the first GSM network was opened in 1991in Finland), and since then they have been expanding and evolving continuously. In September 2002 there were 460 GSM networks on air worldwide, together serving 747.5 million subscribers [3].

In the same year that GSM was commercially launched, ETSI had already started the standardization work for the next-generation mobile telecommunications network. This new system was called the *Universal Mobile Telecommunications System* (UMTS). The work was done in ETSI's technical committee *Special Mobile Group* (SMG). SMG was further divided into subgroups SMG1–SMG12 (SMG5 was discontinued in 1997), with each subgroup specializing in certain aspects of the system.

The 3G development work was not done only within ETSI. There were other organizations and research programs that had the same purpose. The European Commission funded research programs such as *Research on Advanced Communication Technologies in Europe* (RACE I and II) and *Advanced Communication Technologies and Services* (ACTS). The UMTS Forum was created in 1996 to accelerate the process of defining the necessary standards. In addition to Europe, there were also numerous 3G programs in the United States, Japan, and Korea. Several telecommunications companies also had their own research activities.

An important leap forward was made in 1996 and 1997, when both the *Association of Radio Industries and Businesses* (ARIB) and ETSI selected WCDMA as their 3G radio interface candidate. Moreover, the largest Japanese mobile telecommunications operator, NTT DoCoMo, issued a tender for a WCDMA prototype trial system to the biggest mobile telecommunications manufacturers. This forced many manufacturers to make a strategic decision, which meant increasing their WCDMA research activities or at least staying out of the Japanese 3G market.

Later the most important companies in telecommunications joined forces in the 3GPP program, the goal of which is to produce the specifications for a 3G system based on the ETSI *Universal Terrestrial Radio Access* (UTRA) radio interface and the enhanced

GSM/GPRS *Mobile Application Part* (MAP) core network. At the moment it is the 3GPP organization that bears the greatest responsibility for the 3G development work.

The radio spectrum originally allocated for UMTS is given in Figure 2.2 As can be seen, the allocation is similar in Europe and Japan, but in the United States most of the IMT-2000 spectrum has been allocated to 2G PCS networks, many of which are deployed on small 5-MHz sub-bands. Therefore, proposals like CDMA2000 are attractive to North American operators. This 3G proposal is backward compatible with the IS-95B system, and they can both exist in the same spectrum at the same time. The exact IMT-2000 frequency bands are 1,885–2,025 MHz and 2,110–2,200 MHz. From these the satellite component of IMT-2000 takes 1,980–2,010 MHz and 2,170–2,200 MHz [2].
In all, the 3G development work has shown that development of then new systems is nowadays done more and more within the telecommunications industry itself. The companies join to form consortia, which then produce specification proposals for the official standardization organizations for a formal approval. This results in a faster specification development process, as these companies often have more available resources than intergovernmental organizations. Also, the standards may be of higher quality (or at least more suitable for the actual implementation) when they have been written by their actual end users. In contrast, this also means that the standardization process is easily dominated by a few big telecommunications companies and their interests.

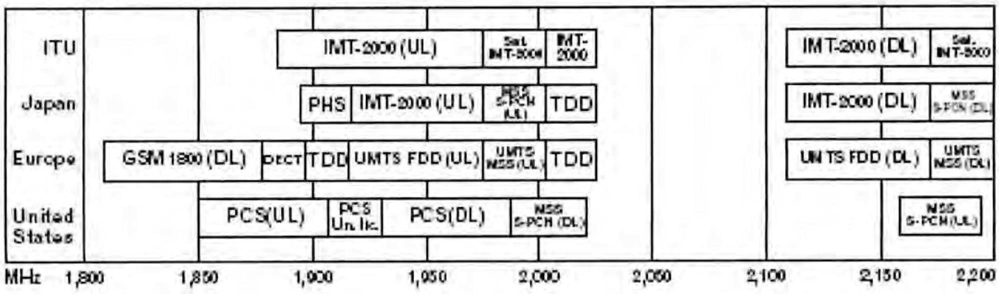


Figure 2.2 IMT-2000 spectrum allocations.

2.3 Proposals for 3G Standard

There have been (and still are) several competing proposals for a global 3G standard. Below, these are grouped based on their basic technology, WCDMA, advanced TDMA, hybrid CDMA/TDMA, and *orthogonal frequency division multiplexing* (OFDM).

2.3.1 WCDMA

By definition, the bandwidth of a WCDMA system is 5 MHz or more, and this 5 MHz is also the nominal bandwidth of all 3G WCDMA proposals [4]. This bandwidth was chosen because:

• It is enough to provide data rates of 144 and 384 Kbps (these were 3G targets), and even 2 Mbps in good conditions.

• Bandwidth is always scarce, and the smallest possible allocation should be used, especially if the system must use frequency bands already occupied by existing 2G systems.

• This bandwidth can resolve more multipaths than narrower bandwidths, thus improving performance.

The 3G WCDMA radio interface proposals can be divided into two groups: network synchronous and network asynchronous. In a synchronous network all base stations are time synchronized to each other. This results in a more efficient radio interface but requires more expensive hardware in base stations. For example, it could be possible to achieve synchronization with the use of *Global Positioning System* (GPS) receivers in all base stations, although this is not as simple as it sounds. GPS receivers are not very useful in high-block city centers (many blind spots) or indoors. Other WCDMA characteristics include fast power control in both the uplink and downlink and the ability to vary the bit rate and service parameters on a frame-by-frame basis using variable spreading. The ETSI/ARIB WCDMA proposal was asynchronous, as was Korea's TTA II proposal. Korea TTA I and CDMA2000 proposals included synchronous networks.

The ETSI/ARIB proposal was the most popular proposal for 3G systems. Originally it had the backing of Ericsson, Nokia, and the big Japanese telecommunications companies, including NTT DoCoMo. Later it was also adopted by the other European manufacturers, and was renamed as UTRAN, more precisely as the UTRAN FDD mode. It is an attractive choice for existing GSM operators because the core network is based on the GSM MAP network, and the new investments are lower than with other 3G system proposals. This also means that all the GSM services are available from day one via the new UMTS network. It would have been difficult to attract customers from existing 2.5G networks to 3G networks if the services in the new network were inferior to those in 2.5G. The specifications for this proposal are further developed by the industry-led 3GPP consortium.

The CDMA2000 proposal is compatible with IS-95 systems from North America. Although CDMA2000 clearly has less support than the 3GPP scheme, it will be an important technology, especially in areas where IS-95 networks are used. In the United States the 3G networks must use the existing 2G spectrum in many cases; thus, CDMA2000 offers an attractive technology choice, as it can coexist with IS-95 systems. Also, the core network is different from GSM MAP, as CDMA2000 uses the ANSI-41 core network. Since CDMA2000 employs a synchronous network, the increased efficiency is attractive to new operators, or existing GSM operators more concerned with deploying an efficient network than attending to the needs of their legacy subscribers. These operators may jump off the GSM track and deploy CDMA2000 instead of upgrading to the UTRAN-FDD mode.

2.3.2 Advanced TDMA

Serious research was conducted around advanced TDMA systems in the 1990s. For some time, the European 3G research was concentrated around TDMA systems, and CDMA was seen only as a secondary alternative. However, in the IMT-2000 process the UWC-136 was the only surviving TDMA 3G proposal, and even that one had backing only in

North America. As of 2002, UWC-136 was no longer supported even by UWCC, but North American TDMA and GSM operators have decided to adopt the WCDMA system, that is, IMT-DS, as their 3G technology.UWC-136 is a system compatible with the IS-136 standard. It uses three different carrier types: 30 kHz, 200 kHz, and 1.6 MHz. The narrowest bandwidth (30 kHz) is the same as in IS-136, but it uses a different modulation. The 200-kHz carrier uses the same parameters as GSM EDGE and provides data rates up to 384 Kbps. This carrier is designed to be used for outdoor or vehicular traffic. The 1.6-MHz carrier is for indoor usage only, and can provide data rates up to 2 Mbps. UWC-136 supporters included North American IS-136 operators. This system is called IMT-SC in IMT-2000 jargon.

However, when advanced TDMA is discussed, it must be noted that a GSM 2.5G system with all the planned enhancements (GPRS, HSCSD, EDGE) is also a capable TDMA system [5]. It might not be called a 3G system, but the boundary between it and a 3G system will be narrow, at least during the first years after the 3G launch. There are still many possibilities to enhance the GSM infrastructure further. Also, the further specification work for GSM has been transferred into 3GPP work groups. Thus, it is likely that those new UTRAN features, which are also feasible in GSM networks, will be specified for GSM systems as well.

2.3.3 Hybrid CDMA/TDMA

This solution was examined in the European FRAMES project. It was also the original ETSI UMTS radio interface scheme. Each TDMA frame is divided into eight time slots and within each time slot the different channels are multiplexed using CDMA. This frame structure would have been backward compatible with GSM. This particular ETSI proposal is no longer supported. However, the UTRAN TDD mode is actually also a hybrid CDMA/TDMA system. A radio frame is divided into 15 time slots, and within each slot different channels are CDMA multiplexed.

2.3.4 OFDM

OFDM is based on a principle of multicarrier modulation, which means dividing a data stream into several bit streams (subchannels), each of which has a much lower bit rate than the parent data stream. These substreams are then modulated using codes that are orthogonal to each other. Because of their orthogonality, the subcarriers can be very close to each other (or even partly overlapping) in the frequency spectrum without interfering each other. And since the symbol times on these low bit rate channels are long, there is no *intersymbol interference* (ISI). The result is a very spectrum-efficient system.

Digital audio broadcasting (DAB) and *digital video broadcasting* (DVB) are based on OFDM. It is also employed by 802.11a, 802.11g, and HiperLAN2 WLAN systems, and by *Asymmetric Digital Subscriber Line* (ADSL) systems. OFDM itself can be based on either TDMA or CDMA. The main advantages of this scheme are:

• Efficient use of bandwidth: Orthogonal subcarriers can partly overlap each other.
• Resistance to narrowband interference;
• Resistance to multipath interference.

The main drawback is the high peak to average power. None of the chosen IMT-2000 technologies employ OFDM. However, as some WLAN technologies use OFDM, and WLAN—cellular interworking is the way of the future—it is quite possible that OFDM will enter the cellular world via a backdoor as part of an interworking WLAN system.

2.3.5 IMT-2000

IMT-2000 is the "umbrella specification" of all 3G systems. Originally it was the purpose of the *International Telecommunication Union* (ITU) to have only one truly global 3G specification, but for both technical and political reasons this did not happen. In its November 1999 meeting in Helsinki, the ITU accepted the following proposals as IMT-2000 compatible [2]:

• IMT Direct Spread (IMT-DS; also known as UTRA FDD);
• IMT Multicarrier (IMT-MC; also known as CDMA2000);
• IMT Time Code (IMT-TC; also known as UTRA-TDD/ TD-SCDMA "narrowband TDD");
• IMT Single Carrier (IMT-SC; also known as UWC-136);
• IMT Frequency Time (IMT-FT; also known as DECT).

The number of accepted systems indicates that the ITU adopted a policy that no serious candidate should be excluded from the new IMT-2000 specification. Thus, the IMT-2000 is not actually a single radio interface specification but a family of specifications that technically do not have much in common.

Since then there has been lots of progress on the 3G system front. IMT-DS and IMT-TC proposals are both being developed by 3GPP consortium. IMT-MC is adopted by another industry consortium, 3GPP2. Doubtlessly the most important IMT-2000 system will be IMT-DS, followed by IMT-MC. The IMT-SC proposal was supported by UWCC, but this organization has made a decision to adopt IMT-DS (i.e., WCDMA) as its 3G technology. In December 2001 the UWCC organization disbanded, and in January 2002 a new organization, 3G Americas, was founded. The mission of 3G Americas is to support the migration of GSM and TDMA networks into WCDMA systems in the Americas. IMT-TC is further divided into two standards: TDD and TD-SCDMA. Both standards are specified, but so far there has not been much commercial interest toward them.

2.4 3GPP

The 3GPP is an organization that develops specifications for a 3G system based on the UTRA radio interface and on the enhanced GSM core network. 3GPP is also responsible for future GSM specification work. This work used to belong to ETSI, but because both 3GPP and GSM use the same core network (GSM-MAP) and the highly international character of GSM, it makes sense to develop the specifications for both systems in one place. 3GPP's organizational partners include ETSI, ARIB, T1, *Telecommunication Technology Association* (TTA), *Telecommunication Technology Committee* TTC), and *China Wireless Telecommunications Standard* (CWTS) group.

The UTRA system encompasses two modes: *frequency division duplex* (FDD) and *time division duplex* (TDD). In the FDD mode the uplink and downlink use separate frequency bands. These carriers have a bandwidth of 5 MHz. Each carrier is divided into 10-ms radio frames, and each frame further into 15 time slots. The UTRAN chip rate is 3.84 Mcps. A chip is a bit in a code word, which is used to modulate the information signal. Since they represent no information by themselves, we call them chips rather than bits. Every second, 3.84 million chips are sent over the radio interface. However, the number of data bits transmitted during the same time period is much smaller. The ratio between the chip rate and the data bit rate is called the *spreading factor*. In theory we could have a spreading factor of one, that is, no spreading at all. Each chip would be used to transfer one data bit. However, this would mean that no other user could utilize this frequency carrier, and moreover we would lose many desirable properties of wideband spreading schemes. In principle, the spreading factor indicates how large a chunk of the common bandwidth resource the user has been allocated. For example, one carrier could accommodate at most 16 users, each having a channel with a spreading factor of 16 (in practice the issue is not so straightforward, as will be shown in later chapters). The spreading factors used in UTRAN can vary between 4 and 512. A sequence of chips used to modulate the data bits is called the spreading code. Each user is allocated a unique spreading code.

The TDD mode differs from the FDD mode in that both the uplink and the downlink use the same frequency carrier. The 15 time slots in a radio frame can be dynamically allocated between uplink and downlink directions, thus the channel capacity of these links can be different. The chip rate of the normal TDD mode is also 3.84 Mcps, but there exists also a "narrowband" version of TDD known as TD-SCDMA. The carrier bandwidth of TD-SCDMA is 1.6 MHz and the chip rate 1.28 Mcps.

UTRAN includes three types of channel concepts. A physical channel exists in the air interface, and it is defined by a frequency and a spreading code (and also by a time slot in the TDD mode). The transport channel concept is used in the interface between layers 1 and 2. A transport channel defines how the data is sent over the air, on common or on dedicated channels. Logical channels exist within layer 2, and they define the type of data to be sent. This data can be either control or user data. In the beginning UTRAN was considered to be a Euro-Japanese system, with close connection to the GSM world, and CDMA2000 was supposed to rule in the Americas. This division is no longer valid, as North American TDMA operators are adopting UTRAN as their 3G system. Also, an increasing number of other operators in America have adopted GSM technology, and thus their 3G future is also linked with UTRAN. On the other hand, CDMA2000 has gained some foothold in East Asia.

2.4.1 TDD

If not otherwise stated, the text in this book generally refers to the FDD system in the 3GPP specifications. Thus, FDD functionality is explained throughout the other chapters. The basic principle of the FDD mode is that separate frequency bands are allocated for both the uplink and downlink directions, but in the TDD mode the same carrier is used for both the uplink and the downlink. Each time slot in a TDD frame can be allocated between uplink and downlink directions. The original ETSI/ARIB proposal for WCDMA was based on the FDD mode alone. The TDD mode was included to the UTRAN scheme later in the standards formulation process.

There are several reasons for using TDD systems. The first one is spectrum allocation. The spectrum allocated for IMT-2000 is asymmetric, which means that an FDD system cannot use the whole spectrum, as it currently requires symmetric bands. Thus the most obvious solution was to give the symmetric part of the spectrum to FDD systems, and the asymmetric part to TDD systems. The proposed spectrum allocations for UTRAN TDD are 1,900–1,920 MHz and 2,010–2,025 MHz. The first granted 3GTDD licenses have been 5 MHz per operator, so each TDD operator could only have one TDD carrier.

Second, many services provided by the 3G networks will require asymmetric data transfer capacity for the uplink and downlink, where the downlink will demand more bandwidth than the uplink. A typical example of this is a Web-surfing session. Only control commands are sent in the uplink, whereas the downlink may have to transfer hundreds of kilobits of user data per second toward the subscriber. As the TDD capacity is not fixed in the uplink and downlink, it is a more attractive technology for highly asymmetric services. The base station can allocate the time slots dynamically for the uplink or downlink according to current needs.

The third reason for TDD is easier power control. In the TDD mode both the uplink and downlink transmissions use the same frequency; thus, the fast fading characteristics are similar in both directions. The TDD transmitter can predict the fast fading conditions of the assigned frequency channel based on received signals. This means that closed-loop power control is no longer needed, but only open loop will be sufficient. However, openloop control is based on signal levels, and if the interference level must be known, then this must be reported using signaling. This "same channel" feature can also be used to simplify antenna diversity. Based on uplink reception quality and level, the network can choose which base station can best handle the downlink transmissions for the MS in question. This means less overall interference. Note that there is no soft HO (SHO) in the TDD mode and all HOs are conventional hard HOs (HHOs) (similar to the ones in GSM). Because the TDD mode is a TDMA system, an UE only has to be active (receiving or transmitting) during some of the time slots. There are always some idle slots during a frame and those can be used for measuring other base stations, and systems [18].

There are also problems with TDD. The first problem is interference from TDD power pulsing. The higher the mobile speed, the shorter the TDD frame so that fast open-loop power control can be used. This short transmission time results in audible interference from pulsed transmissions, both internally in the terminal and with other electronic equipment. Also, the timing requirements for many components are tighter. Both problems can be solved, but the solutions probably require more costly components.

The carrier bandwidth used in UTRA TDD is 5 MHz, and the chip rate used is 3.84 Mcps. The frame structure is similar to the FDD mode in that the length of a frame is 10 ms, and it consists of 15 time slots (see Figure 2.4.1). In principle, the network can allocate these timeslots freely for the uplink and the downlink. However, at least one time slot must be allocated for the uplink and one for the downlink, as the communication between a UE and the network always needs a return channel.

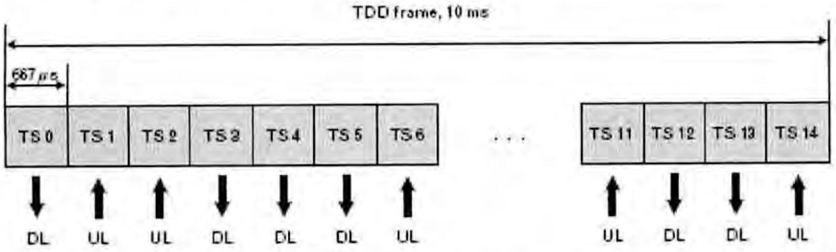


Figure 2.4.1 *An example of a TDD frame.*

Time slots are not exclusively allocated for one user, as in GSM. The TDD mode is a combination of TDMA and CDMA techniques, and each time slot can be accessed by up to 16 users. Different user signals sharing a time slot can be separated because they are modulated with user specific orthogonal chan0nelization codes. These codes can have *spreading factors* (SF) of 1, 2, 4, 8, or 16. The data rate of a user depends on the spreading factor allocated. A spreading factor of 1 gives a user all the resources of a time slot, a spreading factor of 2 gives half of them, and so forth. However, in the downlink only spreading factors 1 and 16 are allowed. A user can still be given "intermediate" data rates with the use of multicodes, that is, a user can be allocated several SF=16 spreading codes to be used in parallel. Also note that a user can be allocated different spreading factors in the downlink and in the uplink directions when there is a requirement for asymmetric data transmission [17].

A TDD system is prone to intracell and intercell interference between the uplink and downlink. The basic problem is that in adjacent cells, the same time slot can be allocated for different directions. It may happen that one UE tries to receive on a slot while another

UE nearby transmits on the same slot. The transmission can easily block the reception attempt of the first UE. This problem can be prevented if all base stations are synchronized, and they all use the same asymmetry in their transmissions. However, this is costly (time-synchronous base stations), and also limits the usability of the system (fixed asymmetry).

Given these facts, it is most probable that FDD is used to provide wide area coverage, and TDD usage will be limited to complement FDD in hot spots or inside buildings. TDD cells will typically be indoors, where they can provide high downlink data rates and the indoor nature of the system prevents the interference problems typical in TDD systems.

1.4.2 TD-SCDMA

In addition to standard UTRA TDD, there is also another TDD specification within the IMT-2000 umbrella. *Time-division synchronous CDMA* (TD-SCDMA) is a narrowband version of UTRA TDD developed by the *China Academy of Telecommunications Technology* (CATT) supported by Siemens. Within 3GPP this system is commonly known as *low chip rate* (LCR) TDD, or just as the 1.28 Mcps TDD option. Whereas the used carrier bandwidth in UTRA TDD is 5 MHz, in TD-SCDMA it is only 1.6 MHz. In some sources the 5-MHz TDD mode is called *high chip rate* (HCR) TDD mode to emphasize the difference between these two modes, but usually it is simply called the TDD mode. The used chip rates are 3.84 Mcps and 1.28 Mcps for the TDD and TDD-LCR systems, respectively. Both UTRA-TDD and TD-SCDMA (TDD-LCR) fit under the IMT-2000 IMT-time code (TC) banner.

The TD-SCDMA technology is promoted by TD-SCDMA Forum. The TD-SCDMA standard drafts are submitted to 3GPP, where they are published as part of the TDD mode standards. In the 3GPP grand scheme the TD-SCDMA mode is thus seen as a submode of the TDD mode. Unofficially this system is also called the *narrowband TDD mode*. TD-

SCDMA is quite similar to the mainstream TDD mode, especially in the higher layers of the protocol stack, but in the physical layer there are some fundamental differences.

First of all, the frame structure is different. The basic frame length is 5 ms, whereas in UTRAN-TDD it is 10 ms. To retain some similarity between the two TDD modes, this 5-ms frame is then called a *subframe*, and two subframes together make a 10-ms frame. One subframe consists of seven normal time slots and of three control slots. The duration of the normal time slot is 675 ms. Time slot 0 is always reserved for the downlink, and time slot 1 for the uplink. Other normal traffic time slots (2–6) can be freely allocated for the uplink or the downlink according to the traffic distribution by moving the location of the single additional switching point (the 5-MHz TDD mode can have multiple switching points). For example, in Figure 2.4.2 there are two uplink and five downlink slots, making this frame suitable for asymmetric downlink-heavy traffic. The only limitation for the time slot allocation is that there has to be one downlink (#0) and one uplink (#1) time slot.

The TD-SCDMA mode is similar to the TDD mode in that a time slot can be shared by up to 16 users. Spreading codes and spreading factors are similar to the TDD mode too, that is, spreading factors of 1, 2, 4, 8, or 16 can be used, but in the downlink only 1 and 16 are allowed. However, multicodes can be employed in the downlink to overcome this limitation.

One advantage of a TD-SCDMA system is that because of the narrower frequency carrier, an operator has more frequencies available for network planning purposes. This is an important factor, especially if the operator has been given only small spectrum allocations. For example a 2□10 MHz allocation can accommodate only two FDD mode carriers, four TDD mode carriers, but altogether 12 TD-SCDMA mode carriers. A typical TDD mode spectrum allocation in the first phase of 3G is only 5 MHz, and that could only accommodate either one TDD mode or three TD-SCDMA mode carriers.

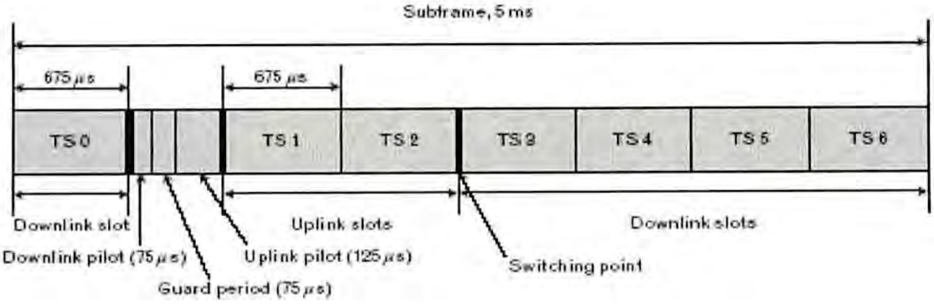


Figure 2.4.2 TD-SCDMA subframe.

Because there can only be a relatively limited number of users (and codes) in each time slot, and the chip rate is slower than in the TDD mode, it is possible to employ joint detection in TD-SCDMA receivers. The receiver can detect and receive all parallel codes and remove the unwanted signals that are declared to be interference from the result. This is not practical in the mainstream FDD mode because of the large number of parallel codes and the faster chipping codes.

To make the migration from GSM into TD-SCDMA easier, an intermediate system called *TD-SCDMA System for Mobile Communication* (TSM) was developed. Whereas a genuine TD-SCDMA 3G system needs a new radio access network, TSM recycles the existing GSM/GPRS access network. In short, the TD-SCDMA physical layer is combined with the modified GSM/GPRS protocol stack. However, here we are combining CDMA technology (TD-SCDMA) with TDMA technology (GSM), which it is not a straightforward task. Figure 2.4.3 shows the GSM/GPRS air interface protocols that need modifications for the TSM system. In case of radio resources (RR) and radio link control/medium access control (RLC/MAC) these modifications are rather extensive. A TSM system can later be upgraded into a genuine TD-SCDMA system.

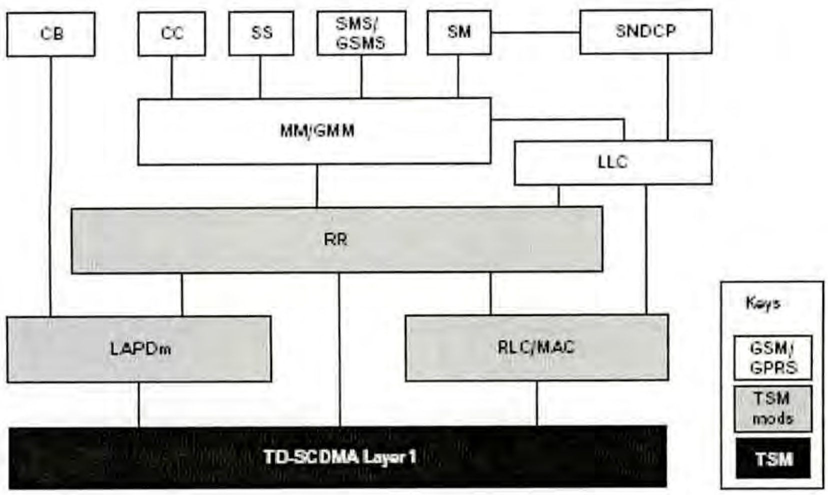


Figure 2.4.3 *TSM protocol stack.*

2.5 3GPP2

The 3GPP2 initiative is the other major 3G standardization organization. It promotes the CDMA2000 system, which is also based on a form of WCDMA technology. In the world of IMT-2000, this proposal is known as IMT-MC. The major difference between the 3GPP and the 3GPP2 approaches into the air interface specification development is that 3GPP has specified a completely new air interface without any constraints from the past, whereas 3GPP2 has specified a system that is backward compatible with IS-95 systems. This approach has been necessary because in North America, IS-95 systems already use the frequency bands allocated for 3G by the *World Administrative Radio Conference* (WARC). It makes the transition into 3G much easier if the new system can coexist with the old system in the same frequency band. The CDMA2000 system also uses the same core network as IS-95, namely, IS-41 (which is actually an ANSI standard:TIA/EIA-41) [40].

The chip rate in CDMA2000 is not fixed as it is in UTRAN. It will be a multiple (up to 12) of 1.2288 Mcps, giving the maximum rate of 14.7456 Mcps. In the first phase of CDMA2000, the maximum rate will be three times 1.2288 Mcps - 3.6864 Mcps. As can be seen, this is quite close to the chip rate of UTRAN. However, it is unlikely that 3x rates will appear, because 1xEV-DO (IS-856) seems to satisfy the needs 3x is designed to address [6].

In CDMA2000 system specifications, the downlink is called the *forward link*, and the uplink is called the *reverse link*. The same naming convention is used in this section. The carrier composition of CDMA2000 can be different in the forward and reverse links. In the forward link the multicarrier configuration is always used (see Figure 1.5). In this configuration, several narrowband (1.25 MHz) carriers are bundled together. The original goal of CDMA2000 was to have a system with three such carriers (3x mode). These carriers have the same bandwidth as an IS-95 carrier and can be used in an overlay mode with IS-95 carriers. It is also possible to choose the spreading codes in CDMA2000 so that they are orthogonal with the codes in IS-95. In the reverse link the direct spread configuration will be employed. In this case the whole available reverse link bandwidth can be allocated to one direct spread wideband carrier. For example, a 5-MHz band could accommodate one 3.75-MHz carrier plus two 625-kHz guard bands. This option can be used in case the operator has 5 MHz of clear spectrum available. The CDMA2000 system does not use the time synchronized reverse link, and thus it cannot use mutual orthogonal codes with IS-95 systems. Therefore, splitting the wideband carrier into several narrowband carriers would not bring any benefits. Note, however, that in case of the 1x mode (the first stage in the CDMA2000 evolution path), there is only one 1.25-MHz carrier in the reverse link, and thus multicarrier and direct spread configurations would mean the same thing anyway. To the extent 1xEV-DO meets its expectations, the single carrier mode will likely be continued.

The evolutionary path from an IS-95A system into a full CDMA2000 system, that is, CDMA2000 3xRTT, can take many forms (see Figure 2.5.1). The first step could be IS-95B, which would increase the data rate from14.4 Kbps to 64 Kbps. However, many IS-95 operators have decided to move straight into CDMA2000 1xRTT systems. Again, there are four levels of 1xRTT systems. The first one is known as 1xRTT release 0, or simply 1xRTT. This release can provide a 144-Kbps peak data rate. The next one is the

1xRTT release A, which can give 384-Kbps rates. The 1xEV-DO standard is the first system that can be regarded as a 3G system according to the ITU, the earlier ones being 2.5G systems. This system can provide 2+-Mbps data rates. The final phase (so far) under the 1xRTT banner is 1xEV-DV. This system is still under development, and it is comparable to the HSDPA upgrade in 3GPP systems. The peak data rate could be around 5 Mbps. Note that this number is already bigger than the planned peak data rate of the CDMA2000 3xRTT system [7]. It remains to be seen whether CDMA2000 operators are actually interested in developing multicarrier (e.g., 3x) systems at all, if a single carrier system can provide comparable throughput. A 1xRTT system is easier to deploy because its carriers can be mapped one-to-one into IS-95 carriers. In any case, it is not necessary for an IS-95 operator to implement all of these evolution phases when upgrading its network; some of them could, and will be, skipped.

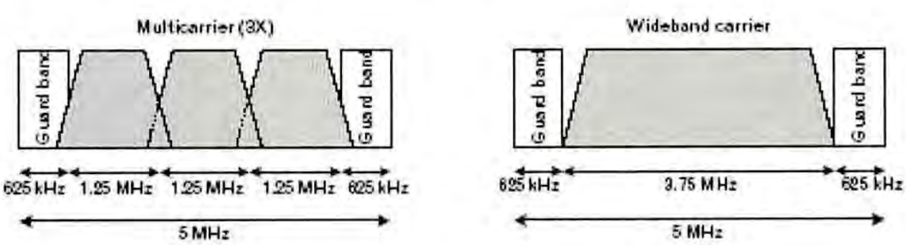


Figure 2.5.1 CDMA2000 carrier types.

There are two kinds of channels in the CDMA2000 system. As in UTRAN, the physical channel exists in the air interface, and it is defined by a frequency and a spreading code. Logical channels exist just above physical channels. They define what kind of data will be transmitted on physical channels. Several logical channels can be mapped onto one physical channel. There is no transport channel concept in CDMA2000 and logical channels have taken their place.

The 3GPP2 membership includes ARIB, CWTS, TIA, TTA, and TTC [40]. Although there are some common features in the 3GPP and 3GPP2 systems and they both belong under the common IMT-2000 umbrella, they are technically incompatible. The Operators' Harmonization Group (OHG) aims to coordinate these systems. The aim of this harmonization is not to produce one common specification for both systems; that would be a much too ambitious and impossible task. Merely, the harmonization work aims to make the life of the telecommunications industry and operators a little bit easier. For example, if certain operational parameters in these systems are close enough to each other, it could be possible to use same components for devices in both systems.

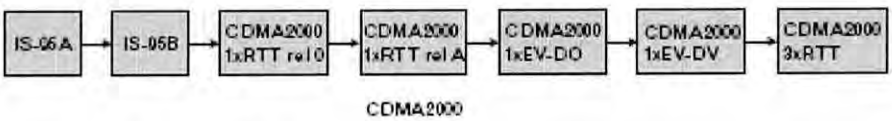


Figure 2.5.2 ***CDMA2000 evolution phases.***

2.6 3G Evolution Paths

Figure 1.6 describes a few possible evolution paths into 3G systems. Even though there are several IMT-2000 compatible systems, it seems that only two of them will survive in the end. WCDMA (IMT-DS), or UTRAN, is the most important one, and CDMA2000 (IMT-MC) will also gain a substantial but secondary market share. There will not be any IMT-SC systems (UWC-136), as the UWCC made a decision to join the WCDMA camp. As of this writing, the biggest question is the future of the IMT-TC, that is, the TDD mode of WCDMA. No operator has so far made orders for TDD mode equipment, and everybody seems to start their 3G deployments with FDD mode equipment. In China the TD-SCDMA systems may or may not become operational; the outcome of this is still too early to say in mid- 2002. In any case, TDD mode systems will be deployed only after FDD mode systems if at all. There are some developments in the 3GPP FDD mode standards, which could threaten the future of TDD mode systems.

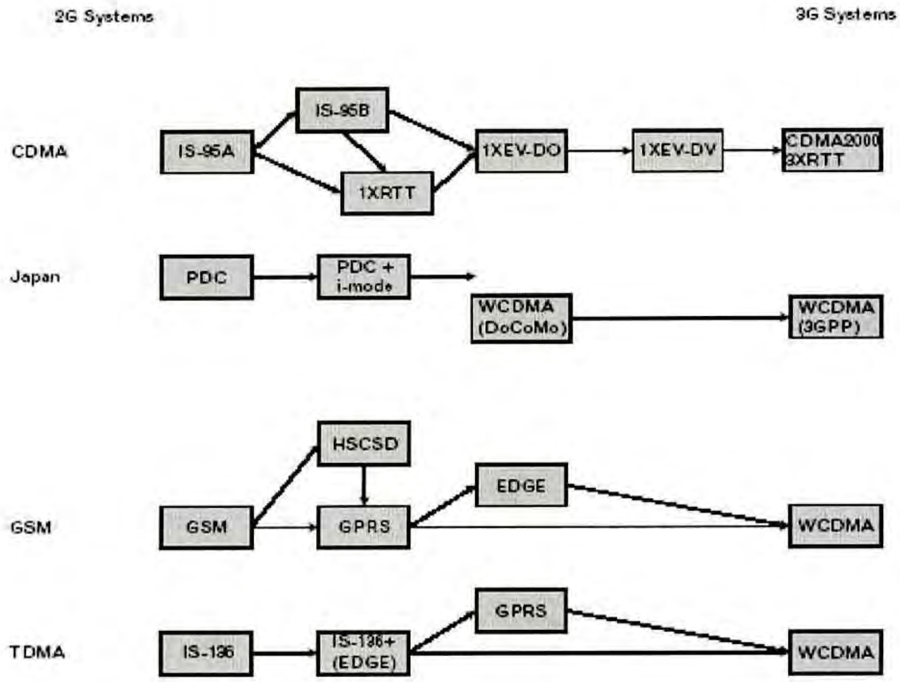


Figure 2.6 3G evolution paths.

CHAPTER 3

Principles of CDMA

3.1 Introduction

In this chapter some basic concepts of CDMA are discussed. These concepts are CDMA specific, and often not used in other technologies, so some explanation may be necessary. An understanding of these concepts will make reading this book much easier. The examples in this section are WCDMA-specific.

3.2 Radio-Channel Access Schemes

The radio spectrum is a scarce resource. Its usage must be carefully controlled. Mobile cellular systems use various techniques to allow multiple users to access the same radio spectrum at the same time. In fact, many systems employ several techniques simultaneously. This section introduces four such techniques:

• Frequency-division multiple access (FDMA);
• Time division multiple access (TDMA);
• Code division multiple access (CDMA);
• Space-division multiple access (SDMA).

An FDMA system divides the spectrum available into several frequency channels (Figure 3.2.1). Each user is allocated two channels, one for uplink and another for downlink communication. This allocation is exclusive; no other user is allocated the same channels at the same time. In a TDMA system (Figure 3.2.2), the entire available bandwidth is used by one user, but only for short periods at a time. The frequency channel is divided into time slots, and these are periodically allocated to the same user so that other users can use other time slots. Separate time slots are needed for the uplink and the downlink.

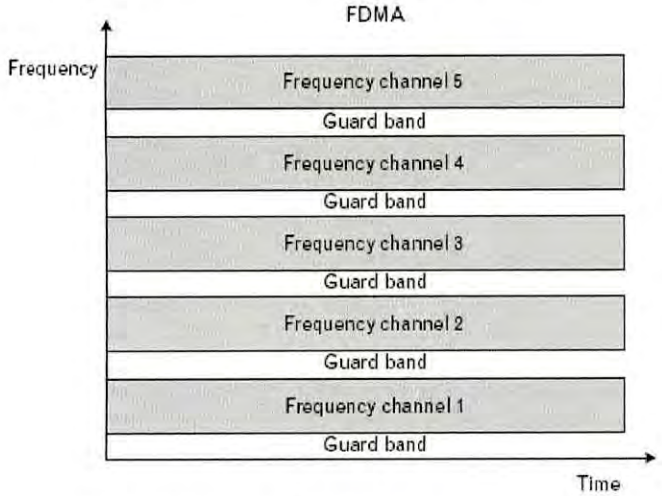


Fig 3.2.1 FDMA

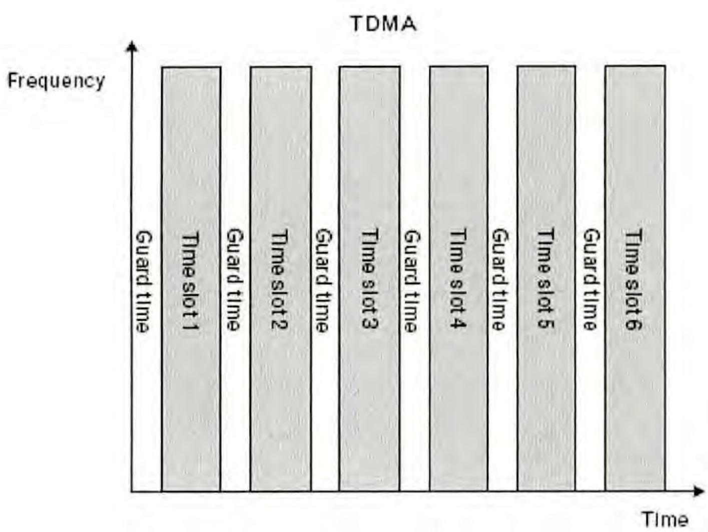


Fig 3.2.2 TDMA

GSM is based on TDMA technology. In GSM, each frequency channel is divided into several time slots (eight per radio frame), and each user is allocated one (or more) slot(s). In a TDMA system, the used system bandwidth is usually divided into smaller frequency channels. So in that sense GSM is actually a hybrid FDMA/TDMA system (as that shown in Figure 3.2.3), as are most other 2G systems.

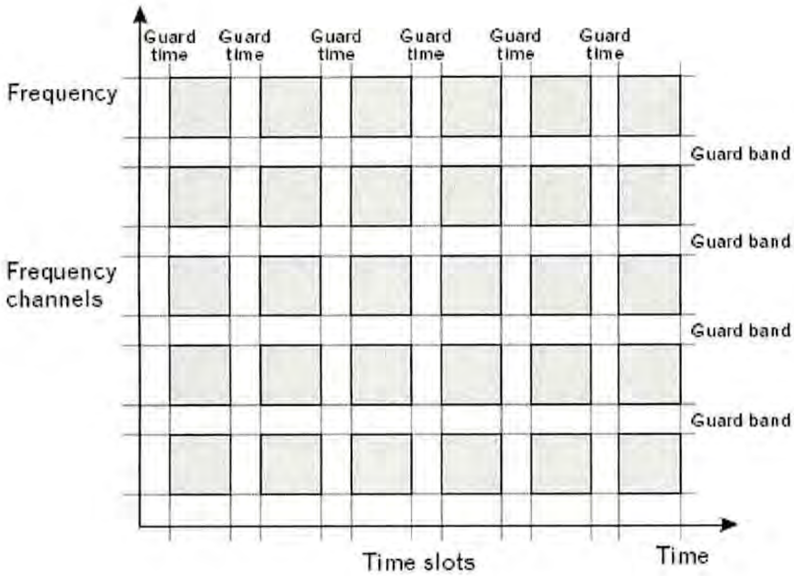


Figure 3.2.3 Hybrid FDMA/TDMA.

In a CDMA system all users occupy the same frequency at the same time, no time scheduling is applied, and their signals are separated from each other by means of special codes (Figure 3.2.4). Each user is assigned a code applied as a secondary modulation, which is used to transform a user's signals into a spread-spectrum-coded version of the user's data stream. The receiver then uses the same spreading code to transform the spread-spectrum signal back into the original user's data stream. These codes are chosen so that they have low cross-correlation with other codes. This means that correlating the received spread-spectrum signal with the assigned code despreads only the signal that was spread using the same code. All other signals remain spread over a large bandwidth. That is, only the receiver knowing the right spreading code can extract the original signal from the received spread-spectrum signal [6].

In addition, as in TDMA systems, the total allocated bandwidth can be divided into several smaller frequency channels. The CDMA spread spectrum scheme is employed within each frequency channel. This scheme is used in the UMTS Terrestrial Radio Access Network (UTRAN) frequency-division duplex (FDD) mode. The TDD mode uses a combination of CDMA, FDMA, and TDMA methods, because each radio frame is further divided into 15 time slots [35].

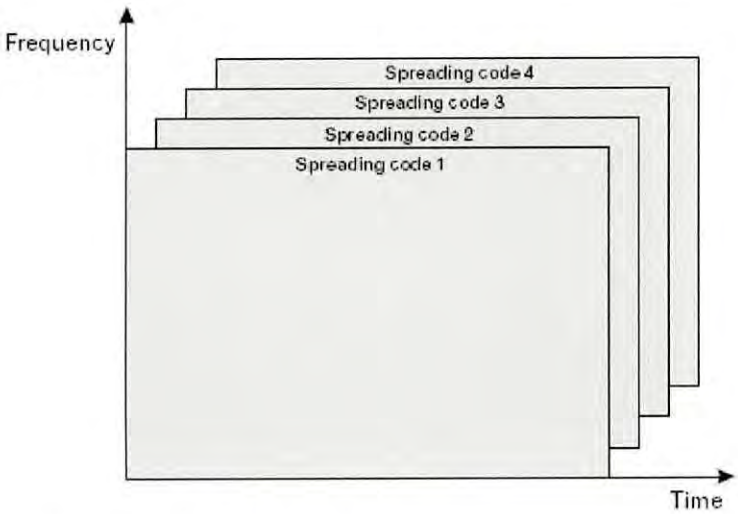
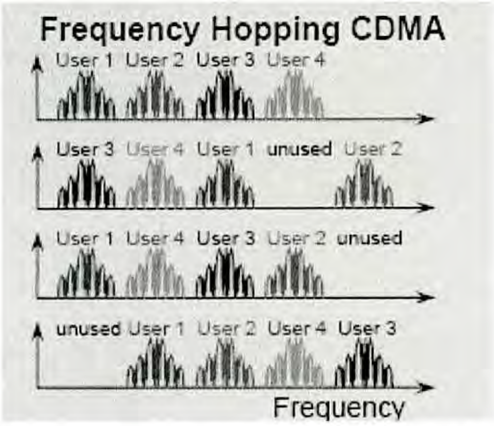


Figure 3.2.4 CDMA.

There are several methods used to modulate CDMA signals [25],[36]. The example in Figure 3.2.4 depicts *direct-sequence spread spectrum* (DS-SS) modulation. With this method, the modulated signal occupies the whole carrier bandwidth all the time. Other modulation schemes include *frequency-hopping spread spectrum* (FH-SS), *time-hopping spread spectrum* (TH-SS), and various combinations of these. All these methods have their own advantageous properties. The 3GPP UTRAN & IS-95 commercial systems system uses DS-SS modulation.



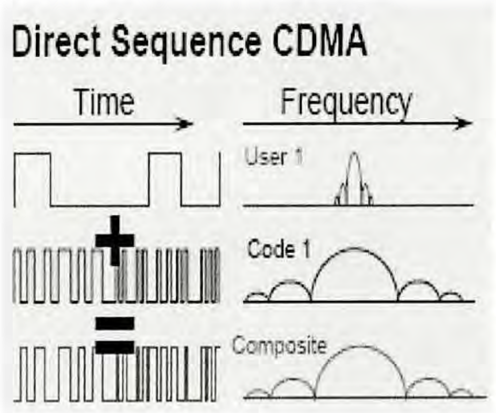


Fig 3.2.5 DS-SS and FH-SS scheme

An SDMA system reuses the transmission frequency at suitable intervals of distance. If the distance between two base stations using the same frequency is large enough, the interference they inflict on each other is tolerable. The smaller this distance, the larger the system capacity. Therefore various techniques have been developed to take advantage of this phenomenon. Sectorization divides a cell into smaller "subcells," some of which can reuse the same frequency. A sector provides a fixed coverage area. Intelligent antennas can form narrow spot beams in desired directions, which increases the system capacity even further. Most digital 2G systems use some form of SDMA in addition to other above-mentioned techniques to improve the system capacity.

3.3 Spread Spectrum

Spread-spectrum transmission is a technique in which the user's original signal is transformed into another form that occupies a larger bandwidth than the original signal would normally need [7]. This transformation is known as spreading. The original data sequence is binary multiplied with a spreading code that typically has a much larger bandwidth than the original signal. This procedure is depicted in Figure 3.3.1. The bits in the spreading code are called chips to differentiate them from the bits in the data sequence, which are called symbols. The term "chip" describes how the spreading operation chops up the original data stream into smaller parts, or chips.

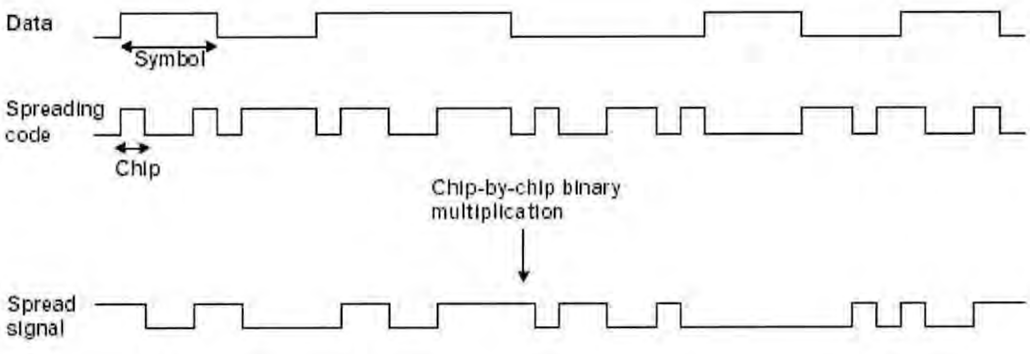


Figure 3.3.1 Spreading.

Each user has its own spreading code. The identical code is used in both transformations on each end of the radio channel, spreading the original signal to produce a wideband signal, and despreading the wideband signal back to the original narrowband signal (see Figure 3.3.2). The ratio between the transmission bandwidth and the original bandwidth is called the processing gain (also known as the spreading factor). Note that this ratio simply means how many chips are used to spread one data symbol. In the UTRAN, the spreading-factor values can be between 4 and 512 (however, in the TDD mode also SF=1 is allowed). While in IS-95 series, the maximum value of SF is 128. The lower the spreading factor, the more payload data a signal can convey on the radio interface.

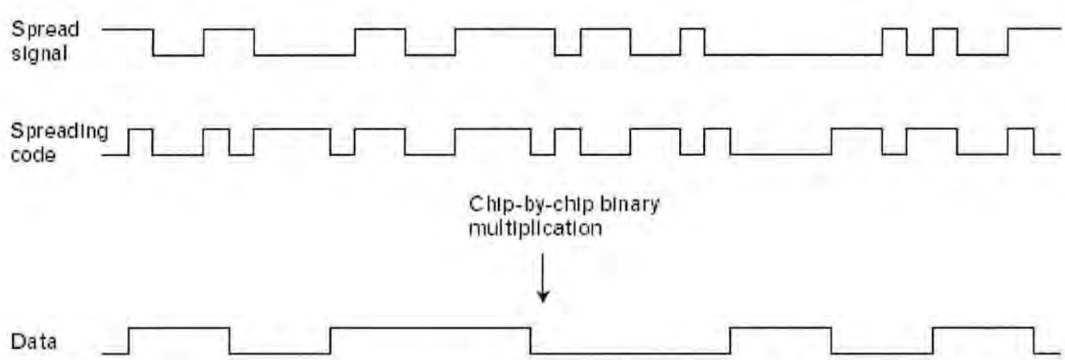


Figure 3.3.2 Despreading.

The spreading codes are unique, at least at the cell level. This means that once a user despreads the received wideband signal, the only component to despread is the one that had been spread with the same code in the transmitter [23-24],[31-35]. Two types of spreading codes are used in the UTRAN: orthogonal codes and pseudo-noise codes. Spreading codes have low cross-correlation with other spreading codes. In the case of fully synchronized orthogonal codes, the cross-correlation is actually zero. This implies that several wideband signals can coexist on the same frequency without severe mutual interference. The energy of a wideband signal is spread over so large a bandwidth that it is just like background noise compared with the original signal; that is, its power spectral density is small. When the combined wideband signal is correlated with the particular spreading code, only the original signal with the corresponding spreading code is despread, while all the other component original signals remain spread (see Figure 3.3.3).

Thus the original signal can be recovered in the receiver as long as the power of the despread signal is a few decibels higher than the interfering noise power; that is, the *carrier-to-interference ratio* (C/I) has to be large enough. Note that the power density of a spread signal can be much lower than the power density of the composite wideband signal, and the recovery of the original signal is still possible if the spreading factor is high enough, but if there are too many users in the cell generating too much interference, then the signal may get blocked and the communication becomes impossible, as depicted in Figure 3.3.4.

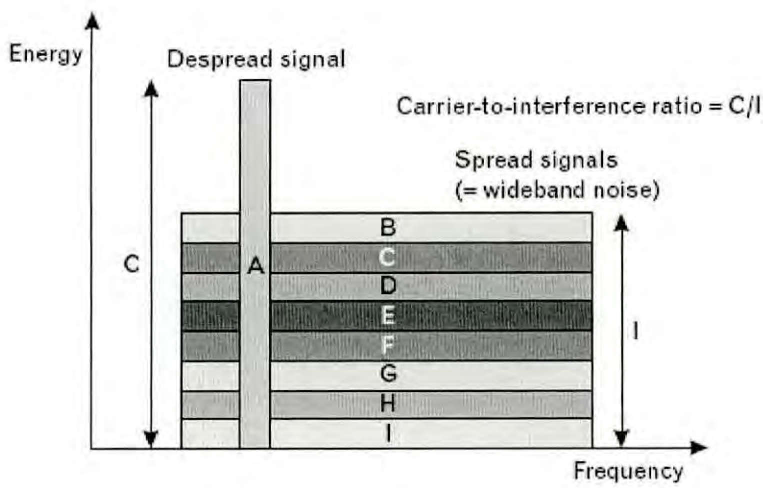


Figure 3.3.3 Recovery of despread signal.

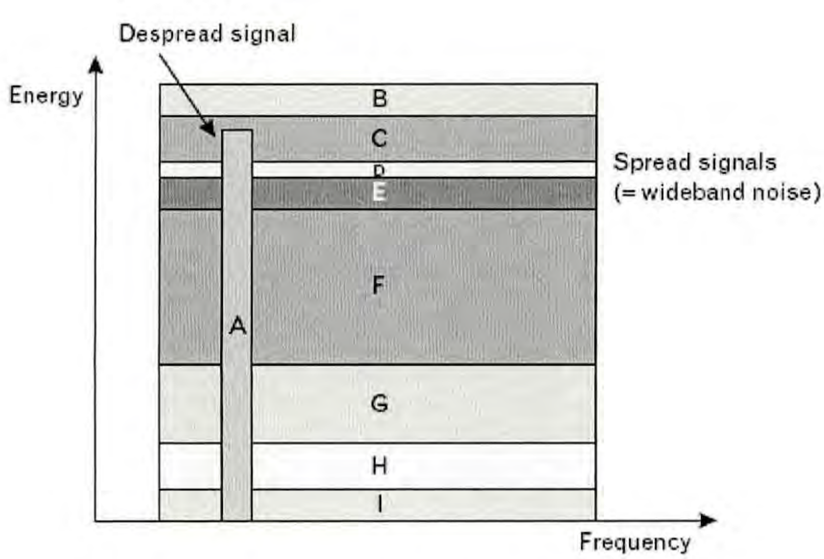


Figure 3.3.4 Unrecoverable signal.

3. 4 Different stages of signal processing

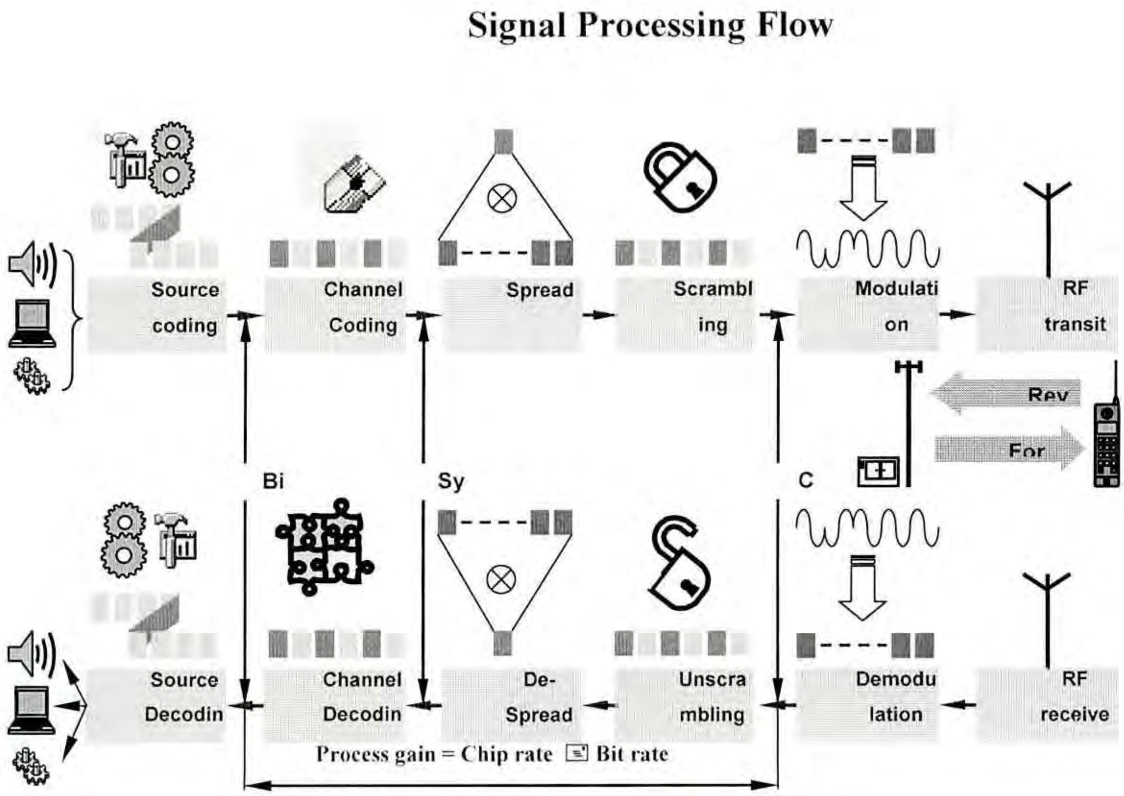


Fig: 3.4.1 : CDMA Signal processing

3.4.1 Source Coding

The purpose of source coding is to convert, compress and organize all the raw analog or digital signals in a standard digital format- frames. 3 advanced voice coding techniques in CDMA system:

-8K QCELP

-13K QCELP

-8K EVRC

QCELP is actually a vocoder device converting a sound signal into the signal which can be transmitted in a circuit. The method adopted generally in a wire communication system is to first sample (8,000 sample values generated per second) a voice signal with a 8KHZ signal and then implement 8-bit quantization coding for each sample value. Therefore, each voice channel in a wired system has the rate of 64K. However, because the air resource in a wireless system is very precious, a more effective coding mode is needed to use a rate as low as possible in the case where voice quality is guaranteed. QCELP vocoder with variable rates is such a device [39]. The main principles of it are to extract some voice feature parameters when a person speaks and transmit these feature parameters to the peer party. Then, the peer party will recover the voice with these parameters based on the promise between the two parties. Thus, a far lower rate is needed. Let's give an example. The information of a triangle can be transmitted from one place to another in two ways: one is to obtain some points by means of sampling and transmit the information of these points to the peer party. The two parties connect these points to obtain a triangle. The other is to transmit the length of a side and the degrees of two angles of this triangle to the peer party, who can likewise recover this triangle based on these pieces of information. Obviously, there is far less information to be transmitted in the second method. What a vocoder does is similar to the latter method, but what a vocoder actually does is more complex than this. But the principles are the same.

Meanwhile, the codes transmitted from the transmit end to the receive end and describing voice feature parameters vary with the rhythm or loudness of a speech. In summary, variable rates mean that a vocoder can change its own code rates based on the loudness or rhythm of a speech to further reduce a code rate. Thus, a code with a higher rate will be adopted when there is a high voice while a code with a lower rate will be adopted when there is a low voice. In a silent period (when a person makes no sound during a speech), the lowest code rate will be adopted. Thus, a code rate can be decreased to reduce the interference with other users.

3.4.2 Channel Coding

Its purpose is to convert data and add redundant data to resist interference and help error correction. Convolution code or TURBO code is used in channel encoding [30].

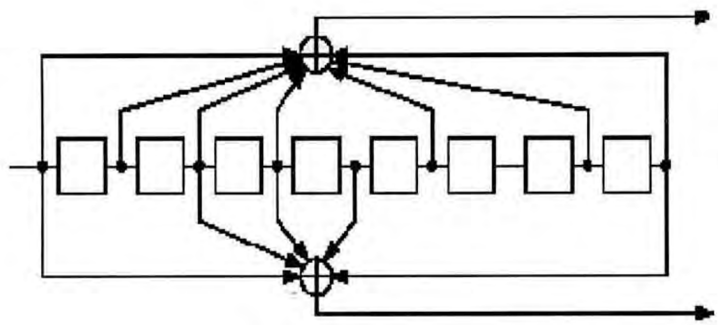


Fig 3.4.2 Channel coding

3.4.3 Interleaving

It can be seen from the figure 3.4.3 that the data are read row by row into an interleaver at the transmit end, read column by column out (this process is called interleaving) and propagated after other modulation process. Then, the data enter the

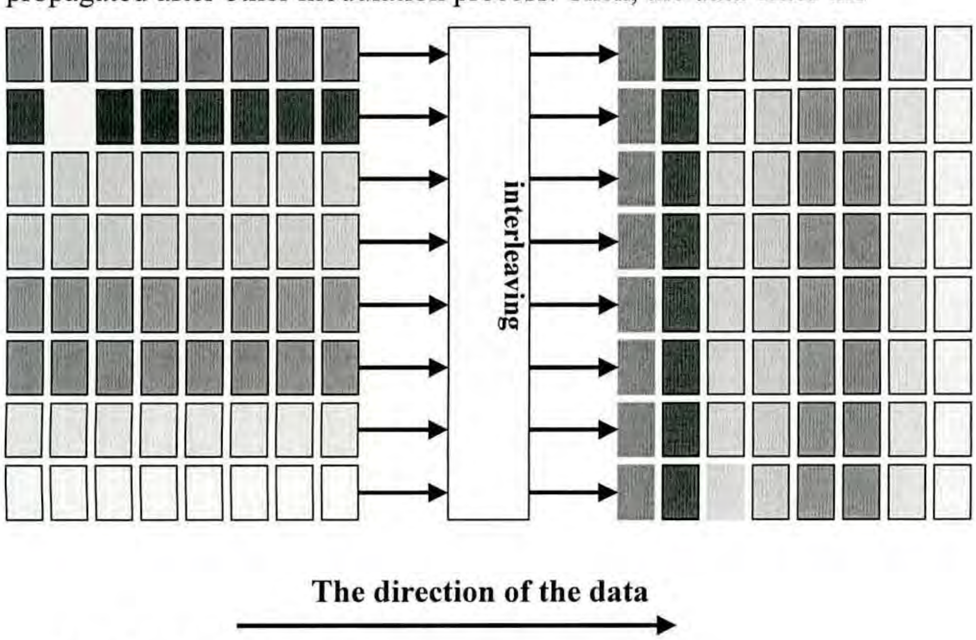


Fig 3.4.3 Interleaving

interleaver at the receive end row by row and are read out column by column (this process is called de-interleaving). Because common error correcting codes can very easily process discrete error codes, the receive end can very easily recover the signals after the anti-interleave into the original signals by means of error correcting, but always cannot recover those signals not interleaved as a result of consecutive error codes. Therefore, interleaving can overcome fast fading caused during the signals transmission in air. The interleave code seldom functions in correcting error codes caused by slow fading, because slow fading may result in long consecutive error codes, even the whole frame may be error. Therefore, there will occur consecutive error codes after de-interleaving.

3.4.4 Scrambling

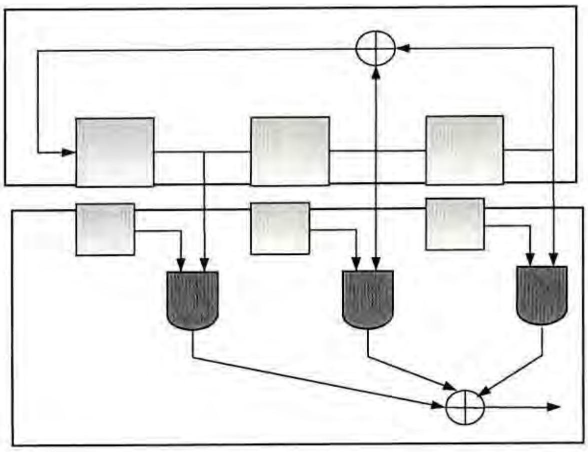


Figure 3.4.4 Scrambling

In CDMA system, user information is encrypted by means of scrambling. The scramble code used here is M-sequence. Shown in the figure is an M-sequence generator made up of a shifting register sequence and a mask. The period of the output sequence is 2^N-1 (N being the number of shifting registers). That is to say, the shifting register sequence resumes to the initial status when every 2^N-1 pieces of codes are output. In a CDMA system, there are two kinds of M-sequence, one being the long code and the other being the short code. The long code is a PN sequence with period of 2^{42}-1chips. In a reverse direction, different long codes are used for the information sent by different users and these are known to the base station and these users. Thus, the base station can identify different mobile stations. Short code is a PN sequence with period of 2^{15} chips. Sequence with different time offset is used to distinguish different sectors. Minimum PN sequence offset used is 64 chips, that is, 512 PN offsets are available to identify the CDMA sectors (215/64=512) [29],[34].

It can be seen that for different masks, a shifting register sequence outputs different M-sequences, which we call different phases. Actually, different masks in CDMA are allocated to different users, who are enabled to obtain different M-sequences.

3.4.5 Spreading

In Forward Link each symbol is spread by a Walsh code. In IS95A/B and cdma2000 1x RC1~RC2, 64-bit Walsh code used. In cdma2000 1x RC3~RC9, variable length Walsh code used to realize different channel rate (from 4.8kbps to 307.2kbps). In Reverse Link every 6 symbols is spread by a Walsh code in IS95A/B or CDMA2000 RC1~RC2. Walsh code is used to distinguish the channels.

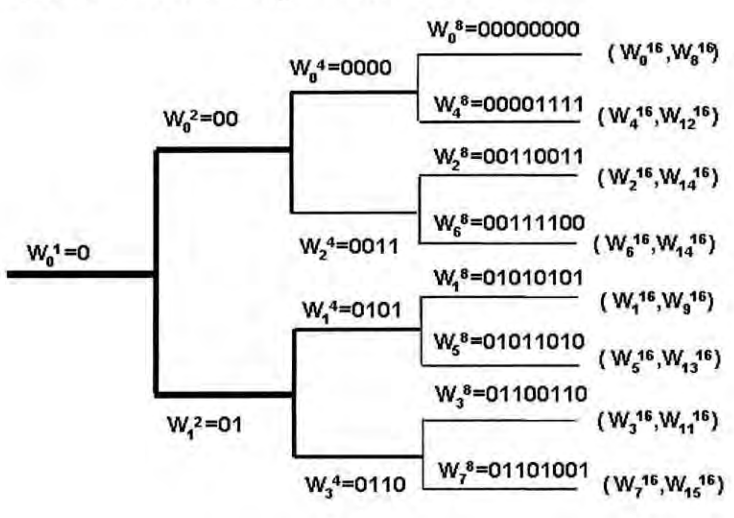


Fig 3.4.5 Walsh tree

3.4.6 Modulation

After being spread, all the forward channels in the same carrier are modulated by means of QPSK (OQPSK in the reverse), converted into simulation signals and transmitted after clustering.

3.5 RAKE Receiver

In a multipath channel, the original transmitted signal reflects off obstacles in its journey to the receiver, and the receiver receives several copies of the original signal with different delays. These multipath signals can be received and combined using a RAKE receiver. A RAKE receiver is made of correlators, also known as RAKE fingers, each receiving a multipath signal. After despreading by correlators with a local copy of the appropriately delayed version of the transmitter's spreading code, the signals are combined. Since the received multipath signals are fading independently, this method improves the overall combined signal quality and performance.

It is called a RAKE receiver for two reasons. One is that most block diagrams of the device resemble a garden rake; each tine of the rake is one of the fingers. The other reason is that a common garden rake can illustrate the RAKE receiver's operation. The manner in which a garden rake eventually picks up debris off a patch of grass resembles the way the RAKE's fingers work together to recover multiple versions of a transmitter's signal (Figure 3.5). An individual signal received by a RAKE finger may be too weak to produce a correct result. However, combining several composite signals in a RAKE receiver increases the likelihood of reproducing the right signal.

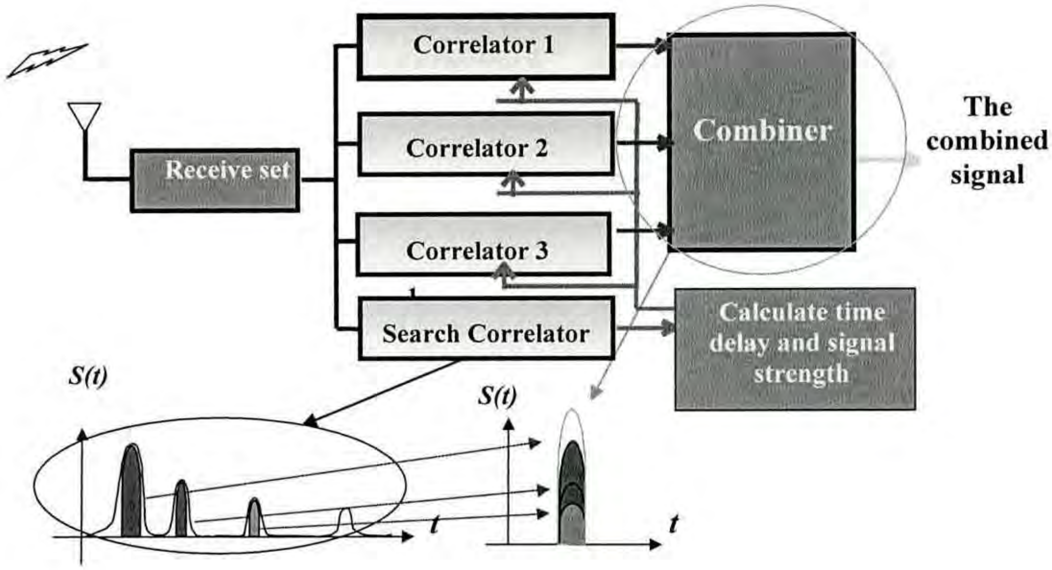


Figure 3.5 RAKE receiver

3.6 Diversity

Diversity technology means that after receiving two or more input signals with mutually uncorrelated fading at the same time, the system demodulates these signals and adds them up. Thus, the system can receive more useful signals and overcome fading [33].

A mobile communication channel is a multi-path fading channel and any transmitted signal reaches a receive end by means of multiple transmission paths, such as direct transmission, reflection, scatter, etc. Furthermore, with the moving of a mobile station, the signal amplitude, delay and phase on various transmission paths vary with time and place. Therefore, the levels of received signals are fluctuating and unstable and these multi-path signals, if overlaid, will lead to fading. The mid-value field strength of Rayleigh fading has relatively gentle change and is called "Slow fading". And it conforms to lognormal distribution.

Diversity technology is an effective way to overcome overlaid fading. Because it can be selected in terms of frequency, time and space, diversity technology includes frequency diversity, time diversity and space diversity.

3.6.1 Frequency diversity

The CDMA signal energy is distributed on the whole 1.23MHZ bandwidth.

3.6.2 Time Diversity

Time diversity means that the signal is spread in the time domain. If there is a short period of time in which signals interfere with each other, which distorts part of the signal, time diversity may help to reconstruct the signal in the receiver despite the errors. The methods for achieving time diversity are channel coding, interleaving, and retransmission protocols.

Time diversity spreads the faulty bits over a longer period of time, and thus makes it easier to reconstruct the original data. If there are 4 successive erroneous bits in one byte, it is very difficult to recover the original data (see Figure 3.6.2). However if these 4 false bits from the radio interface are evenly spread over 4 bytes by means of interleaving, then it is much easier to recover the data, for example, by means of error correcting coding. The longer the interleaving period, the better the protection provided by the time diversity. However, longer interleaving increases transmission delays the delay introduced.

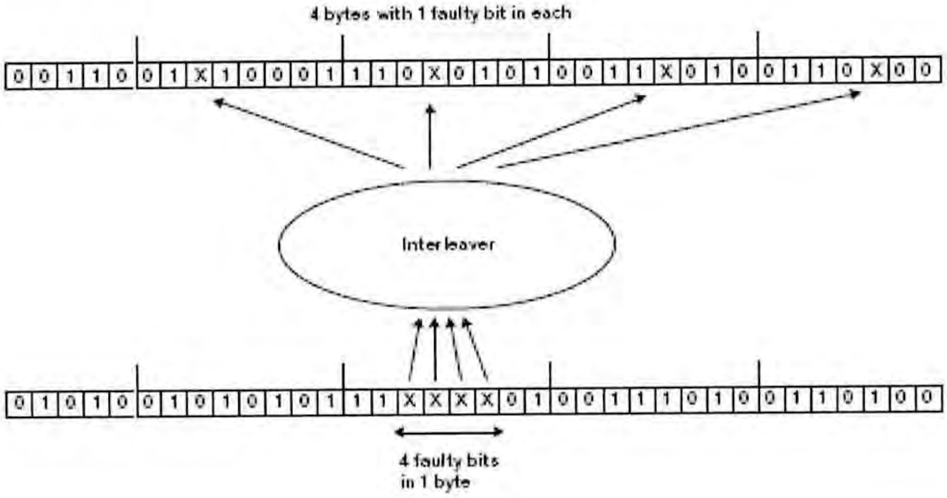


Figure 3.6.2 Time diversity

3.6.3 Space diversity

Space diversity can be divided under two parts-

- Multipath diversity
- Macro diversity

3.6.3-1 Multipath Diversity

Multipath diversity is a phenomenon that happens when a signal arrives at the receiver via different paths (i.e., because of reflections). There is only one transmitter, but various obstacles in the signal path cause different versions of the signal to arrive at the receiver from different directions and possibly at different times (see Figure 3.6.3-1).

In second-generation GSM systems too much multipath diversity means trouble, as GSM receivers are not able to combine the different components, but typically they just have to use the strongest component. In CDMA and WCDMA systems the Rake receiver is able to track and receive several multipath components and combine them into a composite signal. The more energy that can be collected from the multipath components, the better will be the signal estimation.

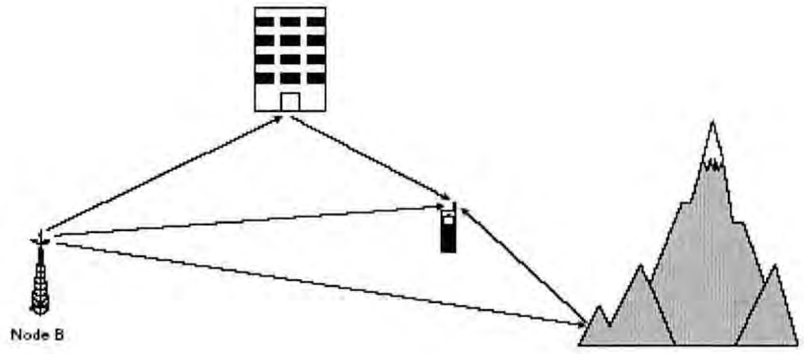


Fig 3.6.3-1 Multipath Diversity

3.6.3-2 Macro diversity

In a CDMA system the same signal can be transmitted over the air interface, on the same frequency, from several base stations separated by considerable distances. This scheme is called the soft handoff (SHO) [19]. In a SHO all the participating base stations use the same frequency, and the result is a macro diversity situation. Note the difference in these concepts: a SHO is a procedure. Once it is performed, the result is a macro diversity situation.

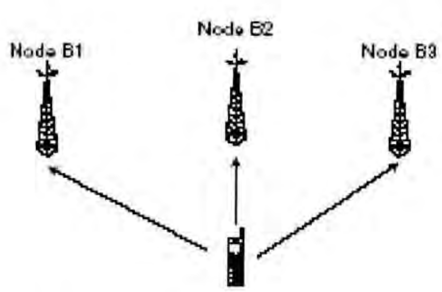


Fig 3.6.3-2 Macro diversity

In macro diversity the mobile's transmission is received by at least two base stations, and similarly the downlink signal is sent by at least two base stations. The gain from macro diversity is highest when the path losses of the SHO branches are about equal. If one of the participating base stations is clearly stronger than the others, then macro diversity cannot provide much gain.

Macro diversity also provides protection against shadowing. Without macro diversity (and multipath diversity) a MS can easily get shadowed if a large obstacle gets between the UE and the base station. In SHO the MS has at least one other path that can maintain the service if one radio link suffers from shadowing.

Macro diversity components will be combined in the physical layer, and not in the protocol stack. The most suitable place to perform this is in the mobile station's RAKE receiver, as this provides the largest gain. There are also other receiver techniques that can perform the combining. Macro diversity is an especially suitable method for improving the gain of services with strict delay requirements. With non-real-time services the same effect could be achieved with time diversity; that is, with longer interleaving periods and retransmission protocols. Macro diversity in the downlink can increase the overall interference level in the system, and thus it should only be used when necessary. Additionally, a SHO requires one channelization code per radio link.

3.7 Different types of CDMA channels

- **Forward channels (mainly 4)**
    - **Pilot channel:** Assists mobile station to be connected with CDMA network, handles multipath searching, provides the phase reference for coherent demodulation and helps the mobile station estimate the transmission power.

- **Synchronization channel:** Helps MS to synchronize with the network.

  The synchronization message includes-

  Pilot PN sequence offset: PILOT_PN

  System time: SYS_TIME

  Long code state: LC_STATE

  Paging channel rate: P_RAT

- **Paging channel:** Paging to MS, assign traffic channel to MS

  The paging channel transmits-

  System parameters message

  Access parameters

  Neighbors list

  CDMA channels list message

- **Traffic Channel:** Used to send data and signaling information to MS

➤ **Reverse Channels (mainly 2)**

- **Access channel:** Used by MS to initiate communication or respond to Paging Channel
- **Traffic channel:** Used to send data and signaling information to BTS

3.8 Power Control

Efficient power control is very important for CDMA network performance. It is needed to minimize the interference in the system, and given the nature of the DS-CDMA (all signals are transmitted using the same frequency at the same time), a good power control algorithm is essential. Power control is needed both in the uplink and in the downlink, although for different reasons.

Main objective of power control

- Ensure the network service quality. Overcome far and near effect via power control to meet the requirement of demodulation threshold and ensure communication quality (guarantee FER, lower call drop ratio and blocking ratio).

- Improve network performance. Reduce the interference, increase the system capacity and guarantee the coverage via power control [10].

For the reverse link, the transmit power of each user is interference for other users. For the forward link, the interference occurs between traffic channels of different users in the same cell, and also exists between the signals among the different cells. The more the interference, the larger the transmit power needed to overcome the interference [37]. But total power of carrier is limited. So, the more the power consumed by the users is, the less the number of the user supported by the system is.

If the power transmitted from each user is the minimum power, which can meet the requirements of demodulation, the capacity of the whole system can be the maximum. The interference among the users is reduced because each MS transmits with the minimum power, and this will lower down the requirements of receiving sensitivity of the receiver and increase coverage area. So, the performance of power control is very significant for CDMA. The quality of power control will directly affect the performances of the system.

3.8.1 Principle of power control

- Control the transmit power of BTS and MS. Firstly, ensure that the signal can meet the requirements of demodulation threshold when reaching the receiver of other side after signal transmitting in the air.
- In case that the above principle can be followed: as long as the transmit power of MSs and BTSs in the network is controlled as much as it can, interference can be controlled. As a result, network performance can be optimized.

- The transmit power of MS closer to BTS is less than that of the MS farther to BTS or the MS in fading area.

When the MS is moving, the radio environment varies continuously caused by slow fading, fast fading, shadow effect, external interference and other factors. The object of power control is to limit the transmit power of forward and reverse link in case that the conversation quality is guaranteed.

In CDMA, power control is also needed for solving the problem of far and near effect. The MSs are randomly located in the space. If the MS is close to the BTS, its signal to the BTS will be large. If the user is far from the BTS, the power as the signal reaches the BTS will be small. So, the smaller signal will be useless in the larger signal, and the user farther from the BTS will not complete the conversation. The power control can also be used to achieve this purpose: the power reached the BTS by the MSs whose distances to the BTS are different will be the same.

Power control can be used for realizing the control of soft capacities such as reducing system interference, increasing system capacity, prolonging the using time of MS's battery, easing the radiation to the body, etc.

3.8.2 Classification of power control

According to the directions, power control can be divided into:

- Reverse power control
- Forward power control

Again Reverse power control can be divided into:

- Reverse open loop power control
- Reverse closed loop power control

3.8.3 Reverse power control

The object of reverse power control is the MS, and the No.1 objective is to ensure the signal received by BTS receiver at least reaches the required minimum Eb/Nt value via adjusting the MS's transmit power. Compared with the forward power control, the requirements of the reverse power control is higher and the procedure is also more complicated. The dynamic variance range of the reverse power control is large and the sensitivity is also high thus to compensate the fast fading margin.

- o Eb/Nt=Bit energy/effective noise power spectrum density
- o Ec/Io=Chip energy/total power spectrum density of carrier

3.8.4 Principle of reverse open loop power control

MS determine the value of transmit power should be according to the total received power of the selected frequency (including pilot, paging and sync channel) via the mode of reverse open loop power control.

MS estimates the channel radio environment only according to the received BS signal quality, and adjusts its reverse transmit power, and it is the unilateral adjustment. For example, when MS detects that the received forward power is too high, this usually indicates that it is very close to BS and the radio environment is good. Therefore, MS can lower down its mean transmit power. This neglects the irrelevance between forward channel 875M frequency and reverse channel 830M frequency (because the carrier difference is 45MHz), and enormous errors may occur in a certain part of time (because of fast fading feature of radio information). So, open loop power control requires faster and more precision correction. The closed loop correction can complete this.

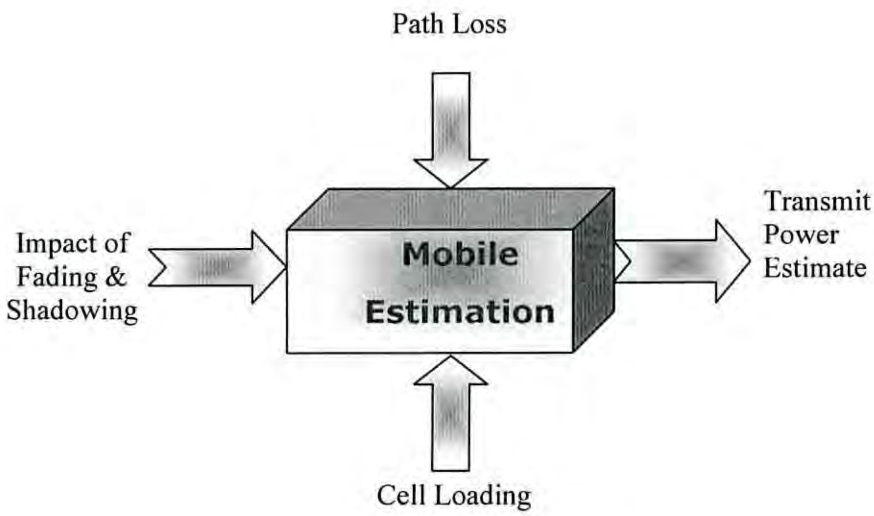
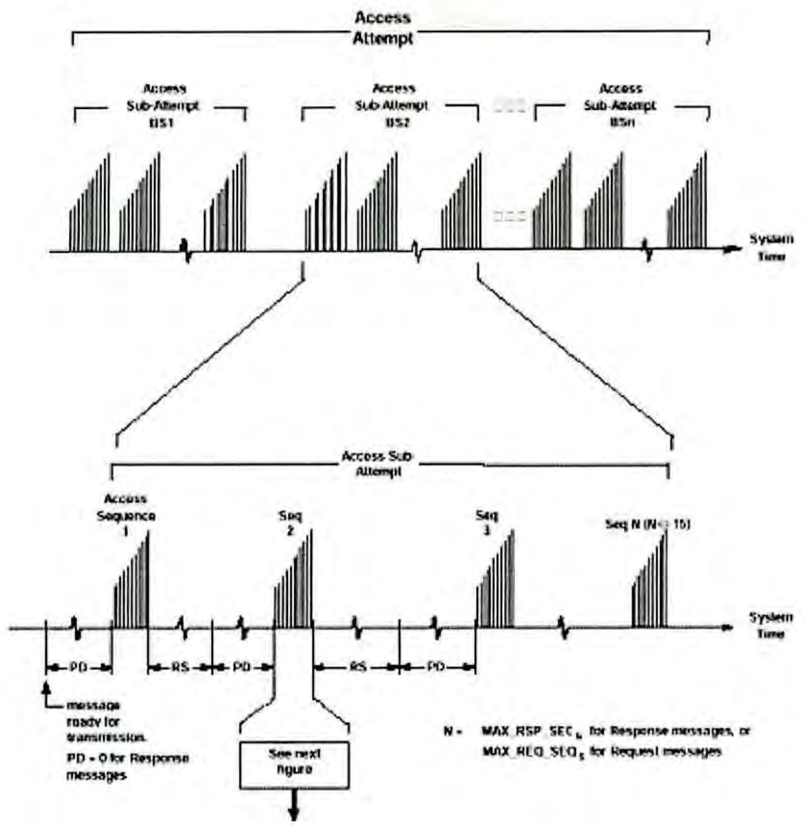


Fig 3.8.4 Reverse open loop power control

3.8.5 Estimation of reverse open loop transmit power

The MS performs open loop estimation in case of access, and sends a probe signal by using the estimated transmit power, then waits for the confirmation information. If the MS cannot receive the confirm information, it will increase the power and re-send it. The MS determines the needed transmit power via multi sequence probe one after another.



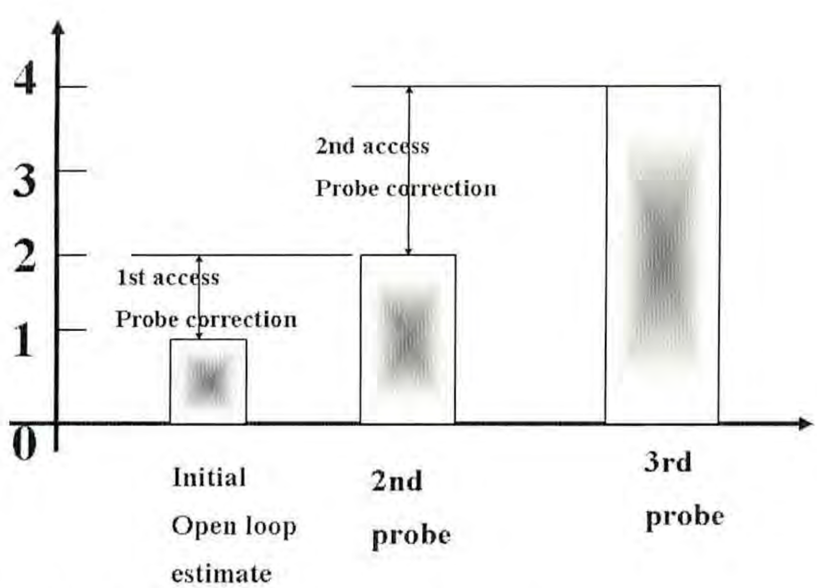


Fig 3.8.5 Estimation of transmit power

Open loop power estimation value can be corrected further via probe access channel. Firstly, transmit with open loop power, and wait for confirmation message; if the MS doesn't receive, it will increase the power to re-send it. The increment is called "access probe correction". The transmit power is decided by the open loop estimation formula.

3.8.6 IS95A open loop estimation formula

Transmit power (dBm)= - Mean Receive Power (dBm) + offset power + NOM_PWR - 16*NOM_PWR_EXTs + INIT_PWR + Access Probe Corrections

- Calculate mean receive power and constant offset power to get the needed transmit power after compensating path loss. MS's transmit power and receive power are in inverse ratio. Offset power is related to RC, frequency band, and channel types.
- NOM_PWR is used to compensate the offset of actual valid radiation power from the nominal power.
- INIT_PWR is used to compensate the differences of the transmit powers of MSs caused by different loads.
- Access probe correction = (n-1)*PWR_STEP; PWR_STEP is the power increase step length between two adjacent access attempts.

3.8.7 IS95B open loop estimation formula

Transmit power (dBm)=- Mean Receive Power(dBm)+ offset power + NOM_PWR - 16* NOM_PWR_EXTs + INIT_PWR + Access Probe Corrections + interference correction

Compared with IS95A, interference correction is added. This value is subject to the strength of service pilot signal.

- When service pilot signal's Ec/Io ≤ -14dB, the correction value is constant "+7";
- When service pilot signal's Ec/Io > -7dB, the correction value is 0;
- If it is between the above two cases, the correction value is (-7-Ec/Io).

3.8.8 IS2000 open loop estimation formula

Transmit power (dBm)=-Mean Receive Power (dBm) + offset power+ RL_GAIN_ADJs+ ACC_CORRECTIONS+ interference correction

- RL_GAIN_ADJs (radio link gain): Transmit power is the adjustment value compared with the transmit power of access channel, and is sent to the MS via ECAM, and is effective only in traffic channel.
- ACC_CORRECTIONS is the function of NOM_PWR, INIT_PWR, NOM_PWR_EXT, and PWR_STEP.
- ACC_CORRECTIONS = NOM_PWRs-16×NOM_PWR_EXTs+ INIT_PWRs + PWR_LVL ×PWR_STEPs

3.8.9 The short comings of reverse open loop power control are-

- Reverse power is estimated by forward link's transmission statistic. But the forward link and the reverse link are not related, and the error is remarkable.
- The receive power is affected by the adjacent cell, and the error is remarkable at the edge of the cell.

3.8.10 Pinciple of reverse closed loop power control

MS quickly corrects its transmit power (800 times per second) according to the power control instruction received in the forward channel with the basis of open loop estimation. The process is divided under 2 parts-

- Inner loop
- Outer loop

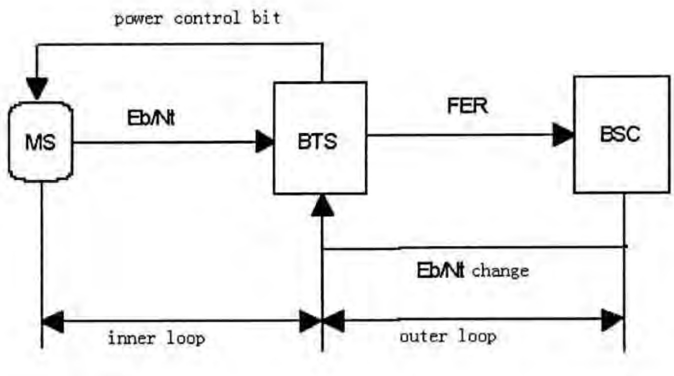


Fig: 3.8.10 Closed loop power control

3.8.11 Inner loop power control

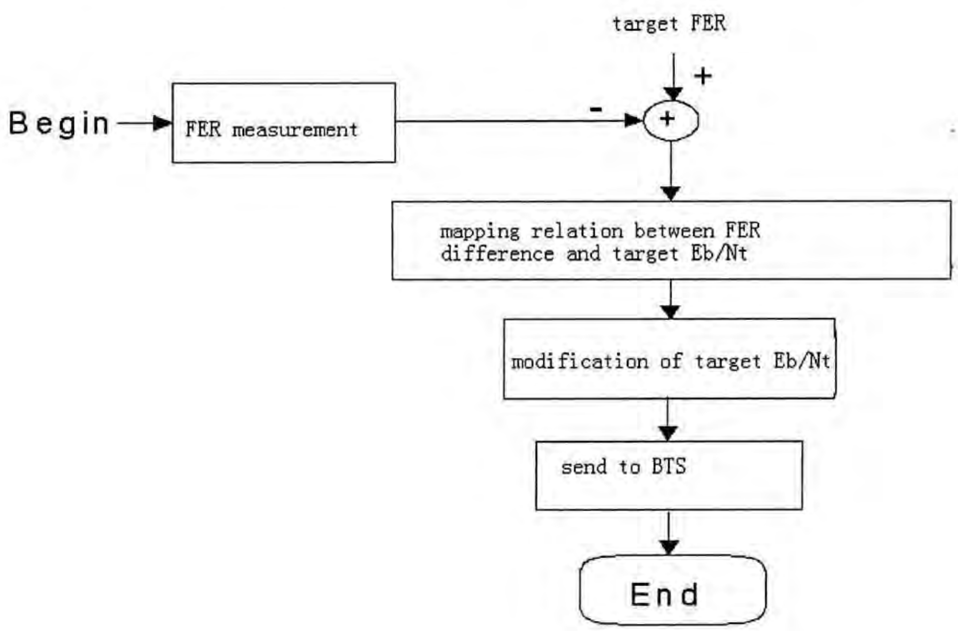
BTS delivers power control bit according to the received signal's Eb/Nt. When the received signal's Eb/Nt is more than or equal to the preset Eb/Nt, the BTS sets power control bit as "1". When the received signal's Eb/Nt is less than the preset Eb/Nt, the BTS sets power control bit as "0". When the MSs receives "1" power control bit, decrease the transmit power; when the MSs receives "0" power control bit, increase transmit power.

3.8.12 Outer loop power control:

BSC adjusts the setting Eb/Nt according to the received reverse signal's FER. FER (Frame Error Rate) has a certain target value. When the actually received FER is higher than the target value, BS needs to increase inner loop threshold to improve MS's reverse transmit power. Contrarily, when the actually received FER is lower than the target value, BS needs to decrease inner loop threshold properly to reduce MS reverse transmit power. With the multiple mechanisms, BS can make MS transmit with the power as low as it can in condition that the receive quality is guaranteed, to reduce the interference to other users, and improve the system's capacity.

3.8.13 Max and min Eb/Nt of BTS in reverse link

If max Eb/Nt is high, the voice quality can be guaranteed when the radio environment is bad, but the system reverse capacity will be decreased; if this value is low, call drop may occur in poor environments like corners. If min Eb/Nt is set too high, the reverse capacity will be badly affected; if it is set too low, under the condition of good power control performance, the voice quality and capacity will not be affected seriously; In case of poor power control algorithm performance, it might be decreased too much, and cannot be increased in time in case of attenuation, and will lead to call drop.



3.8.14.1 Forward power control

Forward CDMA channel power is shared by pilot, sync, paging and traffic channel. The MSs are in different positions, so, the signal strength from BTS to the MSs are different. It is necessary to perform power allocation control on each traffic channel independently. The criterion requires that the MS should monitor the quality of forward traffic channel, and the information should be fed back to the BTS after receiving the BTS's instruction. This "closed loop" process is very similar to the reverse power control.

3.8.15.1 Principle of forward fast power control

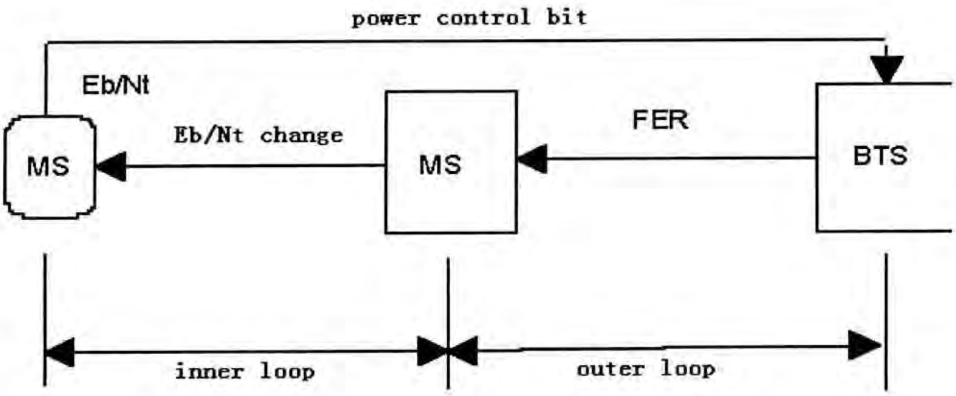


Fig 3.8.14.2 Forward Power control

- **Outer loop:** MS calculates forward FER, and obtains Eb/Nt after comparing with the target FER.
- **Inner loop:** MS compares target Eb/Nt with the measured Eb/Nt, and fills power control bit in reverse power control subchannel.

  Target FER and target Eb/Nt are delivered to the MS via channel assignment message, because different MSs need to adjust independently.

3.9 Handoff algorithm

Handoff of CDMA system not only has close relationship with network quality (conversation quality, call-drop performance, etc.), but also has complicated relationship with coverage, capacity and interference [8], [9], [19].

3.9.1 CDMA handoff types

In CDMA we find mainly 3 types of hanoff-

1. Soft Handoff
2. Softer handoff
3. Hard handoff

3.9.2 Soft handoff

Handoff between the pilot frequencies of different BTSs with the same frequency. Contact with multiple BTSs can be kept simultaneously to realize the diversity receiving effect. Soft handoff branches are selected by frame processing board of BSC.

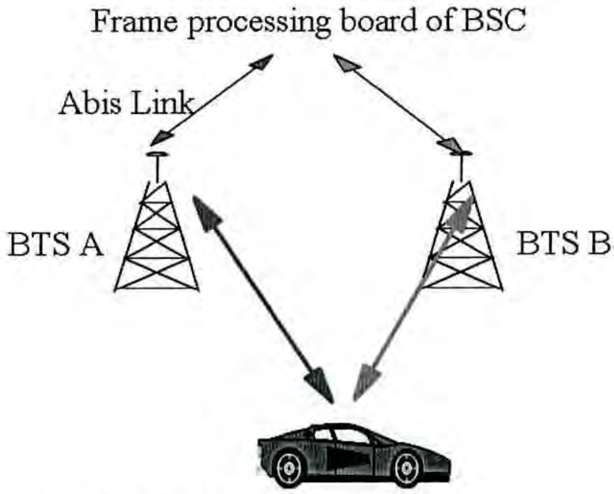


Fig 3.9.2 Soft handoff

3.9.3 Softer handoff

Handoff between different sector pilots of the same BTS with the same frequency, and at the same time macro diversity gain is achieved. Actually, this is the handoff between the pilots of the same channel unit. The difference between soft handoff and softer handoff is softer handoff is generated in the same BTS, and the diversity signals are all combined in BTS as the maximum gain. But soft handoff is generated between two BTSs, the diversity signals are selectively combined in BSC.

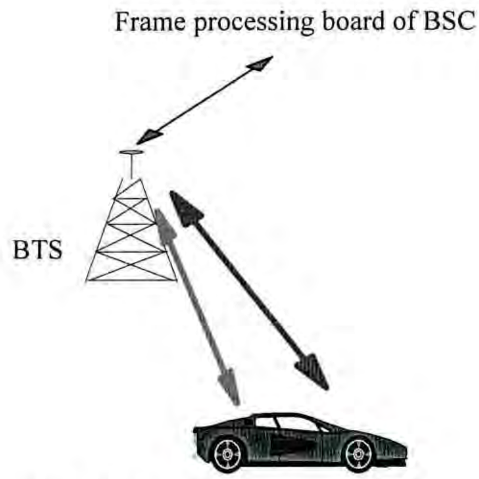


Fig 3.9.3 Softer handoff

3.9.4 Hard handoff

The feature of hard handoff is the short-period interruption of the communication link. The hard handoff includes the handoff from one CDMA carrier to another one and the change of different frame offsets. When the MS is handed off from one CDMA carrier to another one (handoff between carriers), the link must be halted. During the change of frame offsets, the link must be halted as well when the MS changes its frame offset transmission according to the system time. In this case, the MS should be in the same CDMA carrier.

3.10 Pilot set

The pilot set denotes the set of the pilots with the same frequency, but not the same PN code phases. The pilot set includes active set, candidate set, neighbor pilot set and remnant set.

- **Active set**: Pilot set corresponding to the traffic channel connecting to the MS.
- **Candidate set**: The strength of the pilot signal is strong enough, the MS can demodulate successfully and can access in any moment.
- **Neighbor set**: Set of the pilots, which are not in the active set or candidate set,

but may be sent into the candidate set.

- **Remain set**: Set of all the rest pilots.

3.11 Soft handoff procession

- If pilot strength is higher than T_ADD, then MS sends PSMM and add this pilot into candidate set;
- BSC sends EHDM to request MS to add this pilot into active set;
- MS add this pilot into active set and send handoff complete message;
- If pilot strength is lower then T_DROP, then MS triggers drop counter TT_DROP;
- If drop counter TT_DROP is overtime, MS sends PSMM to inform BSC;
- BSC sends EHDM
- MS deletes this pilot from active set and sends handoff complete message;

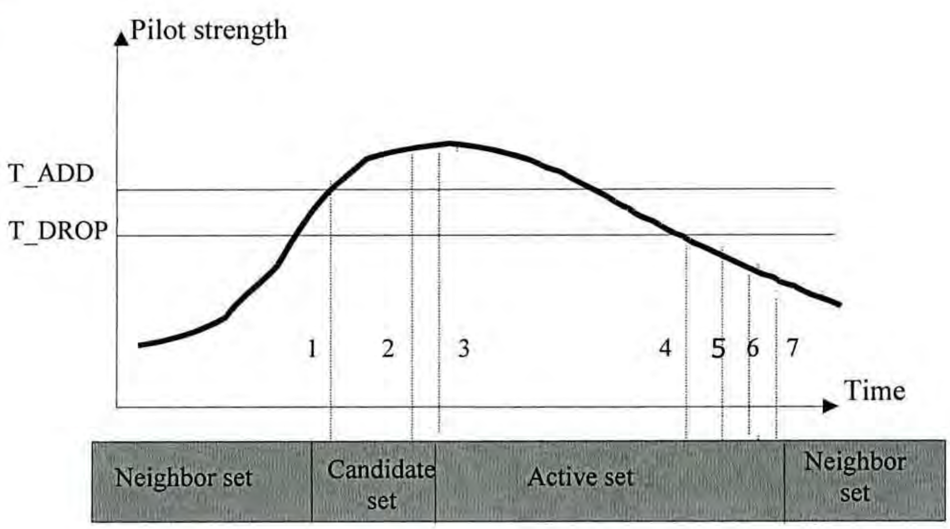


Fig 3.11 Soft handoff Procession

- **T_ADD**: Pilot addition threshold

When the condition Ec/Io>T_ADD is satisfied, MS sends measurement message of pilot strength to move the pilot from the neighbor set to the candidate set.

- **T_DROP**: Pilot DROP threshold (lowest available threshold of pilot.

When the pilot Ec/Io drops to T_Drop, counter TT_Drop will be triggered. If the pilot Ec/Io exceeds T_DROP, the counter will be terminated. And when the counter is full, the pilot will be wiped off from the active set or the candidate set to the neighbor set.

- **TT_DROP:** Active or Candidate Set drop timer

When the pilot dropped time in the pilot set and the candidate set exceeds TT_DROP timer, then the pilot will be wiped off to the neighbor set. If the candidate set is full and there is new pilot satisfying T_ADD requirement, then the pilot closest to TT_DROP threshold will be deleted so that the new pilot can be added

- **TComp:** Active vs. Candidate Comparison threshold.

When the pilot is added to the candidate set under the condition Ec/Io>T_ADD, then the MS will send PSMM. If Ec/Io>Active Ec/Io + TComp*0.5, then the MS will send the supplemental PSMM

3.12 Dynamic soft handoff

In dynamic soft handoff, the thresholds are dynamically decided based on network quality requirement. Static threshold (T_ADD, T_DROP) is used in IS95A. And dynamic threshold needed for the active set has been added to IS95B and CDMA2000. In different cells or different noise environment, the addition/deletion of the absolute threshold of the cell pilot in the Active Set is related to the signal strengths of the best pilot and the weakest pilot. If all the pilot signals in the Active Set are strong, the requirement for other pilots being sent into the Active Set will be lower. On the contrary, if the pilot signals in the Active Set are all weak, the requirement for pilots being sent out from the Active Set will be comparatively higher. After adapting dynamic soft handoff, the soft handoff ratio is expected to decrease in case of high traffic environment and thus overcome overhead limitation on the forward link [19],[39].

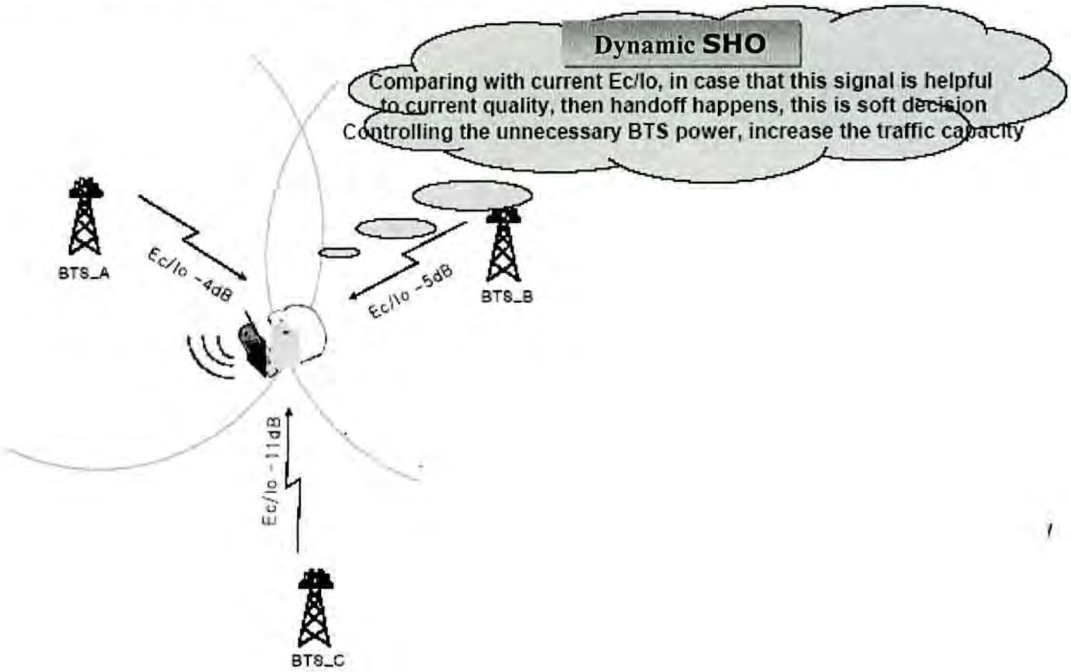


Fig 3.12 Dynamic handoff

3.13.1 Dynamic Handoff Process:

- Pilot P2 strength exceeds T_ADD. Mobile transfers the pilot to the Candidate Set.
- Pilot P2 strength exceeds [(SOFT_SLOPE/8)×10×log10(PS1)+ADD_INTERCEPT/2]. Mobile sends a "PSMM"
- Mobile receives an "EHDM", "GHDM"or "UHDM", transfers the P2 to the Active Set, and sends a "HCM".

- Pilot P1 strength drops below [(SOFT_SLOPE/8) ×10× log10(PS2) +DROP_INTERCEPT/2] mobile starts the handoff drop timer.
- Handoff drop timer expires. Mobile sends a "PSMM".
- Mobile receives an "EHDM", "GHDM"or "UHDM", transfers P1 to the Candidate Set and sends a Handoff Completion Message.
- Pilot P1 strength drops below T_DROP. Mobile starts the handoff drop timer.
- Handoff drop timer expires. Mobile moves P1 from the Candidate Set to the Neighbor Set.

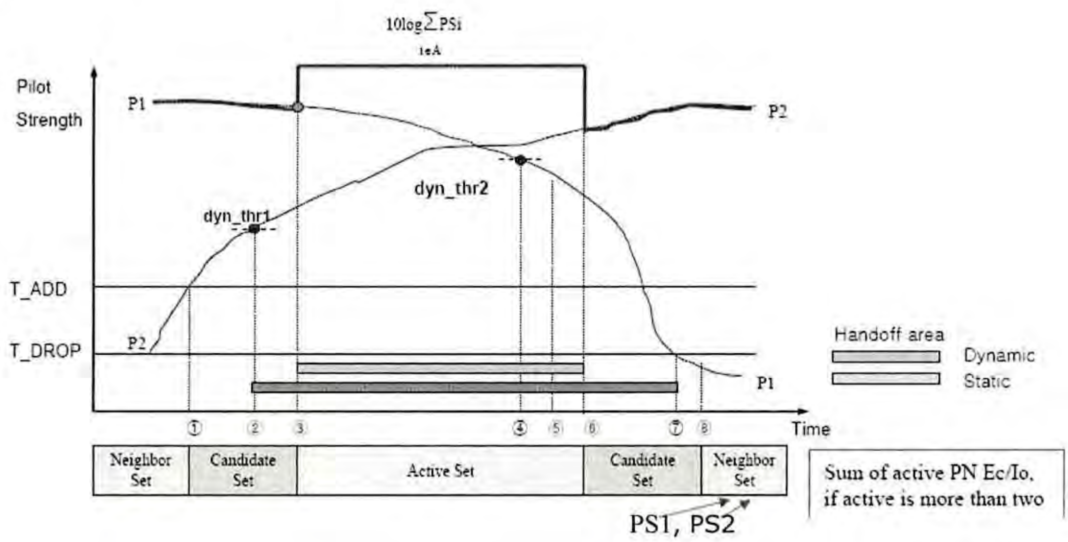


Fig 3.13.1 Dynamic SHO process

➤ **Soft_slope**

The larger value of this parameter, the lower dynamic addition and deletion thresholds calculated on condition that the strength of pilots in the active set remains unchanged. In this case, the soft handoff will decrease.

➤ **Add_intercept:** Add when better than me to some extend.

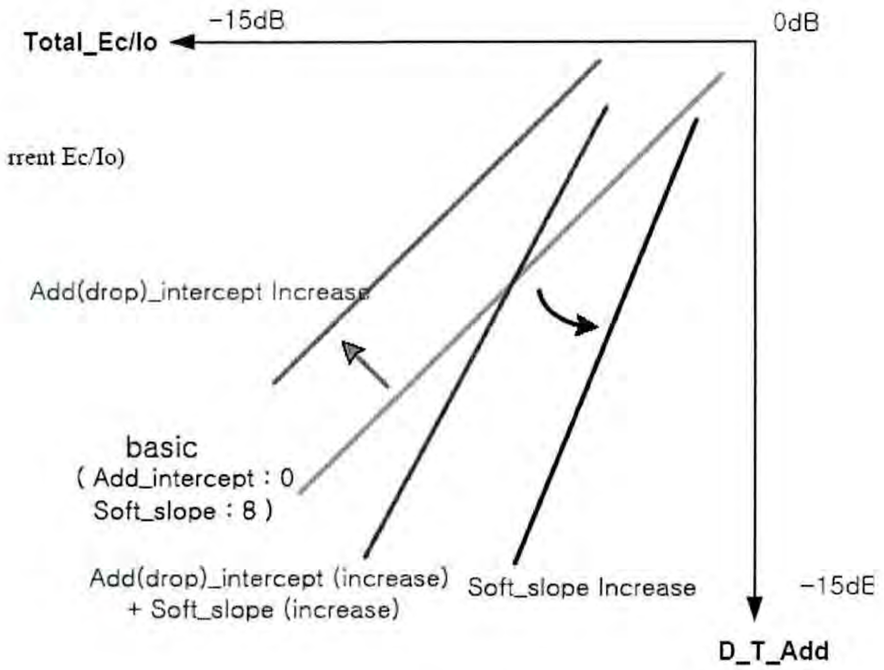


Fig 3.13.2 Add_intercept and Soft_slope

3.14 Conclusion of handoff

Soft handoff technology of the CDMA system fully utilizes the character of direct-spread system. In comparison with the hard handoff technology, it has the following advanced performance-

- During soft handoff, the MS only breaks the connection with the original BTS after it gains the link with the new BTS, thus the probability of communication interruption is greatly reduced.

- During soft handoff, the diversity receive method is adopted for both of the MS and the BTS to against fading. That is to say, addition of transmit power of the MS is unnecessary. At the same time, the macro diversity of BTS can guarantee normal communication if one the BTSs involved in the soft handoff receives the signal of MS. As the reverse power control is used, transmit power of MS can be reduced to the least. And this further reduces the interference caused by the MS to the system.

For the uplink, soft/softer handoff can provide diversity gain to reduce the transmit power of the MS. As a result, the reverse coverage as well as the reverse capacity is improved. For the downlink, the excessive soft/softer handoff branches may occupy too many forward WALSH resources, power resources and CE of the channel unit. In order to limit soft/softer handoff ratio, dynamic handoff can be adopted with careful observation of network quality [8-9].

The MS cannot obtain the link with the new BTS instantly after entering the soft handoff area, but it can join the queue of handoff wait, thus the congestion rate of the system is reduced.

CHAPTER 4

Capacity Analysis

4.1 Introduction

In the CDMA system, all cells can share the same spectrum, which is favorable for increasing the capacity of the CDMA system. However, due to the reuse of the same frequencies, the interference among subscribers exists in the system. This kind of multi-access interference also restrict the system capacity. The capacity of a radio system is determined by both the forward and reverse links. The forward capacity depends upon the total transmitting power of the cell and the distribution of the transmitting power in the traffic channel and other additional channels. While the reverse capacity is limited by multi access interference [11-12].

4.2 Analysis of reverse capacity

4.2.1 Interference analysis

Mainly 4 types of interference exist in CDMA systems- I_{own}, I_{other}, P_N & I_{ext}. Hence the total interference can be described as-

$$I_{TOT} = I_{own} + I_{other} + I_{ext} + P_N$$

I_{TOT} = Total interference

I_{own} = Interference from subscribers in the local cell

I_{other} = Interference from subscribers from the neighboring cells

P_N = Background noise of receiver

I_{ext} = External interference

P_N is described as-

$P_N = 10 * \log(KTB) + NF$

K: Boltzmann constant = 1.38 *10^{-23} J/K

T: Kelvin temperature, the normal temperature is 290 K

W: Signal bandwidth, the bandwidth of CDMA1X signal is 1.2288MHz

NF : Noise figure of receiver

$P_N = 10 * \log(KTB)$ = -113dBm/1.2288MHz

NF = 4 dB (Typical value of BTS)

$P_N = 10 * \log(KTB) + NF$ = -109.8dBm/1.2288MHz

I_{own} is described as-

For each MS, all other MS acts as an interference source. If the power received by user j is Pj, then it should overcome the interference of I_{TOT}.

Provided that the power control is ideal, then:

$$P_j = \frac{I_{TOT}}{1 + \frac{1}{(Eb/N_t)_j} \cdot \frac{W}{R_j} \cdot \frac{1}{v_j}}$$

Here

$(Eb/N_t)_j$ = demodulation threshold for the jth user

$\frac{W}{R_j}$ = processing gain for the jth user.

v_j = voice activity factor

The interference of the subscribers in the local cell is equal to the sum of all other subscribers' power reaching the receiver. Hence

$$I_{own} = \sum_{1}^{N-1} P_j$$

Now we introduce interference factor which is defined as the ratio of interference from the neighboring cell to interference from its own cell. If the subscribers are distributed uniformly, then the typical interference factor for dense urban clutter is 0.55, for urban 0.45 and for suburban the value can be considered as 40-45 [30].

$$f = \frac{I_{other}}{I_{own}}$$

If we ignore the external interference, then

$$I_{TOT} = I_{own} + I_{other} + P_N$$

$$= (1+f)\sum_{1}^{N-1} \frac{I_{TOT}}{1 + \frac{1}{(Eb/N_t)_j} \cdot \frac{W}{R_j} \cdot \frac{1}{v_j}} + P_N$$

Let, $L_j = \dfrac{I_{TOT}}{1 + \frac{1}{(Eb/N_t)_j} \cdot \frac{W}{R_j} \cdot \frac{1}{v_j}}$

Hence, $I_{TOT} = (1+f)\sum_{1}^{N-1} L_j + P_N$

The noise rise is defined as the ratio of I_{TOT} to P_N

Noise rise= $\dfrac{I_{TOT}}{P_N} = \dfrac{1}{1-(1+f)\sum_{1}^{N-1} L_j} = \dfrac{1}{1-n_{ul}}$

Defining n_{ul} as the uplink load factor

$$n_{ul} = (1+f)\sum_{1}^{N-1} L_j = (1+f)\sum_{1}^{N-1} \frac{I_{TOT}}{1 + \frac{1}{(Eb/N_t)_j} \cdot \frac{W}{R_j} \cdot \frac{1}{v_j}}$$

The main components of the reverse interference depend upon the cell load. When the load factor is equal to 1, I_{TOT} reaches infinite. In this case, the corresponding capacity is called the limit capacity.

The relationship between reverse interference and load factor is depicted by the following figure-

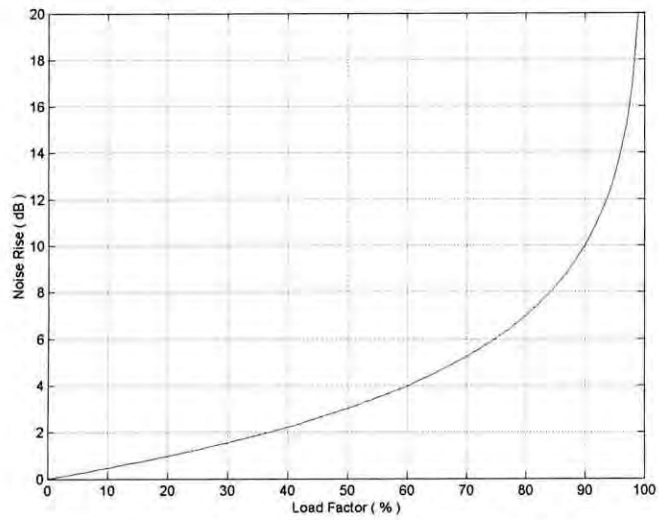


Fig 4.2.1: Interference vs loading characteristic

4.2.2 Soft Blocking Characteristics of CDMA System

Based on the soft capacity characteristics of CDMA, the soft blocking is introduced to analyze the capacity of CDMA. Soft blocking refers to the following process: There are sufficient channels available in the BTS, but there are too many subscribers in the coverage of this BTS. In this case, if an additional subscriber goes into this coverage and makes a call, the interference will exceed the previously set threshold so that the call could be rejected. To obtain a larger system capacity, the operator can reduce the requirement of communication quality and the blocking load so that the system capacity would vary with the quality index. The soft blocking is a kind of index blocking, where the system capacity will vary with the load and service quality [15-16].

Below is the reverse capacity model formula of the system soft blocking in Gaussian Approximation:

$$B_{cdma} = Q\left(\frac{\frac{W}{R} X_0 - \overline{M} \alpha \rho e^{\frac{1}{2}\beta^2\sigma^2}(1+\varepsilon)}{\sqrt{\overline{M\alpha^2}\rho^2 e^{2\beta^2\sigma^2}(1+\varepsilon')}}\right)$$

Where

$$Q(x) = \int_x^{\infty} \frac{1}{2\pi} e^{-t^2/2} dt$$

$$\rho = e^{\beta(E_b/N_t)}, \beta = (\ln 10)/10$$

B_{cdma} : Soft Blocking probability

W/R : Processing gain

$\overline{\alpha}, \overline{\alpha^2}$: 1st and 2nd order voice activity factor

$\varepsilon, \varepsilon'$: 1st and 2nd order Interference factor

σ: Demodulation threshold standard deviation (power control variance)

ρ: Mean demodulation value

X_0 : Blocking load of system

$\overline{M}$: Erl of system.

From the above formula, the reverse capacity of the CDMA 1X system is closely related to power control precision, demodulation threshold of the system (Both the access rate and motion velocity of the subscriber will directly affect the demodulation threshold), assumed average voice activity factor, cell interference, cell load and soft blocking ratio of system, that is to say, the reverse capacity of the CDMA system will fluctuate as the network environment varies. Among these parameters, the power control precision is a device parameter, and demodulation threshold, activity factor and cell interference are system parameters. The soft blocking ratio of system is a planning index. All these parameters can not be adjusted except that the cell load can be adjusted within a certain range during the network planning.

4.3 Analysis of Forward Capacity

In the analysis of the forward capacity of the CDMA1X system, power loss of forward link, subscriber distribution, link signal attenuation, system demodulation threshold and power control precision must be taken into consideration [11],[32]. The forward capacity is characterized by the following:

• Different types of services will affect the total forward capacity of the equipment.

• The motion velocity will lead to different system demodulation thresholds and will greatly affect the forward capacity of the system.

• The forward interference is mainly the multipath components in the centre of a cell, and the neighbour cell interference on the border of the cell,

• The capacity of forward link depends on the total transmit power of the cell as well as the transmit power distribution on the traffic channel and other additional channels.

• The subscriber distribution directly affects the forward capacity of the BTS.

Below is the theoretical analysis result.

$$M(P_{\max}) = \frac{PG_{traf}}{K_{traf}.\alpha.\rho_{traf}}[\frac{10^{-M(dB)/10}.P_{\max}}{N_m L_T(R) + K_f.P_{\max}} - \rho_{pil} - \frac{\rho_{sync}}{PG_{sync}} - N_p \frac{\rho_{pag}}{PG_{pag}}]$$

P_{total}: Transmit power of BTS

P_{pil}: Power of synchronous channel

P_{pag}: Power of paging channel

P_{traf}: Power of traffic channel

N_p: Number of paging channels

K_{traf}: Coefficient of subscriber distribution

α: Voice activity factor of traffic channel

M: Activated subscribers of system

Kf: Coefficient of system interference

ρ_{pil}: Demodulation threshold of pilot channel

ρ_{sync}: Demodulation threshold of synchronous channel

ρ_{pag}: Demodulation threshold of paging channel

ρ_{traf}: Demodulation threshold of traffic channel

G_{pil}: Spreading gain of pilot channel

G_{sync}: Spreading gain of synchronous channel

G_{pag}: Spreading gain of paging channel

Gtraf: Spreading gain of traffic channel

In the central area of a cell, the forward interference is mainly the multipath component. At the borders of a cell, the forward interference is mainly the interference from the neighboring cells. The subscriber distribution has direct influence upon the forward capacity of the BTS.

4.4 Comparison of Capacity Characteristics between IS-95 and CDMA-1X

- **Reverse capacity**

The coherent demodulation of reverse pilot is adopted for traffic channels and the Turbo code is used for the data service so that the reverse demodulation performance is improved. The reverse capacity of the CDMA-1X is two to three times that of the IS-95.

- **Forward capacity**

The quick power control technology is used for the forward channel so that the power control accuracy is improved and the mean forward transmitting power is decreased. The Turbo code is used for the data service. The forward capacity of the CDMA-1X is 1.5 to 2 times that of the IS-95 [13].

CHAPTER 5

Simulation Results and Discussions

5.1 Introduction

Under current fast growing market demand, it has been the most crucial demand for all cellular service providers to improve system capacity per frequency since spectrum can be depleted quickly if system capacity is not maximized. Although CDMA technology has higher system capacity compared to other technologies, the fundamental bottleneck of cellular systems- limited frequency spectrum has not changed. Many cellular service providers only consume 5 MHz of bandwidth, some even less. Under such circumstance, all cellular service providers need to look for a solution to support more and more subscriber demands with limited spectrum resource.

5.2 Study of network performance from Simulation

5.2.1 Traffic Map

In order to realize the fast growing demand of mobile cellular services, a test densely populated city is considered with mixed clutter configuration- Dense urban, urban and suburban. The traffic distribution is considered based on environment. All sites are of S111 type. After 2 years the subscriber density has become double. Network performance like connectivity status, coverage, signal to interference ratio everything has degraded abruptly. Let assume initially the subscriber distribution is as follows-

Dense urban: 3957 subs/sq km

Urban: 1646 subs/sq km

Suburban: 164 subs/sq km

5.2.2 Propagation model

To analyze network performance as well as connectivity status selection of appropriate propagation model is needed for each clutter. The propagation model is the foundation of the coverage planning and is used in prediction of influence on path loss in the radio wave propagation by the terrain and artificial environments. Different propagation models have different working frequency ranges. Some commonly used propogation models are given below [39]:

Several common Propagation model

Model	Application range
Okumura-Hata	Applicable to the 150-1500 MHz macrocell
Cost231-Hata	Applicable to the 1500-2000 MHz macrocell
Walfish-Ikegami	Applicable to prediction in the 800-2000MHz
Keenan-Motley	Applicable to the 800-2000MHz indoor
K parameter Models	Applicable to the 800-2000MHz macrocell

In this thesis, Okumura Hata model is used to realize coverage prediction. The model needs to be adjusted for different clutter.

5.2.2-1 Okumura-Hata and Cost-Hata

Hata Formula

Hata formula empirically describes the path loss as a function of frequency, receiver-transmitter distance and antenna heights for an urban environment. This formula is valid for flat, urban environments and a 1.5 meter mobile antenna height.

Path loss (*Lu*) is calculated (in dB) as follows:

$$L_u = A_1 + A_2 \log(f) + A_2 \log(h_{TX}) + (B_1 + B_2 \log(h_{TX})) \log d$$

Where,

f is the frequency (MHz).

h_{TX} is the transmitter antenna height above ground (m)

d is the distance between the transmitter and the receiver (Km).

The parameters A_1, A_2, A_3, B_1 and B_2 can be user-defined. Default values are proposed in the table below:

Parameters	Okumura-Hata $f \leq$ 1500 MHz	Cost-Hata $f >$ 1500 MHz
A_1	69.55	46.30
A_2	26.16	33.90
A_3	-13.82	-13.82
B_1	44.90	44.90
B_2	-6.55	-6.55

Default Hata parameters

Corrections of Hata Model:

As described above, the Hata formula is valid for urban environment and a receiver antenna height of 1.5m. For other environments and mobile antenna heights, corrective formulas must be applied.

$L_{model1} = L_u - a(h_{RX})$; for large city and urban environment

$L_{model1} = L_u - a(h_{RX}) - 2\log^2(f/28) - 5.4$; for suburban areas

$L_{model1} = L_u - a(h_{RX}) - 4.78\log^2(f) + 18.33\log(f) - 40.94$; for rural areas

$a(h_{Rx})$ is a correction factor to take into account a receiver antenna height different from 1.5m.

Environments	a(Hr)
Rural/Small city	$(1.1\log(f) - 0.7)h_{Rx} - (1.56\log(f) - 0.8)$
Large city	$3.2\log^2(11.75h_{rx}) - 4.97$

5.2.3 Simulation

After defining the area of different clutter and selection of propagation model simulation is done to realize network quality and capacity status. U-net simulation tool of Huawei Technologies has been used to observe capacity enhancement as well as network quality. This tool is specially designed for 3G supporting GSM/TDMA, GPRS-EDGE, cdmaOne, W-CDMA/UMTS and CDMA 2000/1x RTT/EVDO. The simulation process is known as Monta Carlo simulation which is one type of static simulation. U-net randomly distribute user location and user profile based on the number of users and density, then generate a certain quantity of network instantaneous state—"Snapshot". The overall understanding of the network performance is done averaging the results of multiple "Snapshots". This tool is unable to simulate dynamic thresholds [39].

5.3 Enhancement of system capacity

In CDMA system the reverse capacity is mainly interference limited. In this thesis 6 sector configuration BTS is proposed to deploy rather than conventional 3 sector BTS and interference cancellation technique is implemented on the MSs to maximize the capacity both forward and reverse link [15], [16], [38]. Soft handoff thresholds are proposed to optimize since MSs with interference cancellation capability may have a wider soft handoff region than that of regular MSs. Though soft handoff always combats interference, it introduces overhead limitation on the forward link, specially transmit power, channel element and Walsh code. Hence if the soft handoff thresholds are not optimized properly, the overall network capacity will actually be degraded. Intelligent admission control algorithm should be implemented as well so that MSs that are interference capable have a better chance of being admitted and hence occupy less resource than a regular MS thereby increasing network capacity.

In chapter 4, capacity calculation per cell is analyzed in terms of erl. To calculate the capacity of each site, we need to multiply the cell capacity by sectorization gain and no of carriers [27-28]. Suppose for M sector site with N no of carriers the site capacity will be:

$Ts = M * N * \overline{M}$, where $\overline{M}$ = erl per cell (considering no sector to sector interference).

However since CDMA is self interference system, there exists interference between sectors. For 3 sector antenna, typical sectorization gain value is 2.55 [16] and for 6 sector the value can be considered as 4.8.

Hence actual capacity per BTS-

$Tb = m * N * \overline{M}$; where m =sectorization gain

Therefore the capacity of a 3 sector single carrier BTS-

$T_{3S1} = 2.55 * 1 * \overline{M}$;

The capacity of a 3 sector dual carrier BTS-

$T_{3S2} = 2.55 * 2 * \overline{M} = 5.1 * \overline{M}$;

And the capacity of a 6 sector single carrier BTS-

$T_{6S1} = 4.8 * 1 * \overline{M}$;

Hence even with a single carrier it is possible to reach almost the same capacity as that of dual with 6 sector configuration. Here capacity improvement of 6 sector is compared with that of 3 sector using same spectrum resource.

5.4 6 sector BTS configuration

The BTS is divided under mainly following 3 sections-

1、RF Subsystem

CMTR: Multi-Carriers Transceiver Module

CMPA: Multi-Carriers Power Amplifier

CDDU: Indoor-BTS Dual Duplexer unit

IDFU: Indoor-BTS Duplexer Filter Unit

2、Baseband Subsystem

CCPM: Compact-BTS Channel Processing Module (1x)

CECM: Compact-BTS External Channel (1x EV-DO)

BCIM : BTS Control Interface Module

BCKM: BTS Control & Clock Module

3、Power Supply Subsystem

PSU: Power Supply Unit

4、Power consumption:

S111: 20*3=60 Watt

S111111: 20*6=120 Watt

S222: 20*2*3=120 Watt

So it is found that the resource required for 6 sector single carrier and 3 sector dual carrier is almost the same.

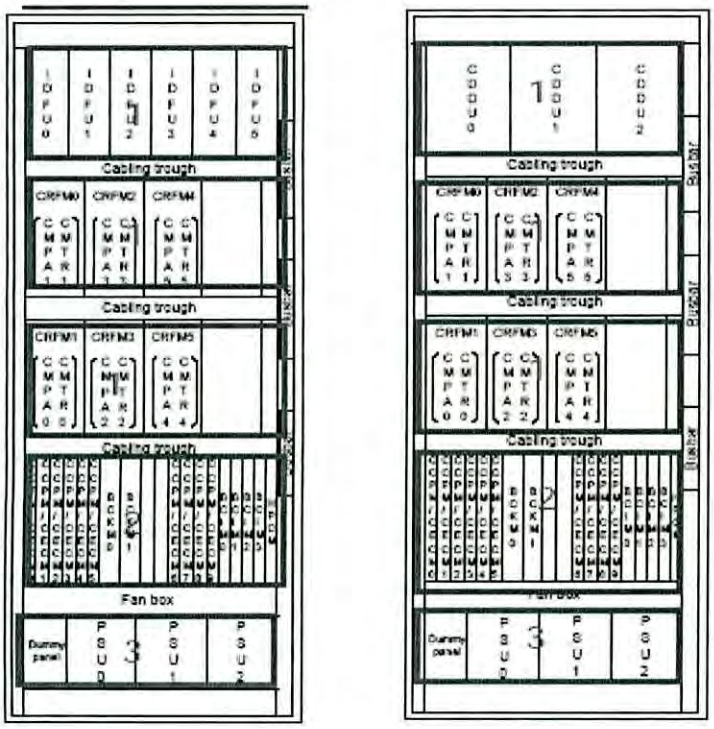


Fig: 5.4(a) 6 sector BTS (b)Fig: 3 sector BTS

5.5 Analysis of capacity improvement from Simulation result

To investigate the performance (in terms of users successfully connected) of 6 sector configuration, the test city is considered to have double the subscriber density than earlier. Under highly loaded condition, too many soft handoff also limits the network capacity. So soft handoff threshold Tadd is optimized as well and finally network performance is observed under 6 types of configuration- 3 sector single carrier BTS with -12 dB Tadd threshold, 3 sector single carrier BTS with -14 dB Tadd threshold, 6 sector single carrier BTS with -12 dB Tadd threshold, 6 sector single carrier BTS with -14 dB Tadd threshold, 3 sector dual carrier BTS with -12 dB Tadd threshold, 3 sector dual carrier BTS with -14 dB Tadd threshold. The higher the threshold the lower the soft handoff ratio and the higher the system capacity [13-14].

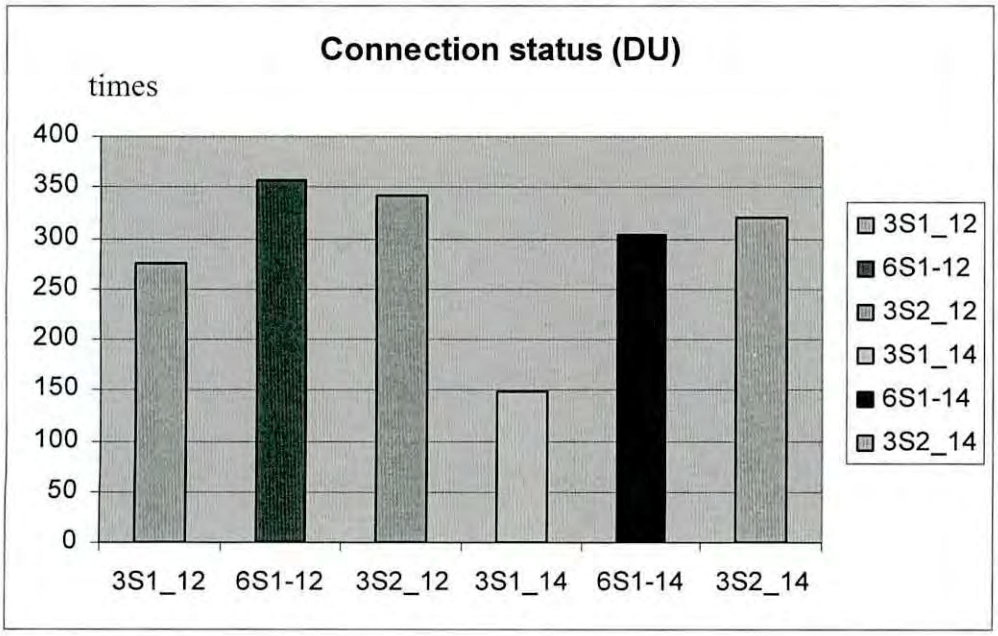


Figure 5.5.1 Dense urban connection status for same subscriber density.

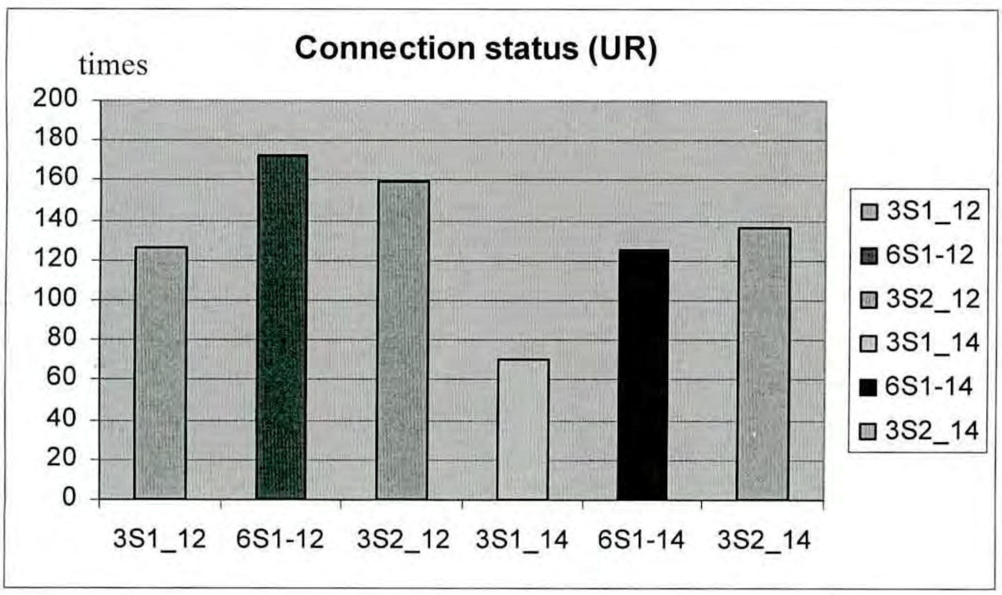


Figure 5.5.2 Urban connection status for same subscriber density.

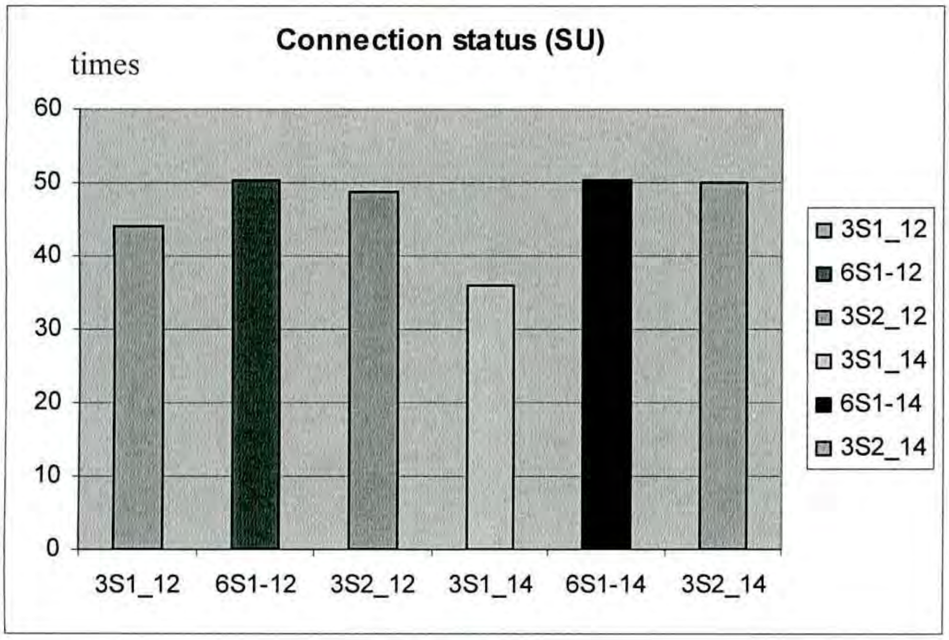


Figure 5.5.3 Suburban connection status for same subscriber density.

For each clutter, the maximum capacity is found under 6 sector configuration with -12 dB Tadd threshold which is even better than the dual carrier.

5.6 Analysis of network performance from Simulation result

Usually in CDMA system 65° beam pattern antenna is chosen for 3 sector. For 6 sector BTS we select 33° beam pattern antenna to limit sector to sector interference. Network performance is observed for different types of clutter separately in terms of Ec/Io (Ec is the pilot channel energy per chip, Io is the interference spectral density), handoff status and Receive level.

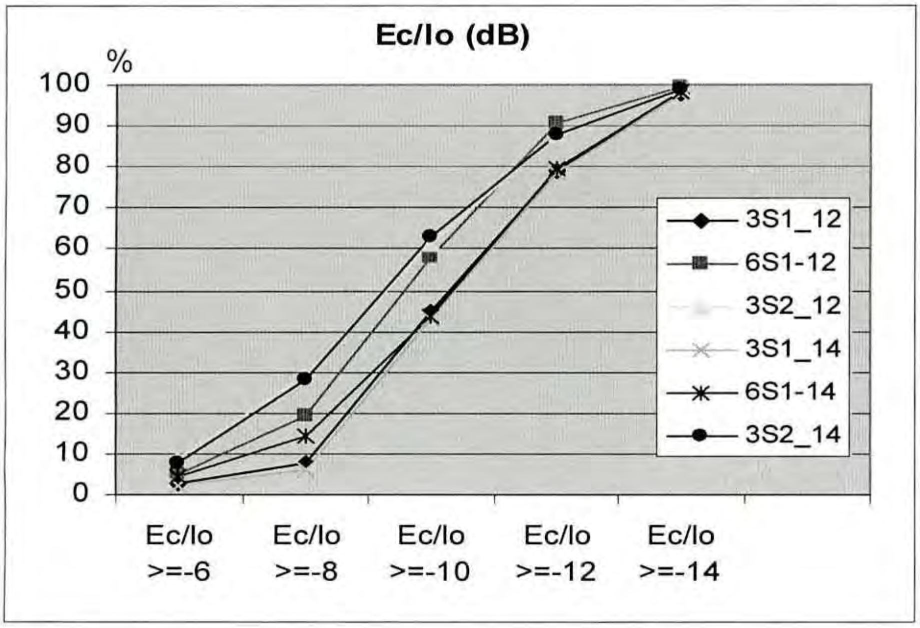


Figure 5.6.1 Ec/Io status under dense urban clutter

Good Ec/Io percentage (above -10 dB) for 6 sector is almost the same as that of 2 carrier.

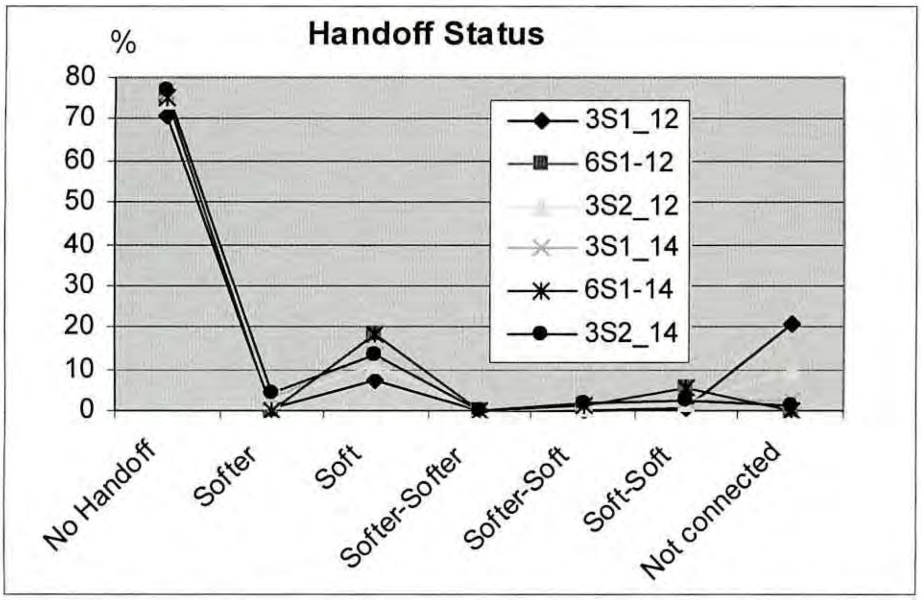


Figure 5.6.2 Handoff status under dense urban clutter

Handoff performance is also better found for 6 sector and no connection failure found for this case.

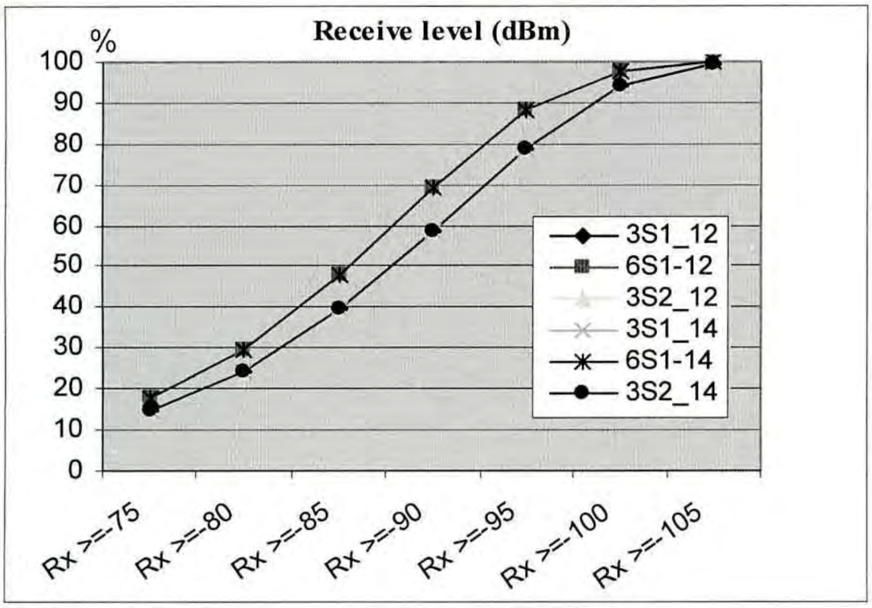


Fig 5.6.3 Rx level under dense urban clutter

Handoff threshold has no influence on Rx level and Rx level is quite better with 6 sector.

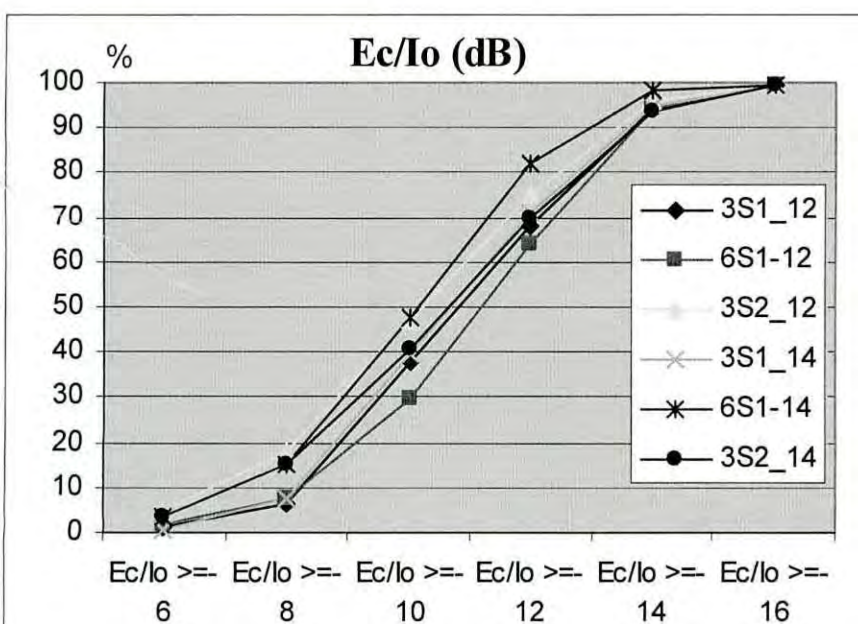


Fig 5.6.4 Ec/Io status under Urban clutter

Here Ec/Io performance of 6 sector with -14dB threshold is almost the same as that of dual carrier but under -12 dB threshold value Ec/Io becomes poor.

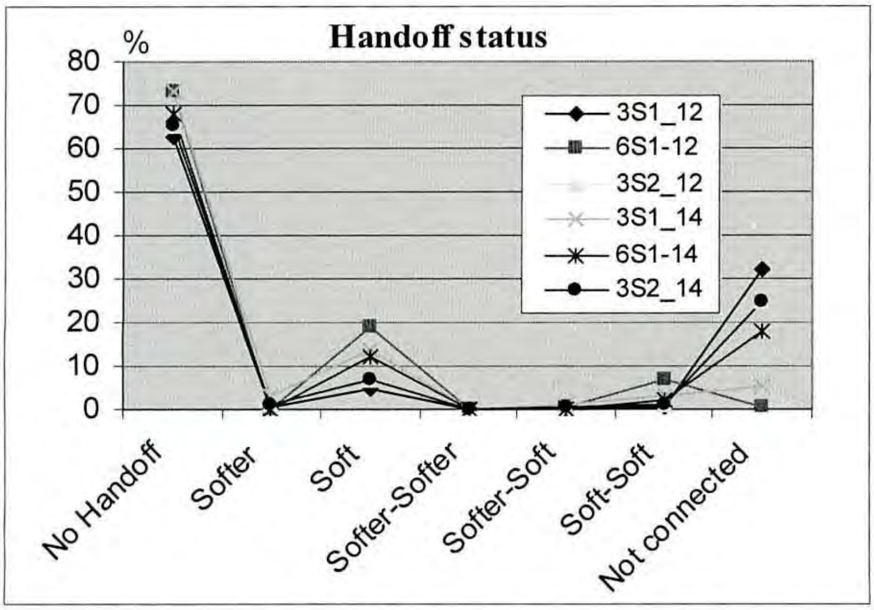


Fig 5.6.5 Handoff status under Urban clutter

6 sector BTS shows better handoff status in terms of "not connected" state.

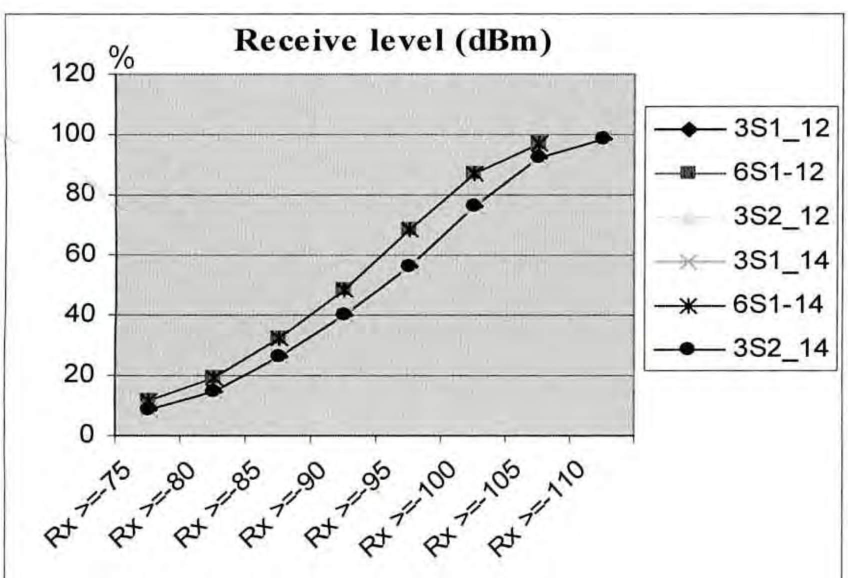


Fig 5.6.6 Rx level under Urban clutter

6 sector BTS has better Rx level compared with 2 carrier and 3 sector.

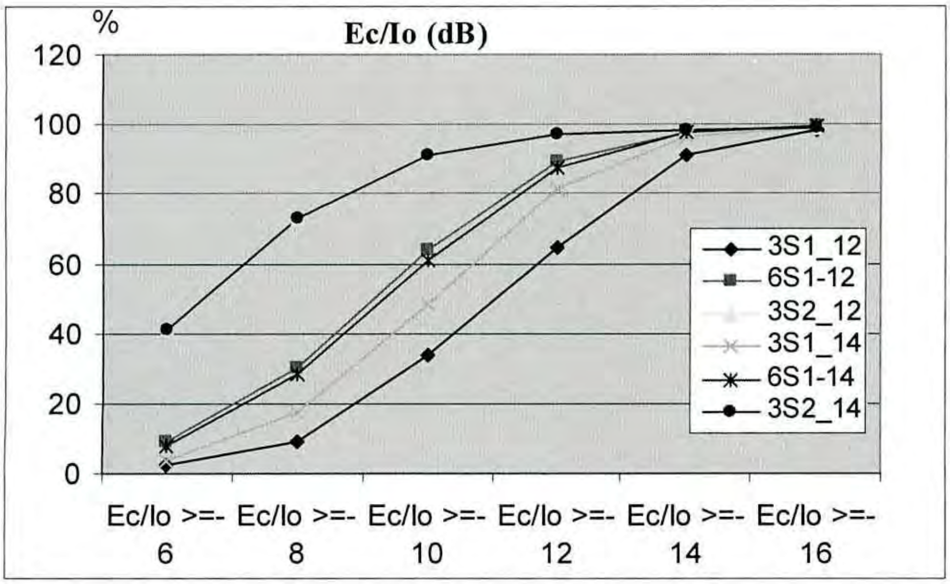


Fig 5.6.7 Ec/Io status under Sub Urban clutter

Foe suburban clutter, 2 carrier BTS show much better Ec/Io performance than that of 6 sector.

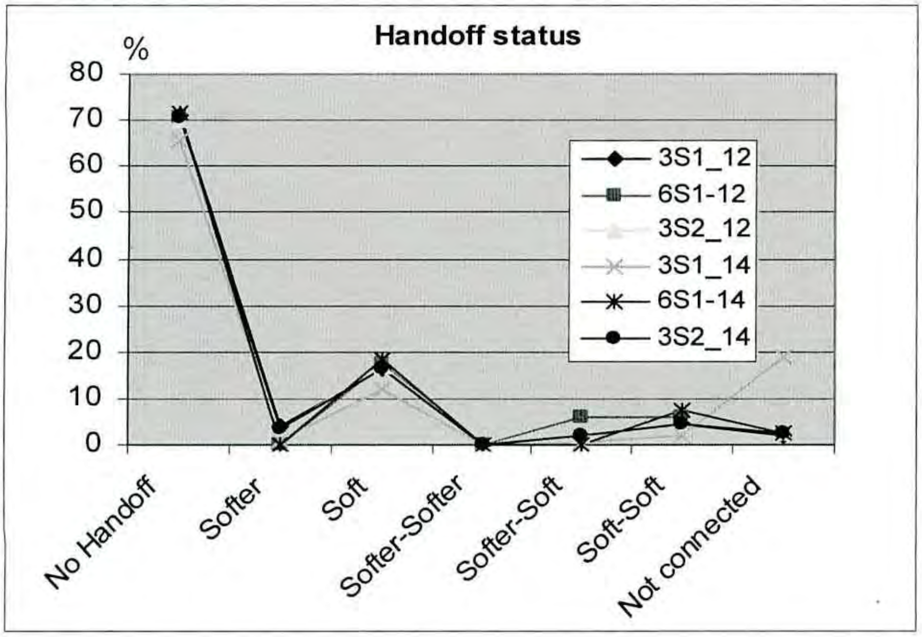


Fig 5.6.8 Handoff status under Sub Urban clutter

6 sector and 2 carrier show almost same handoff performance.

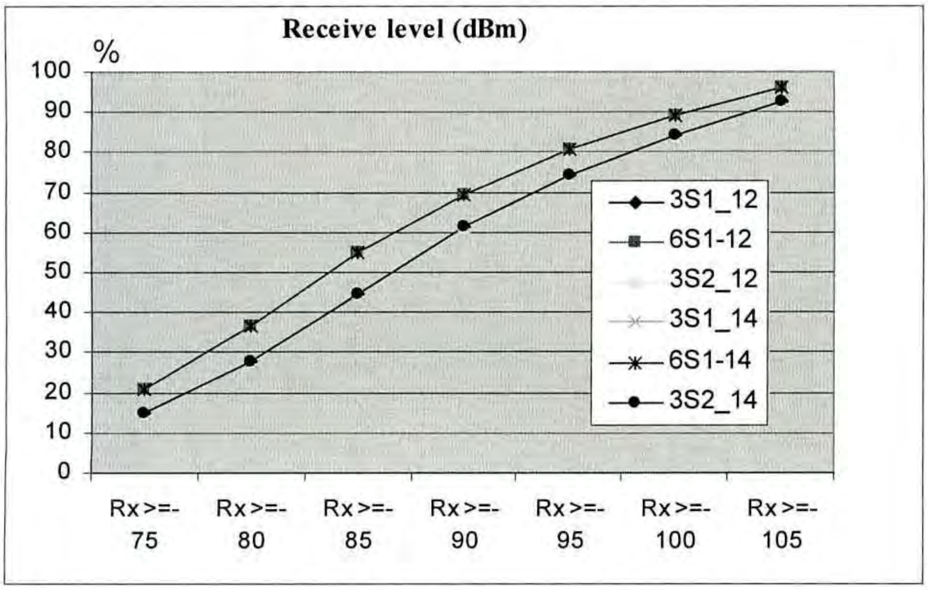


Fig 5.6.9 Rx level under Sub Urban clutter

Rx level performance is similar to dense urban and urban clutter.

5.7 Interference cancellation over system capacity

From interference analysis it is found that the lower the threshold (Eb/Nt) requirement the higher the system capacity. If interference cancellation technique is applied on the MSs along with intelligent admission control algorithm, the threshold requirement will be lower and the system capacity will be increased [13-14]. From the following figure, the capacity relationship with demodulation threshold is seen for different clutter type.

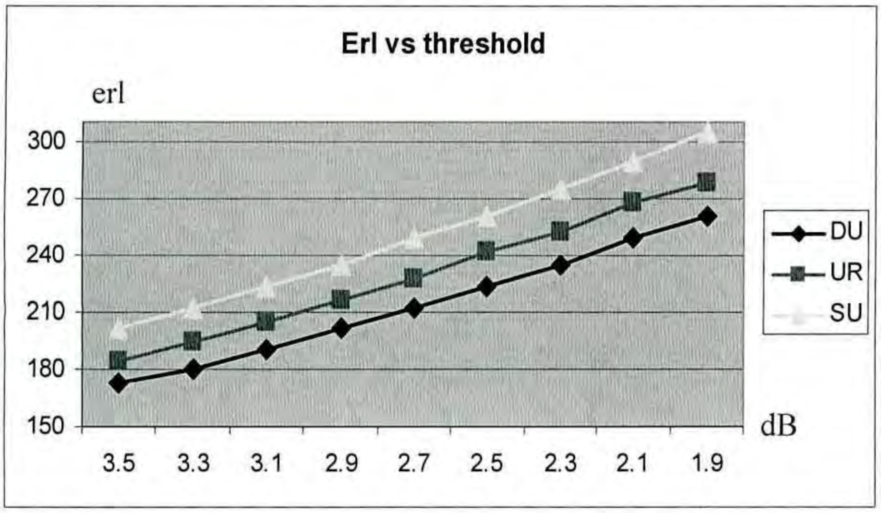


Fig 5.7 Relationship of Capacity with threshold

CHAPTER 6

Conclusions and Suggestions

6.1 Conclusion

We have successfully demonstrated the capacity improvement of CDMA system with 6 sector configuration rather than conventional 3 sector and also compared its performance with dual carrier network. Optimization of soft handoff setting has a significant impact on the capacity gain particularly with 3 sector. The maximum capacity is found under 6 sector configuration with -12 dB Tadd threshold. The result is pretty impressive since-

- Without introducing any advanced technologies of CDMA system (e.g., improved coding gain, fast power control, modulation or demodulation techniques etc) we can reach almost twice the capacity within same spectrum resource with good network quality.

- This 6 sector configuration is particularly effective in dense urban areas with scattered congested sites. This will eliminate the need to upgrade the whole area to dual carrier to avoid hard handoff. Only the RF subsystem of the highly congested sites needs to be upgraded for 6 sector configuration, no need to upgrade all sites altogether.

- 6 sector configuration is cost-effective compared to dual carrier since it requires least bandwidth. Hence the license fee cost for spectrum usage will be almost half.

- 6 sector configuration with optimized soft handoff threshold can be implemented to any CDMA system i.e., IS-95, CDMA20001x, WCDMA and its evolutions.

6.2 Suggestions

- **Cell Split antenna**

For 6 sector configuration, 33° narrow beam pattern antenna is used to keep the sector to sector interference within a tolerable range. 65° cell split antenna can also be implemented which in some cases shows better performance than 33°. Cell-split antenna is a Cell-split based technology which emerges as a solution for growing overlay and capacity demand of mobile networks. It can be realized by antenna arrays with special feeding network.

According to the split cellular coverage shape, there must be a split antenna pattern, that the conventional 65°antenna pattern is split into two halves. The cell-split antenna has 4 ports. Refer to figure 6.2.1, port 1 and port 2 are at the one sector but the polarization is different. Port 3 and port 4 are at anther sector with different polarization.

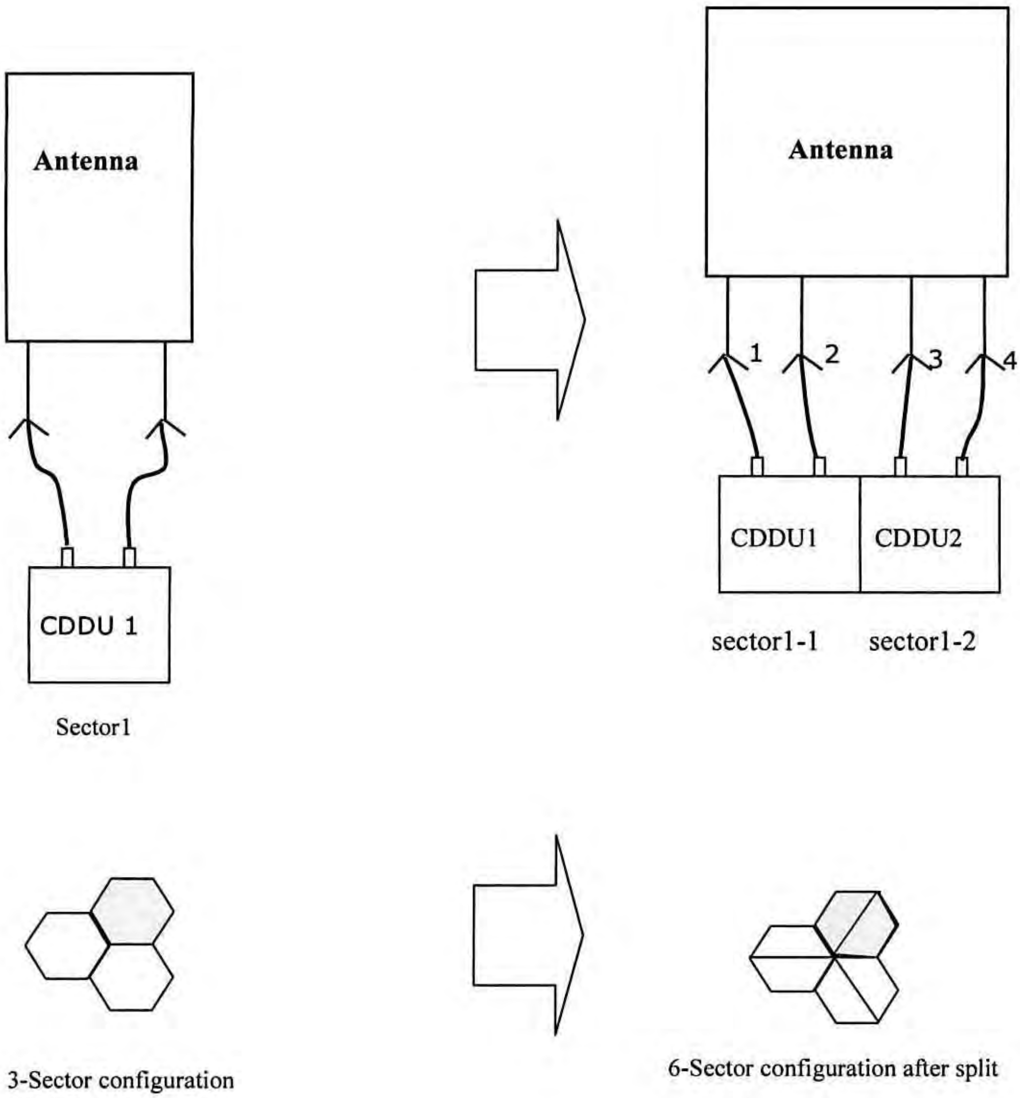


Figure 6.2.1 Concept of cell split antenna

The ideal pattern of a split antenna is shown in Figure 6.2.2-(a). Figure 6.2.2-(b) is a practical pattern

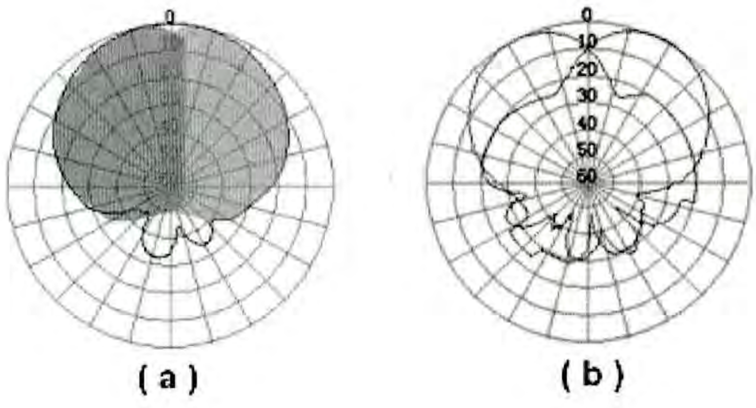


Figure 6.2.2 the pattern of a split antenna

The profile of two halves pattern of a Cell-split antenna is similar to a 3-sector, so the coverage with a Cell-split antenna is somewhat like a common 65°antenna. In this way, network planning can be forecasted and simple to plan the networks.

Unlike the general 33° six-sector antenna, the Cell-split antenna has a asymmetric azimuth pattern, this property make the split antenna have smaller overlap over the 6-sector 33° antenna pattern reducing softer handoff rate, on the other hand, it improves Ec/Io in between sectors due to low sector to sector interference. A Cell-split antenna is composed of two X-polar antenna in a physical radome entity, its size is larger than general 33° antenna, but it occupies much smaller space than general 33° antenna because of the need of three Cell-split antenna in 6-sector cell.

- **PN planning and Neighbor list planning**

For 6 sector configuration, the PN planning and neighbor cell planning will be more complex and need to carefully optimize otherwise the network will suffer from high interference which in turn will increase call drop.

- **Product support**

  6 sector configuration must be supported by the product.

- **Dynamic soft handoff**

To reduce the soft handoff ratio in high traffic area, dynamic soft handoff can be implemented. But soft handoff thresholds have to be carefully optimized so that call drop ratio doesn't increase because 90% of the call drop occurs due to handoff failure.

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