NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

CODE DIVISION MULTIPLE ACCESS

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EE – 400

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Finally, I want to thank my family, especially my parents. Without their endless support and love for me. I would never achieve my current position.

ABSTRACT

AMPS analog systems are referred to as first generation wireless technology and digital systems such as CDMA, TDMA and GSM are referred to as second generation. This type of technology planning ensures a graceful and cost effective migration when the market does require the introduction of advanced services and features.

CDMA is one of the most important concepts in any cellular telephony system. The advantages of CDMA system are longer portable talk time, better security, less fading due to wider bandwidth, simpler handoff procedures since the same set of frequencies are always used, and less quality loss per added user than Frequency Division Multiple Access (FDMA) or TDMA.

Good wireless networks have solved many of our networking problems and will continue to do so in the future. It is almost impossible to know exactly what the future will bring and how this technology will change, but it promises to continue to evolve and become more important in people's daily life.

CONTENTS

INTRODUCTION

Communication in the past few decades has gone through various trends and stages. In the past, voice based technologies such as cellular phones revolutionized communication, but in the future, data based wireless communication services will be deployed to provide "anywhere, anytime" communication.

In order to achieve this goal, these technologies must have the capability to support multimedia and high data rate services like voice, audio, image, video and data. High quality end-users services place stringent demands on the design of both single user systems waveforms and multiple-access schemes. Spread spectrum based techniques such as the Code Division Multiple Access (CDMA) has been recently proposed as candidates for continued high rate services that degrade gracefully as new users enter the communication cell.

The chapter 1 discusses introduction to code division multiple access. In this chapter we discuss basic functions of CDMA. Like how it works, physical layers, signal structure, which tells its channels and codes. Network layers in which we will see the message bits.

The chapter 2 address direct sequence CDMA, which is a type of CDMA. In this chapter we see the basic elements DS CDMA. Properties of ds cdma.its basic elements.

In chapter 3 we see another type of CDMA which is wideband CDMA. This chapter tells about its physical channels . that how its better then other techniques.It is know used in most part of the world.

Chapter 4 is about Optical CDMA systems. This is also another type of CDMA. In this chapter we will see implementation methods and applications of code division multiple access using an optical carrier in both the fiber optic and the wireless optical channel. The differences of synchronous and asynchronous systems and coherent and noncoherent systems are described.

CHAPTER ONE

INTRODUCTION TO CDMA

1.1 Introduction

CDMA (Code Division Multiple Access) is an advanced digital wireless transmission technology. It is one of driving forces behind the rapidly advancing personal communications industry. In this chapter, we presents an overview of concepts related to CDMA technology, describes the principal attributes and techniques of CDMA system. We also introduces some of applications in the CDMA system. We finally gives a brief introduction to management of CDMA network and CDMA standards.

Wireless communications have shown a profound effect on our daily life. In less than ten years, cellular telephones have attracted more than a hundred million subscribers in the United States, Europe, and Asia. Since mobile personal communications have been introduced, the service providers have been limited by short-term capacity solutions offered by both technology of industry and the frequency real estate relinquished by FCC.

At the beginning, cellular service providers were given 50 MHz of channel spectrum, divided by two systems (A&B), further divided by forward and reverse communication paths, effectively leaving just 12.5MHz each way per system. Since this spectrum is not expected to increase in foreseeable future, the cellular industry must look at different technologies to increase capacity without sacrificing quality of service.
The most popular one is 30kHz analog channels, which is known as FDMA, Frequency Division Multiple Access. As larger capacity is needed due to the high growth rate of cellular mobile subscribers, a transition from analog to digital system is expected. Digital communication based on time Division Multiple Access (TDMA) has been a popular solution to some of the shortcomings of AMPS (Advanced Mobile Phone System) technology.

In the TDMA system, the cell sequentially scans through the mobiles, each of which uses the same 30 kHz frequency band, but at different time slot. In this way, the number of cells does not increase. But since there are now more than one user per 30kHz channel, the total number of users per cell increases.

Currently, TDMA has the ability to service 3 (up to 6 in the near future) conversations per 30kHz bandwidth, effectively tripling the capacity of AMPS equipment while providing privacy through it's intrinsic complexity of signal generation.

As an alternative to TDMA, a digital cellular system using Code Division Multiple Access or CDMA has been developed. CDMA uses a digital wideband spread-spectrum technology to transmit multiple, independent conversations across single or multiple 1.25 MHz segments of radio spectrum. All of signal's power in a CDMA wireless link are spread simultaneously over a wide frequency band, transmitted over the same frequency band, and then collected onto their original signals at the receiving end. The spread signal would then appear in a noise like signal scattered over the same wide transmission band with a much lower power per bandwidth.

The key to success in this operation is that the signal meant for a given user is "tagged" with a distinctive Pseudo-random Noise (PN) code pattern that only the user's receiver can recognize. The receiver knows in advance how the transmitter will spread the spectrum and based on this information, it compresses and reconstitutes the desired signal, leaving the unwanted signals spreading over the available frequency band as background noise.

Figure 1.1 CDMA analogy

The above picture is a CDMA analogy. Four speakers are simultaneously giving a presentation, and they each speak a different native language: Spanish, Korean, English, and Chinese. You are in the audience, and English is your native language. You only understand the words of the English speaker and tune out the Spanish, Korean, and Chinese speakers. You hear only what you know and recognize. The same is true for CDMA. Multiple users share the same frequency band at the same time, yet each user only hears his or her own conversation. Each conversation is specially encoded and decoded for each particular user.

The world's first CDMA network began commercial operation in Hong Kong in September 1995. This was followed in 1996 by the launch of two public CDMA systems in Korea. These three networks were closely monitored by the cellular industry to see if the promises of the new technology could really be delivered. By the middle of 1997, with one and a half million users being supported on these systems, it was clear that most of the questions had been satisfactorily answered. CDMA is now fully accepted as a mainstream cellular standard and the number of systems on-the-air is rapidly rising.

Qualcomm has been at the forefront of CDMA with its IS-95 technology forming the basis for most current networks. However, other variations of CDMA are being proposed and trialed for future services. Some of these are aimed at wireless local loop applications for developing countries; others will provide support for wireless connected broadband data applications. CDMA has emerged as the dominant technology for the new PCS networks in the USA. Japan has adopted CDMA as the answer to its long term cellular capacity. In the UK, Vodafone has begun trials that will integrate a CDMA air interface into a GSM network structure. Overall, forecasts for future CDMA subscriber numbers and market shares are being constantly revised upwards.

1.2 Multiple Access

Wireless systems transmit and receive signals over a common resource: the air. This may lead to conflicts if several users want to transmit at the same time. Multiple access means that multiple, simultaneous users can be supported. In other words, a large number of users share a common pool of radio channels and any user can gain access to any channel (each user is not always assigned to the same channel). A channel can be thought of as merely a portion of the limited radio resource which is temporarily allocated for a specific purpose, such as someone's phone call. A multiple access method is a definition of how the radio spectrum is divided into channels and how channels are allocated to the many users of the system.The original system was called the Advanced Mobile Phone System, or AMPS. It is the system we use throughout North America. Similar systems, with slight variations, are Nordic Mobile Telephone (NMT) in Scandinavia, and Total Access Communications System (TACS) used in the United Kingdom, China, and other countries. Spectral allocations are in the 800-900 MHz region.

Several hundred channels are available within the spectrum allocation. One channel of one base station is used for each conversation. Upon handoff, the subscriber station is directed via messaging to discontinue use of the old channel and tune to the new one, on which it will find the new cell.

1.2.1 Frequency Reuse

The concept of frequency reuse is quite central to the cellular concept. Although there are hundreds of channels available, if each frequency were assigned to only one cell, total system capacity would equal to the total number of channels, adjusted for the Erlang blocking probability: only a few thousand subscribers per system. By reusing channels in multiple cells the system can grow without geographical limits.

Reuse is critically dependent upon the fact that the electromagnetic field attenuation in the cellular bands tends to be more rapid with distance than it is in free space. Measurements have shown repeatedly that typically the field intensity decays like R^{-n}, with $3 < n < 5$. In free space $n = 2$. In fact, it is easily shown that the cellular concept fails completely due to interference that grows without bound if the propagation is exactly free space. Typical cellular reuse (pre-CDMA) is easily rationalized by considering an idealized system. If we assume that propagation is uniformly R^{-n}, and that cell boundaries are at the equisignal points, then a planar service area is optimally covered by the classical hexagonal array of cells

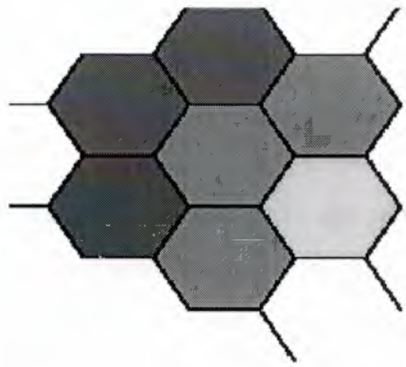


Figure 1.2 Hexagonal array of cells

Seven sets of channels are used one set in each colored cell. This seven-cell unit is then replicated over the service area.

Figure 1.3 Seven-cell unit

No similarly colored cells are adjacent, and therefore there are no adjacent cells using the same channel. While real systems do not ever look like these idealized hexagonal tilings of a plane, the seven-way reuse is typical of that achieved in practice.

The capacity of a K-way reuse pattern is simply the total number of available channels divided by K. With K=7 and 416 channels, there are approximately 57 channels available per cell. At a typical offered load of 0.05 Erlangs per subscriber, each site supports about 1140 subscribers.

1.2.2 Antenna Sectorization

The pictures above assume that the cells are using omnidirectional antennas. It might be expected that system capacity could be increased by antenna sectorization. Sites are in fact sectorized by the operators, usually three-ways. That is, each site is equipped with three sets of directional antennas, with their azimuths separated by 120°. Unfortunately the sectorization does not in practice lead to an increase in capacity. The reason is that the sector-to-sector isolation, often no more than a few dB, is insufficient to guarantee acceptably low interference. Only in part is this due to the poor front-to-back ratio of the antennas. The vagaries of electromagnetic propagation in the real world also conspire to mix signals between sectors. The practical result of sectorization is only an increase in coverage because of the increased forward gain of the directional antenna. Nothing is gained in reuse. The same seven-way cell reuse pattern applies in sectored cells as in omnidirectional cells. Viewed from the standpoint of sectors, the reuse is K=7*3=21 instead of 7.

1.3 FDMA, TDMA and CDMA

In order to separate each user so that they do not interfere with one another, service providers may use one of three primary multiple access systems: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA).

1.3.1 FDMA: Frequency Division Multiple Access

FDMA divides radio channels into a range of radio frequencies and is used in the traditional analog cellular system. With FDMA, only one subscriber is assigned to a channel at a time. Other conversations can access this channel only after the subscriber's call has terminated or after the original call is handed off to a different channel by the system. FDMA cellular standards include AMPS (Advanced Mobile Phone Service) and TACS (Total Access Communications System).

1.3.2 TDMA: Time Division Multiple Access

TDMA is a common multiple access technique employed in digital cellular systems. It divides conventional radio channels into time slots to obtain higher capacity. Hence, channelization of users in the same band is achieved through separation in time. Its standards include North American Digital Cellular, Global System for GSM (Mobile Communications), and PDC (Personal Digital Cellular). As with FDMA, no other conversations can access an occupied TDMA channel until the channel is vacated.

1.3.3 CDMA: Code Division Multiple Access

CDMA assigns each subscriber a unique "code" to put multiple users on the same wideband channel at the same time. The codes, called "pseudo-random code sequences", are used by both the mobile station and the base station to distinguish between conversations. The signals are separated at the receiver by using a correlator that accepts only signal energy from the desired channel. Undesired signals contribute only to the noise. The IS-95 CDMA standard was adopted by the TIA (Telecommunications Industry Association) and became a digital cellular standard in 1992. The J-STD-008 standard for personal communications services was also accepted by ANSI. CDMA is the first digital technology which meets the exacting standards of the CTIA (Cellular Telecommunications Industry Association). Depending on the level of mobility of the system, it provides 10 to 20 times the capacity of AMPS, and 4 to 7 times the capacity of TDMA. CDMA is the only one of the three technologies that can efficiently utilize spectrum allocation and offer service to many subscribers without requiring extensive frequency planning.

1.4 CDMA Concepts

CDMA stands for "Code Division Multiple Access." It is a radically new concept in wireless communications. It is a form of spread-spectrum, an advanced digital wireless transmission technique. The core principle of spread spectrum is the use of noise-like carrier waves, and, as the name implies, bandwidths much wider than that required for simple point-to-point communication at the same data rate.Instead of using frequencies or time slots, as do traditional technologies, CDMA uses mathematical codes to transmit and distinguish between multiple wireless conversations. Its bandwidth is much wider than that required for simple point-to-point communications at the same data rate because it uses noise-like carrier waves to spread the information contained in a signal of interest over a much greater bandwidth. However, because the conversations taking place are distinguished by digital codes, many users can share the same bandwidth simultaneously.

CDMA changes the nature of the subscriber station from a predominately analog device to a predominately digital device. Commercial applications became possible because of two evolutionary developments. One was the availability of very low cost, high density digital integrated circuits, which reduce the size, weight, and cost of the subscriber stations to an acceptably low level. The other was the realization that optimal multiple access communication requires that all user stations regulate their transmitter powers to the lowest that will achieve adequate signal quality. The advanced methods used in commercial CDMA technology improve capacity, coverage and voice quality, leading to a new generation of wireless networks.

Old-fashioned radio receivers separate stations or channels by filtering in the frequency domain. CDMA receivers do not eliminate analog processing entirely, but they separate communication channels by means of a pseudo-random modulation that is applied and removed in the digital domain, not on the basis of frequency. Multipleusers occupy the same frequency band. This universal frequency reuse is not fortuitous. On the contrary, it is crucial to the very high spectral efficiency that is the hallmark of CDMA.

Handoff is a very important concept in wireless communications. It occurs when a call has to be handed off from one cell to another as the user moves between cells. In a traditional "hard" handoff, at the very least, the person will hear some static or a glitch of some sort because the transmission had to be placed on a new carrier wave. This is relatively acceptable, except in cases when there are no more channels available to any mobile. In this case the call is just dropped, i.e.: the connection to the current cell is broken, and then the connection to the new cell is made. This is known as a "break-before-make" handoff.

Since all cells in CDMA use the same frequency, it is possible to make the connection to the new cell before leaving the current cell. As the mobile nears the boundary of a neighboring cell, it receives transmissions from both cells. The mobile will receive some message from one cell, and some from the other until it has moved into one or the other cells. This is known as a 'make-before-break" or "soft handoff" because the user never experiences any glitch and certainly never a dropped call. Soft handoffs require less power, which reduces interference and increases capacity.

When implemented in a cellular telephone system, CDMA systems provide operators and subscribers with significant advantages over analog and conventional TDMA-based systems. The main advantages of CDMA are as follows:

- Increased capacity
- Improved voice quality, eliminating the audible effects of multipath fading
- Enhanced privacy and security
- Improved coverage characteristics which reduce the number of cell sites
- Simplified system planning reduces deployment and operating costs
- Reduced average transmitted power, thus increasing talk time for portable devices
- Reduced interference to other electronic devices
- Reduction in the number of calls dropped due to handoff failures
- Development of a reliable transport mechanism for wireless data communications
- Coexistence with previous technologies, due to CDMA and analog operating in two spectras with no interference.

1.5 The Spread spectrum

Spread spectrum (SS) multiple access transmits the entire signal over a bandwidth that is much greater than that required for standard narrow band transmissions in order to gain signal-to-noise (S/N) performance. In channels with narrowband noise, increasing the transmitted signal bandwidth results in an increased probability that the received information will be correct. Because each signal is a compilation of many smaller signals at the fundamental frequency and its harmonics, increasing the frequency results in a more accurate reconstruction of the original signal. The effective drawback of narrowband data communications is the limitation of bandwidth; thus signals must be transmitted with enough power so the corruption by gaussian noise isn't as effective and the probability that the data received is correct will remain low. This means that the effective SNR must be high enough so that the receiver can recover the transmitted code without error.

From a system viewpoint, the performance increase for very wideband systems is referred to as "process gain". This term is used to describe the received signal fidelity gained at the cost of bandwidth. Errors introduced by a noisy channel can be reduced to any desired level without sacrificing the rate of information transfer using Claude Shannon's equation describing channel capacity:

$$C = W \log_2(1 + S/N)$$

where C = Channel capacity in bits per second, W = Bandwidth, S/N = Energy per bit/Noise power.

The benefits of increasing bandwidth become more clear. The S/N ratio may be decreased without decreasing the bit error rate. This means that the signal may be spread over a large bandwidth with smaller spectral power levels and still achieve the required data rate. If the total signal power is interpreted as the area under the spectral density curve, then signals with equivalent total power may have either a large signal power concentrated in a small bandwidth or a small signal power spread over a large bandwidth.

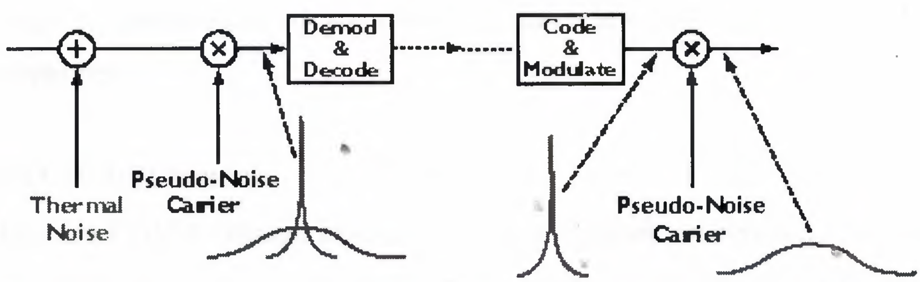


Figure 1.4 Block diagram of pseudo-noise

A CDMA spread spectrum signal is created by modulating the radio frequency signal with a spreading sequence (a code consisting of a series of binary pulses) known as a pseudo-noise (PN) digital signal because they make the signal appear wide band and "noise like". The PN code runs at a higher rate than the RF signal and determines the actual transmission bandwidth. Messages can also be cryptographically encoded to any level of secrecy desired with direct sequencing as the entire transmitted/received message is purely digital.

A SS receiver uses a locally generated replica pseudo noise code and a receiver correlator to separate only the desired coded information from all possible signals. A SS correlator can be thought of as a specially matched filter .

1.6 Physical Layer of CDMA

In CDMA, the entire 1.25-MHz transmission bandwidth is occupied by every station. In the forward direction (base station to mobile station), Walsh codes are used to distinguish different channels. On the reverse channel (mobile station to base station), different pseudorandom noise (PN) sequences are used to distinguish different channels. The Walsh functions are chosen so that the set of functions are all orthogonal to each other. All base stations in the system are on the same frequency and use the same set of time-shifted Walsh functions. Every base station in the system is synchronized to every other base station in the system. Different base stations use time-shifted versions of the PN sequence to permit mobile stations to select transmissions from different base stations. Thus, for CDMA, the frequency reuse factor N is 1. The PN sequences used by the MS are found by computer simulation and are chosen to have low autocorrelation and cross-correlation properties.

1.6.1 Forward CDMA Channel

The forward CDMA channel consists of a pilot channel, an optional sync-channel, optional (to a maximum of seven) paging channels, and several forward traffic channels. Each of these channels is orthogonally spread by the appropriate orthogonal function and is then spread by a quadrature pair of PN sequences. All the channels are added together and sent to the modulator. Many of the processes for constructing the forward and reverse channels are the similar. When a base station supports multiple forward CDMA channels, frequency division multiplex is used.

1.7 Signal Structure of Farward CDMA Channel

Here, We briefly discuss the signal structure of CDMA forward channel in the following way: channelization, coding and interleaving, Walsh codes, spreading and modulation

1.7.1Channelization

The forward link consists of up to 64 logical channels (code channels). The channels are independent in that they carry different data streams, possibly at different rates, and are independently adjustable in amplitude

1.7.2 Coding and Interleaving

The figure shows the core processing that generates one forward code channel, rate set 1. Rate set 2 is identical except the coding rate is 3/4 rather than 1/2, yielding the same code symbol rate with 3/2 times the data rate.

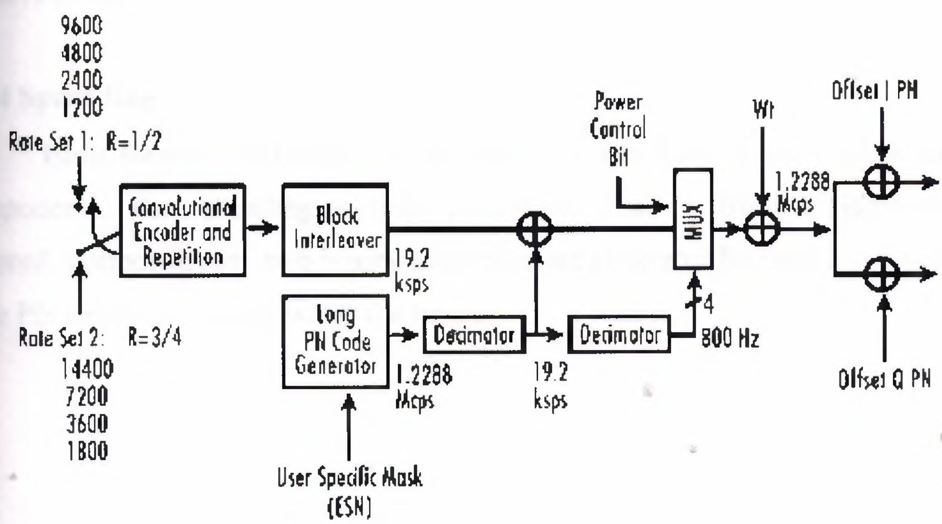


Figure 1.5 Coding and Interleaving

1.7.3 Walsh Codes

The code channels, as transmitted, are mathematically orthogonal. The orthogonality is established by covering the FEC code symbols with one of a set of 64 so-called Walsh functions. "Mutually orthogonal" means that their cross correlations are small (ideally zero). Because only whole periods of the Walsh functions occur in each code symbol, the effect of the Walsh cover is to make the channels completely separable in the receiver, at least in the absence of multipath. The orthogonality not only means that there is no co-mingling of channels, it means there is no interference between users in the same cell, again in the absence of multipath. This has a substantial beneficial effect on the forward link capacity.

Multipath delay spread that exceeds a chip does introduce mutual interference between users in one cell. In any particular Rake finger the uncorrelated channels contribute an effective interference level. This level varies from zero, when there is only one multipath component, up to (N-1)/N of the total signal power if there are N discrete, equal-amplitude multipath components. Note that one of the Walsh functions is always a constant, code number zero, by the numbering convention. This channel is always reserved to serve as the pilot.

1.7.4 Spreading

Each forward code channel is spread by the Short Code, which has I- and Q-components. The spreading is thus quadrature. That is, from a single binary-valued, covered, symbol stream, two binary sequences are generated by mod 2 addition of the short code PN sequences, as shown in the figure.

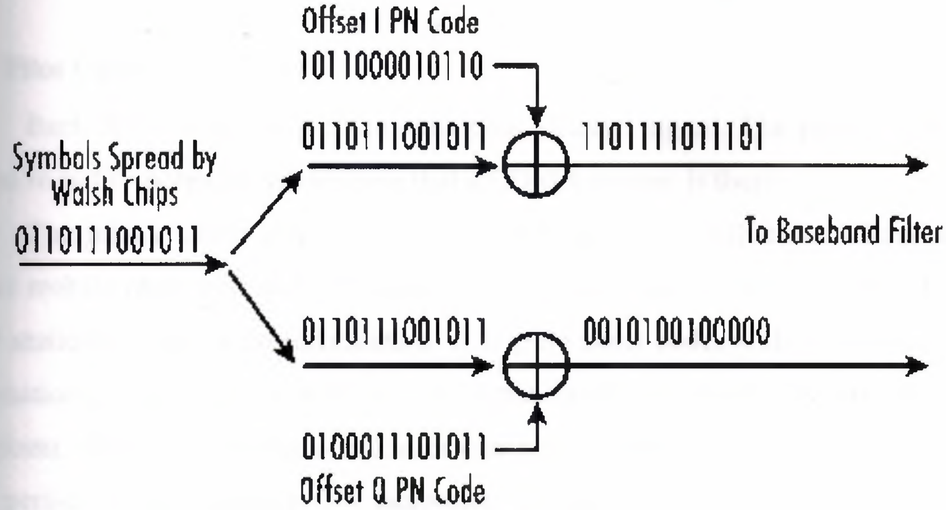


Figure 1.6 Quadrature spreading

1.7.5 Modulation

The two coded, covered, and spread streams are vector-modulated on the RF carrier. The spreading modulation is thus QPSK, superimposed on a BPSK code symbol stream. The spectrum shaping of the forward link is carefully prescribed in the IS-95A air interface and the IS-97 performance specification. The latter is in terms of the so-called Rho meter, a measurement of the correlation between the actual transmitter output with the ideal transmitter output. The air interface also specifies a slightly nonlinear phase characteristic the purpose of which is partial pre-equalization of the mobile receiver.

In-band ripple is specified as less than ±1.5 dB. Stopband rejection is 40 dB beginning 740 kHz from band center. An equi-ripple, 48 tap FIR baseband filter is suggested, although not required.

1.8 Overhead Channels

There are three types of overhead channel in the forward link: pilot, sync, and paging. The pilot is required in every station.

1.8.1 Pilot Channel

Each BTS transmits a continuous pilot channel signal. The pilot channel acts as a beacon to notify potential subscribers that a CDMA system is there.

The pilot channel is always code channel zero. It is both a demodulation reference for the mobile receivers, and for handoff level measurements, and thus must be present in every station. It carries no information. It is pure short code, with no additional cover or information content. All stations use the same short code, and thus have the same pilot waveform. They are distinguished from one another only by the phase of the pilot. The short period of the short code, 2^{15}, facilitates rapid pilot searches by the mobiles. The air interfaces stipulate that pilot phases always be assigned to stations in multiples of 64 chips, giving a total of $2^{15-6} = 512$ possible assignments. The 9-bit number that identifies the pilot phase assignment is called the Pilot Offset.

1.8.2 Sync Channel

The Sync channel is transmitted by a base station to enable the MS to obtain frame synchronization of the CDMA signal. The sync channel carries a repeating message that identifies the station, and the absolute phase of the pilot sequence. The data rate is always 1200 bps. The interleaver period is 80/3 = 26.667 ms, equal to the period of the short code. This simplifies finding frame boundaries, once the mobile has located the pilot.

1.8.3 Forward Paging Channel

The paging channel is the vehicle for communicating with mobile stations when they are not assigned to a traffic channel. As the name implies, its primary purpose is to convey pages, that is, notifications of incoming calls, to the mobile stations. It carries the responses to mobile station accesses, both page responses and unsolicited origination. Successful accesses are normally followed by an assignment to a dedicated traffic channel. Once on a traffic channel, signaling traffic between base and mobile can continued interspersed with the user traffic.

1.8.4 Forward Traffic Channel

Traffic channels are assigned dynamically, in response to mobile station accesses, to specific mobile stations. The mobile station is informed, via a paging channel message, which code channel it is to receive (it is tempting, but inappropriate to use the word "tune"!).

1.8.5 Soft Handoff

During soft handoffs each base station participating in the handoff transmits the same traffic over its assigned code channel. The code channel assignments are independent, and in general will be different in each cell. Whatever code channels are not in use for overhead channels are available, up to either a total of 64 or the available equipment limit, whichever is smaller.

1.8.6 Rate

Traffic channels carry variable rate traffic frames, either 1, ½, ¼, or 1/8 of the maximum rate. In IS-95A only a 9600 bps rate family is currently available in the standard. In J-STD-008 a second rate set, based on a maximum rate of 14,400 bps is available. The Rate Set 2 will be added in a future revision of IS-95. The rate variation is accomplished by 1, 2, 4, or 8-way repetition of code symbols. Transmission is continuous, with the amplitude reduced at the lower rates so as to keep the energy per bit approximately constant, regardless of rate. The rate is independently variable in each 20 ms frame.

1.8.7 Power Control Subchannel

The 800 bps reverse link power control subchannel is carried on the traffic channel by puncturing 2 from every 24 symbols transmitted. The punctured symbols both carry the same power control bit, so they can be coherently combined by the receiver. Each base station participating in a soft handoff makes its own power control decision, independent of the others, unless they are different sectors of the same cell, in which case they all transmit a common decision. This special circumstance is made known to the mobile when the handoff is set up.

1.8.8 Timing

All base stations must be synchronized within a few microseconds for the station identification mechanisms to work reliably and without ambiguity. Any convenient mechanism can be used for this purpose, but the system was designed under the assumption that the Global Positioning System (GPS) would be used. This is a family of low-earth-orbit satellites that broadcast a spread-spectrum signal and ephemeris information from which a sophisticated Kalman filter algorithm in a receiver can derive both a very accurate position and a very accurate time.

1.9 The Reverse CDMA Channel

The Reverse CDMA Channel is the mobile-to-cell direction of communication. It carries traffic and signaling. Any particular reverse channel is active only during calls to the associated mobile station, or when access channel signaling is taking place to the associated base station.

1.10 Signal Structure of Reverse CDMA Channel

There is some difference in the signal structure of the reverse channel from that of the forward channel.

1.10.1 Channelization

The Reverse CDMA Channel consists of 2^{42}-1 logical channels. One of these logical channel is permanently and uniquely associated with each mobile station. That logical channel is used by the mobile whenever it passes traffic. The channel does not change upon handoff .Other logical channels are associated with base stations for system access. This reverse link addressing is accomplished through manipulation of period 2^{42}-1 Long Code, which is part of the spreading process.

1.10.2 Coding and Interleaving

Figure 1 shows the core processing that generates one Reverse CDMA Channel.

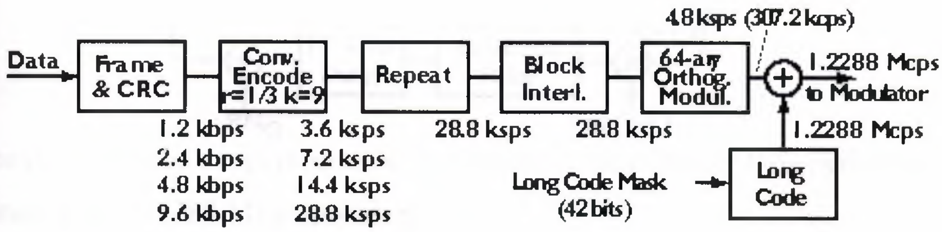


Figure 1.7 Reverse CDMA Channel signal generation.

1.10.3 Separation of Users

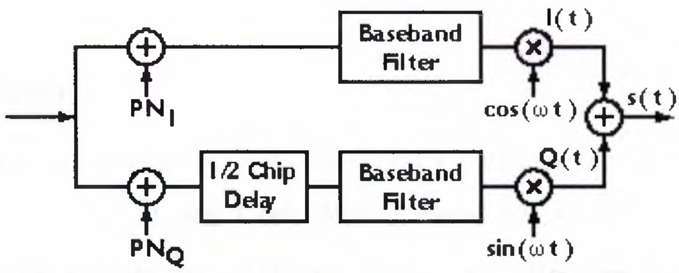
The reverse CDMA Channel, in contrast to the Forward CDMA Channel, does not use strict orthogonality in any sense to separate logical channels. Rather, it uses a very long period spreading code, in distinct phases. The correlations between stations are not zero, but they are acceptably small.

1.10.4 Orthogonal Modulation

Reverse link data modulation is 64-ary orthogonal, and is applied prior to the spreading. Groups of six code symbols select one of 64 orthogonal sequences. The 64-ary orthogonal sequences are the same Walsh functions that are used in the Forward CDMA Channel, here are used for a totally different purpose. Each period of the Walsh sequence (a Walsh Chip) is four PN chips in duration. The modulation symbol rate is thus always 4,800 sps.

1.10.5 Spreading

Each Reverse CDMA Channel is spread by both the channel-unique Long Code and the Short Code, which has I- and Q-components. The spreading is thus quadrature. That is, from a single binary-valued symbol stream, two binary sequences are generated by mod 2 addition of the short code PN sequences (Figures 1 and 2). The effect of adding long and



short codes is to produce a supersequence that has an extraordinarily long period, about 2^{57}, or 3700 years at the 1.2288 MHz spreading rate.

Figure 1.8 Reverse CDMA Channel modulation·

1.10.6 RF Modulation

The two coded, covered, and spread streams are vector-modulated on the RF carrier. The Q-axis modulation is delayed by 1/2 chip. The spreading modulation is thus offset QPSK. Offset modulation was chosen in an effort to reduce the envelop modulation of the RF signal and reducing performance requirements on the power amplifiers in the subscriber station.

The spectrum shaping of the reverse link is carefully prescribed in the IS-95A air interface and the IS-98 performance specification. The latter is in terms of the so-called Rho meter, a measurement of the correlation between the actual transmitter output with the ideal transmitter output. The air interface also specifies a slightly nonlinear phase characteristic the purpose of which is partial pre-equalization of the mobile receiver.

1.10.7 Access Channel

There is only one type of overhead channel in the Reverse CDMA Channel: the Access Channel. The Access Channel is the vehicle for communicating with mobile stations when they are not assigned to a traffic channel. As the name implies, its primary purpose is to service originations and page responses by the mobile stations. Successful accesses are normally followed by an assignment to a traffic channel. Once on a traffic channel, signaling traffic between base and mobile can continued interspersed with the user traffic. The access channel always runs at 4800 bps.

1.10.8 Traffic Channel

Traffic channels are in the Reverse CDMA Channel are mobile-unique. That is, each station has a unique Long Code Mask, based on its electronic serial number. Whenever the mobile is assigned to traffic, it uses its specific long code mask. The traffic channel always carries data in 20 ms frames. Frames at the higher rates of Rate Set 1, and in all frames of Rate Set 2, include CRC codes to help assess the frame quality in the receiver.

1.11 Data Link And Network Layer of CDMA

Information flows from the BS to the MS via the forward CDMA channel, on the pilot channel, the sync channel, the paging channel, and the forward traffic channel. Information flows from the MS to the BS on either the access channel or the reverse traffic channel. The BS/MS communications take place on the page/access channel during call setup and on the forward/reverse traffic channel during a call. All cellular and personal communications systems air interfaces (except GSM) used in the North America share a common approach to the operation of a MS. The CDMA system combines the operation of the data link and network layers and treats them as one layer.

When an MS is first powered up, it must find and decode data on a control channel before any further processing can be done. For the messages described here, we assume that the BS to MS channels are properly synchronized in the receivers of both sides and that the receivers are properly decoding data.

1.11.1 Forward CDMA Channel

Data can be transmitted from a BS to a MS over the sync channel, the paging channel, or the information stream on the forward traffic channel. Some of the data are *specific to a particular channel. Other data (e.g. orders) can be sent on the paging channel* or the traffic channel.

1.11.2 Sync Channel

The forward sync channel operates at a data rate of 1200 bps and transmits information that is specific to the BS and needed by the MS to access the system.

Table 1.1 CDMA message framing on the forward sync channel and paging channel.

Message Length (in bytes)	Data	CRC	Padding =....000....
8 bits	Nmsg=2~1146 bits	30 bits	

Nmsg= Message length in bits (including length field and CRC). Padding bits are not used for Unsynchronized Paging Channel Messages. Sync Channel Data Rate =1200 bps. Paging Channel Data Rate =4800 bps or 9600 bps

The Sync Channel message is shown above. If the sync channel messages are less than an integer multiple of 93 bits, they are padded with 0 bits at the end of the message.

Table1.2 CDMA channel framing on forward sync channel

SOM	Sync Channel Frame Body
1 bit	31 bits

SOM = 1 for first Body of Sync Channel Message= 0 for all other Bodies in Sync Channel Message

After a message is formed, it is segmented into 31-bit groups and sent in a sync channel frame consisting of a 1-bit start of message (SOM)

Table 1.3 CDMA superframe structure on forward sync channel

Sync Channel Frame	Sync Channel Frame	Sync Channel Frame
31 bits	31 bits	31 bits

Three sync channel frames are combined to form a sync channel superframe of length 80 ms (96 bits). The entire sync channel message is then sent in N superframes. The only message sent on the sync channel is the Sync Channel message that transmits information about the BS and the serving CDMA System, such as the system identification (SID), the network identification (NID), the offset of the PN sequence for the BS and the long code state for that BS. The sync channel also sends information about the system time, leap seconds, offset from UTC. Finally, the sync channel transmits information on the data rate used on the paging channel (4800 or 9600 bps)

1.11.3 Paging Channel

The paging channel operates at a data rate of 4800 or 9600 bps and transmits overhead information, pages, and orders to an MS. The paging channel message is similar in form to the Sync Channel message. The message length includes the header, body, and CRC, but not the padding. Paging Channel messages can use synchronized capsules that end on a half-frame boundary or unsynchronized capsules that can end any where within a half-frame.

Table 1.4 CDMA channel half-framing on forward paging channel

SCI	Paging channel half frame body
1 bit	47 bits (R=4800 bps) 95 bits (R=9600 bps)

SCI = 1 for first new capsule of Sync Paging Channel Message = 0 for all other capsules in Paging Channel Message

After a message is formed, it is segmented into 47- or 95-bit chunks and sent in a sync channel half-frame. Eight paging channel half-frames are combined to form a paging channel slot of length 80ms(384 bits at 4800bps and 768 bits at 9600). The entire Paging channel message is then sent in N (<= 2048). The paging channel sends many different types of messages. Some of the messages follow:

- System Parameters Message: This message is sent to all MSs in the area to specify the characteristics of the serving cellular/PCS system.
- Access Parameters Message: This message is sent to all MSs in the area to specify et characteristics of the messages sent on the access channel.
- Order Message: This message directs the MS to perform an operation and confirms a request from the MS.
- Channel Assignment Message: This message informs the MS of the correct traffic channel to use for voice or data.
- TMSI Assignment Message: This message assigns a temporary mobile station identification (TMSI) to the MS. It is sent as part of the registration process

1.11.4 Traffic Channel

Channels not used for paging or sync can be used for traffic. The total number of the traffic channels at a BS is 63 minus the number of paging and sync channels in operation at the BS. Information on the traffic channels consists of primary traffic (voice or data), secondary traffic (data), and signaling in the frames of length 20 ms.

When the forward traffic channel is used for signaling, the message is similar in the form to the Paging Channel Message.

Some typical messages that can be sent are the following:

- **Order Message**: similar to the order messages sent one the paging channel.

- **Authentication** Challenge Message: when the BS suspects the validity of the MS, it can challenge the MS to prove its identity.
- **Send Burst Dual -Tone Multifrequency (DTMF)**: when the BS needs dialed digits, it can request them in this message. This message would be used for a three-way call.
- **Extended Hand-off Direction Message:** This message is one of several handoff messages sent by the BS.

1.11.5 Reverse CDMA Channel

The MS communicates with the BS over the access channel or the reverse traffic channel. The access channel is used to make originations, process orders, and respond to pages. After voice or data communications are established, all communications occur on the reverse traffic channel.

1.11.6 Access Channel

Whenever an MS registers with the network, processes an order, sends a data burst, makes an origination, responds to a page, or responds to an authentication challenge, it uses the (reverse) access channel.

Table1.5 CDMA access channel preamble

access channel preamble =000...000
96 x (1+PAM_SZ) bits (1+PAM_SZ) frames

The message on the reverse access channel consists of an access preamble of multiple frames of 96 zero bits with a length of 1+PAM_SZ frames, followed by an access channel message capsule with length of 3 +MAX_CAP_SZ frames.

Table 1.6 CDMA message framing on access channel.

Message Length (in bytes)	Data	CRC	Padding =....000....
8 bits	Nmsg=2~842 bits	30 bits	

Notes: Nmsg = Message length in bits (including length field and CRC

The Actual start of the transmission on the access channel is randomized to minimize collisions between multiple MSs accessing the channel at the same time. All access channels corresponding to a paging channel have the same length. Different BSs may have different slot lengths

Table 1.7 CDMA access channel framing

access channel frame body	Encoder tail bits
88 bits	Encoder 30bits tail bits

Each access channel frame contains either preamble bits (all zeros) or message bits. Multiple frames are combined with an access channel preamble to form an access channel slot.

Table 1.8 CDMA Access Channel Slot

Access Channel permeable	Access Channel Frame		Access Channel Frame

1.11.7 Traffic Channel

Information on the reverse traffic channels consists of primary traffic (voice or data), secondary traffic (data), and signaling using frames of length 20 ms. The message format is identical to the forward traffic channel. When the reverse traffic channel is used for signaling, framing format is shown below.

Table 1.9 CDMA message framing on the reverse traffic channel

Message Length (in bytes)	Data	CRC	Padding =…. 000….
8 bits	Nmsg=2~2016 bits	30 bits	

When the reverse traffic channel is used for signaling, some of the following example messages can be sent:

- **Order**: This message is either a response to a BS request or a request for service from the MS.
- **Authentication Challenge Response**: This message is sent in response to the challenge by the BS.

- **Flash with Information**: When the user requires special services from the BS, a flash message is sent. This message is similar to depressing the switch-hook on a wireline phone. The message may or may not contain additional information.
- **Handoff Completion**: When the MS completes the handoff process, it sends this message.

1.12 SIGNALLING APPLICATIONS IN CDMA

In this chapter, we discuss the end-to-end call flow for some typical basic and supplementary services. These end-to-end call flows are synthesized for examination of the various standards and do not appear in any one document within the standards.

We trace call flows from a mobile station to a base station, to the MSC, and to other network elements. The flows are based on the TR-45/TR-46 reference modal and A-interface (the interface between the base station and the MSC supporting signaling and traffic) based on the Integrated Services Digital Network.

1.12.1 Basic Services

Before a mobile station can originate or receive a call, it will register with the wireless system. An exception is made for emergency (911) calls. During the registration process, the MS is given a temporary mobile station identity (TMSI) that is used for all subsequent call processing

1.12.3 Registration

Registration is the means by which a mobile station informs a service provider of its presence in the system and its desire to receive service from that system. The MS may initiate registration for several different reasons.

A mobile station registering on an access channel may perform any of the following registration types:

- Distance-Based Registration is down when the distance between the current base station and the base station where the MS last registered exceeds a threshold.

- Ordered Registration is done when the system sets parameters on the forward paging channel to indicate that all or some of the MSs must register.
- Parameter Change Registration is done when specific operating parameters in the MS are changed
- Power-Down Registration is done when the mobile station is switched off. This allow the network to deregister a mobile station immediately upon its power-down
- Power-up Registration is done when power is applied to the mobile station and is used to notify the network that the MS is now active and ready to place or receive calls.
- Time-Based Registration is done when a timer expires in the mobile station.
- Zone-Based Registration is done whenever an MS enters a new area of the same system.

Two other forms of registration occur when the mobile station takes certain actions:

1. Implicit Registration occurs when a mobile station successfully communicates with the base station for a page response or an origination.
2. Traffic Channel Registration occurs when the mobile station is assigned a traffic channel. The base station can notify the MS that it is registered.

1.12.4 Call Origination

Call origination is the service wherein the MS user calls another telephone on the world-wide telephone network. It is a cooperative effort among the MSC, the VLR, and the base station.

1.12.5 Call Termination

Call termination is the service wherein an MS user recieves a call from other telephones in the world-wide telephone network. The following discussion is for calls terminating to a MS registered at its home MSC. Calls terminating to roaming MSs will be discussed in section of Roaming. Call termination is a cooperative effort among the MSC, the VLR, and the base station.

1.12.6 Call Clearing

When either party in a conversation wishes to end a call, then the call clearing function is invoked. The exact call flows depend on which side ends the call first. It is a cooperative effort among the MSC, the VLR, and the base station.

1.12.7 Roaming

Roaming is the ability to deliver services to mobile stations outside of their home area. When an MS is roaming, registration, call origination and call delivery will take extra steps. Whenever data will be retrieved from the VLR, and the data are not available, then the VLR will send a message to the appropriate HLR to retrieve the data. The most logical time to retrieve this data is when the MS registers with the system.

Once the data on a roaming MS are stored in the VLR, then call processing for any originating services (basic or supplementary) is identical to that of home MSs. However, there may be times when the MS originates a call before registration has been accomplished or when the VLR data are not available. At those times, an extra step will be added for the VLR to retrieve the data from the HLR. Thus any originating service has two optional steps where the VLR sends a message (using IS-41 signaling over SS7) to the HLR requesting data on the roaming MS. The HLR will return a message with the proper call information.

There are two cases of call delivery to roaming MS:

1. The MS has a geographic-based directory number (indistinguishable from a wireline number) and
2. The MS has a nongeographic number.

1.12.8 Unique Challenge

The unique challenge protects the network from fraudulent use by illegal mobile stations. At various times throughout a call, the network may want to challenge the validity of a mobile station communicating with the network. If the radio link communications are encrypted, it is unlikely that some hijacker may have stolen the radio link from a legitimate user.

The unique challenge can be sent to a MS at any time. It is typically initiated by the

MSC in response to some event (registration failure and after a successful handoff are the most typical cases).

1.12.9 Supplementary Services

IS-41 supports several supplementary services, of which Call waiting provides notification to a wireless subscriber of an incoming call while the user's mobile station is in the busy state. Subsequently, the user can either answer or ignore the incoming call. Once the call is answered, the user can switch between the calls until one or more parties hang up.

1.13 Handoffs

A wireless telephone (mobile station) moves around a geographic area. The process whereby a mobile station moves to a new traffic channel is called handoff. The original analog cellular system processed handoffs by commanding the mobile station tune to a new frequency. For analog cellular, the handoff process caused a short break in the voice path and a noticeable "click" was heard by both parties in the telephone call. For data modems, the click often causes data errors or loss of data synchronization.

For the CDMA systems, the characteristics of the spread spectrum communications permit the system to receive the mobile transmissions on two or more base stations simultaneously. WIth these capabilities, it is possible to process a handoff without any perceptible disturbance in the voice or data communications. The handoff messages are transmitted on the system's paging channels.

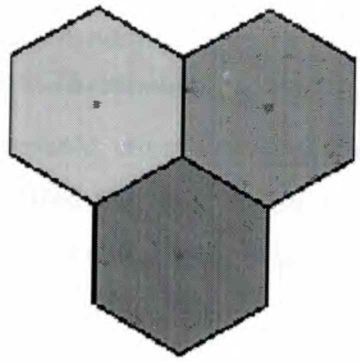


Figure 1.9 Soft handoff

1.13.1 Types of Handoffs

The CDMA system defines several types of handoffs.

- **Soft Handoff** occurs when the new base station begins communications with the mobile station while the mobile station is still communicating with the old base station. The network (MSC) combines the received signals from both base stations to process an uninterrupted signal to the distant party. The mobile station will receive the transmissions from the two base stations as additional mutipaths in the RAKE receiver and will process them as one signal.
- **Softer Handoff** occurs when the mobile station is in handoff between two different sectors at the same base station. Typically , a base station is designed so that an antenna transmits and receives over a 60° or 120° sector rather than a full 360°.
- **Hard Handoff** occurs when the two base stations are not synchronized or are not on the same frequency and an interruption in voice or data communications occurs.
- **Semisoft Handoff** occurs when the handoff appears as a soft handoff within the network but the mobile station processes it as a hard handoff.

Handoffs requested by a mobile station are called mobile-assisted handoffs, and those requested by the base station are called base station-assisted handoffs. Either side can initiate the handoff process whenever the following triggers occurs:

- **Base Station Traffic Load.** The network can monitor loads at all base stations and trigger handoffs to balance loads between them.

- **Distance Limits Exceeded.** When the distance limit is exceeded, either base station or mobile station can request a handoff
- **Pilot Signal Strength Below Threshold**. When the received signal strength of the pilot signal falls below a threshold, either side can initiate a handoff.
- **Power Level Exceeded.** WHen the base station commands a mobile station to increase its power and maximum power level of the mobile station is exceeded, then either side can request a handoff.

1.13.2 Flow steps for a CDMA soft handoff (beginning)

The handoff process is a cooperative effort among the old and new base stations, the mobile station, and the MSC. The following call flows are based on a frame relay A-interface between the base station and the MSC. The detailed call flow steps for a CDMA soft handoff (beginning) follow:

1. The mobile station determines that another base station has a sufficient pilot signal to be a target for handoff.
2. The mobile station sends a Pilot Strength Measurement message to the serving base station.
3. The serving base station sends an Interbase Station Handoff Request message to the MSC.
4. The MSC accepts the Handoff Request and sends an Interbase Station Handoff Request message to the target base station.
5. The target base station establishes communication with the mobile station by sending it a Null Traffic message.
6. The target base station sends a Join Request message to the MSC.
7. The MSC conferences the connections from the two base stations ao that the handoff can be processed without a break in the connection and sends a Join Acknowledge message to the target base station.
8. The target base station sends an Interbase Station Handoff Acknowledgment message to MSC.
9. The MSC sends a Interbase Station Handoff Acknowledgment message to the serving base station.

10. The serving base station sends a Handoff Direction message to the mobile station.
11. The mobile station sends a Handoff complete message to the serving base station.
12. The new serving base station sends a Handoff Information message to the MSC.
13. The MSC confirms the message with a Handoff Information Acknowledgment message.
14. The target base station sends a Pilot Measurement Request Order to the mobile station.
15. The mobile station sends a Pilot strength Measurement message to the target base station.

The mobile station is now communicating with the target base station (new serving base station).

1.13.3 Flow steps for a CDMA soft handoff with the target base station dropping off

The procedures to drop a target base station from a soft handoff are similar to those that drop the serving base station. The detailed call flow steps for a CDMA soft handoff with the target base station dropping off follow:

1. The mobile station determines that the target base station has insufficient pilot signal to continue to be a base station in the soft handoff.
2. The mobile station sends a Pilot Strength message to he serving base station. The message requests that the target base station drop off from the handoff.
3. The serving base station send a Handoff Direction message to the mobile station, which indicates the base station is to be dropped from the soft handoff.
4. The mobile station send a Handoff Complete message to the serving base station.
5. The serving base station sends an Interbase Station Remove message to the MSC.
6. The MSC sends an Interbase Station Remove message to the appropriate base station.
7. The serving base station then sends a Handoff Information message to the MSC.
8. The MSC sends a Handoff Information Acknowledge message to the serving base station.
9. The target base station sends a Remove Request message to the MSC.
10. The MSC sends a Remove Acknowledge message to the target base station.

11. After the target base station removes its resource from the call, it send an Interbase Station Remove Acknowledge message to the MSC.
12. The MSC send a Remove Acknowledge message to the serving base station.
13. The serving base station sends a Pilot Measurement Request Order to the mobile station.
14. The mobile station sends a Pilot Strength Measurement message to the serving base station.

The mobile station is now communicating only with the serving base station.

1.14 Voice Applications in the CDMA SYSTEM

Conventional wireline systems transmit voice by digitizing the voice signal using Pulse Code Modulation (PCM) at a rate of 64 kbps. While it is possible to use PCM in wireless systems (the W-CDMA system uses it as an option), the capacity of the wireless system is lower compared to using other digitizing methods for voice. The two CDMA systems use different approaches to digitizing the voice signal. The CDMA system uses a code-excited linear prediction (CELP) at 8 or 13.2 kbps to digitize voice. CELP systems model the operation of human vocal tract to code speech efficiently. One class of speech -coding techniques consists of algorithms called vocoders, which attempt to describe the speech production mechanism in terms of a few independent parameters serving as the information-bearing signals. These parameters attempt to model the creation of the voice by the vocal tract, decompose the information, and send it to the receiver. The receiver attempts to model an electronic vocal tract to produce the speech output. Nonspeech signals are often not modeled well, so this method works poorly for analog modems.

Vocoders are medium-complexity systems and operate at low bit rates, typically 2.4 kbps, with synthetic-quality speech. In the bit rates, from about 5 to 16 kbps, the best speech quality is obtained by using hybrid coders, which use suitable combinations of waveform-coding and vocoding techniques. A simple hybrid coding scheme for telephone-quality speech with a few integrated digital signal processors os the residual excited linear prediction (RELP) coding. This belongs to a class of coders known as an analysis-synthesis coder based on linear predictive coding (LPC).

The RELP systems employ short-term (and in certain cases, long-term) linear prediction to formulate a difference signal (residual) in a feed-forward manner. RELP systems are capable of producing communications quality speech at 8 kbps. These systems use either pitch-aligned high-frequency regeneration procedures or full-band pitch prediction in time domain to remove the pitch information from the residual signal prior to band-limitation/decimation. At bit rates less than 9.6 kbps, the quality o the recovered speech signal can be improved significantly by an analysis (AbS) optimization procedure to define the excitation signal. In these systems, both the filter and the excitation are defined on a short-term basis using a closed-loop optimization process that minimizes a perceptually weighted error measure formed between the input and decoded speech signals.

CDMA uses a variation of RELP called code-excited linear prediction. With this technique, the CELP decoder uses a codebook to generate inputs to a synthesis filter. The codebook is characterized by its codebook index I and gain G. The spectral filter is characterized by three sets of parameters: the pitch spectral lines a, the pitch lag L, and the pitch gain b. The output of the filter is processed by a post filter and gain adjustment.

CDMA implements a rate 1 encoder at 8.55 kbps and supports rates of 4, 2, and 0.8 kbps (rates 1/2. 1/4 and 1/8, respectively). Each of the rates uses successively less bits for encoding the values of I, G, L, b, and a, At rate of 1/8, insufficient bits are available to send the code-book index I, and a pseudorandom code generator (synchronized at both ends) is used and seeded by a random seed of value CBSEED.

The basic frame for CDMA is 20 ms. At rate 1, 160 bits are sent for encoding the data plus an 11-bit parity check field. Fewer bits are used at lower data rates.

The CELP speech encoder requires three steps to implement. First the line spectral pairs (LSP) i values are determined. Then the LSP values are used in an analysis by synthesis process to determine the values for the pitch lag L and gain b. Finally, the values of i, L, and b are used in a second AbS step to determine the codebook indices I and gains G.

1.15 MANAGMENT OF CDMA

In a CDMA system, it needs some elements to keep the system operating on a day-to-day basis. These elements are referred to as the operations, adminisrtation, maintenance, and provisioning systems. With OAM&P systems, cellular and PCS service providers monitor the health of all network elements, add and remove equipment, test software and hardware, diagnose problems, and bill subscribers for services.

Some specific goals for network management are as followings:

- Operation in a mixed vendor environment.
- Availability of multiple solutions.
- Use of existing resources.
- Support for multiple and interconnected systems.
- Support for sharing system and information among multiple service providers.
- Support for common solutions between end users and service providers.
- Transparent.
- Flexible.
- Modular.
- Fail-safe.

A standard management approach is TMN (Telecommunication Management Network). TMN defines the major function for network management. It is organized around OSI concepts and employs five management functional areas: fault, configuration, performance, accounting, and security management.

1.15.1 Fault Management

Fault management consists of a set of functions that enable the detection, isolation, and collection of an abnormal operation of a network element reported to an operations system. Fault management uses surveillance data collected at one or more network elements. The collection and reporting of the surveillance data are controlled by a set of generic functions. Fault management functions for operations system/network element interfaces deal with maintaining and examing error logs, reporting error conditions, and localizing and tracing faults by conducting diagnostic tests. The fault management supports the following management service components:

- Alarm surveillance.
- Fault localization or identification.
- Fault restoration, correction, or recovery.
- Testing.
- System monitoring and fault detection.

1.15.2 Configuration Management

Configuration management is concerned with provisioning, status and control, and installation support of the network. Provisioning is the procedures necessary to bring network resources into service. Service provisioning is to select and initialize appropriate resources to provide service to users. Configuration management application should maintain a resource and service inventory, which provides with availability information and resource location. Based on such type of database, each service request can be translated to facilities that need to be assigned from the inventory.

Status and control mechanism is responsible to update network element service state. It also sets the service criteria, such as error rates and throughput, for service provisioning.

Installation support is responsible to introduce new services or capabilities. Software installation aims to support correct creation of the administrable attribute set related to the installed software and support acceptance testing for the software being installed. Installation support provides capability to insure that hardware and its associated software will be maintained in a compatible state to ensure service continuity.

1.15.3 Performance Management

Performance management is concerned with evaluating and reporting on the behavior of managed resources and effectiveness of the network elements. It is responsible to track resource activities to collect monitored parameters for determining performance and control performance management functions and performance related criteria. Its objective is to make sure the system operation is within QoS limits and to detect service degradation as early as possible.

Generally, data are required to be produced by the network elements to support the following areas of performance evaluation:

- Traffic levels within the wireless network, including the level of both user traffic and signaling traffic;
- Verification of network configuration;
- Resource access measurements;
- Quality of service (e.g., delays during call setup); and
- Resource availability.

1.15.4 Accounting Management

Accounting management is concerned with collection and processing of accounting records, which contain service identifications, resource usage measurements, equipment ids, and customer ids. Its objective is to render a bill to the customer using the wireless service. The customer could be the end user or another network.

Accounting records will first be collected. For a roaming mobile subscriber, there can be more than one records generated for a delivered call. Accounting records for a single service instance will be correlated to generate a consolidated bill for a call event. Each call detail record needs to be validated to ensure that their contents meet specific integrity checks and all necessary information is included. Upon successful validation, the record should be converted to a standard format. Charges for each service instance may be determined and applied to the CDR (Call Detail Recording). CDRs are now ready to be disposed to provide access for different destinations.

1.15.5 Security Management

Security management is concerned with protecting managed objects. It provides functions for authentication procedures, access control and maintenance of authorization and security logs. Its objective is to avoid eavesdropping, masquerading, message tampering and replaying.

When access to a resource is requested, it needs to be authenticated to verify the identification of the party before access is granted. After a user has been authenticated for access, control access mechanisms are applied to applied to allow the user to manage only those domains belonging to him/her. All security activities should be logged to audit trails. Audit trail management controls audit trails behavior for data integrity and user access. When a security threat is detected, a security alarm should be reported. The security alarm report should identify its event cause and severity. In case of hardware and software anomalies, system integrity mechanisms should be triggered to detect if any data and system corruption has occurred. If so, intrusions recovery should be invoked to restore service after a security violation.

1.16 CDMA STANDARD

The following table lists some major CDMA Standards. The standards specifying the air interface (i.e., the messaging between the base station and the mobile station) are briefly discussed thereafter.

Table 1.10 major CDMA Standards

CDMA Standard	Designator	Description
Basic air interface	TIA/EIA/IS-95-A	Cellular
	ANSI J-STD-008	PCS
Network	TIA/EIA/IS-634	MAS-BS
	TIA/EIA/IS/651	PCSC-RS
	TIA/EIA/IS-41-C	Intersystem operations
	TIA/EIA/IS-124	Nom-signaling data comm.
Service	TIA/EIA/IS-96-B	Speech codec
	TIA/EIA/IS-99	Asyn data and fax
	TIA/EIA/IS-637	Short message service
	TIA/EIA/IS-657	Packet data
Performance	TIA/EIA/IS-97	Cellular base station
	TIA/EIA/IS-98	Cellular mobile station
	ANSI J-STD-018	PCS personal station
	ANSI J-STD-019	PCS base station
	TIA/EIA/IS-125	Speech codec

TIA/EIA/IS: Telecommunications Industry Association/Electronic Industries Association/Interim Standard

ANSI J-STD: American National Standard Institute, Inc. Joint industry standard

1.16.1 Cellular CDMA Standard: IS-95A

TIA/EIA/IS-95-A, Mobile Station - Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum. Cellular System. It is a formal definition of the cellular (800 MHz) CDMA air interface - heavy on rigor, light on explanations.

The technical requirements specified in IS-95A define a compatibility standard for wideband spread spectrum cellular mobile telecommunications. They ensure that a mobile station can obtain service in any cellular system manufactured according to this standard. IS-95A does not address the quality of reliability of the system. Additionally, many areas of operation are not fully specified if they do not impact compatibility.

To ensure compatiblity, both the radio interface and call processing protocols are specified. The Base Station is subject to fewer compatibility requirements than the subscriber stations. IS-95A describes the generation of the channels, Power control, Call processing, Handoffs, and Registration techniques for cellular system operation. IS-95 was first published in July of 1993. The IS-95A revision was published in May of 1995.

An additional specification, TSB-74, has been published that describes interaction between an IS-95A system and PCS CDMA systems that conform to ANSI J-STD-008.

1.16.2 PCS CDMA Standard: ANSI-J-STD-008

ANSI J-STD-008, Personal Station - Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum PCS System. It is a formal definition of the PCS (1900 MHz) air interface.

The PCS standard differs from IS-95-A primarily in the frequency plan and in call processing related to subscriber station identity, such as paging and call origination. The basic signal structure (message formats, coding, and modulation) are identical .

The specification does not address the quality or reliability of the service. The specification includes provisions for future service additions and expansion of system capabilities. J-STD-008 was published in 1995.

CHAPTER TWO

DIRECT SEQUENCE CDMA

2.1 Introduction

In DS-CDMA the modulated information-bearing signal (the data signal) is directly modulated by a digital, discrete-time, discrete-valued code signal. The data signal can be either analog or digital; in most cases it is digital. In the case of a digital signal the data modulation is often omitted and the data signal is directly multiplied by the code signal and the resulting signal modulates the wideband carrier. It is from this direct multiplication that the direct sequence CDMA gets its name.

In figure 2.1 a block diagram of a DS-CDMA transmitter is given.

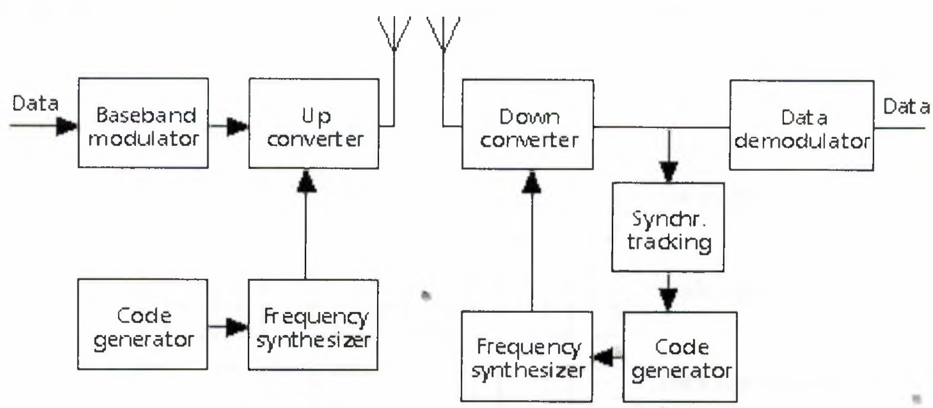


Figure 2.1 Block diagram of a DS-SS transmitter

The binary data signal modulates a RF carrier. The modulated carrier is then modulated by the code signal. This code signal consists of a number of code bits called "chips" that can be either +1 or -1. To obtain the desired spreading of the signal, the chip rate of the code signal must be much higher than the chip rate of the information signal. For the code modulation various modulation techniques can be used, but usually some form of phase shift keying (PSK) like binary phase shift keying (BPSK), differential binary phase shift keying (D-BPSK), quadrature phase shift keying (QPSK), orminimum shiftkeying (MSK) is employed.

If we omit the data modulation and use BPSK for the code modulation, we get the block diagram given in figure 2.2.

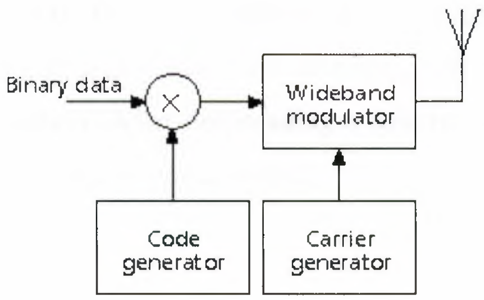


Figure 2.2 Modified block diagram of a DS-SS transmitter

The DS-SS signal resulting from this transmitter is shown in figure 2.3

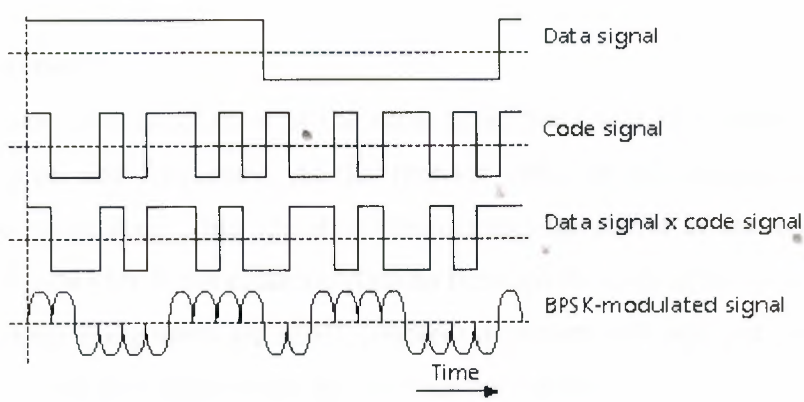


Figure 2.3 Generation of a BPSK-modulated SS signal.

The rate of the code signal is called the chip rate; one chip denotes one symbol when referring to spreading code signals. In this figure, 10 code chips per information symbol are transmitted (the code chip rate is 10 times the data rate) so the processing gain is equal to 10.

After transmission of the signal, the receiver uses coherent demodulation to despread the SS signal, using a locally generated code sequence. To be able to perform the despreading operation, the receiver must not only know the code sequence used to spread the signal, but the codes of the received signal and the locally generated code must also be synchronized. This synchronization must be accomplished at the beginning of the reception and maintained until the whole signal has been received. The code synchronization/tracking block performs this operation. After despreading a data modulated signal results, and after demodulation the origina data can be recovered.

2.2 Properties of DS-CDMA

In the previous section a number of advantageous properties of spread-spectrum signals were mentioned. The most important of those properties from the viewpoint of CDMA is the multiple access capability, the multipath interference rejection, the narrowband interference rejection, and with respect to secure/private communication, the LPI. We explain these four properties for the case of DS-CDMA.

2.2.1 Multiple Access

If multiple users use the channel at the same time, there will be multiple DS signals overlapping in time and frequency. At the receiver coherent demodulation is used to remove the code modulation. This operation concentrates the power of the desired user in the information bandwidth. If the crosscorrelations between the code of the desired user and the codes of the interfering users are small, coherent detection will only put a small part of the power of the interfering signals into the information bandwidth.

2.2.2 Multipath interference

If the code sequence has an ideal autocorrelation function, then the correlation function is zero outside the interval $[-T_c, T_c]$, where T_c is the chip duration. This means that if the desired signal and a version that is delayed for more than $2T_c$ are received, coherent demodulation will treat the delayed version as an interfering signal, putting only a small part of the power in the information bandwidth.

2.2.3Narrowband interference

The coherent detection at the receiver involves a multiplication of the received signal by a locally generated code sequence. However, as we saw at the transmitter, multiplying a narrowband signal with a wideband code sequence spreads the spectrum of the narrowband signal so that its power in the information bandwidth decreases by a factor equal to the processing gain.

2.2.4 LPI

Because the direct sequence signal uses the whole signal spectrum all the time, it will have a very low transmitted power per hertz. This makes it very difficult to detect a DS signal.

Apart from the above-mentioned properties, DS-CDMA has a number of other specific properties that we can divide into advantageous (+) and disadvantageous (-) behavior:

+ The generation of the coded signal is easy. It can be performed by a simple multiplication.

+ Since only one carrier frequency has to be generated, the frequency synthesizer (carrier generator) is simple.

+Coherent demodulation of the DS signal is possible.

+No synchronization among the users is necessary.

- It is difficult to acquire and maintain the synchronization of the locally generated code signal and the received signal. Synchronization has to be kept within a fraction of the chip time.

- For correct reception the synchronization error of locally generated code sequence and the received code sequence must be very small, a fraction of the chip time. This combined with the nonavailability of large contiguous frequency bands practically limits the bandwidth to 10-20 MHz.
- The power received from users close to the base station is much higher than that received from users further away. Since a user continuously transmits over the whole bandwidth, a user close to the base will constantly create a lot of interference for users far from the base station, making their reception impossible. This near-far effect can be solved by applying a power control algorithm so that the base station with the same average power receives all users. However this control proves to be quite difficult.

2.3 Basic DS-CDMA Elements

In this section, we review the fundamental elements for understanding direct sequence CDMA and its application into third-generation systems, namely, RAKE receiver, power control, soft handover, interfrequency handover, and multiuser detection.

2.3.1 RAKE Receiver

A spread-spectrum signal waveform is well matched to the multipath channel. In a multipath channel, the original transmitted signal reflects from obstacles such as buildings, and mountains, and the receiver receives several copies of the signal with different delays. If the signals arrive more than one chip apart from each other, the receiver can resolve them. Actually, from each multipath signal's point of view, other multipath signals can be regarded as interference and they are suppressed by the processing gain. However, a further benefit is obtained if the resolved multipath signals are combined using RAKE receiver. Thus, the signal waveform of CDMA signals facilitates utilization of multipath diversity. Expressing the same phenomenon in the frequency domain means that the bandwidth of the transmitted signal is larger than the coherence bandwidth of the channel and the channel is frequency selective (i.e., only part of the signal is affected by the fading). RAKE receiver consists of correlators, each receiving a multipath signal. After despreading by correlators, the signals are combined using, for example, maximal ratio combining.

Since the received multipath signals are fading independently, diversity order and thus performance are improved. Figure 2.4 illustrates the principle of RAKE receiver.

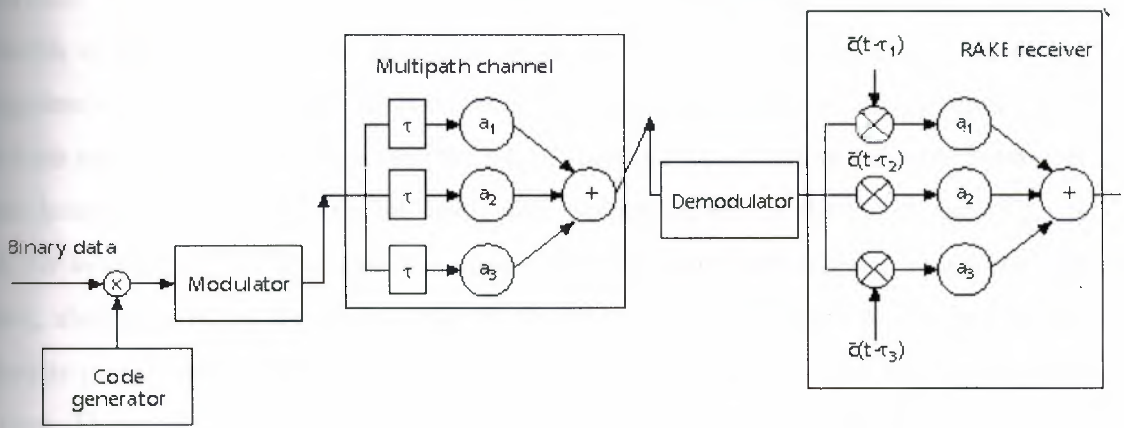


Figure 2.4 Principle of RAKE receiver.

After spreading and modulation the signal is transmitted and it passes through a multipath channel, which can be modeled by a tapped delay line (i.e., the reflected signals are delayed and attenuated in the channel). In Figure 2.4 we have three multipath components with different delays (*1, *2, and *3) and attenuation factors (a1, a2, and a3), each corresponding to a different propagation path. The RAKE receiver has a receiver finger for each multipath component. In each finger, the received signal is correlated by a spreading code, which is time-aligned with the delay of the multipath signal. After despreading, the signals are weighted and combined. In Figure 2.4 maximal ratio combining is used, that is, each signal is weighted by the path gain (attenuation factor). Due to the mobile movement the scattering environment will change, and thus, the delays and attenuation factors will change as well. Therefore, it is necessary to measure the tapped delay line profile and to reallocate RAKE fingers whenever there is need. Small-scale changes, less than one chip, are taken care of by a code tracking loop, which tracks the time delay of each multipath signal.

2.3.2 Power Control

In the uplink of a DS-CDMA system, the requirement for power control is the most serious negative point. The power control problem arises because of the multiple access interference. All users in a DS-CDMA system transmit the messages by using the same bandwidth at the same time and therefore users interfere with one another. Due to the propagation mechanism, the signal received by the base station from a user terminal close to the base station will be stronger than the signal received from another terminal located at the cell boundary. Hence, the distant users will be dominated by the close user. This is called the *near-far effect*. To achieve a considerable capacity, all signals, irrespective of distance, should arrive at the base station with the same mean power. A solution to this problem is power control, which attempts to achieve a constant received mean power for each user. Therefore, the performance of the transmitter power control (TPC) is one of the several dependent factors when deciding on the capacity of a DS-CDMA system. In contrast to the uplink, in the downlink all signals propagate through the same channel and thus are received by a mobile station with equal power. Therefore, no power control is required to eliminate near-far problem. The power control is, however, required to minimize the interference to other cells and to compensate against the interference from other cells. The worst-case situation for a mobile station occurs when the mobile station is at the cell edge, equidistant from three base stations. However, the interference from other cells does not vary very abruptly. In addition being useful against interfering users, power control improves the performance of DS-CDMA against fading channel by compensating the fading dips. If it followed the channel fading perfectly, power control would turn a fading channel into AWGN channel by eliminating the fading dips completely. There exist two types of power control principles: open loop and closed loop. The open loop power control measures the interference conditions from the channel and adjusts the transmission power accordingly. However, since the fast fading does not correlate between uplink and downlink, open loop power control will achieve the right power target only on average. Therefore, closed loop power control is required. The closed loop power control measures the signal-to-interference ratio (SIR) and sends commands to the transmitter on the other end to adjust the transmission power.

2.3.3 Soft Handover

In soft handover a mobile station is connected to more than one base station simultaneously. Soft handover is used in CDMA to reduce the interference into other cells and to improve performance through macro diversity. Softer handover is a soft handover between two sectors of a cell. Neighboring cells of a cellular system using either FDMA or TDMA do not use the frequencies used by the given cell (i.e., there is spatial separation between cells using the same frequencies). This is called the frequency reuse concept. Because of the processing gain, such spatial separation is not needed in CDMA, and frequency reuse factor of one can be used. Usually, a mobile station performs a handover when the signal strength of a neighboring cell exceeds the signal strength of the current cell with a given threshold. This is called hard handover. Since in a CDMA system the neighboring cell frequencies are the same as in the given cell, this type of approach would cause excessive interference into the neighboring cells and thus a capacity degradation. In order to avoid this interference, an instantaneous handover from the current cell to the new cell would be required when the signal strength of the new cell exceeds the signal strength of the current cell. This is not, however, feasible in practice. The handover mechanism should always allow the mobile station to connect into a cell, which it receives with the highest power (i.e., with the lowest pathloss). Since in soft handover the mobile station is connected to either two or more base stations, its transmission power can be controlled according to the cell, which the mobile station receives with the highest signal strength. A mobile station enters the soft handover state when the signal strength of neighboring cell exceeds a certain threshold but is still below the current base station's signal strength. Fortunately, the signal structure of CDMA is well suited for the implementation of soft handover. This is because in the uplink, two or more base stations can receive the same signal because of the reuse factor of one; and in the downlink the mobile station can coherently combine the signals from different base stations since it sees them as just additional multipath components. This provides an additional benefit called macro diversity (i.e., the diversity gain provided by the reception of one or more additional signals). A separate channel called pilot is usually used for the signal strength measurements for handover purposes. In the downlink, however, soft handover creates more interference to the system since the new base station now transmits an additional signal for the mobile station. It is possible that the mobile station cannot catch all the energy that the base station transmits due to a limited number of RAKE fingers. Thus, the gain of soft handover in the downlink depends on the gain of macro diversity and the loss of performance due to increased interference. Figure 2.5 illustrates the soft handover principle with two base stations involved. In the uplink the mobile station signal is received by the two base stations, which, after demodulation and combining, pass the signal forward to the combining point, typically to the base station controller (BSC). In the downlink the same information is transmitted via both base stations, and the mobile station receives the information from two base stations as separate multipath signals and can therefore combine them.

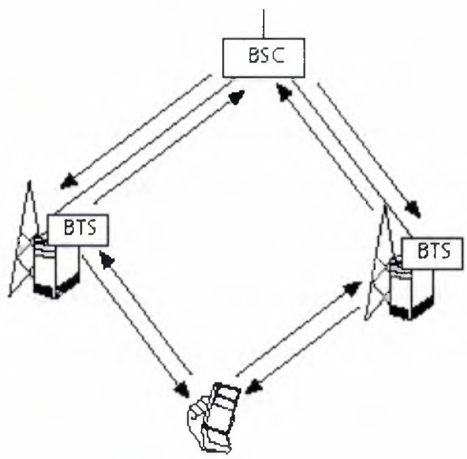


Figure 2.5 - Principle of soft handover with two base station transceivers (BTS).

2.3.4 Interfrequency Handover

The third-generation CDMA networks will have multiple frequency carriers in each cell, and a hot-spot cell could have a larger number of frequencies than neigboring cells. Furthermore, in hierarchical cell structures, micro cells will have a different frequency than the macro cell overlaying the micro cells. Therefore, an efficient procedure is needed for a handover between different frequencies. A blind handover used by second-generation

CDMA does not result in an adequate call quality. Instead, the mobile station has to be able to measure the signal strength and quality of an another carrier frequency, while still maintaining the connection in the current carrier frequency. Since a CDMA transmission is continuous, there are no idle slots for the interfrequency measurement/ as in the TDMA-based systems. Therefore, compressed mode and dual receiver have been proposed as a solution to interfrequency handover . In the compressed mode, measurements slots are created by transmitting the data of a frame, for example, with a lower spreading ratio during a shorter period, and the rest of the frame is utilized for the measurements on other carriers. The dual receiver can measure other frequencies without affecting the reception of the current frequency.

2.3.5 Multiuser Detection

The current CDMA receivers are based on the RAKE receiver principle, which considers other users' signals as interference. However, in an optimum receiver all signals would be detected jointly or interference from other signals would be removed by subtracting them from the desired signal. This is possible because the correlation properties between signals are known (i.e., the interference is deterministic not random). The capacity of a direct sequence CDMA system using RAKE receiver is interference limited. In practice this means that when a new user, or interferer, enters the network, other users' service quality will go below the acceptable level. The more the network can resist interference the more users can be served. Multiple access interference that disturbs a base or mobile station is a sum of both intra- and inter-cell interference. Multiuser detection (MUD), also called joint detection and interference cancellation (IC), provides a means of reducing the effect of multiple access interference, and hence increases the system capacity. In the first place MUD is considered to cancel only the intra-cell interference, meaning that in a practical system the capacity will be limited by the efficiency of the algorithm and the inter-cell interference. In addition to capacity improvement, MUD alleviates the near/far problem typical to DS-CDMA systems. A mobile station close to a base station may block the whole cell traffic by using too high a transmission power. If this user is detected first and subtracted from the input signal, the other users do not see the interference. Since optimal multiuser detection is very complex and in practice impossible to implement for any reasonable number of users, a number of suboptimum multiuser and interference cancellation receivers have been developed. The suboptimum receivers can be divided into two main categories: linear detectors and interference cancellation. Linear detectors apply a linear transform into the outputs of the matched filters that are trying to remove the multiple access interference (i.e., the interference due to correlations between user codes). Examples of linear detectors are decorrelator and linear minimum mean square error (LMMSE) detectors. In interference cancellation multiple access interference is first estimated and then subtracted from the received signal. Parallel interference cancellation (PIC) and successive (serial) interference cancellation (SIC) are examples of interference cancellation.

CHAPTER THREE

WIDEBAND CDMA

3.1 Introductuion

Wideband CDMA has a bandwidth of 5 MHz or more. The nominal bandwidth for all third-generation proposals is 5 MHz. There are several reasons for choosing this bandwidth. First, data rates of 144 and 384 Kb/s, the main targets of third-generation systems, are achievable within 5 MHz bandwidth with a reasonable capacity. Even a 2-Mb/s peak rate can be provided under limited conditions. Second, lack of spectrum calls for reasonably small minimum spectrum allocation, especially if the system has to be deployed within the existing frequency bands occupied already by second-generation systems. Third, the 5-MHz bandwidth can resolve (separate) more multipaths than narrower bandwidths, increasing diversity and thus improving performance. Larger bandwidths of 10, 15, and 20 MHz have been proposed to support higher data rates more effectively. Several wideband CDMA proposals have been made for third-generation wireless systems. They can be characterized by the following new advanced properties:

- Provision of multirate services
- Packet data
- Complex spreading
- A coherent uplink using a user dedicated pilot
- Additional pilot channel in the downlink for beamforming
- Seamless interfrequency handover
- Fast power control in the downlink
- Optional multiuser detection

The third-generation air interface standardization for the schemes based on CDMA seems to focus on two main types of wideband CDMA: network asynchronous and synchronous. In network asynchronous schemes the base stations are not synchronized, while in network synchronous schemes the base stations are synchronized to each other within a few microseconds. There are three network asynchronous CDMA proposals: WCDMA in ETSI and in ARIB, and TTA II in Korea have similar parameters. A network synchronous wideband CDMA scheme has been adopted by TR45.5 and is being considered by Korea (TTA I). W-CDMA systems are being commercialized in the twenty-first century. In the United States, the counterpart of W-CDMA in Japan and Europe is CDMA2000. CDMA2000 plans to incorporate Multicarrier-CDMA (MC-CDMA), a combination of Multicarrier modulation and CDMA, into its design as an evolution path for one of the currently deployed second-generation standards, IS-95.

3.2 Wideband CDMA Schemes

This section presents the wideband CDMA air interface being developed by the standardization organizations in Europe, Japan, the United States, and Korea for third-generation communication systems. Figure 3.1 illustrates the different schemes and their relations to standards bodies and to each other.

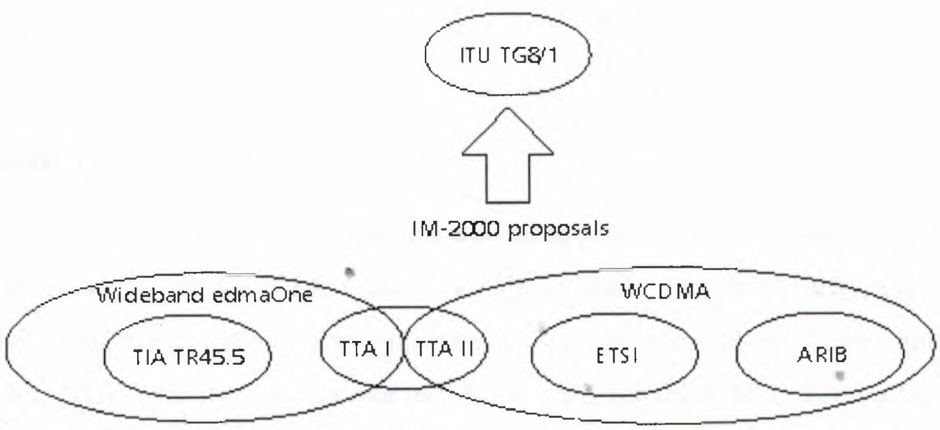


Figure 3.1 Relationship between wideband CDMA schemes and standards bodies

The third-generation air interface standardization for the schemes based on CDMA seems to focus on two main types of wideband CDMA: network asynchronous and network synchronous. In network asynchronous schemes the base stations are not synchronized, while in network synchronous schemes the base stations are synchronized to each other within a few microseconds. There are three network asynchronous CDMA proposals: WCDMA in ETSI and ARIB, and TTA II wideband CDMA in Korea have similar parameters . In addition, T1P1 in the United States has joined the development of WCDMA. TR46.1 in the United States is also developing a wideband CDMA scheme, Wireless Multimedia & Messaging Services (WIMS), which has been recently harmonized with WCDMA. A network synchronous wideband CDMA scheme has been proposed by TR45.5 (cdma2000) and is being considered by Korea . All schemes are geared towards the IMT-2000 radio transmission technology selection process in ITU-R TG8/1. In addition to the above main wideband CDMA schemes, we introduce two more that are interesting from a wideband CDMA development perspective. These are CODIT and IS-665 W-CDMA. Several attempts have been made to harmonize the different wideband CDMA approaches in search of a unified global air interface. However, due to the evolution of current systems and the strong commercial interests of their supporters, at the moment it seems that there will be at least two wideband CDMA standards for third-generation. It should be noted that several changes of parameters have occurred during the development of these proposals and the detailed concepts and standards will be developed during 1998 and 1999. In this section we try to reflect the latest information available in the literature.

3.3 Technical Approaches

In the following, we discuss the main technical approaches of WCDMA and cdma2000. These differences apply to the TTA I and TTA II as well. The main differences between WCDMA and cdma2000 systems are chip rate, downlink channel structure, and network synchronization. cdma2000 uses a chip rate of 3.6864 Mc/s for the 5-MHz band allocation with the direct spread downlink and a 1.2288-Mc/s chip rate for the multicarrier downlink [5]. WCDMA uses direct spread with a chip rate of 4.096 Mc/s. The multicarrier approach is motivated by a spectrum overlay of cdma2000 with existing IS-95 carriers. Similar to IS-95B, the spreading codes of cdma2000 are generated using different phase shifts of the same M-sequence. This is possible because of the synchronous network operation. Since WCDMA has an

... expansion. The code structure further impacts how code ... cell acquisition, and handover synchronization are performed. ... bandwidth for all third-generation proposals is 5-MHz. There are several reasons ... this bandwidth. First, data rates of 144 and 384 Kb/s are achievable within 5-MHz [illegible] Mb/s peak rate can be provided under limited conditions. Second, lack of spectrum calls for reasonably small minimum spectrum allocation, especially if the system has to be deployed within the existing frequency bands already occupied by the second-generation systems. Third, the large 5-MHz bandwidth can resolve more multipaths than a narrower bandwidth, thus increasing diversity and improving performance. Larger bandwidths of 10, 15, and 20 MHz have been proposed to support highest data rates more effectively.

3.4 WCDMA

The WCDMA scheme has been developed as a joint effort between ETSI and ARIB during the second half of 1997 . The ETSI WCDMA scheme has been developed from the FMA2 scheme in Europe and the ARIB WCDMA from the Core-A scheme in Japan . The uplink of the WCDMA scheme is based mainly on the FMA2 scheme, and the downlink on the Core-A scheme. In this section, we present the main technical features of the ARIB/ETSI WCDMA scheme.

3.4.1 Carrier Spacing and Deployment Scenarios

The carrier spacing has a raster of 200 kHz and can vary from 4.2 to 5.4 MHz. The different carrier spacings can be used to obtain suitable adjacent channel protections depending on the interference scenario. Figure 3.2 shows an example for the operator bandwidth of 15 MHz with three cell layers.

Larger carrier spacing can be applied between operators than within one operator's band in order to avoid inter-operator interference. Interfrequency measurements and handovers are supported by WCDMA to utilize several cell layers and carriers.

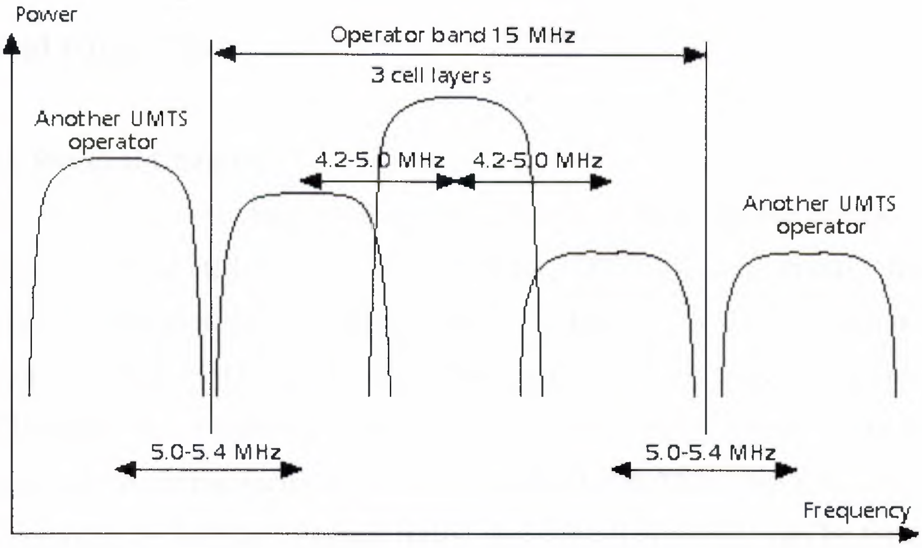


Figure 3.2 Frequency utilization with WCDMA.

3.4.2 Logical Channels

WCDMA basically follows the ITU Recommendation M.1035 in the definition of logical channels . The following logical channels are defined for WCDMA. The three available common control channels are:

- Broadcast control channel (BCCH) carries system and cell specific information
- Paging channel (PCH) for messages to the mobiles in the paging area
- Forward access channel (FACH) for massages from the base station to the mobile in one cell.

In addition, there are two dedicated channels:

- Dedicated control channel (DCCH) covers the two dedicated control channel stand-alone dedicated channel (SDCCH) and associated control channel (ACCH)
- Dedicated traffic channel (DTCH) for point-to-point data transmission in the uplink and downlink

3.5 Physical Channels

3.5.1 Uplink Physical Channels.

There are two dedicated channels and one common channel on the uplink. User data is transmitted on the dedicated physical data channel (DPDCH), and control information is transmitted on the dedicated physical data channel (DPDCH). The random access channel is a common access channel. Figure 3.3 shows the principle frame structure of the uplink DPDCH. Each DPDCH frame on a single code carries 160 x 2^k bits (16 x 2^k Kb/s), where k = 0,1, ..., 6, corresponding to a spreading factor of $256/2^k$ with the 4.096-Mc/s chip rate. Multiple parallel variable rate services (= dedicated logical traffic and control channels) can be time multiplexed within each DPDCH frame.

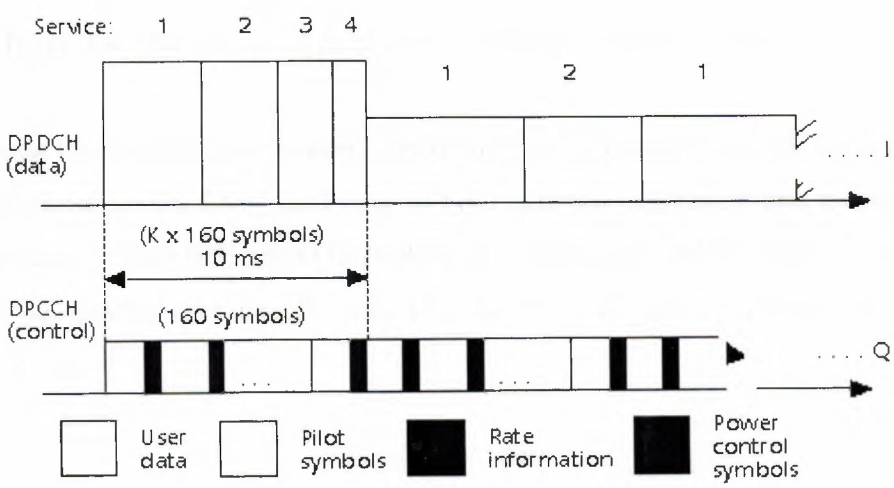


Figure 3.3 WCDMA uplink multirate transmission

The overall DPDCH bit rate is variable on a frame-by-frame basis. In most cases, only one DPDCH is allocated per connection, and services are jointly interleaved sharing the same DPDCH. However, multiple DPDCHs can also be allocated (e.g. to avoid a too low spreading factor at high data rates). The dedicated physical control channel (DPCCH) is needed to transmit pilot symbols for coherent reception, power control signaling bits, and rate information for rate detection. Two basic solutions for multiplexing physical control and data channels are time multiplexing and code multiplexing. A combined IQ and code multiplexing solution (dual-channel QPSK) is used in WCDMA uplink to avoid electromagnetic compatibility (EMC) problems with discontinuous transmission (DTX). The major drawback of the time multiplexed control channel are the EMC problems that arise when DTX is used for user data. One example of a DTX service is speech. During silent periods no information bits need to be transmitted, which results in pulsed transmission as control data must be transmitted in any case. This is illustrated in Figure 3.4.

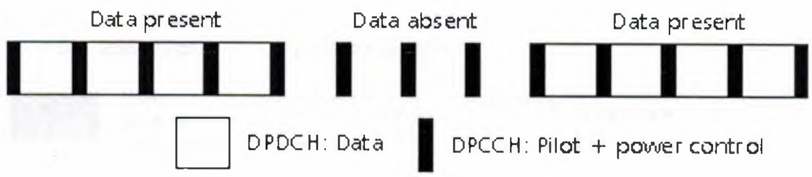


Figure 3.4 Illustration of pulsed transmission with time multiplexed control channel.

Because the rate of transmission of pilot and power control symbols is on the order of 1 to 2 kHz, they cause severe EMC problems to both external equipment and terminal interiors. This EMC problem is more difficult in the uplink direction since mobile stations can be close to other electrical equipment, like hearing aids.The IQ/code multiplexed control channel is shown in Figure 3.5

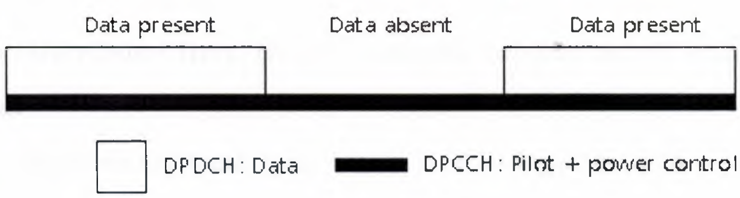


Figure 3.5 Illustration of parallel transmission of DPDCH and DPCCH channel when data is present/adsent

Now, since pilot and power control are on a separate channel, no pulse-like transmission takes place. Interference to other users and cellular capacity remains the same as in the time multiplexed solution. In addition, link-level performance is the same in both schemes if the energy allocated to the pilot and the power control bits is the same.The structure of the random access burst is shown in Figure 3.6.

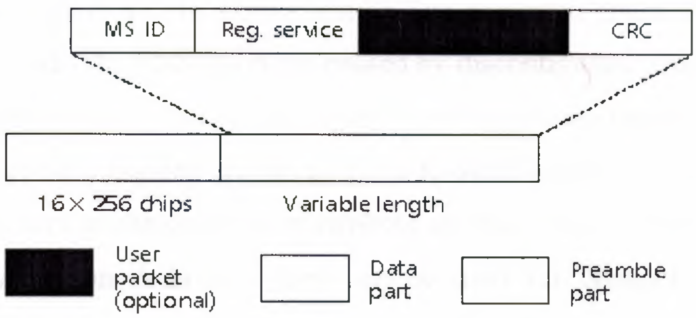


Figure 3.6 Structure of WCDMA random access burst

The random access burst consists of two parts, a preamble part of length 16 x 256 chips (1 ms) and a data part of variable length. The WCDMA random access scheme is based on a slotted ALOHA technique with the random access burst structure shown in Figure 3.6. Before the transmission of a random access request, the mobile terminal should carry out the following tasks:

- Achieve chip, slot, and frame synchronization to the target base station from the synchronization channel (SCH) and obtain information about the downlink scrambling code also from the SCH
- Retrieve information from BCCH about the random access code(s) used in the target cell/sector
- Estimate the downlink path loss, which is used together with a signal strength target to calculate the required transmit power of the random access request

It is possible to transmit a short packet together with a random access burst without settting up a scheduled packet channel. No separate access channel is used for packet traffic related random access, but all traffic shares the same random access channel. More than one random access channel can be used if the random access capacity requires such an arrangement

3.5.2 Downlink Physical Channels.

In the downlink, there are three common physical channels. The primary and secondary common control physical channels (CCPCH) carry the downlink common control logical channels (BCCH, PCH, and FACH); the SCH provides timing information and is used for handover measurements by the mobile station.The dedicated channels (DPDCH and DPCCH). are time multiplexed. The EMC problem caused by discontinuous transmission is not considered difficult in downlink since (1) there are signals to several users transmitted in parallel and at the same time and (2) base stations are not so close to other electrical equipment, like hearing aids. In the downlink, time multiplexed pilot symbols are used for coherent detection. Since the pilot symbols are connection dedicated, they can be used for channel estimation with adaptive antennas as well. Furthermore, the connection dedicated pilot symbols can be used to support downlink fast power control. In addition, a common pilot time multiplexed in the BCCH channel can be used for coherent detection.The primary CCPCH carries the BCCH channel and a time multiplexed common pilot channel. It is of fixed rate and is mapped to the DPDCH in the same way as dedicated traffic channels. The primary CCPCH is allocated the same channelization code in all cells. A mobile terminal can thus always find the BCCH, once the base station's unique scrambling code has been detected during the initial cell search.
The secondary physical channel for common control carries the PCH and FACH in time multiplex within the super frame structure. The rate of the secondary CCPCH may be different for different cells and is set to provide the required capacity for PCH and FACH in each specific environment. The channelization code of the secondary CCPCH is transmitted on the primary CCPCH.

The SCH consists of two subchannels, the primary and secondary SCHs. Figure 3.7 illustrates the structure of the SCH.

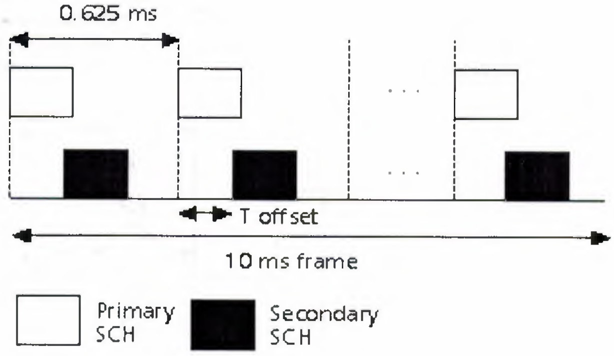


Figure 3.7 Structure of the synchronization channel (SCH).

The SCH applies short code masking to minimize the acquisition time of the long code. The SCH is masked with two short codes (primary and secondary SCH). The unmodulated primary SCH is used to acquire the timing for the secondary SCH. The modulated secondary SCH code carries information about the long code group to which the long code of the BS belongs. In this way, the search of long codes can be limited to a subset of all the codes.The primary SCH consists of an unmodulated code of length 256 chips, which is transmitted once every slot. The primary synchronization code is the same for every base station in the system and is transmitted time aligned with the slot boundary, as illustrated in Figure 3.7 The secondary SCH consists of one modulated code of length 256 chips, which is transmitted in parallel with the primary SCH. The secondary synchronization code is chosen from a set of 16 different codes depending on to which of the 32 different code groups the base station downlink scrambling code csc belongs.The secondary SCH is modulated with a binary sequence of length 16 bits, which is repeated for each frame. The modulation sequence, which is the same for all base stations, has good cyclic autocorrelation properties. The multiplexing of the SCH with the other downlink physical channels (DPDCH/DPCCH and CCPCH) is illustrated in Figure 3.8.The SCH is transmitted only intermittently (one codeword per slot), and it is multiplexed with the DPDCH/DPCCH and CCPCH after long code scrambling is applied on DPDCH/DPCCH and CCPCH. Consequently, the SCH is nonorthogonal to the other downlink physical channels.

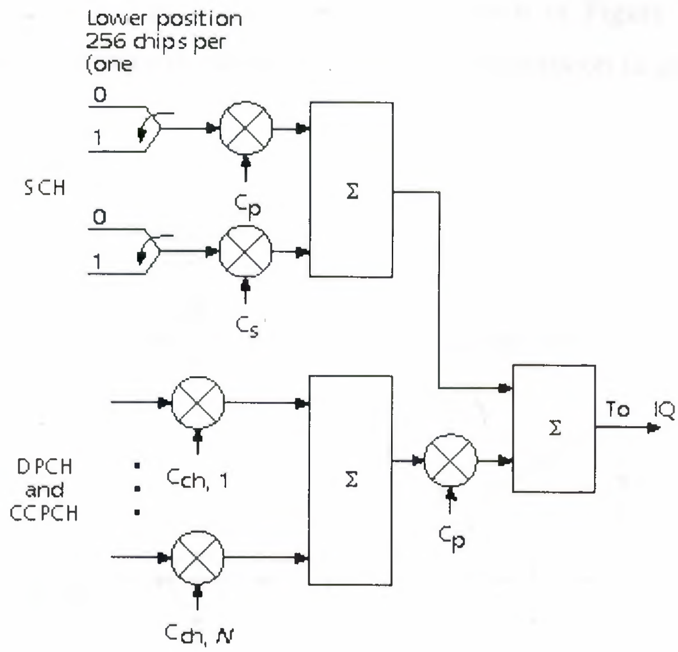


Figure 3.8 Multiplexing of the SCH (s_p = primary spreading code; s_c = secondary spreading code; c_{ch} = orthogonal code; c_{sc} = long scrambling code).

3.6 Spreading

The WCDMA scheme employs long spreading codes. Different spreading codes are used for cell separation in the downlink and user separation in the uplink. In the downlink, Gold codes of length 2^{18} are used, but they are truncated to form a cycle of a 10-ms frame. The total number of available scrambling codes is 512, divided into 32 code groups with 16 codes in each group to facilitate a fast cell search procedure. In the uplink, either short or long spreading (scrambling codes) are used. The short codes are used to ease the implementation of advanced multiuser receiver techniques; otherwise long spreading codes can be used. Short codes are VL-Kasami codes of length 256 and lond codes are Gold sequences of length 2^{41}, but the latter are truncated to form a cycle of a 10-ms frame. For channelization, orthogonal codes are used. Orthogonality between the different spreading factors can be achieved by the tree-structured orthogonal codes. IQ/code multiplexing leads to parallel transmission of two channels, and therefore, attention must be paid to modulated signal constellation and related peak-to-average power ratio (crest factor). By using the complex spreading circuit shown in Figure 3.9, the transmitter power amplifier efficiency remains the same as for QPSK transmission in general.

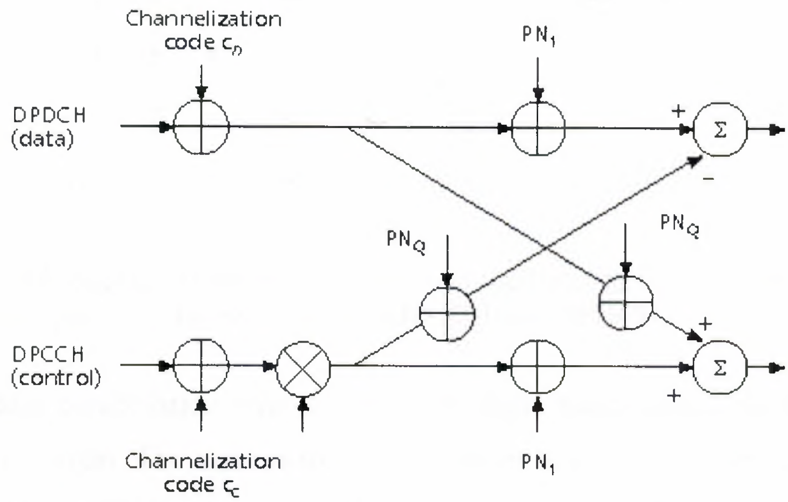


Figure 3.9 IQ/code multiplexing with complex spreading circuit.

Moreover, the efficiency remains constant irrespective of the power difference G between DPDCH and DPCCH. This can be explained with Figure 3.10, which shows the signal constellation for IQ/code multiplexed control channel with complex spreading.

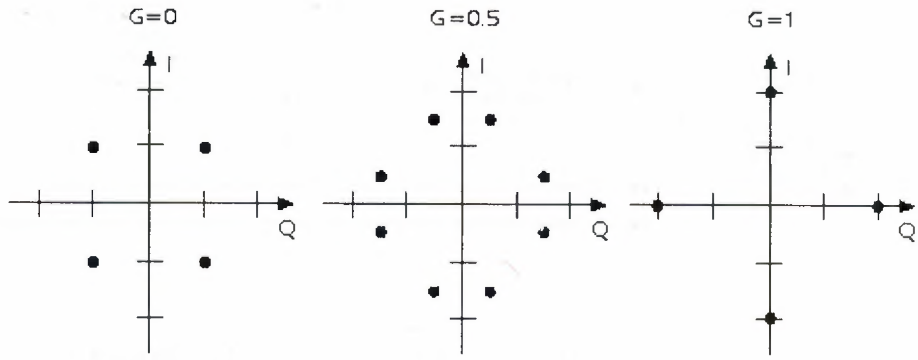


Figure 3.10 Signal constellation for IQ/code multiplexed control channel with complex spreading. G is the power difference between DPCCH and DPDCH.

In the middle constellation with $G = 0.5$ all eight constellation points are at the same distance from the origin. The same is true for all values of G. Thus, signal envelope variations are very similar to the QPSK transmission for all values of G. The IQ/code multiplexing solution with complex scrambling results in power amplifier output backoff requirements that remain constant as a function of power difference. Furthermore, the achieved output backoff is the same as for one QPSK signal.

3.7 Multirate

Multiple services of the same connection are multiplexed on one DPDCH. Multiplexing may take place either before or after the inner or outer coding, as illustrated in Figure 3.12.

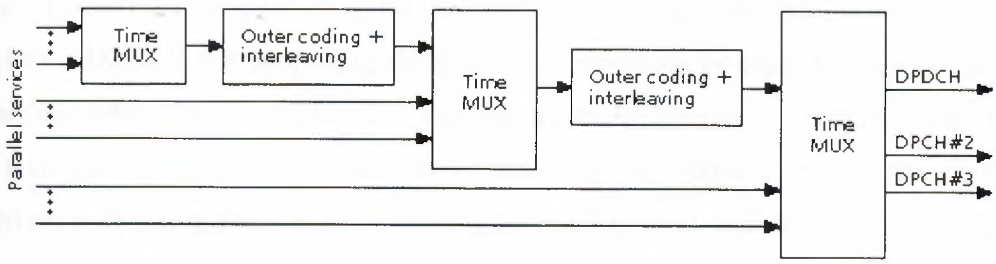


Figure 3.12 Service multiplexing in WCDMA.

After service multiplexing and channel coding, the multiservice data stream is mapped to one DPDCH. If the total rate exceeds the upper limit for single code transmission, several DPDCHs can be allocated. A second alternative for service multiplexing would be to map parallel services to different DPDCHs in a multicode fashion with separate channel coding/interleaving. With this alternative scheme, the power, and consequently the quality of each service, can be separately and independently controlled. The disadvantage is the need for multicode transmission, which will have an impact on mobile station complexity. Multicode transmission sets higher requirements for the power amplifier linearity in transmission, and more correlators are needed in reception. For BER = 10^{3} services, convolutional coding of 1/3 is used. For high bit rates a code rate of 1/2 can be applied. For higher quality service classes outer Reed-Solomon coding is used to reach the 10^{6} BER level. Retransmissions can be utilized to guarantee service quality for non real-time packet data services. After channel coding and service multiplexing, the total bit rate can be almost arbitrary. The rate matching adapts this rate to the limited set of possible bit rates of a DPDCH. Repetition or puncturing is used to match the coded bit stream to the channel gross rate. The rate matching for uplink and downlink are introduced below.

For the uplink, rate matching to the closest uplink DPDCH bit rate is always based on unequal repetition (a subset of the bits repeated) or code puncturing. In general, code puncturing is chosen for bit rates less than (20 percent above the closest lower DPDCH bit rate. For all other cases, unequal repetition is performed to the closest higher DPDCH bit rate. The repetition/puncturing patterns follow a regular predefined rule (i.e., only the amount of repetition/puncturing needs to be agreed on). The correct repetition/puncturing pattern can then be directly derived by both the transmitter and receiver side. For the downlink, rate matching to the closest DPDCH bit rate, using either unequal repetition or code puncturing, is only made for the highest rate (after channel coding and service multiplexing) of a variable rate connection and for fixed-rate connections. For lower rates of a variable rate connection, the same repetition/puncturing pattern as for the highest rate is used, and the remaining rate matching is based on discontinuous transmission where only a part of each slot is used for transmission. This approach is used in order to simplify the implementation of blind rate detection in the mobile station.

3.8 Packet Data

WCDMA has two different types of packet data transmission possibilities. Short data packets can be appended directly to a random access burst. This method, called *common channel packet transmission*, is used for short infrequent packets, where the link maintenance needed for a dedicated channel would lead to an unacceptable overhead. When using the uplink common channel, a packet is appended directly to a random access burst. Common channel packet transmission is typically used for short, infrequent packets, where the link maintenance needed for a dedicated channel would lead to unacceptable overhead. Also, the delay associated with a transfer to a dedicated channel is avoided. Note that for common channel packet transmission only open loop power control is in operation. Common channel packet transmission should therefore be limited to short packets that only use a limited capacity. Figure 3.13 illustrates packet transmission on a common channel

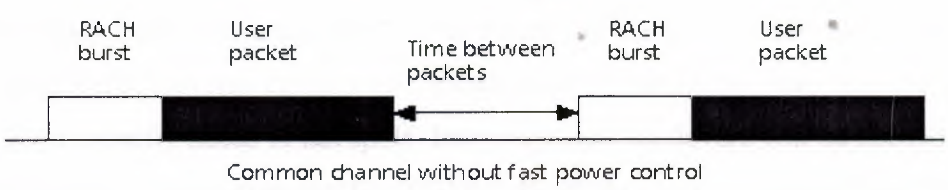


Figure 3.13 Packet transmission on the common channel

Larger or more frequent packets are transmitted on a dedicated channel. A large single packet is transmitted using a *single-packet scheme* where the dedicated channel is released immediately after the packet has been transmitted. In a *multipacket scheme* the dedicated channel is maintained by transmitting power control and synchronization information between subsequent packets.

3.9 Handover

Base stations in WCDMA need not be synchronized, and therefore, no external source of synchronization, like GPS, is needed for the base stations. Asynchronous base stations must be considered when designing soft handover algorithms and when implementing position location services. These two aspects are considered in this section. Before entering soft handover, the mobile station measures observed timing differences of the downlink SCHs from the two base stations. The structure of SCH is presented in a section to follow, "Physical Channels." The mobile station reports the timing differences back to the serving base station. The timing of a new downlink soft handover connection is adjusted with a resolution of one symbol (i.e., the dedicated downlink signals from the two base stations are synchronized with an accuracy of one symbol). That enables the mobile RAKE receiver to collect the macro diversity energy from the two base stations. Timing adjustments of dedicated downlink channels can be carried out with a resolution of one symbol without losing orthogonality of downlink codes.

3.10 Interfrequency Handovers.

Interfrequency handovers are needed for utilization of hierarchical cell structures; macro, micro, and indoor cells. Several carriers and interfrequency handovers may also be used for taking care of high capacity needs in hot spots. Interfrequency handovers will be needed also for handovers to second-generation systems, like GSM or IS-95. In order to complete interfrequency handovers, an efficient method is needed for making measurements on other frequencies while still having the connection running on the current frequency. Two methods are considered for interfrequency measurements in WCDMA:

- Dual receiver
- Slotted mode

The dual receiver approach is considered suitable especially if the mobile terminal employs antenna diversity. During the interfrequency measurements, one receiver branch is switched to another frequency for measurements, while the other keeps receiving from the current frequency. The loss of diversity gain during measurements needs to be compensated for with higher downlink transmission power. The advantage of the dual receiver approach is that there is no break in the current frequency connection. Fast closed loop power loop is running all the time. The slotted mode approach depicted in Figure 3.14 is considered attractive for the mobile station without antenna diversity.

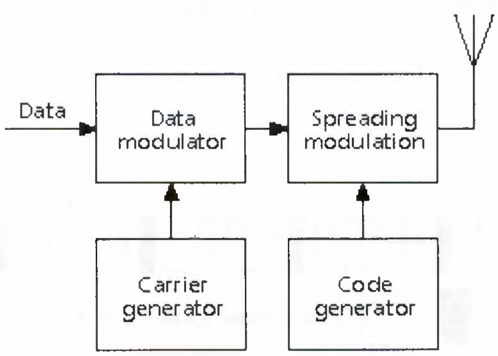


Figure 3.13 Slotted mode structure

The information normally transmitted during a 10-ms frame is compressed time either by code puncturing or by changing the FEC rate.

3.11 Inter-operability Between GSM and WCDMA

The handover between the WCDMA system and the GSM system, offering worldwide coverage already today, has been one of the main design criteria taken into account in the

WCDMA frame timing definition. The GSM compatible multiframe structure, with a superframe multiple of 120 ms, allows similar timing for intersystem measurements as in the GSM system itself. Apparently the needed measurement interval does not need to be as frequent as for GSM terminal operating in a GSM system, as intersystem handover is less critical from intra-system interference point of view. Rather, the compatibility in timing is important that when operating in WCDMA mode, a multimode terminal is able to catch the desired information from the synchronization bursts in the synchronization frame on a GSM carrier with the aid of frequency correction burst. This way the relative timing between a GSM and WCDMA carriers is maintained similar to the timing between two asynchronous GSM carriers. The timing relation between WCDMA channels and GSM channels is indicated in Figure 3.14 where the GSM traffic channel and WCDMA channels use similar 120 ms multiframe structure. The GSM frequency correction channel (FCCH) and GSM synchronization channel (SCH) use one slot out of the eight GSM slots in the indicated frames with the FCCH frame with one time slot for FCCH always preceding the SCH frame with one time slot for SCH as indicated in the Figure 3.14

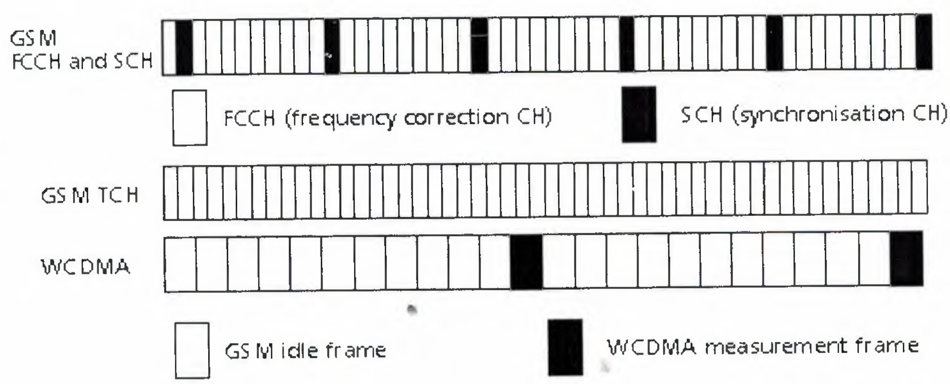


Figure 3.14 Measurements timing relation between WCDMA and GSM frame structure

A WCDMA terminal can do the measurements either by requesting the measurement intervals in a form of slotted mode where there are breaks in the downlink transmission or then it can perform the measurements independently with a suitable measurement pattern. With independent measurements the dual receiver approach is used instead of the slotted mode since the GSM receiver branch can operate independently of the WCDMA receiver branch. For smooth interoperation between the systems, information needs to be exchanged between the systems, in order to allow WCDMA base station to notify the terminal of the existing GSM frequencies in the area. In addition, more integrated operation is needed for the actual handover where the current service is maintained, taking naturally into account the lower data rate capabilities in GSM when compared to UMTS maximum data rates reaching all the way to 2 Mb/s.

The GSM system is likewise expected to be able to indicate also the WCDMA spreading codes in the area to make the cell identification simpler and after that the existing measurement practises in GSM can be used for measuring the WCDMA when operating in GSM mode. As the WCDMA does not rely on any superframe structure as with GSM to find out synchronization, the terminal operating in GSM mode is able to obtain the WCDMA frame synchronization once the WCDMA base station scrambling code timing is acquired. The base station scrambling code has 10-ms period and its frame timing is synchronized to WCDMA common channels.

CHAPTER FOUR

OPTICAL CDMA SYSTEMS

4.1 Introdction

During the last 15 years the number of optical communication systems has rapidlyincreased. Using optical fiber together with semiconductor laser transmitter has madeit possible to transmit high bit rate signals with low attenuation. CDMA has becomevery popular during the last years in cellular radio networks. This has given the reason to study if the advantages of CDMA could also be utilized in optical communication links.

In a CDMA system all the users are transmitting simultaneously on the same carrier frequency. To distinguish the signals of the different users each information bit is coded by a signature sequence which has pseudonoise character and the same temporal length as the information bit. Each user has a different 0,1 -code pair which is known by the transmitter and the receiver. The receiver identifies the information bits of the user by correlating the received signal with the user's 0- and 1- sequences. The signature sequence consists of chips having the value 0 or 1.

The optical CDMA communication system can be all-optical or partly optical. In a partly optical CDMA system at least the communication channel is optical. It may be optical fiber or wireless channel. The information bits may be originally optical orelectrical. The all-optical CDMA system is usually a fiber optic noncoherent system. It usually has no separate modulation operation. The signature coding is performed by an optical wave guide structure. The 1-chips are given a certain intensity level in the signature coding. In the fiber optic coherent system signature coding is performed electrically and after that the optical carrier of the laser transmitter is modulated coherently. In the wireless systems the signature coding and sub carrier modulation are performed electrically and then this signal is used to modulate the laser or LED transmitter. At the receiving side the operations are performed in the reversed order. The optical CDMA system may be asynchronous or synchronous (S-CDMA). In a synchronous system the bits and chips are synchronized. In the asynchronous system the bits are not synchronized but the chips may be transmitted synchronously.

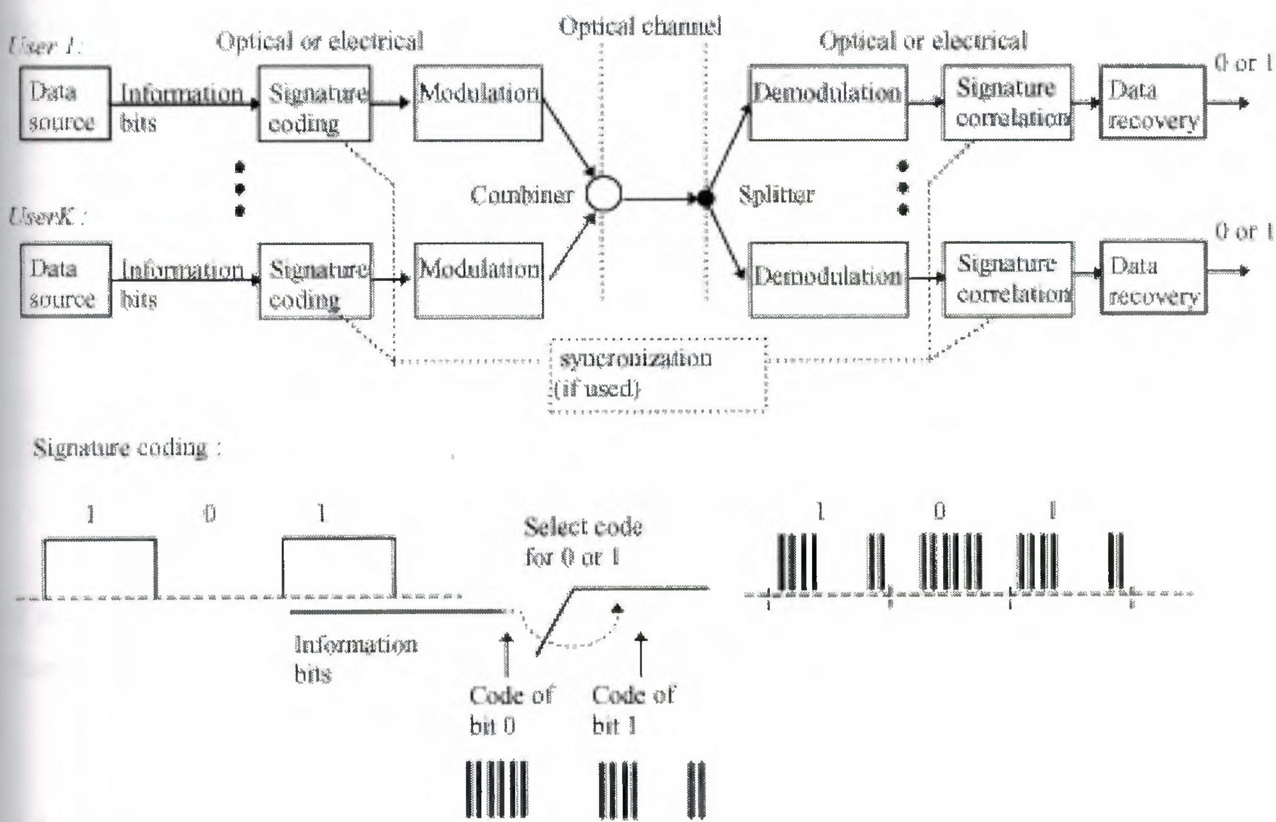


Figure 4.1 Optical CDMA system

4.2 NONCOHERENT OPTICAL CDMA SYSTEMS

4.2.1 Intensity modulation and direct detection

The noncoherent communication systems use direct detection receivers. In direct detection (DD) the photo detector gives the output current i_D which is proportional to the average power of the received optical (modulated) signal. Because only the power level is detected the laser or LED transmitter is intensity modulated (IM). Amplitude-shift keying

(ASK) is performed on all the optical carrier frequencies at the same time by changing the drive current of the transmitter so that the wanted optical power level is obtained. Each receiver correlates its own signature sequence with the combined received of all the users. The correlation function c(t) is obtained as the output of a filter matched to the user's own signature sequence .The output is sampled at the end of the bit interval T_b and compared to the threshold value of logical0 and 1. The optical correlation is shown in the Figure 4.2.

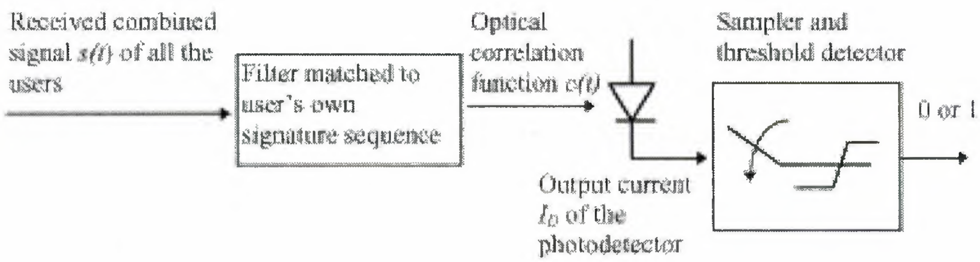


Figure 4.2 Direct detection using optical correlator

If the signature correlation is performed electrically the operation principle is the same. Then only the photo detector is located before the matched filter.

4.3 Signature codes for non-coherent optical CDMA systems

Because the noncoherent detection is based on the received optical power the chip of logical 0 has zero power level and the chip of logical 1 has a real positive power level. To avoid interference from other users the signature sequences should be as orthogonal as possible. However because the chip values are always non-negative orthogonality can be achieved only so that when the chip has the value 1 at some chip position the chips values of other signature sequences at the same chip position must be 0.

Because of this the optical codes are sparse in 1s, which means that to get a certain energy per bit, either the peak power level or the number of chips per bit (or both) must be larger than for the traditional electronic CDMA systems that use waveforms in which every chip contains energy. Thus, while optical codes can be designed that have few coincidences of 1 between the desired signal and the many interfering signals, the link budget suffers drastically. If there were no system noise in the system this could be tolerated, but in a real network with losses in the star couplers and with propagation over useful distances, this sparseness constraint on the signaling waveforms is a significant problem in optical CDMA with non-coherent detection.

To get a good discrimination of the 0- and 1-levels and because the number of signature codes are limited usually the zero power level is used for the signature sequence of the bit 0.When the received bit is 1 the interference from other users does not disturb the level detection but when the received bit is 0 the interference may cause a wrong decision. The sensitivity of the noncoherent system to overlapping 1´s is demonstrated in the following simplified example. There are 4 synchronized users and the length of the bit
is 16 chips.

$s_1(t)$,$s_2(t)$,$s_3(t)$,$s_4(t)$ = Signature codes of users 1, 2, 3 and 4 . 1-bit is transmitted to the users 1, 2 and 3. Bit 0 is transmitted to the user 4. The receiver of the user 4.6makes a wrong decision when it correlates its own signature sequence $s_4(t)$ with the
received signal $s_1(t)+s_2(t)+ s_3(t)+s_4(t)$.

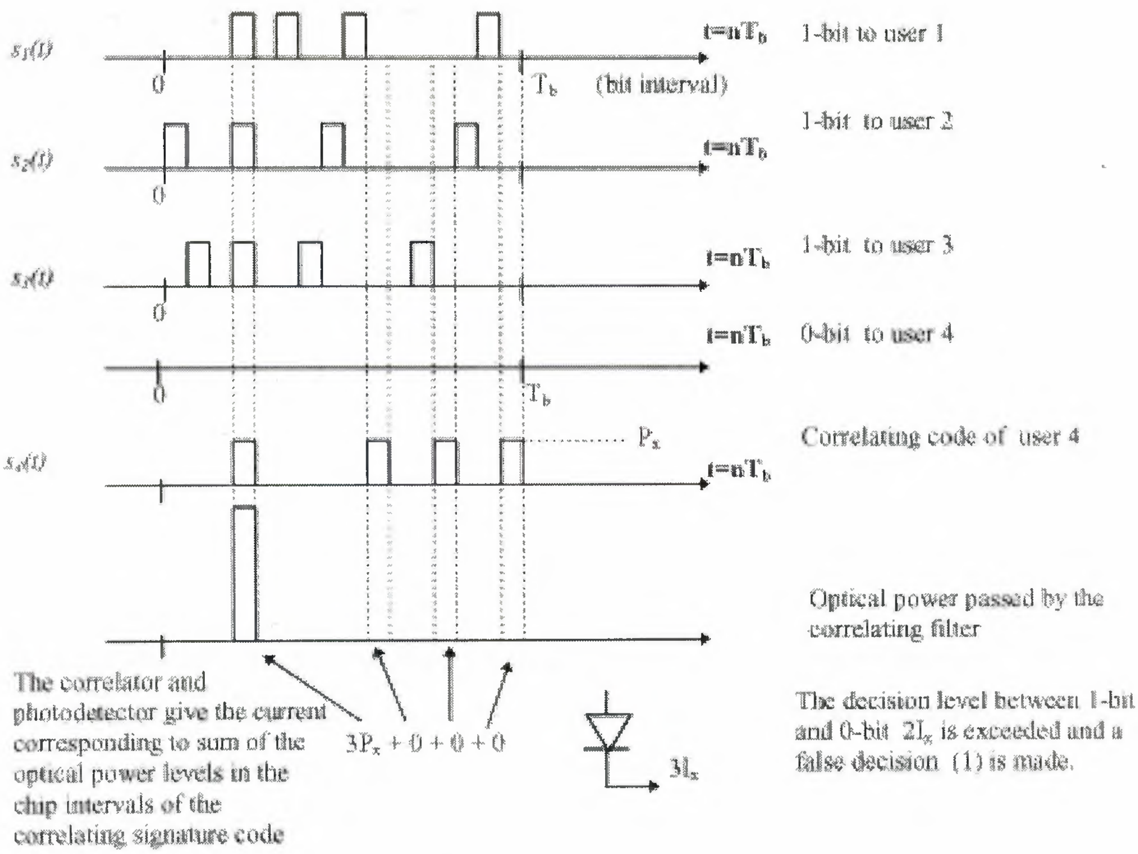


Figure 4.3 Wrong decision caused by overlapping 1's in signature codes

One way to reduce the interference power is to use an optical hard-limiter. It is a nonlinear device which clips the power to the normal chip power level during every chip interval.

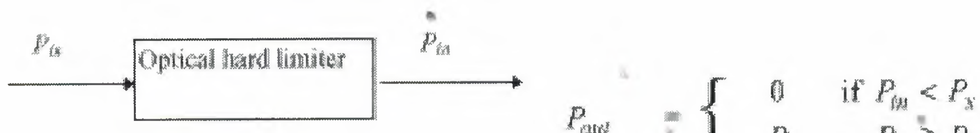


Figure 4.4 Operation of an optical hard-limiter

In the previous example the power level would be clipped to P_x and a correct decision would be made.

The achievable bit error rate and maximum number of users for a certain link length and bit rate depend on the multiple access interference (MAI), channel noise and photodetector noise. In a noncoherent fiber optic CDMA system the MAI level is the dominant factor. The signature code of each user should be distinguished from a shifted version of itself and from the shifted versions of the codes of other users. When x_n and y_n are signature codes of two users the code design problem reduces to constructing codes that satisfy the following two conditions of periodic correlation

$$\left|\sum_{n=0}^{F-1} x_n x_{n+L}\right| = \begin{cases} K \\ \lambda_c \end{cases} \tag{4.1}$$

$$\left|\sum_{n=0}^{F-1} x_n x_{n+L}\right| = \lambda_c \tag{4.2}$$

The in-phase autocorrelation K is the number 1's in x_n. It is called the weight of the code. L is the amount of shifting between the code sequences and F is the length of code sequence. The out-of-phase autocorrelation λ_a and the cross-correlation between the codes λ_c should minimum. However, a small out-of-phase autocorrelation is important for acquiring and maintaining the code synchronization. Because in noncoherent CDMA systems x_n , y_n are unipolar (0,1) all the terms in the correlation sums are non-negative and the codes designed to be used in radio CDMA systems in which both positive and negative values are available do not give λ_a and λ_c values small enough. For this reason so called optical orthogonal codes (OOC) with $\lambda_a = \lambda_c = 1$ have been developed. They are generated by starting from orthogonal codes of short length and extending the number of codes and the code length step by step. Their drawback is that the number of different code words, i.e. the number of users in the system is limited to

$$M \leq \left|\frac{F-1}{K(K-1)}\right| \tag{4.3}$$

,where x denotes the integer portion of the real value of x. When the optical orthogonal codes are used the error probability will increase if the number of 1's (K) is decreased. The error probability for the code length F = 1000 and for different number of users in an optical fiber CDMA systems.

Because the number of simultaneous users is upper bounded by $M \leq \lfloor (F-1)/K(K-1) \rfloor$ because the error probability increases when the K decreases there is a tradeoff between the number of users and the error performance. For typical parameters of F =1000 and K = 4 we have at most 83 users with OOCs. When the bit error probability less than 10exp-9 is wanted the number of simultaneous users can be about 10 .The number of simultaneous users can be increased without losing in the error performance by using the prime sequence codes. They allow the cross correlation $\lambda_c = 2$ and the out-of-phase autocorrelation l_a even higher than 2.The prime sequence codes are a set of codes having the code length $F=p^2$ derived from prime sequences of length p, where p is a prime number. Starting with the Galois field GF(p) = {0,1,...,j,...,p-1}, each element $s_{x,j}$ of a prime sequence $s_x = (s_{x,0}, s_{x,1}, \ldots, s_{x,j}, \ldots, s_{x,(p-1)})$ is constructed by multiplying every element from GF(p) by x, and then reducing the product by modulo p. Each prime sequence is then mapped into a binary code sequence $c_x = (c_{x,0}, c_{x,1}, \ldots, c_{x,i}, \ldots, c_{x,(p-1)})$ according to

$$C_{xj} = \begin{cases} 1, for i = s_{x,j} + jp, jp = 0,1,\ldots,p-1 \\ 0, otherwise \end{cases} \tag{4.4}$$

There are p binary code prime sequences with length p^2 generated by the above rule.

In the Figure 4.5 a is shown the autocorrelation of the code sequence c_3 for the bit stream 1110010100. In the Figure 4.5b is shown the cross-correlation of the code sequence c_3 with the code sequence c_2 for the same bit stream.

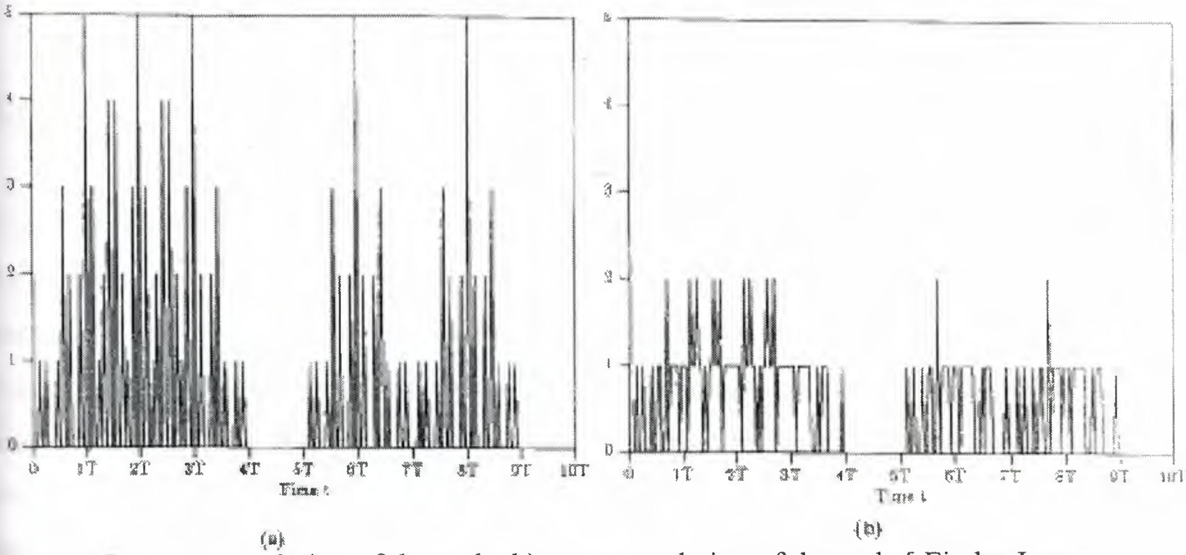


Figure 4.5 a) autocorrelation of the code b)cross-correlation of the code [Fig by Jarmo Osaka, Nokia Telecommunications,Fixed Access Systems/Regional Transport]

The probability of error in an optical fiber CDMA system is plotted in the Figure 4.6 for various prime numbers p. As an example, for p=31 (code length F=961) 23 simultaneous users are allowed with a probability of errors less than 10exp-9 .

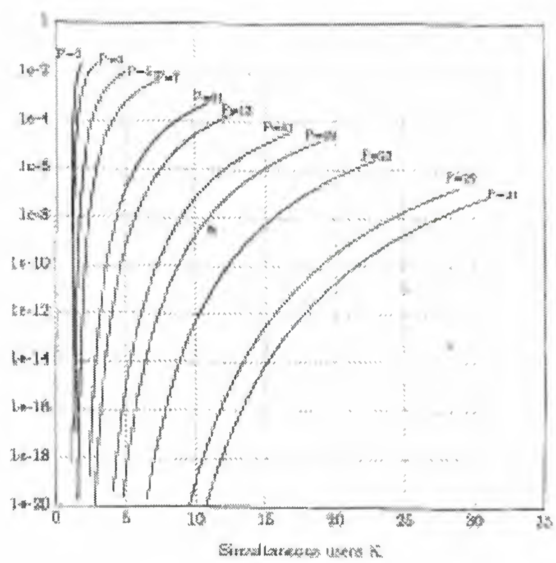


Figure 4.6 Error in an optical fiber CDMA system [Fig by Jarmo Osaka, Nokia Telecommunications,Fixed Access Systems/Regional Transport]

4.5 Synchronous and asynchronous non-coherent optical CDMA systems

For prime sequence codes of length p^2, the number of code sequences is limited to p, and therefore so is the number of total users. In order to generate more code sequences for the same length, modified prime sequence codes can be used. However, synchronization among the users is required. Modified prime sequence codes are time-shifted versions of prime sequence codes. With these code sequences, the cross-correlation peak between two time-shifted versions of a code sequence can be as high as the autocorrelation peak, but always occurs delayed from the autocorrelation peak. By synchronizing the receiver to the expected position of the autocorrelation peak, it can be distinguished from adjacent cross-correlation peaks. Each of the original p prime sequences s_x is taken as a seed from which a group of new code sequences can be generated. The code sequences of the first group (x=0) are obtained by left-rotating the prime sequence code can be left-rotated p-1 times before the original c_0 is recovered, so that p-1 new sequence codes can be generated from c_0. For the other p-1 groups (x = {1, ... , p-1}), the elements of the corresponding prime sequence s_x can be left-rotated p-1 times in a similar way to create new prime sequences $s_{x,r} = (s_{x,r,0}, s_{x,r,1}, \ldots, s_{x,r,(p-1)})$ where r represents the number of times s_x has been left-rotated. Therefore, p prime sequences per group are obtained Each prime sequence $S_{x,r}$ is then mapped into a binary code sequence $C_{x,r}$

$$C_{x,r,ij} = \begin{cases} 1, fori = s_{x,j} + jp, jp = 0,1,\ldots,p-1 \\ 0, otherwise \end{cases} \qquad 4.5$$

Each code sequence has p binary 1's. Considering all groups, the total number of modified prime sequence codes is p^2. For a synchronous system, the cross-correlation between the modified prime sequence codes of the xth and the yth userscan be written as

$$\Gamma_{x,y} = \begin{cases} p, & \text{when } x = y \\ 0, & \text{when } x \text{ and } y \text{ are in the same group} \\ 1, & \text{when } x \text{ and } y \text{ are in the different groups} \end{cases}$$

Figure 4.6a shows the autocorrelation of S-CDMA code sequence $c_{1,1}$ for the bit stream 1110010100. The arrows indicate instants at which the synchronization is applied. The cross-correlation between S-CDMA code sequences $c_{1,0}$ and $c_{1,1}$ (same group), and the cross-correlation between S-CDMA code sequences $c_{2,2}$ and $c_{1,1}$ (different groups) for the same data stream are shown in the Figure 4.6b and Figure 4.6c respectively.

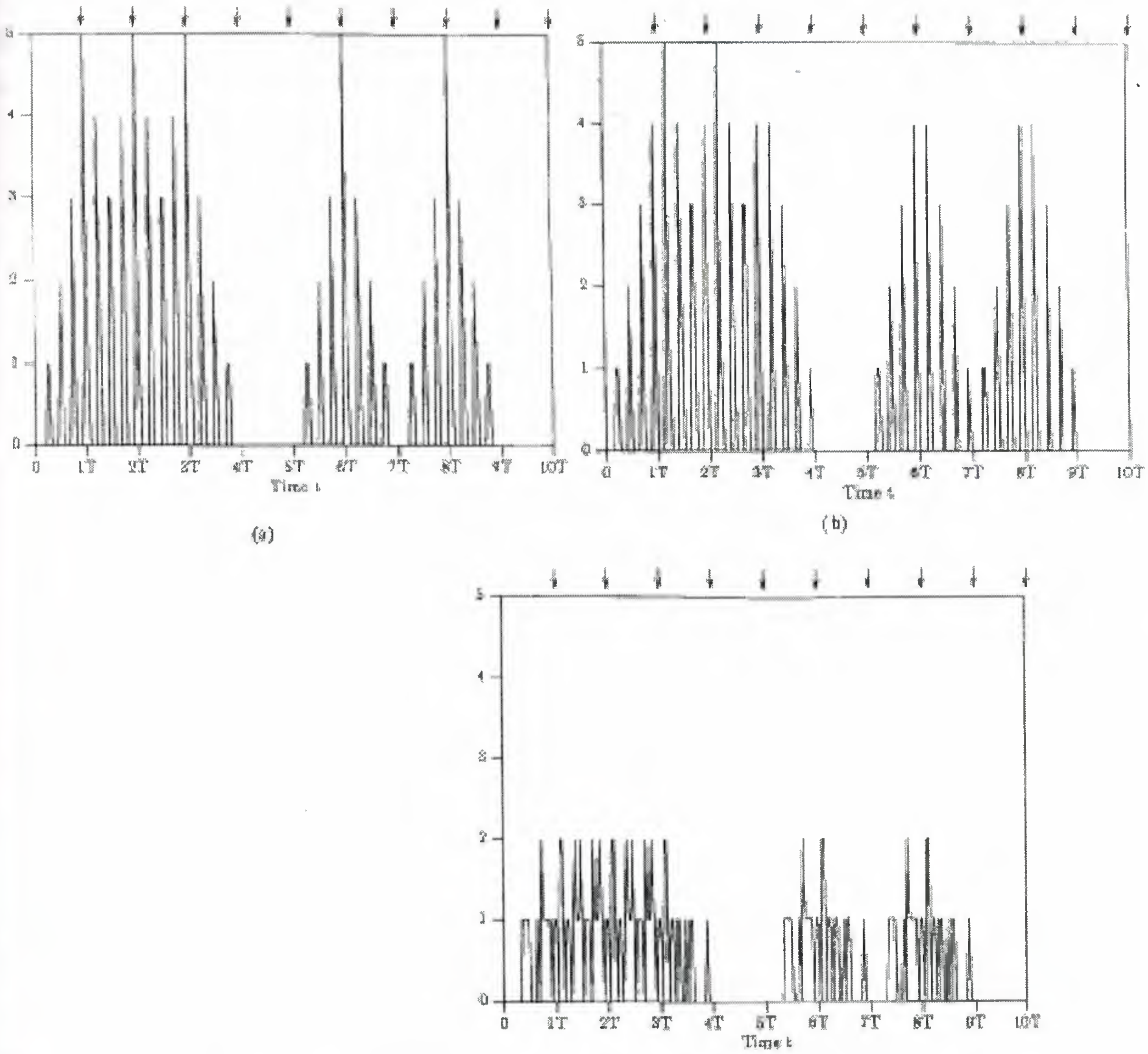


Figure 4.6 a) Autocorrelation of S-CDMA b) Cross-correlation of S-CDMA code c) Cross-correlation of S-CDMA [Fig by Jarmo Osaka, Nokia Telecommunications,Fixed Access Systems/Regional Transport]

The probability of error versus the number of simultaneous users as a function of p in an optical fiber transmission system is shown in the Figure 4.7. S-CDMA always provides a lower probability of error than the asynchronous CDMA for the same value of p.

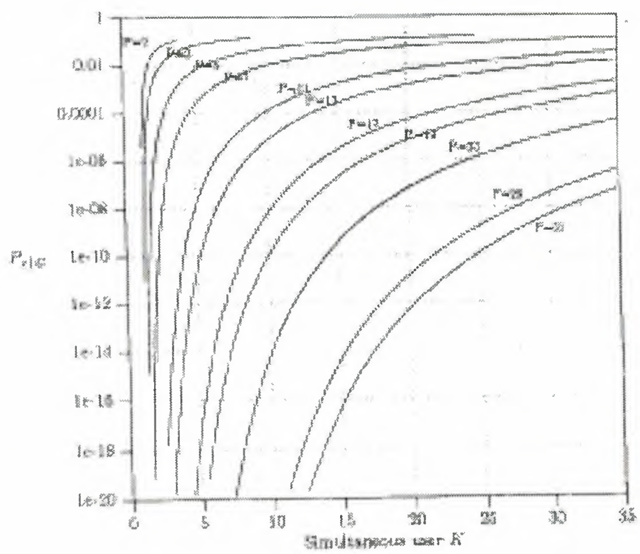


Figure 4.7 **Error versus the number of simultaneous users** [Fig by Jarmo Osaka, Nokia Telecommunications,Fixed Access Systems/Regional Transport]

Bit error probability of S-CDMA versus the number of simultaneous users K (=M) as a function of p in an optical fiber system. Because two overlapping chips can add the value 1 to the cross-correlation of the code sequences, while the peak of autocorrelation function is p, S-CDMA can accommodate at least K= p-1 simultaneous users without errors. With p-1 simultaneous users, the receiver can still discriminate the autocorrelation peak from the cross-correlation peak, of amplitude at most equal to p-1 .However, when the number of simultaneous users exceeds p (i.e. $K \geq p$), errors in the detection process may result. When the allowed bit error rate is ≤ -10 9 S-CDMA can support 31 simultaneous users for p=31 which is 8 more than by using the basic prime codes and 21 more than by using the OOCs in an asynchronous optical CDMA system. For a certain bit error probability a S-CDMA system can always accommodate a greater number of simultaneous users than the asynchronous CDMA system. The number of simultaneous users K versus p with the probability of error ≤ – 10exp9 forboth the asynchronous CDMA and S-CDMA are shown in the Figure 4.8

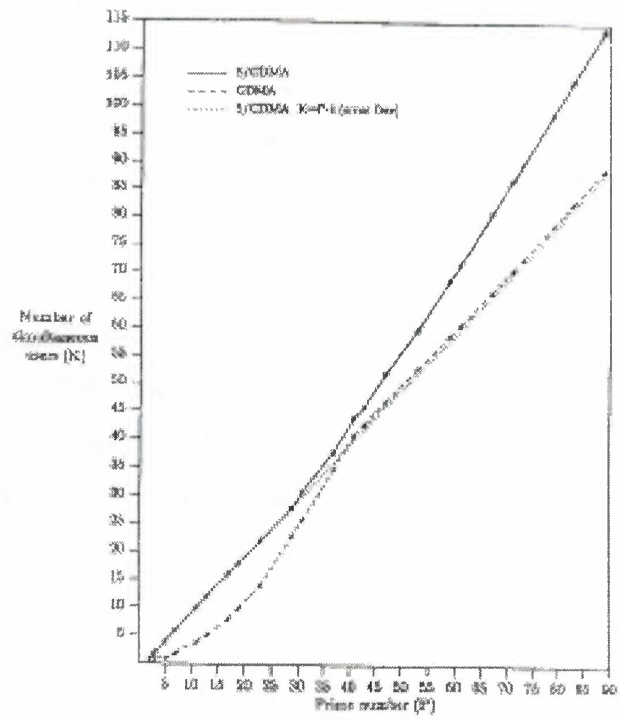


Figure 4.8 Number of simultanous users K (=M) versus p both for asynchronous CDMA [Fig by Jarmo Osaka, Nokia Telecommunications,Fixed Access Systems/Regional Transport]

S-CDMA systems using optical hard-limiter have been shown to have better performance than S-CDMA systems without the hard-limiter when the number of simultaneous users is not large. When their number is large the performance of the S-CDMA system is better without the optical hard-limiter. In asynchronous CDMA systems the optical hard-limiter improves the performance for any number of simultaneous users. In asynchronous CDMA systems the performance in the chip synchronous case is worse than in the chip asynchronous case.

4.5 Coherent optical CDMA systems

In a coherent optical communication system a locally generated signal from an optical local oscillator (LO) is mixed at the receiver with the information-bearing signal When the mixed light falls on the photodetector it produces a detector current with the frequency equal to the difference between the optical frequencies of the received signal $F_C + F_S$ and the local oscillator F_{LO}, where F_C is the frequency of the optical carrier and F_S the frequency of baseband signal. There are two types of coherent receivers. In the heterodyne receiver the output signal of the photodetector is on an intermediate carrier frequency (IF) $F_C - F_{LO}$ and must be demodulated electrically to get the baseband signal. In the homodyne receiver $F_{LO} = F_C$ and the baseband signal is obtained directly as the output of the photodetector.

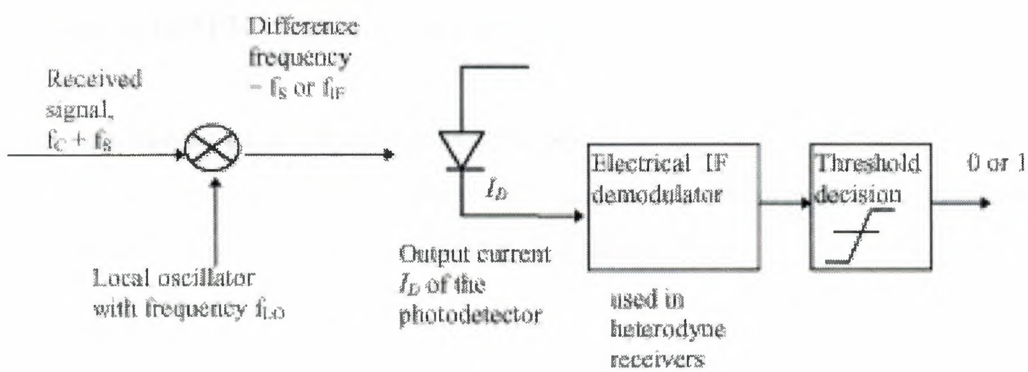


Figure 4.9 Coherent optical CDMA receiver

In general the coherent optical system offers two advantages when compared to the incoherent system. Remarkably better receiver sensitivity and frequency selectivity can be achieved by the coherent system. Because of the high frequency selectivity great capacity can be achieved by using different carrier frequencies close to each other. An important advantage of the coherent CDMA systems is that different kinds of modulation methods (e.g. ASK, FSK, PSK, QAM) can be used. So the chip values are not restricted to the non-negative 0 and 1 levels of the power based incoherent systems. So the signature codes and multiuser detection methods developed for the radio based systems are available. Because of this greater number of simultaneous users can be achieved. Both synchronous and asynchronous operation is possible. However, there are many serious problems that make it difficult to implement a coherent optical system. The frequency of the transmitted optical carrier and local oscillator must have the accuracy of the order 01 0.. ... 01·10 exp -6 (0.01 ... 0.1ppm) which about is 2 ... 50 Mhz depending on the used wavelength region. To achieve this temperature stabilization is needed. Only FSK modulation can be implemented by directly changing the control current of the laser transmitter. Other types of modulation require special lasers with separate sections for the continuous wave (CW) generation and modulation or using an external optical modulator after the laser transmitter. In fiber optic systems the fiber changes the polarization of the signal. making it difficult to adjust the phase of local oscillator signal to have the same phase as the incoming optical carrier

4.6 FIBER OPTIC CDMA SYSTEMS

4.6.1 Noncoherent Fiber Optic CDMA Systems

The chip sequence can be generated electronically and after that it can be used to control the laser to give the optical CDMA chip sequence.

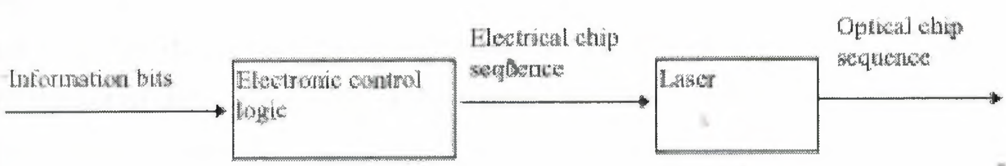


Figure 4.10 Electrical generation of the code sequence

However, in this implementation the achievable chip rate is limited by the speed of the control logic electronics. To get a higher chip rate the optical chip sequence $s_0(t)$ is generated without the electronic control logic so that the laser generates a high power pulse of the chip duration T_{ic}. This laser pulse is then used as an input to a group of parallel delay nes. The outputs of the delay lines are combined by an optical coupler which gives out the ptical chip sequence. The greatest possible number of optical delays in one delay line is K, T T c b · = , where Tb = bit period. The number of 1's are defined by the number of the elay lines and the positions of 1's by the numbers of delays. For example when there are 8 hips in a bit and three 1's :

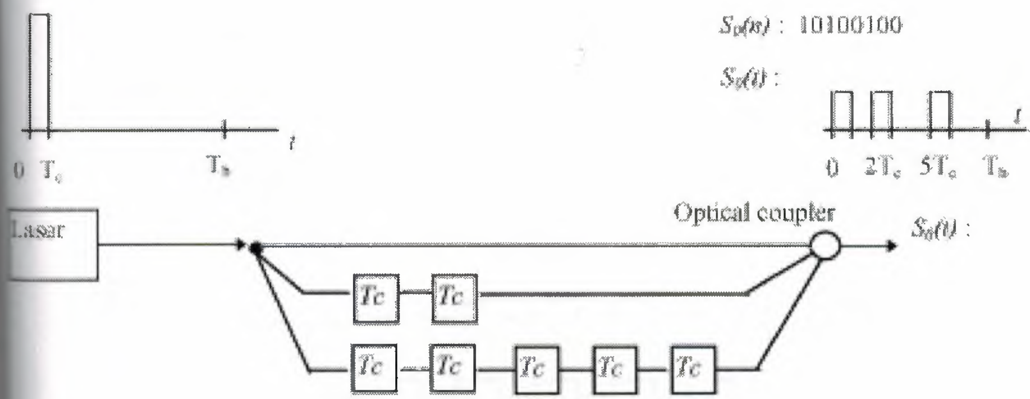


Figure 4.11 Example of the optical generation of the code sequence

e delay line can be implemented by optical fiber when the chip rate is high (about 100 Hz ... 10 GHz). The fiber length is selected to give the total delay of the delayline. other implementation which can be used also at low chip rates is to use a LiNbO3 based tical waveguide as a delay element. The light passing through the component is delayed changing the refractive index of the material. This can be done by a changing electric ld. At the receiver the optical correlator used to recognize the desired signature code is a of optical delay lines inversely matched to the pulse spaces. It is a time reversed version the set of delay lines used in the transmitter. When the desired optical sequence passes ough the correlator, the output light power traces out the correlation function of the quence. At the last chip position, the sum of the received optical power located in the ne positions as the positions of 1 in the desired code is obtained. The receiver rresponding the transmitter of the Figure 4.11is the following :

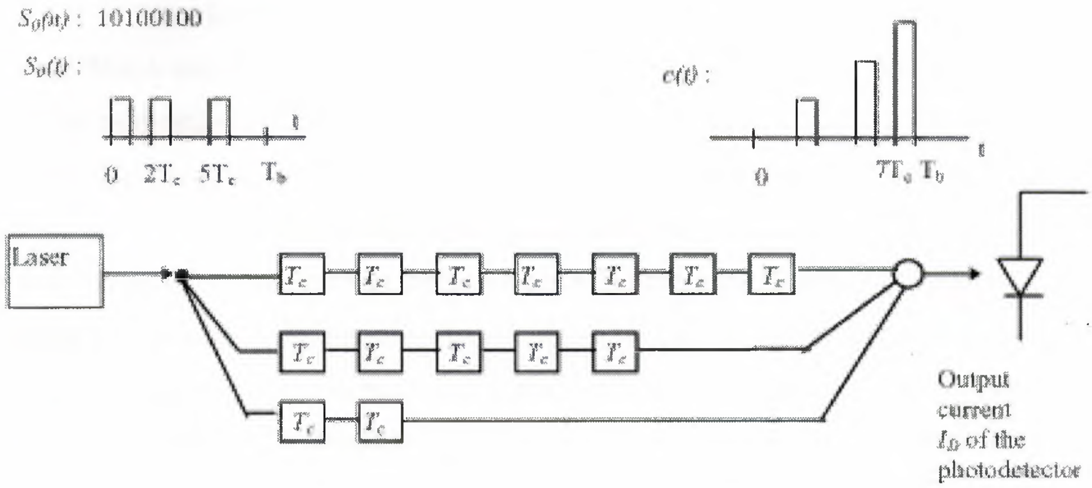


Figure 4.12 Example of the optical correlation

$$c(n - T_c) = \sum s_0(k) r((k-n).T_c) \tag{4.6}$$

The output of the correlator is converted to an electrical signal by a photodetector and integrated over the chip periods. This signal value is sampled at the last chip position and compared to the decision threshold of the bit values 0 and 1

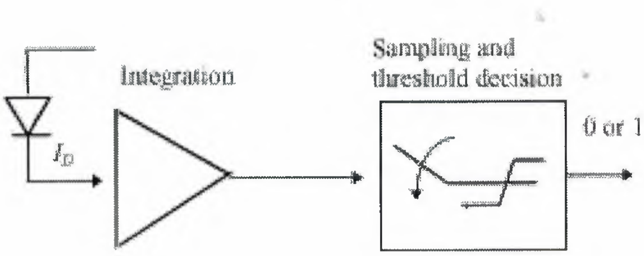


Figure 4.12 Calculation of correlation sample for threshold decision

4.6.3 Other fiber optic CDMA systems

In addition to the traditional noncoherent and coherent systems a new type of fiber optic CDMA systems has been proposed. It is an intermediate form of them. The final detection is based on the received optical power level as in the noncoherent systems ut not on the power of the separate chips. An extra separate modulation level for the chip sequence is used, but only in the transmission channel. When the signal is received from the channel it is transformed back to intensity modulated (IM) signal. So different modulation methods can be used in the transmission channel. The chip alues are not restricted to the non-negative 0 and 1, but the final detection is based on the power of the signal and the difficult implementation of the coherent detection can e avoided. An example of this method is the pulse spreading fiber optic CDMA system. A narrow (about 10exp -12 s) optical pulse is directed to an optical signature encoder consisting of a pair of diffraction gratings and a phase mask. The intensity of the pulse is spread by the first grating and phase modulated when it passes through the mask. Each transmitter has a distinct phase mask. A receiver consists of a decoder and an optical threshold device. The decoder is similar to the optical encoder except that its phase mask is the conjugate of the coding mask. So the original pulse is reconstructed and detected using a power based threshold device. The intensity profiles of the signal versus time before and after signature coding NO . is the number of the chips, T is the bit period.

4.7 Comparison of CDMA with TDMA and WDMA in Fiber Optic Systems

4.7.1 CDMA compared with TDMA

In a CDMA system the signal bandwidth is increased considerably because of the signature coding. The CDMA system requires a greater channel bandwidth than the TDMA system for a certain bit rate. Optical fiber has a great bandwidth. This is why the optical channel seems to be ideal for CDMA. However, the usefulness of CDMA in optical communication is limited by the high bitrate already used in the fiber systems. In the optical fibers the signals usually are high bit rate TDMA-signals which often already use

In a CDMA system the signal bandwidth is increased considerably because of the signature coding. The CDMA system requires a greater channel bandwidth than the TDMA system for a certain bit rate. Optical fiber has a great bandwidth. This is why the optical channel seems to be ideal for CDMA. However, the usefulness of CDMA in optical communication is limited by the high bitrate already used in the fiber systems. In the optical fibers the signals usually are high bit rate TDMA-signals which often already use great part of the fiber bandwidth. For example when 16 signals each of them having the bit rate 155 Mbit/s are multiplexed the capacity of 2.48 Gbit/s is obtained. If the 155 Mbit/s signals are CDMA multiplexed the spreading factor needed is about 100 ...1000. High bit rate optical communication links are usually dispersion limited. The optical pulses become wider in time causing intersymbol interference because the different wavelength components have different velocities. So the amount of dispersion in a CDMA system having the capacity of 16 155Mbit/s signals is about the same as in a TDMA system having the capacity of over 100 155Mbit/s signals. Using the present technology the dispersion in these systems (e.g. STM-256) limits the link length to short distances. The advantages given by the CDMA in radio systems are related to the tolerance of the multipath fading, soft hand-over in cellular systems and immunity to the channel noise. In the fiber optic CDMA noise immunity is the only one of these factors giving benefit compared to TDMA. However it does not have the same importance as in the radio systems because the channel noise is not a significant factor in optical fiber systems. The number of simultaneous users in TDMA systems for the same signal bandwidth is much greater than in noncoherent CDMA systems. The important advantage of the optical CDMA is that the users can transmit completely independently. No coordination with other users is required. Also new connections can be added causing only the steady increase of multiple access interference (MAI) until the maximum number of users is reached. Because CDMA. provides the user independent access to the network and because the dispersion limits the distance at high bit rates CDMA suits best to local area networks (LANs).

4.7.2 CDMA compared with WDMA

When the signals are code (CDMA) or time (TDMA) division multiplexed the signal bandwidth is increased causing dispersion problems at high bit rates. In Wavelength

Division Multiple Access (WDMA) each user is transmitting on its own wavelength which eliminates the dispersion problems. Because of this at least now WDMA is the only practical way to increase the capacity in very high bit rate (2.5 -10 Gbit/s) systems. International Telecommunications Union (ITU) has standardized 45 wavelengths to be used in the region 1530nm - 1560 nm. WDMA also gives the same kind of independent access to the network as CDMA. Earlier using WDMA was limited by the need to do the opto-electric conversion separately on each wavelength in the repeaters of the communication link. This problem was solved by the optical fiber amplifiers (OFAs) which amplify all the wavelengths simultaneous in the optical domain. The development of the OFAs and optical couplers for cross-connecting different wavelengths has caused a rapid growth in WDMA applications.

4.8 Wireless optical CDMA systems

4.8.1 Structure of the wireless optical CDMA system

Implementing a coherent fiber optic system is difficult. It is even more difficult to implement a coherent optical wireless system because the phase of the local oscillator light should be adjusted to the phase of the free space signal. Because of this practical systems are noncoherent (Intensity Modulated / Direct Detection IM/DD) systems. Implementing lens and optical waveguide structures for optical signature coding and for correlating the received signal with the desired signature code are also difficult. So they are usually performed electrically. The signature code can be used directly to modulate the intensity the laser or LED transmitter (On-Off-Keying, OOK) or subcarrier modulation may be used. Pulse position modulation (PPM) or Binary Phase Shift Keying (PSK) are often used as the modulation method. In the subcarrier modulation the intensity of the transmitter is varied on a radio frequency. This subcarrier is modulated by the chip values. Because the wireless system does not suffer from the material dispersion the channel.

Figure 4.13 Wireless optical CDMA system.

bandwidth is not limited. So a high spreading factor can be used and high bit rates can be achieved. Unlike in a fiber optic system the relation between optical output power X(t) from the laser or LED and the output current Y(t) of the photodetector is linear in the wireless optical system. So a linear baseband model can be used

By using this model the following signal to noise ration is obtained :

$$Y(t)=R\,.X(t)*h(t)+N(t) \qquad 4.7$$

By using this model the following signal to noise rotation is obtained.

$$SNR=\frac{R^2.P^2}{R_B.N_0} \qquad 4.8$$

When P decreases SNR decreases relative to P_2. This limits the achievable distance d and sets a requirement to the average power efficiency of the used multiple access method. The AWGN channel model can be used because there is no fast fading in the wireless optical systems. The minimums of the received signal locate about a wavelength apart from each other but they do not affect the received power because typical detector areas are millions of square wavelengths. The multipath distortion causes intersymbol interference but N(t) can be assumed to be dominated by a white Gaussian component having double-sided power spectral density 0.

4.8.2Comparison of the CDMA with other multiple access methods in optical wireless system

TDMA has a high power efficiency. The power efficiency achieved by CDMA varies depending on the selection of the signature code and the possibly used modulation method. When the subcarrier modulation is used different users can transmit simultaneously at different subcarrier frequencies. The power efficiency of this frequency division multiple access (FDMA) method is poor. Differences of the wireless optical multiple access methods are summarized in the Table 4.1

Table 4.1 Differences of the wireless optical multiple access methods

Technique	Nature	Necessary loss of per unit capacity	Optical average power efficiency	Permits simulations transmission
Wavelength division	Optical	No	High	Yes
Space division multiplixingwith angle reciver	Optical	No	High	Yes
Time division	Electrical	Yes	High	No
Code division	Electrical	Yes	Modarate	Yes
Subcarrier FD	Electrical	Yes	Low	Yes

Comparison of multiple access methods in wireless optical system. Figure 4.12 presents a comparison of the power efficiency in a wireless cellular LANfor TDMA with 4-PPM, 2-PPM modulation and with OOK. The power efficiency ofFDMA is shown with BPSK modulation. The power efficiency of CDMA is shownwith 2 signature codes : m-sequence and an optical orthogonal code without modulation.

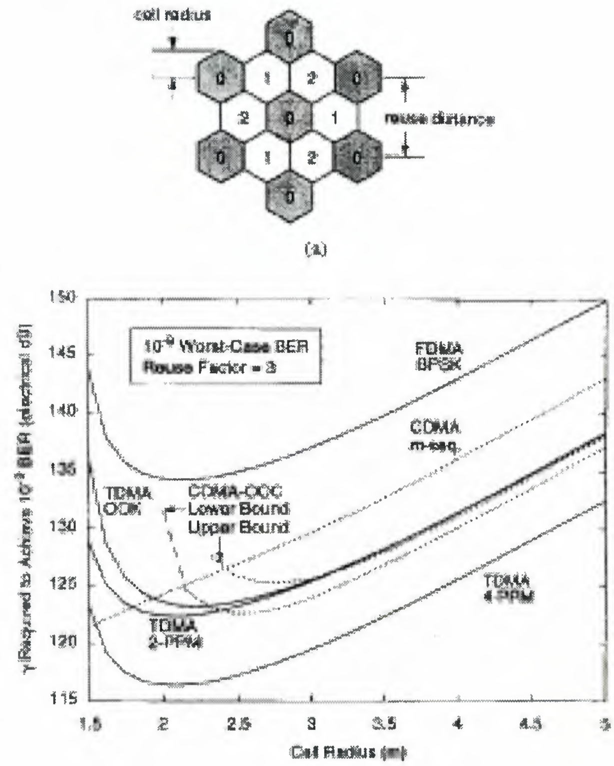


Figure 4.12 a) Fixed assignment of channels in a optical system having a reuse factor of three. b) Performance comparison of six methods

The required power level to achieve BER 10^{-9} increases when very small cells are used because of the co-channel interference. When the radius of the cell is > 3 m the performance does not depend on the co-channel interference. Then only the background light and multipath distortion noise are affecting. The best performance is achieved by TDMA 4-PPM. Achieving high power efficiency is so important that all the current infrared multiple access LANs are using some form of TDMA although CDMA has a better tolerance for noise on the same received power level. WDMA is technically a competitive method but the laser transmitters and large-area, tunable bandpass filters are at this moment too expensive for commercial products. Space division multiple access (SDMA) involves the use of an angle-diversity receiver to separate signals that are received form different directions. An angle-diversity receiver can reduce the impact of co-channel interference and multipath distortion. The advantages depend on how the signals received in the different elements of the receiver are processed and detected. However, as the number of mobile users increase the spot overlap becomes more probable and SDMA needs to be combined with some other multiple accessmethod to achieve reliable operation.

CONCLUSION

Multiple access is a crucial concept in wireless communications, which means that multiple, simultaneous users can be supported. In order to separate each user so that they do not interfere with one another, service providers may use one of three primary multiple access systems: Frequency Division Multiple Access (FDMA) , Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA).

CDMA is an advanced digital wireless transmission technology that uses the principle of spread spectrum communication. Instead of using frequencies or time slots, as do traditional technologies, CDMA uses mathematical codes to transmit and distinguish between multiple wireless conversations.

The intent of CDMA technology is to provide increased bandwidth in a limited frequency system, but has also other advantages including extended range and more secure communications. In a CDMA system, a narrowband message signal is multiplied by a spreading signal, which is a pseudo-noise code sequence that has a rate much greater than the data rate of the message. CDMA uses these code sequences as a means of distinguishing between individual conversations. All users in the CDMA system use the same carrier frequency and may transmit simultaneously.

CDMA is a driving technology behind the rapidly advancing personal communications industry. Because of its greater bandwidth, efficiency, and multiple access capabilities, CDMA is becoming a leading technology for relieving the spectrum congestion caused by the explosion in popularity of cellular mobile phones, fixed wireless telephones, and wireless data terminals. Since becoming an officially recognized digital cellular protocol, CDMA is being rapidly implemented in the wireless communications networks of many large communications corporations.

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