STUDY OF CODE DIVISION MULTIPLE ACCESS (CDMA) TECHNIQUE FOR MOBILE COMMUNICATION SYSTEMS

By

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ABSTRACT

This report presents details study of CDMA technique for mobile communication systems. The objective of this project is to understand the spread spectrum techniques including DS-CDMA and also to explain IS-95A system. The test results for simulation on the IS-95A Reverse traffic channel are included to evaluate the performance of the channel under various traffic conditions. Various conditions are applied to the system to decide on the best performance. The performance of the channel was measured in terms of BER. Reasonable Doppler shift frequency is determined. It is found that performance of the system vary with the reduced of data rate. Amount of AWGN added to the signal represents the interference generated by other base station nearer. Therefore changes of SNR in the AWGN Channel provoke the system performance. The detection performance improves with an increase in the SNR.

ABSTRAK

Projek ini mempersembahkan teknologi CDMA untuk sistem rangkaian telefon bimbit. Objektif projek ini adalah memahami teknik-teknik spektrum rebak termasuk DS-CDMA dan juga menerangkan sistem IS-95A. Keputusan ujian simulasi ke atas IS-95A saluran trafik songsang juga disertakan untuk menilai prestasi saluran. Beberapa kaedah dilaksanakan ke atas sistem untuk mencari kaedah terbaik untuk prestasi sistem tersebut iaitu dengan mengubah kadar data, frekuensi anjakkan Doppler dan juga kadar isyarat ke hingar (SNR). Prestasi ini dinilai dengan jumlah BER. Frekuensi anjakkan Doppler yang digunakan diubah untuk mengira BER yang minimum. Didapati bahawa prestasi sistem juga berubah dengan perubahan kadar data. Jumlah AWGN yang ditambah kedalam sistem adalah bagi mewakili isyarat yang terjana dari gangguan luar oleh antenna berdekatan yang turut menggunakan frekuensi yang sama. Maka dengan mengubah SNR didalam saluran AWGN akan memberi kesan ke atas prestasi sistem. Secara keseluruhannya, dengan meningkatkan SNR akan turut meningkatkan prestasi sistem perhubungan tersebut.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TERMS AND ABBREVIATIONS

AWGN	Adds White Gaussian Noise
AMPS	Advance mobile phone system
FDMA	Frequency Division Multiple Access
BER	Bit Error Rate
BPSK	Binary phase shift keying
BTS	Base Transceiver Station
BS	Base Station
BSC	Base Station Controller
BWA	Broadband Wireless Access
CRC	Code Redundancy Check
CDMA	Code Division Multiple Access
DSSS	Direct sequence Spread Spectrum
FCC	Federal Communications Commission
FDM	frequency division multiplexing
FDD	Frequency Division Duplex
FHSS	Frequency Hoping Spread spectrum
GSM	Global System for Mobile Communications
GPS	Global Positioning System
HLR	Home location register
IS-95A	North American CDMA Standard
IS-136A	North American TDMA Standard
IS-41	International Standard 41
MS	Mobile Station
PDC	Packet Data cellular
PN	Pseudo-noise
PSK	Phase Shift Keying
PSTN	Public Switch Telephone Network
QPSK	Quadrature phase shift keying
RF	Radio Frequency
SN	Subscriber Number, maximum 10 decimals
SNR	Serial Number, 6 decimals, assigned by manufacturer
SSMA	Spread spectrum multiple access
TDMA	Time Division Multiple Access
THS	Time-Hopping System
TIA	Telecommunications Industry Association
TR-45	Mobile and Personal Communications Standards.
VLR	Visitor location register

1.0 INTRODUCTION

It is widely accepted that cellular mobile system is important. The wireless communications industry has grown extremely rapidly over the past decade, with markets doubling roughly every 2 years. Much of this growth has been due to the public's increasing demand for mobile telephones, and more recently, wireless data systems. The increasing number of wireless users has spurred communications engineers to improve the quality of service and to use the available spectrum resources more efficiently. [2]

This is where CDMA technology fits in. CDMA consistently provides better capacity for voice and data communication than other commercial mobile technologies, allowing more subscribers to connect at any given time.

As its name implies, CDMA assigns unique codes to each communication to differentiate it from others in the same spectrum. CDMA is a spread spectrum technology, allowing many users to occupy the same time and frequency allocations in a given band/space. Therefore, in a world of finite spectrum resources, CDMA enables many more people to share the airwaves at the same time compared to alternative technologies.

Cellular radio has evolved into digital radio technologies, using the systems standards of GSM (at 900 and 1800 MHz) in Europe, PDC in Japan, and IS-136A and IS-95A in the United States. The CDMA air interface is used in both 2G and 3G networks. 2G CDMA standards are branded ‘cdmaOne’ and include IS-95A and IS-95B.

Designing, implementing, and maintaining mobile network is a challenging task that falls under several engineering disciplines such as traffic engineering, RF propagation, antenna engineering, frequency planning, and cell site provisioning. However in this project, we are only focus in traffic engineering.

This project is concerned with the detailed study of the IS-95A CDMA receiver for the mobile system and the simulation of the Reverse Traffic Channel using MATLAB and SIMULINK. As we know, CDMA air-link is based on a forward link (from base station to mobile) and a reverse link (from mobile to base station) but this project will only emphasis on reverse link.

Figure 1.1 shows the simplified diagram of the IS-95A Reverse Channel. The IS-95A reverse link uses two types of channels which are the access channel and traffic channel to transmit voice and control data to the BTS.

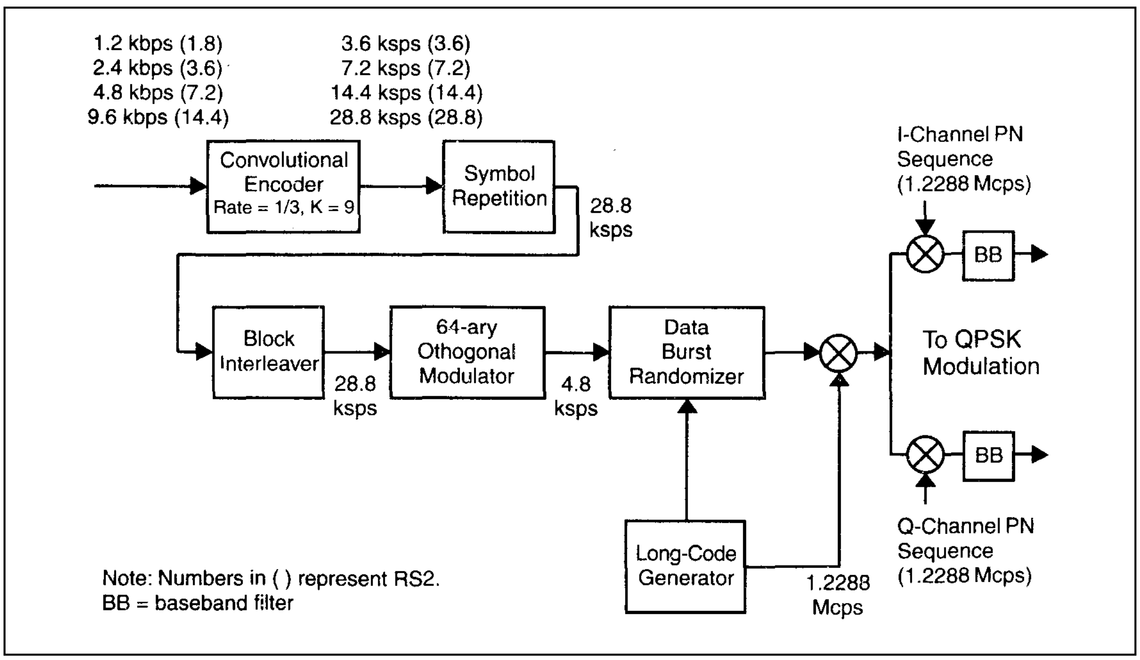

Figure 1.1: Simplified diagram of the IS-95A reverse channel

The simulation studies of the reverse channel will be carried out with reference to the block diagram of the reverse channel as shown in Figure 1.2. The transmitter section includes channel coding, modulation and spreading, and filtering. The receiver section includes filtering, despreading and demodulation, and channel decoding.

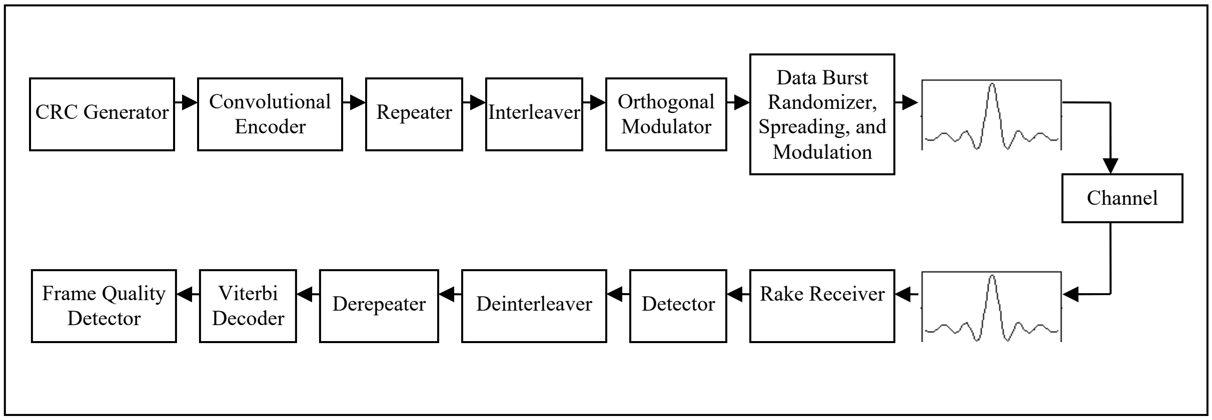

Figure 1.2: IS-95A Reverse Channel Diagram

The IS-95A Reverse Traffic Channel will be simulated using MATLAB to study the process of demodulation and despreading of the IS-95A CDMA signal. The performance of the channel will then be measured in terms of the Bit Error Rate (BER). The effect of BER depends on the channel conditions and the number of rake receiver active fingers. As the signal-to-noise ratio or the channel conditions are changed, the effect of these on the BER can be seen using the simulation. [3]

1.1 Scope of the Project

The scope of the project comprises items as following:

i. Study of Spread Spectrum techniques
ii. Study of Direct Sequence Spread Spectrum (DSSS) systems
iii. Detailed study on the application of CDMA
iv. Discuss the IS-95A System
v. Simulation of Reverse traffic channel
vi. Discussions and conclusions

1.2 Structure of the Project

This project describes CDMA technique, and simulation of reverse traffic channel in wireless and mobile communication.

Chapter 2 covers the access technologies that are used for cellular systems. Distinction between basic multiple access schemes, FDMA, TDMA and CDMA are given.

Chapter 3 carries out a detailed study of the spread spectrum technique and also explains the Direct Sequence Spread Spectrum technique and its use in CDMA systems.

IS-95A System and communication protocol within the cellular environment are discussed in Chapter 4.

Chapter 5 explains how CDMA works in terms of physical and logical channels including modulation schemes, bit repetition, block interleaving, and channel coding that are used in processing logical channels on IS-95A CDMA reverse and forward links. Details about information processing, message types and message framing are presented for the pilot, sync, paging, and traffic channels on the forward link. Similar details are provided for the access and traffic channels in the reverse link.

Chapter 6 explains the simulation of IS-95A Reverse Traffic Channel using MATLAB and SIMULINK. This process is used to evaluate the performance of the channel under various traffic conditions.

Chapter 7 discusses the result obtained in the simulation and final conclusion presented.

Chapter 8 completes the project with a brief conclusion.

2.0 MULTIPLE ACCESS TECHNOLOGIES

This chapter explains the access technologies that used for cellular system. There are basically two types of multiple access technologies:

1) Narrowband - Frequency Division Multiple Access (FDMA) &
   Time Division Multiple Access (TDMA)
2) Wideband - Code Division Multiple Access (CDMA)

2.1 FDMA

In FDMA, signals from various users are assigned at different frequency. In other words, no other user can share the same frequency channel during the period of time using FDD (Frequency Division Multiplexing). FDMA is a frequency domain duplexing technique, which transmission for any user is continuous. FDD is frequency domain technique that provides two distinct frequency bands for downlink and uplink for every user. The channel bandwidth and modulation scheme will determine the bit rate that can be sustained. In practical, guard bands must be introduced between these channels to avoid adjacent channel interference.

Advantages of FDMA:

1) Capacity can be increased by reducing information bit rate and using efficient digital codes.
2) Implementations are simple.

Disadvantages of FDMA:

1) FDMA involves narrowband filter, but these are not realized in VLSI digital circuits and this may set a high cost.
2) The maximum bit rate per channel is fixed and small, inhibiting the flexibility in bit rate capability.

2.2 TDMA

In TDMA, rather than assigning each user a channel with its own frequency, users share a channel of a wider bandwidth, which we shall call a frequency carrier, in time domain. This is achieved by introducing a framing structure with each TDMA frame subdived into N time-slots, if N user channels are to be supported. User i is then allowed to access the carrier only during time-slot. In order to sustain a continuous gross source bit rate of R_s bits/s, the transmission speed during the burst transmission must at least N R_s bits/s.

Provided that enough spectrums are available, multiple carriers may be assigned to each cell. Therefore, such TDMA systems feature typically also an FDMA element, and are in reality hybrid TDMA/FDMA systems.

Advantages of TDMA:

1) Allows flexibility bit rate.
2) Potentially integrates in VLSI without narrowband filters and set the cost low.
3) Frame by frame monitoring of signal strength/bit error rates to enable either mobiles or base station to initiate and execute handoffs.
4) Bandwidth used efficiently because no frequency guardband is needed between channels.

5) Transmits each signal with sufficient guard time between time slots and accommodates time in accuracies.

Disadvantages of TDMA:

1) For mobile handsets, TDMA demands high peak power in transmission mode. This reduces battery life span.
2) TDMA requires a substantial amount of signal processing for matched filtering and correlation detection for synchronizing with a time slot.

2.3 CDMA

CDMA uses codes to convert between analog voice signals and digital signals. CDMA also uses codes to separate (or divide) voice and control data into data streams called "channels." In CDMA, narrowband signals are transformed through spectrum spreading into signals with a wider bandwidth, the carrier bandwidth. Like in TDMA, multiple users share the carrier, but like in FDMA, they transmit continuously during the call or session. The multiple access capability derives from the use of different spreading codes for individual users. Because of the spreading of the spectrum, CDMA systems are also referred to as spread spectrum multiple access (SSMA) systems. Code sequences are used to separate one user from another. This in turns makes CDMA an attractive multi-user scheme and a very active area of research and development.

Each user in CDMA system is given its own PN sequence for data transmission, which is approximately orthogonal to other users PN sequence in system. Due to the orthogonality between PN sequences, the problem of multi-user interference in the system is eliminated. The resource assigned to an individual user in a CDMA system is therefore not so much a code, but rather a certain power level. This is illustrated in Figure 2.1, which shows sharing of resources in the time, frequency, and in terms of power levels, for FDMA, TDMA and CDMA respectively.

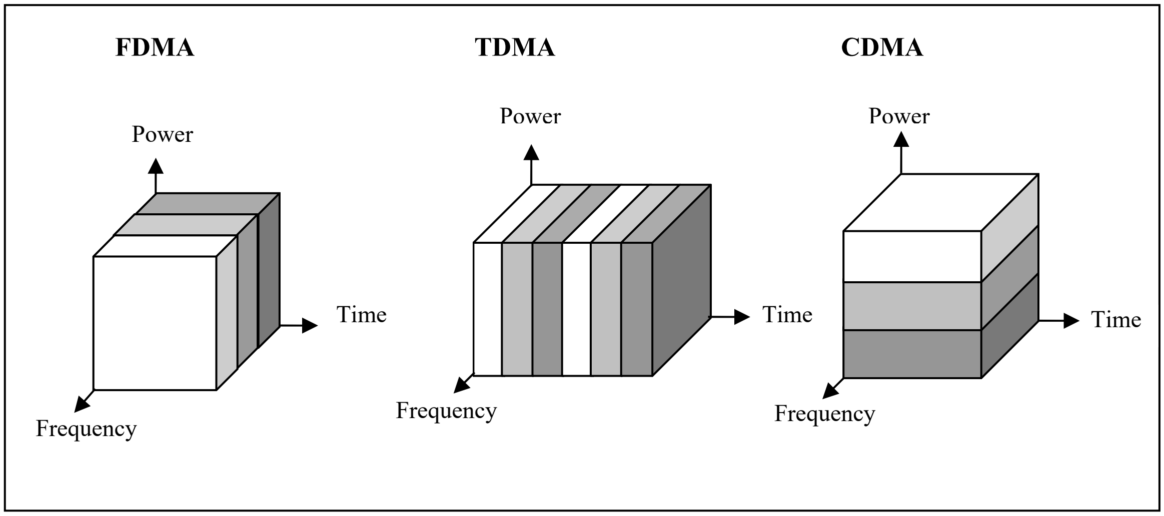

Figure 2.1: Sharing of time, frequency and power resources between three users in FDMA, TDMA and CDMA respectively

As a benchmark, CDMA is able to offer up to six times the capacity of TDMA, and about seven to ten times the capacity of analogue technologies such as AMPS and FDMA, and now holds over 600 millions subscriber worldwide. CDMA also provides enhanced services such as short messaging, e-mail, and Internet access. [5]

3.0 SPREAD SPECTRUM SYSTEM AND SPREADING CODES

The objective of this chapter is to present the spread spectrum techniques and also explains the Direct Sequence technique and its use in CDMA systems. Spread Spectrum technology was developed for military, single user, anti-jam applications where the intent was to conceal the signal being communicated in the presence of a jammer (a signal that is intended to make communications unreliable). Invented by the female American actress Heddy Lamar during World War II [she actually invented FHSS ---see below].

3.1 Principle Of Spread Spectrum System

Spread Spectrum modulation techniques are defined as being those techniques in which:

- The bandwidth of the transmitted signal is much greater than the bandwidth of the original message.
- The bandwidth of the transmitted signal is determined by the message to be transmitted and by an additional signal known as the Spreading Code.

By transmitting the message energy over a bandwidth much wider than the minimum required, Spread Spectrum modulation techniques present two major advantages: low power density and redundancy.

Low power density relates to the fact that the transmitted energy is spread over a wide band, and therefore, the amount of energy per specific frequency is very low. The effect of the low power density of the transmitted signal is that such a signal will not disturb (interfere with) the activity of other systems' receivers in the same area and that such a signal can not be detected by intruders, providing a high level of intrinsic security.

Redundancy relates to the fact that the message is (or may be) present on different frequencies from where it may be recovered in case of errors. The effect of redundancy is that Spread Spectrum systems present high resistance to noises and interference, being able to recover their messages even if noises are present on the medium.

Spread Spectrum modulation techniques are composed of two consecutive modulation processes executed on the carrier signal (Fig.31):

- Process 1 - executed by the spreading code. It is the spreading process that generates the wide bandwidth of the transmitted signal.
- Process 2 - executed by the message to be transmitted.

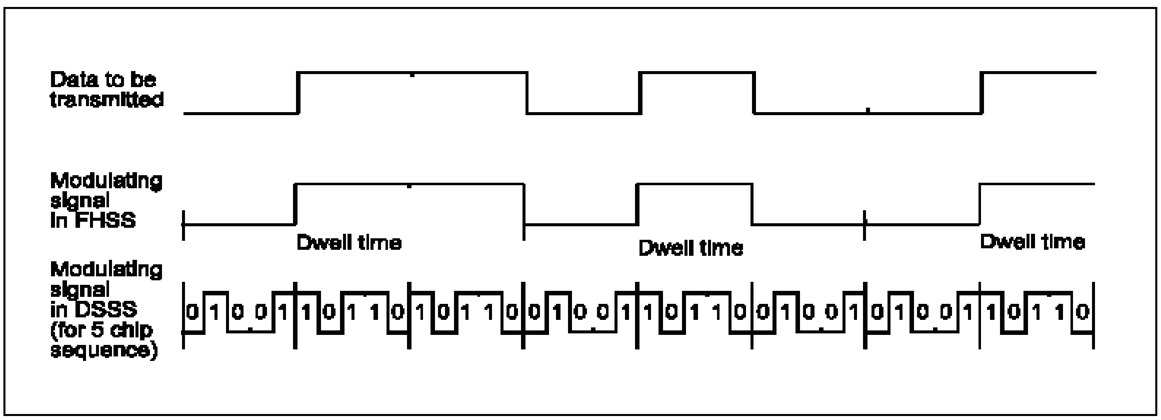

Figure 3.1: Signals used to modulate the carrier in FHSS and DSSS

3.2 Three general approaches to implement Spread Spectrum systems:

They are basically three types of Spread Spectrum modulation techniques:

1) Direct Sequence Spread Spectrum (DSSS)
2) Frequency Hopping Spread Spectrum (FHSS)
3) Time-Hopped System (THS)

The following subtopics presents these three competing technologies comparing their performance in data transfer capacity.

3.2.1 DSSS

In a direct sequence system, the transmitted baseband signal is multiplied by a pseudonoise code digital stream. For DSSS, two consecutive modulation processes executed on the carrier signal are:

- Process 1 - Spreading code modulation
  For the duration of every message bit, the carrier is modulated (PSK) following a specific sequence of bits (known as chips). The process is known as 'chipping' and results in the substitution of every message bit by (same) sequence of chips. In DSSS, the spreading code is the chip sequence used to represent message bits.
- Process 2 - Message modulation
  For message bits '0', the sequence of chips used to represent the bit remains as dictated by process 1 above. For message bits '1', the sequence of chips dictated by process 1 is inverted. In this way message bits '0' and '1' are represented over the air by different chip sequences (one being the inverted version of the other one).

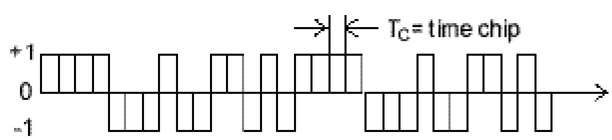

Figure 3.2: DSSS Signal

Redundancy is achieved by the presence of the message bit on each chip of the spreading code. Even if some of the chips of the spreading code are affected by noise, the receiver may recognize the sequence and take a correct decision regarding the received message bit.

In conclusion, DSSS has the advantage of providing higher capacities than FHSS, but it is a very sensitive technology, influenced by many environment factors (mainly reflections). The best way to minimize such influences is to use the technology in either (i) point to multipoint, short distances applications or (ii) long distance applications, but point to point topologies. In both cases the systems can take advantage of the high capacity offered by DSSS technology, without paying the price of being disturbed by the effect of reflections.

3.2.2 FHSS

In a frequency-hopping spread system the signal frequency is constant for specified time duration, referred to as a time chip T_c (Fig:3.2). FHSS has two type of system, fast-hop or slow-hop. A fast-hop system, the frequency-hopping takes place at a rate that is greater than the message bit rate. In a slow-hop system, the hop rate is less than the message bit rate.

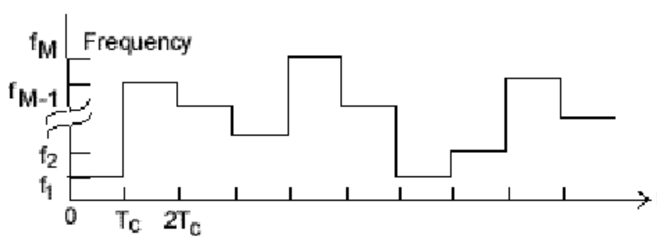

Figure 3.3: FSSS signal

Two consecutive modulation processes executed on the FHSS carrier signal are:

- Process 1 - Spreading code modulation

  The frequency of the carrier is periodically modified (hopped) following as specific sequence of frequencies.

In FHSS systems, the spreading code is the list of frequencies to be used for the carrier signal, a.k.a. the “hopping sequence”. The amount of time spent on each hop is known as dwell time and is typically in the range of 100 ms.

- Process 2 - Message modulation

  The message modulates the (hopping) carrier (FSK), thus generating a narrow band signal for the duration of each dwell, but generating a wide band signal, if the process is regarded over periods of time in the range of seconds.

Redundancy is achieved through the possibility to execute re-transmissions on different carrier frequencies (hops).

In contrast to DSSS, FHSS is a very robust technology, with little influence from noises, reflections, other radio stations or other environment factors. In addition, the number of simultaneously active systems in the same geographic area (collocated systems) is significantly higher than the equivalent number for DSSS systems. All these features make the FHSS technology the one to be selected for installations designed to cover big areas where a big number of collocated systems is required and where the use of directional antennas in order to minimize environment factors influence is impossible. Typical applications for FHSS include cellular deployments for fixed Broadband Wireless Access (BWA), where the use of DSSS is virtually impossible because of its limitations. [7]

3.2.3 THS

In a time-hopping system the transmission time is divided into intervals known as frames. Each frame is divided into M time slots. During each frame one and only one time slot will be modulated with a message. All of the message bits accumulated in the previous frame are transmitted in a burst during the selected time slot.

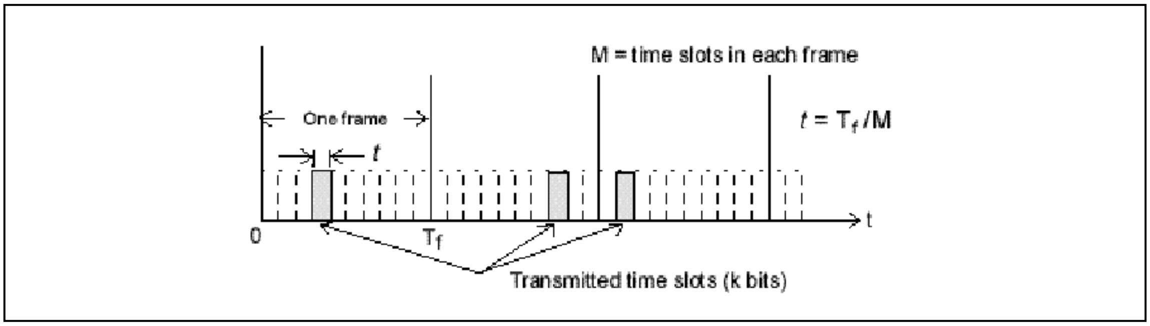

Figure 3.4: THS Signal

A list of the advantages and disadvantages of the three types of systems is shown below:

Table 3.1: Advantages and disadvantages of the three types of systems

System	Advantages	Disadvantages
Direct Sequence	Best noise and antijam performance	Requires wideband channel
Frequency-Hopping	Greatest amount of spreading Can be programmed to avoid portions of the spectrum Relatively short acquisition time Less affected by near/far problem	Complex frequency synthesizer Not useful for range-rate measurement
Time-Hopping	High bandwidth efficiency Implementation simpler than frequency hopping Useful when transmitter is average power limited, but not peak power limited Near/far problem avoided in a coordinated system	Long acquisition time Error correction needed

3.3 The Concept of Spread Spectrum System

The Theoretical capacity of any communication channel is defined by Shannon Capacity formula:

$$C = \mathrm{B}_w \log_2\left(1+\frac{S}{N}\right) \qquad (3.1)$$

Where B_w = Bandwidth in Hertz

C = Channel capacity in bits per second
S = Signal power
N = Noise power

Equation (3.1) gives the relationship of theoretical ability of channel to transmit information without errors.

Channel capacity is increased by increasing the channel bandwidth, the transmitted power, or combination of both.

In CDMA channel bandwidth can be traded for the SNR to achieve good performance at very low SNR. From Equation (3.1), we can write the equation as below:

$$\frac{C}{B_w} = 1.44 \log_e \left(1 + \frac{S}{N} \right) \tag{3.2}$$

Since,

$$\log_e \left(1 + \frac{S}{N} \right) = \frac{S}{N} - \frac{1}{2}\left(\frac{S}{N} \right)^2 + \frac{1}{3}\left(\frac{S}{N} \right)^3 - \frac{1}{4}\left(\frac{S}{N} \right)^4 + \cdots\cdots\cdots$$

Since the SNR is small, we can neglect the higher orders in logarithmic expansion an equation (3.1) become,

$$B_w \approx \frac{C}{1.44}\left(\frac{N}{S} \right) \tag{3.3}$$

The most common method to modulate information into spread spectrum signal is to add the information to the spread-spreading code before it is used for modulating the carrier frequency as illustrated in Figure 3.5.

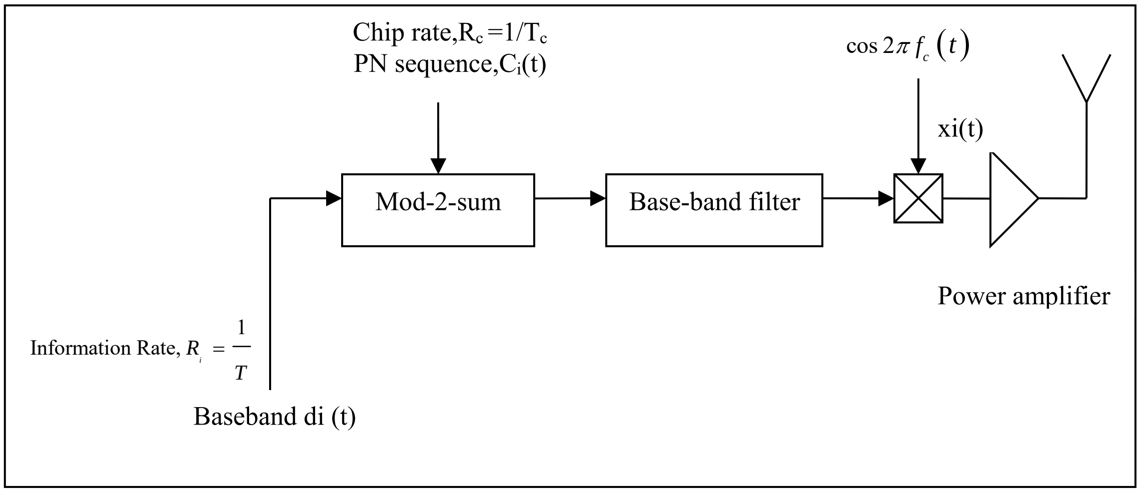

Figure 3.5: Basic DSSS System Transmitter

3.4 Processing Gain

Process gain is due to spectrum spreading, defined as:

$$G_s = 10\log\left(\frac{B_w}{R_b}\right) \tag{3.4}$$

Where B_w = Bandwidth in Hertz

R_b = Bit rate

G_s = Process gain

The input and output SNR are related as:

$$\left(\frac{S}{N}\right)_o = G_s\left(\frac{S}{N}\right)_i \tag{3.5}$$

3.5 The Performance of DSSS

3.5.1 The DSSS System

The DSSS system is a wideband system in which the entire bandwidth of the system is available to each user. A system is defined as a DSSS system if it satisfies the following requirements. [5]

1) The spreading signal has a bandwidth much larger than the minimum bandwidth required to transmit the desired information.
2) The spreading of data is performed by means of spreading signal, called a code signal. The code signal is independent of the data and of much higher rate than data signal.
3) At the receiver, despreading is accomplished by the cross-correlation of the received spread signal with synchronized replica of the same signal used to spread the data.

3.5.2 Coherent Binary Phase-Shift Keying

Binary phase shift keying (BPSK) commonly used for data modulation.
Encoded DSSS BPSK signal is given by the equation below. [5]

$$x(t) = c(t)d(t)\sqrt{2S}\cos\omega_c t \tag{3.6}$$

$d(t)$ = The baseband signal at the transmitter input and receiver output
$c(t)$ = The spreading signal
S = The signal power
ω_c = The carrier frequency
And $s(t) = d(t)\sqrt{2S}\cos\omega_c t$

In equation (3.8), the modulation of $c(t)$ and $d(t)$ represented as a multiplication because the binary signals 0 and 1 represents values of 1 and -1 into the modulator. The signal

$s(t)$ has a $\left[(\sin x)/x\right]^2$ spectrum of bandwidth of approximately $1/T$, while the SS signal $x(t)$ has a similar spectrum but with a bandwidth of $1/T_c$ where T_c is the periodicity of the spreading signal. The processing gain of the system is $G_p = \frac{B_w}{R} = \frac{T}{T_c}$. If interfering signal is represented by $I(t)$ and it is assumed much larger compare to noise, then the signal at the receiver is given as:

$$r(t)^* = x(t) + I(t) \tag{3.7}$$

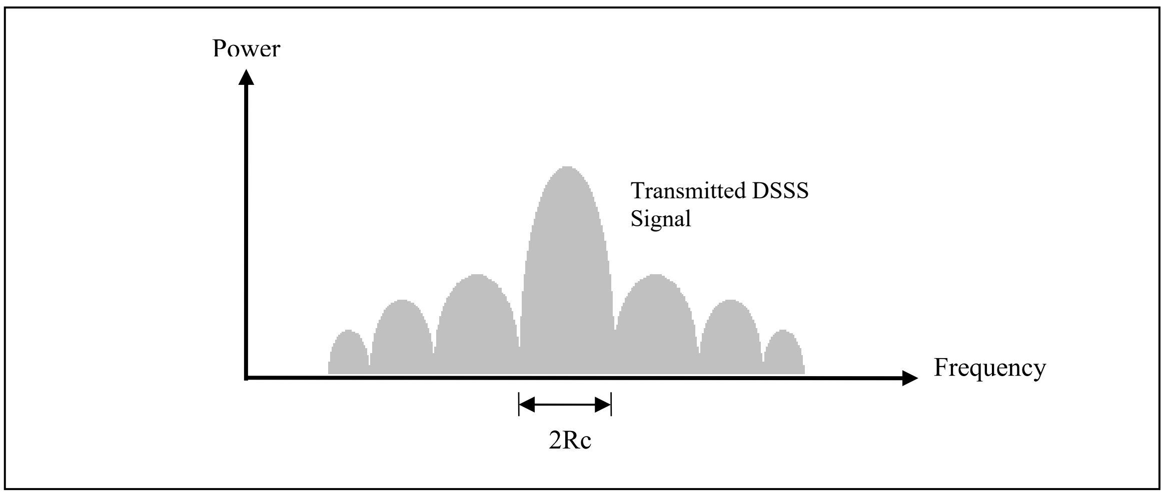

Figure 3.6: BPSK DSSS Spectrum

The spectral content of an SS signal is shown in Fig. 3.6. Note that this is just the spectrum of a BPSK signal with a (sin x / x) ^{2} form. The bandwidth in DSSS systems is often taken as the null-to-null bandwidth of the main lobe of the power spectral density plot (indicated as 2Rc in Fig. 3.6). The half power bandwidth of this lobe is 1.2 Rc, where Rc is the chip rate.

Therefore, the bandwidth of a DSSS system is a direct function of the chip rate; specifically 2Rc/R_{INFO}. This is just an extension of the previous equation for process gain. It should be noted that the power contained in the main lobe comprises 90 percent

of the total power. This allows a narrower RF bandwidth to accommodate the received signal with the effect of rounding the received pulses in the time domain. [9]
The receiver multiplies this by the PN, $c(t)$ waveform to obtain the signal,

$$\begin{aligned} r(t) &= c(t)\left[x(t)+I(t)\right] \\ &= c(t)\left[c(t)s(t)+c(t)I(t)\right] \\ &= s(t)+c(t)I(t) \end{aligned} \tag{3.8}$$

Since $\left[c(t)\right]^2 = 1$, and $c(t)I(t)$ is the effective noise waveform due to interference.
The conventional BPSK detector output is given as:

$$r = d\sqrt{Eb} + n \tag{3.9}$$

Where d = data bit for the T second interval
Eb = bit energy
n = equivalent noise component

The spreading-despreading operation does not affect the signal, nor does not affect the spectral and probability density of the noise. So the bit error probability, P_b would be,

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{Eb}{No}}\right) \tag{3.10}$$

3.5.3 Quadrature Phase Shift Keying

Quadrature phase shift keying commonly used for spreading modulation. For QPSK modulation, the in-phase, $d_c(t)$ quadrature data waveforms, $d_s(t)$ and the corresponding PN binary waveform as $c_c(t)$ and $c_s(t)$ can be representing as:

$$x(t) = c_c(t)d_c(t)\sqrt{S}\cos\omega_c t + c_s(t)d_s(t)\sqrt{S}\sin\omega_c t \qquad (3.11)$$

Where each QPSK pulses is of duration $T_c = 2T$.

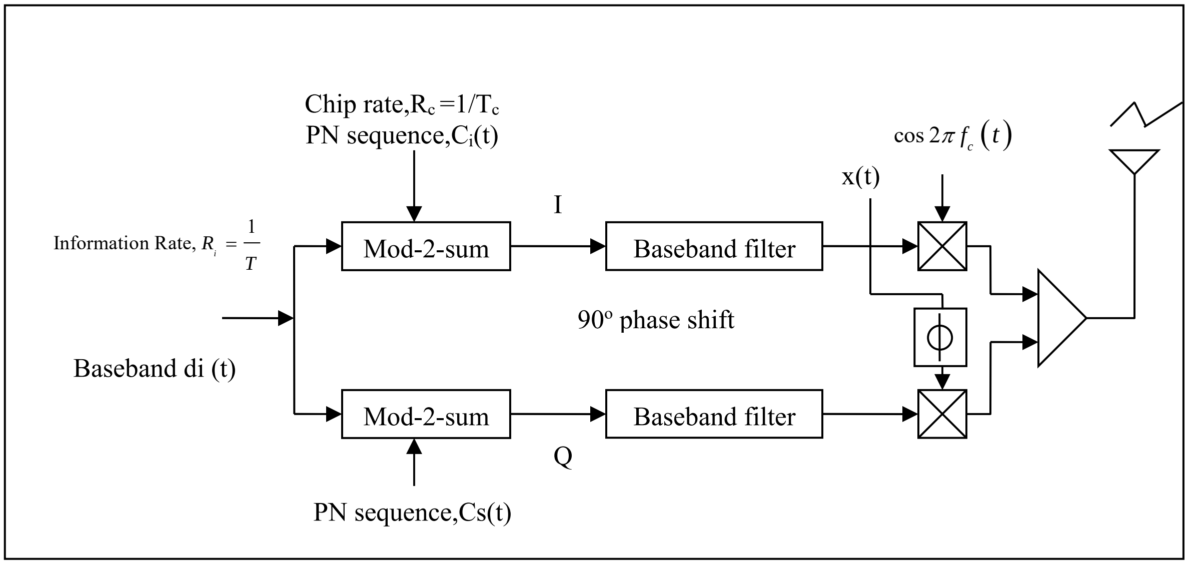

Figure 3.7: DSSS System with QPSK Transmitter

The in-phase output component is

$$r_c = d_c\sqrt{Eb} + n_c \qquad (3.12)$$

Where,

$$n_c = \sqrt{\frac{2}{Ts}}\int_0^{Tc} c_c(t)\cos\omega_c t dt$$

$$n_s = \sqrt{\frac{2}{Ts}}\int_0^{Tc} c_s(t)I(t)\sin\omega_c t dt$$

And the quadrature component is

$$r_s = d_s\sqrt{Eb} + n_s \qquad (3.13)$$

The bit error probability for AWGN is given as:

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{Eb}{No}}\right)$$
$$= Q\left(\sqrt{\frac{2Eb}{No}}\right) \tag{3.14}$$

Where,

$$Q(u) \approx \frac{e^{-u^2/2}}{\sqrt{2\pi u}} \qquad \text{u >1} \tag{3.15}$$

3.6 Bit Scrambling

3.6.1 Operations with Modulo-2-addition

Table 3.2: Operations with Modulo-2-addition

Transmitter	1	Si(t)	1	1	0	1	0	0	1	1	1	1
	2	Ci(t)	1	0	0	1	1	1	0	1	0	0
	3	Si(t)Ci(t)	0	1	0	0	1	1	1	0	1	1
Receiver	4	Si(t)Ci(t)	0	1	0	0	1	1	1	0	1	1
	5	Ci(t)	1	0	0	1	1	1	0	1	0	0
	6	Si(t)Ci(t)Ci(t)=Si(t)	1	1	0	1	0	0	1	1	1	1

1) An arbitrary data sequence Si(t) is generated by a digital source.
2) An arbitrary code sequence Ci(t) is generated by a direct spread (DS) generator.
3) Two sequences are modulo-2 added and transmitted to a distant receiver assuming there is no propagation delay.
4) At the distant location, the resulting sequence (assuming no propagation delay) is picked up by the receiver.
5) The code Ci(t) used at the transmitter is also available at the receiver.
6) The original data sequence is recovered by modulo-2 adding the received sequence with locally available code Ci(t).

3.6.2 Operation without Modulo-2-addition

Table 3.3: Operation without Modulo-2-addition

Transmitter	1	Si(t)	-1	-1	1	-1	1	1	-1	-1	-1	-1
	2	Ci(t)	-1	1	1	-1	-1	-1	1	-1	1	1
	3	Si(t)Ci(t)	1	-1	1	1	-1	-1	-1	1	-1	-1
Receiver	4	Si(t)Ci(t)	1	-1	1	1	-1	-1	-1	1	-1	-1
	5	Ci(t)	-1	1	1	-1	-1	-1	1	-1	1	1
	6	Si(t)Ci(t)Ci(t)=Si(t)	-1	-1	1	-1	1	1	-1	-1	-1	-1

1) An arbitrary data sequence Si (t) is generated by a digital source. In this case, +1s and –1s used to represent 0s and 1s.
2) An arbitrary code sequence ci(t) is generated by a DS generator.
3) We multiply Si (t) and Ci(t). The output of the multiplier is transmitted to a distant receiver.
4) At the distant location, the resulting sequence (again assuming no propagation delay) is picked up by the receiver.
5) The code Ci(t) used at the transmitting location is assumed to be available at the receiver.
6) The original data sequence is recovered by multiplying the received sequence by the locally available code Ci(t).

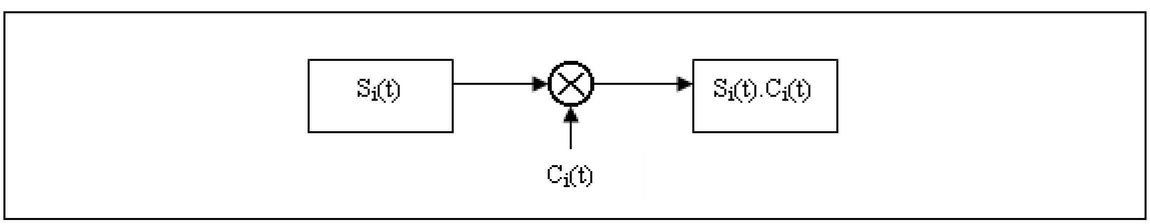

Figure 3.8: Transmitter

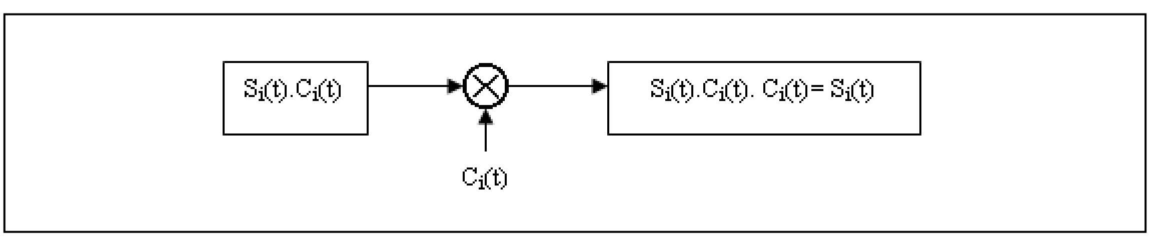

Figure 3.9: Receiver

The modulo-2-addition using 1s and 0s binary data is equivalent to multiplication using -1 and +1 data as long as we remain consistent in mapping 0s to +1s and 1s to -1 as shown in Table 3.2 and 3.3.

In this section, we consider that no propagation delay and no other processing delay occur between transmitter and receiver input and the codes are in phase or in synchronization. But in practice, there is a propagation delay and other processing delay. Therefore, the receiver may be time shifted relative to the initial code at the transmitter, and the two codes are no longer in synch. As a result, the receiver will no longer be identical to the original data, $S_i(t)$.

By synchronizing or tuning the receiver code to the phase of the incoming code, the original data that are shifted by propagation delay can now be recovered at the output of the receiver. In this example, the data sequence and code sequence have the same length (one code bit for each data bit) and are used for encrypting. This referred as bit scrambling.

3.7 The Performance of a CDMA System

In wideband CDMA system, there is a single carrier which is modulated by the speech signals of many users. Instead of allocating each user a different time slot, each is allocated a different modulation code. Mobile users in adjacent cells all use the same frequency band. Each user contributes some interfering energy to the receivers of the users, the magnitude of which depends on the process gain. Each mobile station introduces a unique level of interference that depends on:

1) Received power level at cell site
2) Timing synchronization relative to other signals at the cell site
3) Cross-correlation with other CDMA signals

Numbers of CDMA channels in network are depending on level of total interference that can be tolerated in the system. The quality of system design also plays role in capacity.

Well design system will have bit error probability with higher level interference. FEC technique improves tolerance for interference and increase overall CDMA capacity.

At cell site, received signal level of each mobile user is the same and the interference seen by each receiver is modeled as White Gaussian Noise. Each modulation method defines BER as a function of Eb/No. By knowing performance of coding methods used on the signals, tolerance of digitalized voice and data-to-errors, the minimum Eb/No ratio for proper system operation can be defined. If operation maintained at this minimum Eb/No, the best performance of the system can be obtained.

Relationship between numbers of users, m process gain, G_s and Eb/No define as:

$$m \approx \frac{G_s}{Eb/No} \tag{3.16}$$

For,

$$m \approx \frac{G_s}{Eb/No} \times \frac{1}{1+\beta} \times \alpha \times \frac{1}{v} \times \lambda$$

provides error-free communications.

For Shannon limit, the number of users we can have is,

$$m = 1.45G_s$$

CDMA cell capacity is affected by the receiver modulation performance, power control accuracy, interference from other non-CDMA systems sharing the same frequency band, and other effects.