Chapter 1

Introduction

1.1 History

Cellular systems were first established in 1980 such as Nordic Mobile Telephones (NMT), Analog Advance Mobile Phone Service (AMPS), Total Access Communication Systems (TACS). Those are regarded as the first generation mobile phone (1G) and the transmitted signals are sent as analog signals by having frequency range from 824-894 MHz and using Frequency Division Multiple Access (FDMA) but the drawback of this system is the limitation of the number of users.

In 1990, the researchers developed the new standard in digital system which is called the second generation mobile phone (2G). This can be separated into 2 systems which are Time Division Multiple Access (TDMA), sharing time among users which can support more users compare with 1G; the example of this system is Global System for Mobile Communication (GSM), and another method is Code Division Multiple Access (CDMA), by using different codes to separate users; the example of this system is IS-95.

At this present, the mobile phone system is moving toward the third generation (3G) which is developed from TDMA and CDMA systems and improved the performance by increasing the speed in data transmission for supporting some extra functions other than voices communication, such as sending or receiving e-mail, downloading songs, sending or receiving pictures and video clips, etc.

1.2 The Development of Mobile Phone System

1.2.1 The First Generation Mobile Phone System (1G)

Cellular system was first established in 1979 by Nippon Telephone and Telegraph (NTT) from Japan. It is an analog system which is operated at frequency 800 MHz with total bandwidth 30 MHz and 25 kHz for each user bandwidth. Therefore, this system can handle only 600 duplex channels. Two years ago, this system was in fashion to many countries in Europe. Especially for the Scandinavian, they developed the system and changed the

name to Nordic Mobile Telephones (NMT) in 1981. NMT-450 network was developed to operate at frequency band 450 MHz and 900 MHz with total bandwidth of 10 MHz. Then in 1982, Total Access Communication Systems (TACS) was developed in England which can be operated at frequency band 900 MHz with total bandwidth 25 MHz and 25 kHz for each user bandwidth.

On the other hand, in America, another analog system mobile phone which was developed in 1982 called "Advanced Mobile Phone System" (AMPS) which has operating frequency band 800-900 MHz with total bandwidth of 40 MHz. Thus, the first generation mobile phone can transmit and receive wireless signal by employing the analog system in the frequency band 800-900 MHz and using frequency division multiple access (FDMA) technique in data transmission and reception. The drawback of this system is the limitation of the user bandwidth, so it can hardly increase the number of users.

1.2.2 The Second Generation Mobile Phone System (2G)

Because of the limitation and problems from the analog system mobile phone, then in 1990, researcher groups in Europe developed a new standard for digital wireless system, so called Global System for Mobile Communications (GSM). GSM uses a total bandwidth of 50 MHz and employs a time division multiple access (TDMA) technique by sharing time among users. The advantage of TDMA over FDMA is the larger size of user bandwidth, so the number of users can be significantly increased.

On the other hand, in America, many digital systems mobile phone were developed such as IS-136 which is employing TDMA method same as GSM and IS-95 which employs code division multiple access (CDMA) technique by coding the signal to separate users and each user has different code. Therefore, the receiver can receive data from all users at the same time even when the sending data was transmitted at the same time or same frequency.

In Japan, Personal Digital Cellular (PDC) was developed and was first commercialized in 1993 by NTT company; this system has an operating frequency band of 800 MHz in 1993 and up to 1.5 GHz in 1994 also by employing TDMA technique. The standard and specifications of the second generation mobile phone is shown in Table 1.1.

Table 1.1 Standard and Specifications of 2^{nd} generation mobile phone

	GSM	IS-136	IS-95	PDC
Multiple Access	TDMA	TDMA	CDMA	TDMA
Modulation	GMSK	p/4-DQPSK Coherent p/4-DQPSK Coherent 8-PSK	QPSK/O-QPSK	p/4-DQPSK
Carrier Spacing	200 kHz	30 kHz	1.25 kHz	25 kHz
Carrier Bit Rate	270.833 kbit/s	48.6 kbit/s (p/4-DQPSK) 72.9 kbit/s (8-PSK)	1.2288 Mchip/s	42 kbit/s
Frame Length	4.615 ms	40 ms	20 ms	20 ms
Slot per Frame	8/16	6	1	3/6
Frequency Band (uplink/downlink) (MHz)	880-915/935-960 1720-1785/1805-1880 1930-1990/1850-1910	824-849/869-894 1930-1990/1850-1910	824-849/869-894 1930-1990/1850-1910	810-826/940-956 1429-1453/1477-1501
Maximum possible Data Rate (kbit/s)	HSCSD: 57.6 GPRS: 115.2-182.4	IS-136+: 43.2	IS-95A: 14.4 IS-95B: 115.2	28.8

After 1997, the new applications such as e-mail, photos, video clips, and etc. are required but the speed of the data rate in 2G system is not sufficient. That was the reason that researchers developed new systems to support those applications such as HSCSD, GPRS, and EDGE since these three systems were also based on the GSM system.

HSCSD system is the first system that step forward from the GSM system to support higher speed in data transmission by allowing one user to use four channels at the same time. Thus, the maximum transmission data rate for each user is up to 57.6 kbit/s (4×14.4). So, the advantage of this system is easy to improve the performance of the system because this system is not too complex but the disadvantage is the number of the channels must be expanded.

Next, GPRS system is developed from HSCSD system which still allows one user to use many channels at the same time but adding the channel coding and changing form of transmission to packet switched services which allow users to use that channel when data is only sent or received at that time, so time slots can be shared among users in transmission, theoretically, this system can be supported the information bit rate up to 160 kbit/s.

Even, this system is quite complicated and hardly improved but the advantages of this system are
1) the ability to support higher speed in transmitting data, and
2) the ability to handle more users without adding more channels, compared with HSCSD system. Therefore, it is practical to invest.

The last system is EDGE system, also employing the basis of GSM system but the modulation is changed from GMSK to 8-QPSK, as a result the maximum speed in data transmission is up to three times of the normal rate by using the same bandwidth. Thus, by employing the EDGE system with GPRS, this system can be supported the maximum information bit rate up to 384 kbit/s.

1.2.3 The Third Generation Mobile Phone System (3G)

From the success in 2G, it is forced to going into 3G for supporting new applications which are required very high speed in data transmission and reception such as TV-mobile, video telephony, video conference, and etc.

In 1999, International Telecommunication Union (ITU) proposed the standard and specifications for the wireless network of 3G system such as IMT-2000 (International Mobile Telephony) which has 5 systems followed this standard, namely, UWC-136, DECT, WCDMA or UMTS, CDMA2000, and TS-SCDMA.

The 3G system which is based on TDMA technique such as UMC-136 is developed from the standard of IS-136 in 2G by separating into three phases which are IS-1361, IS-

136 HS Outdoor/Vehicular, and IS-136 HS Indoor. Phase I, IS-1361, the transmission of the data rate does not exceed 64 kbps but still use 30 kHz bandwidth same as in 2G and use 8-PSK technique in modulation for transmitting data at higher rate. Phase II, IS-136 HS Outdoor/Vehicular, the transmission of the data rate is not greater than 384 kbps with 200 kHz for bandwidth same as the standard of enhanced data rates for GSM evolution (EDGE) of GSM system which supports the transmission and reception of IP-based protocol. Phase III, IS-136 HS Indoor has 1.6 MHz for bandwidth and can support data rate up to 2 Mbps.

The better choices for the 3G system are WCDMA and CDMA2000 systems because these two systems are developed from the direct sequence code division multiple access (DS-CDMA) technique in data transmission and reception but the difference between CDMA2000 and WCDMA is the base station; CDMA2000 always has to synchronize by using the signal from Global Position System (GPS). The benefit of the synchronization is that the closest base station can use the same code to communicate with the same mobile phone because the time of data transmission from the base station are always different while each base station in WCDMA network has no synchronization to the others; the time of data transmission can be either the same or different, so the signal used in synchronization from GPS is not needed and for the closest base station, they always use different codes for easing mobile phone to communicate with the base station.

The standard and specifications for IMT-2000 network can be expressed as follows:

- Support a very high information bit rates e.g. transmitting data at rate 2 Mbps for user is not moving or moving with low speed, at 384 kbps for the normal speed outside the building such as walking or running, and at 144 kbps for high speed such as driving, and etc.

- Global Roaming System: the ability to be used anywhere, anytime even that user changes from one network to another network around the world.

- Support many applications such as SMS, MMS, image, video, and etc. Moreover, it must be supported another applications e.g. internet, e-mail, and video conference.

- Ability to handle many functions at the same time.

- High flexibility for handle further new applications or services.

1.3 Standard and Specifications of WCDMA system

In Thailand, WCDMA system is expected to be launched because it employs the basics from the GSM network, which is widely used in Thailand. The standard and specifications of WCDMA system are shown in Table 1.2 and can be described as follows.

- WCDMA system is based on CDMA system which has more bandwidth; the data of

each user is despreaded for the whole bandwidth by multiplying the data of each user with the spreading code and scrambling code before sending through the air.

- The transmission of data rate of WCDMA system is 3.84 Mchip/s and with bandwidth 5 MHz, more than GSM (200 kHz) by 25 times and more than IS-95 (1.25 MHz) by 4 times. Therefore WCDMA system can support very high speed data rate transmission.

- WCDMA can handle both frequency division duplex (FDD) and time division duplex (TDD). In FDD, the carrier frequency for uplink and downlink is different while TDD has the same carrier frequency but it will separate the operating time of the uplink not to coincide with the downlink's.

- Each base station in WCDMA system has not to synchronize to the others like IS-95 system. Therefore, the reference signal such as GPS signal is not needed and it is comfortable to establish in the building or offices.

1.4 Overview of Data Transmission and Reception in WCDMA System

All of users are sending data at the same time by using the same carrier frequency but the spreading code of each user is different to ease to the receiver to separate user signals and allow each user to use bandwidth more than usual. At the receiver, the received signal will be correlated with the code of each user. With this technique, the receiver can separate each user signal correctly even the data from all of users are transmitting at the same time and the same carrier frequency.

The transmitter for both base station and mobile phone in WCDMA system will start from the narrowband signal which has 12.2 kbps for data rate (in practice the data rate can be varied but not exceed 2 Mbps). After encoding and interleaving, the data rate will be increased to 30 ksps. Finally, after spreading process and scrambling process are done, the data rate will become higher and the unit of data rate has changed from symbol/sec to chip/sec. At last, the transmission rate for WCDMA system is up to 3.84 Mcps and has 5 MHz for the bandwidth.

The receiver for both base station and mobile phone, the received signal will be correlated with the scrambling code (SC) which is the unique code used for each base station and mobile phone for researching the signal from which user in the network is transmitting the information and separate that user out from the others. Then, the orthogonal variable spreading factor (OVSF) code is employed for separating the type (channel) of the sending data from that user. Therefore, cooperation between SC and OVSF makes the receiver of the base station to receive the same kind of data such as voice signals or video signals which are sent from the different mobile phone.

In base station receiver, it is composed of three main components which are Multi-

Table 1.2 Standard and Specifications of WCDMA System

Channel Bandwidth	5 MHz
Duplex Mode	FDD and TDD
Downlink RF Channel Structure	Direct Spread
Chip Rate	3.84 Mbps
Frame Length	10 ms
Spreading Modulation	Balanced QPSK (downlink) Dual-Channel QPSK (uplink) Complex Spreading Circuit
Data Modulation	QPSK (downlink)
	BPSK (uplink)
Channel Coding	Convolution and Turbo Codes
Coherent Detection	User dedicated time multiplexed pilot (downlink and uplink), common pilot in the downlink
Channel Multiplexing in downlink	Data and Control Channels Time Multiplexed
Channel Multiplexing in uplink	Control and Pilot Channel Time Multiplexed I and Q Multiplexing for data and control channel
Multirate	Variable Spreading and Multicode
Spreading Factor (SF)	4-256 (downlink), 4-512 (uplink)
Power Control	Open and fast closed loop (1.6 kHz)
Spreading (downlink)	OVSF sequences for channel separation
	Gold sequences $2^{18} - 1$ for cell and user separation (truncated cycle 10 ms)
Spreading (uplink)	OVSF sequences, Gold sequence 2^{41} for user separation (different time shifts in I and Q channel, truncated cycle 10 ms)
Handover	Soft handover, Inter-frequency handover

path Searcher, Rake Finger, and Combiner namely Maximum Ratio Combining (MRC) as represented in Figure 2.4.

1.5 Motivations and Goals of this thesis

Since the base station is the main part in wireless-communication system because it effects the quality of service and the capacity of users in the commercial environment. The references or information about the base station are hardly found in public due to its high commercial value. Then the goals of this thesis are:

1) To study processes of the mobile transmitter to create the base station receiver.

2) To study characteristics of the multipath fading as the channel model.

3) To find the complete algorithms that used in the base station receiver of WCDMA system such as “Multipath Searcher”, “Rake Receiver”, including “Channel Estimator” by adjusting and adapting some parts of mobile receiver of WCDMA system and some algorithms of DS-CDMA system. After suitable algorithms are found by simulations using Matlab version 6.5 and C++ then the algorithms will be used to test in the hardware by using VHDL to communicate with the FPGA board.

4) To improve the performance of the WCDMA receiver in the base station further to be used in real world or used in commercial environments.