

# Wideband Code Division and Multiplication Access

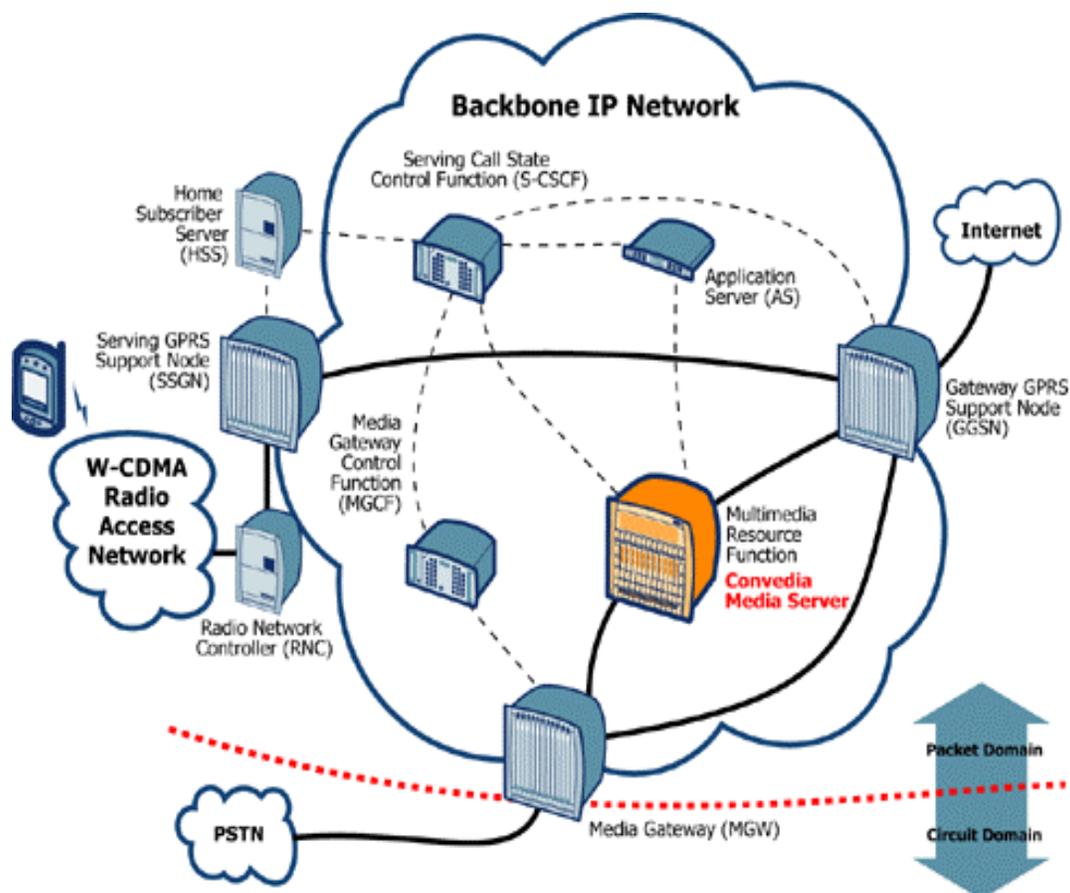
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**Abstract**

When we talk about first generation systems we think about analog cellular systems. The second-generation systems are GSM (Global System for Mobile Communication), PDC (Personal Digital Cellular, 2<sup>nd</sup> generation system in Japan), cdmaOne (IS-95) and US-TDMA (IS-136). Third generation systems, which are designed for multimedia communication are to have high quality images and videos and to access higher data rate information and services on public and private networks. WCDMA technology has emerged as the most widely adopted third generation air interface.

**Introduction:**

The WCDMA specification has been created in 3GPP (the 3<sup>rd</sup> Generation Partnership Project), which is the joint standardization project from Europe, Japan, Korea, the USA and China. Within 3GPP, WCDMA is called UTRA (Universal Terrestrial Radio Access), FDD (Frequency Division Duplex) and TDD (Time Division Duplex), the name WCDMA being used to cover both FDD and TDD operation.

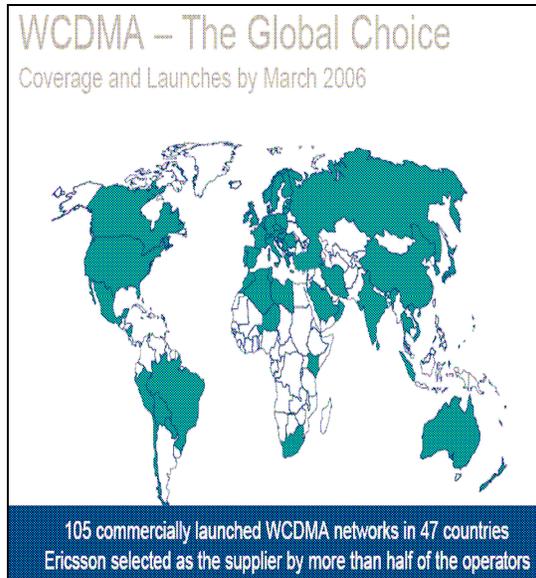


Figure 1: WCDMA global market

**1. Key Players:**

In the United States, the major users for WCDMA is Sprint communications and AT&T. However, Nokia and Erickson have just signed an agreement with Tmobile to upgrade to 3<sup>rd</sup> generation WCDMA from GSM. Qualcomm still

makes chips for WCDMA, CDMA, and GSM, but it is pushing for older generations for upgrades to UMTS (Universal Mobile Telecommunication Serives) WCDMA. In Europe, Spirent Communications in Paris is a big user for WCDMA including many other companies. 90% of the cellular phone industry in Japan has already upgraded to 3-G WCDMA and working on upgrading to 4-G such as Wi-Fi, WiMax, and Wibro.

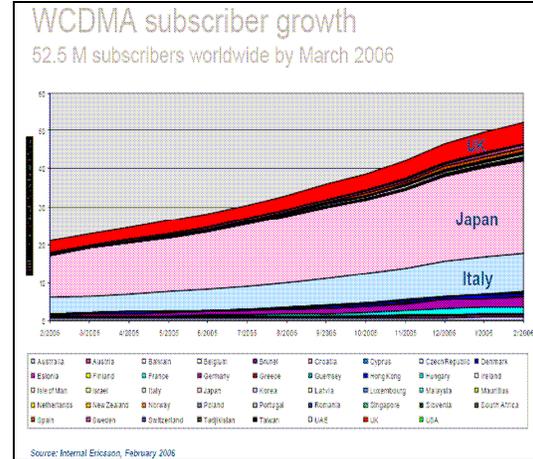


Figure 2: WCDMA global growth

**2. Frequency Band:**

**Uplink:** means that multiple users send signals to the base station

**Downlink or broadcast:** Means that the base sends different signals to different users.

In the United States

	Uplink	Downlink	Total
WCDMA	1710-1770	2110-2170	2x60 MHz

In Europe and Asia

	Uplink	Downlink	Total
UMTS-FDD	1920-1980	2110-2170	2x60 MHz
UMTS-TDD	1900-1920	2110-2025	20 +15 MHz

**3. Standard Body:**

The work to develop third generation mobile systems started when the World Administrative Radio Conference (WARC) of the International Telecommunications Union (ITU), at its 1992 meeting identified the frequencies around 2GHz for 3<sup>rd</sup> generation mobile systems, both terrestrial

and satellite. Within the ITU these third generation systems are called International Mobile Telephony 2000 (IMT-2000). In North America, that spectrum has already been auctioned for operators using second-generation systems, and no new spectrum is available for IMT-2000. Thus, third generation services must be implemented within the existing bands.

The WCDMA concept was formed around the WCDMA proposals from FRAMES/FMA2 (Future Radio Wideband Multiple Access System, EU research project), Fujitsu, NEC and Panasonic. Several European, Japanese and US companies contributed to the development of the WCDMA concept. The physical layer of the WCDMA uplink was adopted mainly from FRAMES/FMA2, while the downlink solution was modified following the principles of the other proposals made to the WCDMA concept group.

#### 4. Modulation and Error Control Coding:

##### Baseband Transmitter Architecture

This section describes the digital architecture of a downlink transmitter that supports the W-CDMA standard. Figure 1 shows a block diagram of the transmitter. Blue blocks can be implemented in an Altera FPGA; orange blocks can be implemented in software in the Nios II embedded processor.

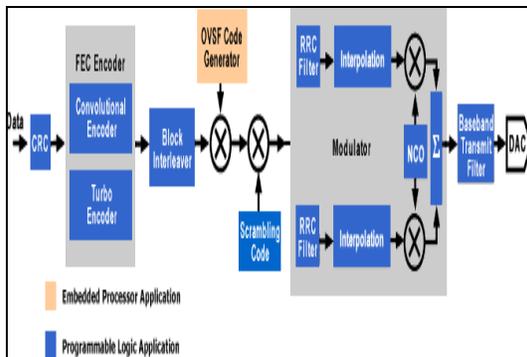


Figure 3: Baseband Transmitter

**CRC** = cyclic redundancy check  
**DAC** = digital to analog converter  
**NCO** = numerically controlled oscillator  
**OVSF** = orthogonal variable spreading factor  
**RRC** = root raised cosine

To conform to the W-CDMA standard, cyclic redundancy check bits are added for error

detection, and error correction bits are added for channel coding. The data is then spread with a user or channel-specific code to produce a DataStream at a given chip-rate. The spread data stream is scrambled with Gold code so that multipath signals can be uniquely identified and decoded by the receiver. To transmit a signal within the specified bandwidth, the data bits are shaped using a pulse-shaping filter. Next, the signal goes through carrier modulation and up-conversion to radio frequency (RF), and is then sent to the antenna to be transmitted over the air.

##### A) Cyclic Redundancy Check

The standard specifies four different polynomials for CRC checking:

- $gCRC24(D) = D^{24} + D^{23} + D^6 + D^5 + D + 1$
- $gCRC16(D) = D^{16} + D^{12} + D^5 + 1$
- $gCRC12(D) = D^{12} + D^{11} + D^3 + D^2 + D + 1$
- $gCRC8(D) = D^8 + D^7 + D^4 + D^3 + D + 1$

Altera provides the CRC MegaCore<sup>®</sup> function, which can implement these polynomials and therefore meets the third-generation standard requirements. The CRC function is fully parameterized, including:

- Variable length generator polynomial
- Variable data width from 1 bit to the width of the polynomial
- Any initial value

##### B) Forward Error Correction

The standard defines two encoding schemes to support different quality of services. For voice and MPEG4 applications, the standard employs convolutional encoding, which gives a bit error rate (BER) of up to  $10^{-3}$ . For data applications, the standard uses turbo encoding, which gives a BER of up to  $10^{-6}$ .

##### Convolutional Encoder

The required specification for a convolutional encoder is given below:

- Base station: K = 9 and rate = 1/2 and 1/3
- Mobile: K = 9 and rate = 1/3

A convolutional encoder uses delay elements and XORs. Altera provides building blocks

optimized for Altera PLDs in the library of parameterized modules (LPM). You can use these functions, such as LPM\_SHIFTREG and LPM\_XOR, to implement a convolutional encoder.

### Turbo Encoder

Turbo encoding gives a relatively large encoding gain with a reasonable computational complexity. This encoding scheme is useful for data services that permit longer transmission delays. The W-CDMA specifications are:

- Parallel concatenated convolutional code (PCCC) with two 8-state constituent encoders and an interleaver
- Block size: 40 to 5,114 bits
- Puncturing: rate = 1/3 (no puncturing); rate = 1/2 (puncturing)

Altera provides the Turbo Encoder MegaCore function, which meets the W-CDMA standard. The turbo encoder uses 3,000 logic elements (LEs) and 10 embedded system blocks (ESBs) when implemented in an APEX 20K device.

### *C) Interleaver / Deinterleaver*

Systems that transmit digital data require error correction to reduce the effect of spurious or burst noise from the channel that can corrupt data. A block interleaving function writes data into a rectangular matrix and then reorders the columns of the matrix based on the transmission time interval (TTI) value. APEX device embedded system blocks (ESBs) can store a matrix of elements. To permute the columns, the data is read out column by column in the right sequence. A software routine running in an embedded processor can generate the correct read address.

The deinterleaver performs the reverse operation of the interleaver.

### *D) OVFSF Code Generator*

Transmissions from a single source are separated by channelization codes: download connections within one sector and the dedicated physical channel on the uplink. The orthogonal variable spreading factor (OVFSF) channelization code preserves the orthogonality between different physical channels using a tree-structured orthogonal code. The tree-structured code is

generated recursively using the following equation:

$$C_{2N} = \begin{bmatrix} C_{2N, 1} \\ C_{2N, 2} \\ C_{2N, 2N} \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} C_{N, 1} & C_{N, 1} \\ C_{N, 1} & -C_{N, 1} \end{bmatrix} \\ \begin{bmatrix} C_{N, N} & C_{N, N} \\ C_{N, N} & -C_{N, N} \end{bmatrix} \end{bmatrix}$$

Because the process is recursive, you can implement OVFSF code generation in software in an Excalibur embedded processor PLD. The device's memory blocks can store the intermediate results.

Other operations within base station subsystems may need to refer to the OVFSF code assigned to different users. The content-addressable memory (CAM) in Altera devices can store the code so that it can be quickly accessed when needed.

### *D) Scrambling Code*

Scrambling codes make the direct sequence CDMA (DS-SS) technique more effective in a multipath environment. It significantly reduces the auto-correlation between different time delayed versions of a spreading code so that the receiver can uniquely decode the different paths. Additionally, scrambling codes separate users and base station sectors from each other by allowing them to manage their own OVFSF trees without coordinating amongst themselves. The W-CDMA specification for the scrambling code generator is described below.

#### Downlink:

- 38,400 chips of 218 Gold code
- 512 different scrambling codes
- Grouped for efficient cell search

#### Uplink:

- Long Code: 38,400 chips of 225 Gold code
- Short Code: 256 chips of very large Kasami code

You can design the scrambling code generator using the same library of parameterized modules (LPM) functions used for the convolutional encoder (i.e., LPM\_SHIFTREG and LPM\_XOR).

### E) Modulator/Demodulator

Using a digital in phase and quadrature modulator instead of an analog one has several advantages:

- Channels can be selected in the digital domain using a numerically controlled oscillator (NCO) and a digital mixer
- Direct digital synthesizer gives more precise frequency selection and shorter settling time; it also provides good amplitude and phase balance
- Digital filter provides extremely linear phase and a very low shape factor

To meet the W-CDMA requirements, the following elements are needed:

- Nyquist filter
  1. Root raised cosine filter:  $a = 0.22$
  2. Sampling rate: 3.84 mega samples per second (Msps)
- NCO Compiler
  1. 60-MHz bandwidth for channel mapping
  2. High spurious free dynamic range (SFDR)

Altera provides the following cores, which you can use to build a complete modulator:

- FIR Compiler to create a root raised cosine interpolation filter
- NCO Compiler to create an NCO
- LPM\_MULT LPM function to create a digital mixer

### F) Baseband Transmit Filter

Digital-to-analog (D/A) converters demonstrate a  $\text{sinc}/x$  rolloff amplitude response. To minimize the distortion incurred from the sampling process, you can use a FIR filter with an inverse  $\text{sinc}/x$  response to pre-distort the signal so that with the D/A converter the overall response is flat.

### Baseband Receiver Architecture:

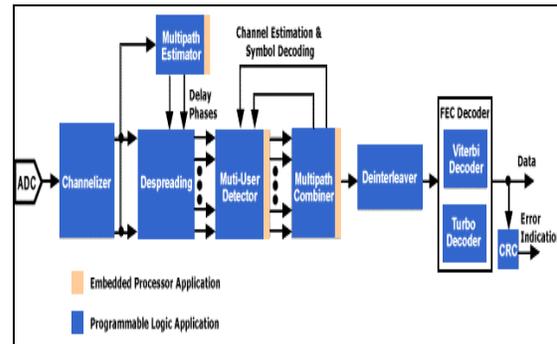


Figure 4: Baseband Receiver

#### A) Despreader

The radio environment of a wireless network system is a multipath environment. To be effective, the system requires a despreader that can simultaneously despread the numerous multipaths of both a single user as well as multiple users (if doing a joint detection). A RAKE receiver, with its multiple fingers to despread different multipaths, is well suited for this function.

The traditional approach uses a coarse delay estimation unit to find the appropriate tap values, and then triggers delay-locked loops (DLLs) connected to the finger to track the multipath. This implementation is not desirable because it is complex and decentralizes the process of tracking the multipaths.

A more desirable implementation is a full-matched filter that gives a new tap value every sample time. A full-matched filter eliminates the need for dedicated DLLs and creates a centrally controlled RAKE receiver that is simpler than a distributed one with DLLs. High-density Excalibur embedded processor PLDs can implement a full-matched filter in programmable logic and control logic in the embedded processor.

#### Channel Estimator & Signal Decoder

To correct for channel distortion, the system has complex amplitude and phase estimation. This action is part of the RAKE receiver, and is required for coherent detection. One of the schemes used to estimate complex amplitudes is a pilot symbol-assisted channel estimation filter, called a weighted multi-slot averaging (WMSA)

channel estimation filter. In this scheme, the wideband signal is converted to a narrowband signal using a binary correlator. The pilot symbols are then demultiplexed from data symbols. The pilot symbols are averaged over multiple slots to get a better average over the slot. Excalibur PLDs can implement a RAKE receiver with the correlator portion in logic and the control portion in the embedded processor.

#### Sequential Correlator

In the sequential correlator, each incoming sample is multiplied by a PN sequence that advances at the chip rate. In a practical implementation, the data values are soft symbols where a large value indicates more confidence that the symbol has been received correctly. Results from multiplication stage are accumulated over the symbol period. At the end of the period, the correlation sum is dumped. You can use the Sequential Correlator function from Nova Engineering, Inc., an Altera Mega function Partners Program (AMPP<sup>SM</sup>) partner, to implement the finger of a RAKE receiver as well as the correlator in multi-user detection (MUD) blocks.

#### ***B) Multi-User Detector/Interference Cancellor***

The capacity of a DS-CDMA system is interference-limited. Every user acts as an interference for every other user. The more resistant the system is to interference, the more users can be served. Multi-user detection (MUD) techniques—also called joint detection and interference cancellation (IC)—reduce the effects of multiple access interference and increase system capacity.

The maximum likelihood sequence estimator (MLSE) is a well-known optimal detection algorithm. However, it is too complex for practical DS-CDMA systems. Therefore, most research and development efforts are focused on developing sub-optimal schemes. There are two classes of sub-optimal schemes: linear and IC.

Simulation has shown that group-wise successive IC is the most promising scheme. In this scheme, users are grouped according to their spreading factor and then IC or a de-correlator is applied within the group. Processing starts with the lowest SF group and processes towards the highest SF group.

To illustrate how to implement MUD in a PLD, two IC-based schemes are discussed, wideband SIC and narrowband SIC.

#### Wideband SIC

In this scheme, the interfering signals are cancelled in a wideband domain. First, the RAKE receiver de-correlates the number of users and their multipaths. Next, the de-correlated signals are grouped based on their signal strength and spreading factor. The appropriate signals are regenerated using their corresponding spreading code and cancelled from the incoming wideband signal. Finally, the residual signal from the cancellation process is added back to the different signals that are tracked before they are de-correlated with their respective codes.

All of the blocks except the combiner can be implemented in programmable logic. The combiner—with its complex algorithm for weighted combining and low-speed signal processing requirement (3.84 mega samples per second)—can be implemented effectively in software running in an Excalibur embedded processor PLDs.

#### Narrowband SIC

In this scheme, the interfering signals are cancelled in the narrowband domain. After the signals are grouped and regenerated (as they would be in a wideband SIC scheme), they are de-correlated by a cross-correlation matrix. The cross-correlation matrix contains the auto-correlation and cross-correlation coefficients between the different spreading codes.

Canceling the signals removes the interference due to correlation with other spreading codes. Evaluating the cross-correlation matrix is a computationally intensive task. A new matrix must be calculated and inverted every time the user profile changes or multipath tap changes. Therefore, the W-CDMA specification uses a 245 chips short code (called very long Kasami code). With short spreading code, this implementation is more feasible.

To evaluate the cross-correlation matrix, a number of algorithms that exploit the special structure of the matrix—namely the band and block Toeplitz structures—can be used. One approach is to extend the block-Toeplitz system matrix into a block circulant matrix that can be

inverted using a block fast Fourier transform (FFT) function. Altera provides the FFT MegaCore function, which is also suited for this application.

### C) Decoders

There are two types of decoders that can be used in the receiver. The Viterbi decoder is used to decode signals encoded using convolutional encoders; the turbo decoder is used with the turbo encoder.

#### Viterbi Decoder

The Viterbi algorithm is the optimal algorithm to decode convolutionally encoded data. The complexity of Viterbi decoding is an exponential function of the constraint length. W-CDMA requires a decoder with a constraint length of 9, which poses an implementation challenge. Altera provides the Viterbi MegaCore<sup>®</sup> function that meets W-CDMA requirements.

There are two different Viterbi implementations depending on the throughput requirements.

Implementation	Logic Elements	Speed
Serial	1,300	500 Kbps
Serial/parallel	2,600	2 Mbps

#### Turbo Decoder

The turbo decoder is used to decode turbo-encoded data. The decoder should handle codes of different rates and block sizes encoded by the encoder. Altera provides the turbo decoder MegaCore function, which has the following features:

- Max-logMAP decoder for maximum performance
- Includes UMTS-specific interleaver
- Fully parameterized to tailor decoder to system requirements
- Memory bank swap mechanism for increased throughput

### D) Parallel Correlator

In the parallel correlator, data samples are held in a long shift register, and the pilot PN sequence is held in a reference pattern register. Each time a new sample is loaded into the data shift register, the contents of the two registers are multiplied

and integrated to give a new correlation sum. You can use the Parallel Correlator function from Nova Engineering, Inc. to implement the multipath delay estimator.

### 5. Rake Receivers and Constellations:

In a typical WCDMA rake receiver, channel estimates are used to combine different paths using Maximum Ratio Combining (MRC).  $r(t)$  is the received signal which is split into  $r(t, \tau_i)$ , where  $g(t, \tau_i)$  is the corresponding channel estimate for each path is  $r(t - \tau_i)$ . The objective is to estimate the channel phase and amplitude for each of the identified paths. This information is then used for combining each path of the received signal.

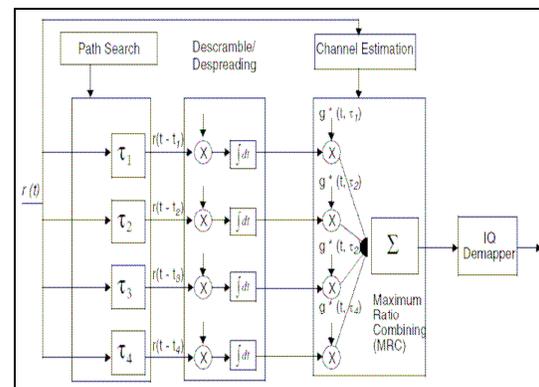


Figure 5: Rake Receiver

The following steps occur in a WCDMA receiver:

**1. Descrambling:** Received signals are multiplied by the scrambling code and delayed versions of the scrambling code. A path searcher determines the delays prior to descrambling. Each delay corresponds to a separate multipath that is to be combined by the rake receiver

**2. Despreading:** The descrambled data of each path is despread by simply multiplying the descrambled data by the spreading code.

**3. Integration and dump:** The despread data is integrated over one symbol period, giving one complex sample output per QPSK symbol. This process is carried out for all paths to be combined by the rake receiver.

**4. Symbol combining:** The same symbols obtained via different paths are then combined

using the corresponding channel information and a combining scheme such as MRC.

5. The combined output is sent to a simple decision device to decide on the transmitted bits.

### Modulation

WCDMA uses quadrature phase-shift keying (QPSK) modulation for downlink transmission. Besides QPSK, high-speed downlink shared channel (HS-DSCH) can also use 16-quadrature amplitude modulation (16QAM) to provide higher data rates. Because 16QAM has twice the peak rate capability for QPSK, it makes more efficient use of bandwidth than QPSK. Nevertheless, it also requires better radio channel conditions than QPSK.

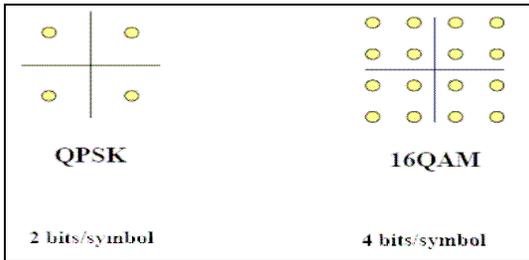


Figure 6: WCDMA Constellation

**DPDCH:** Dedicated Physical Control Channel.  
**DPDCH:** Dedicated Physical Data Channel.  
**G:** The relative Strengths of the DPDCH and DPCCH.

### I-Q Uplink Modulator:

For the best power amplifier efficiency, peak to average ratio (PAR) should be as low as possible. With I-Q code multiplexing, level of DPDCH and DPCCH are different, and since we want to maintain identical  $E_b$ , when data rate increases, it could lead to BPSK-like transmission, which is unbalanced. Thus, complex spreading is used to “share” I-Q info with two branches.

For an uplink modulator:

1. Efficiency remains the same as with balanced QPSK
2. Efficiency of the power amplifier does not depend on G
3. Power difference between DPDCH and DPCCH quantized to 4 bits

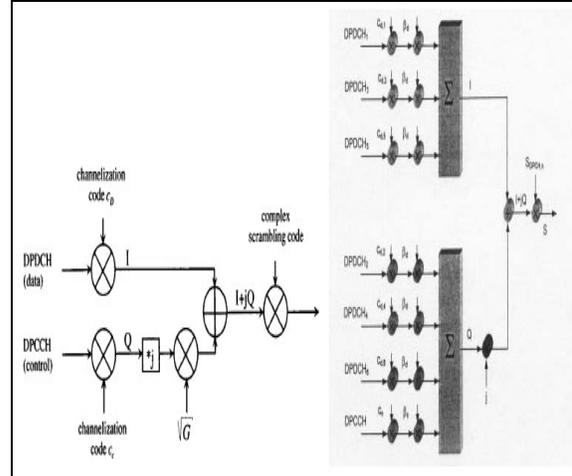


Figure 7: I-Q Uplink Modulator

### I-Q downlink Modulator:

In downlink modulation, audible interference is not an issue because common channels have continuous transmission. Also, variable bit rate is taken care of by rate matching or discontinuous transmission, if multi-code transmission for a single user, parallel code channels have different channelization codes.

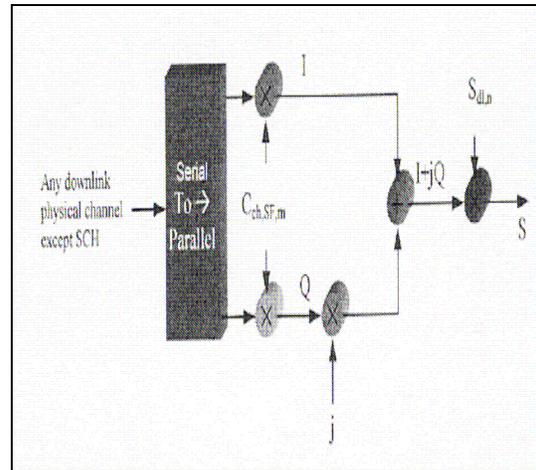


Figure 8: I-Q Downlink modulator

### 6. Pulse Shape Used:

WCDMA uses the “Root Raised-Cosine” with a roll-off = 0.22. The purpose of using a root raised cosine and root raised cosine filters at each end of the communication system is to reduce InterSymbol Interference (ISI) as much as we can. The following plot is a generated Matlab code for Root Raised Cosine with K=9 and roll-off alpha = 0.22.

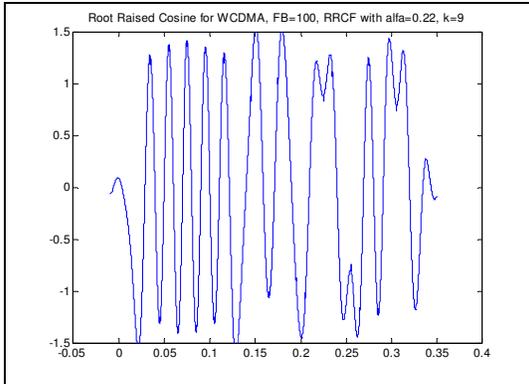


Figure 9: Root Raised Cosine pulse

### 7. Multi-antenna Technology:

WCDMA uses multi-antenna technology, however, doing so lead to several engineering issues such us ISI that resulted from multi-code and multiple input multiple output (MIMO) scheme. Several research has been conducted in this area and one of the main solutions is to modify the receiver to be a generate RAKE receiver which is in these days is known as GRAKE. GRAKE is used to cancel multiple access interference (MAI), which improved the signal to interference-plus-noise (SINR).

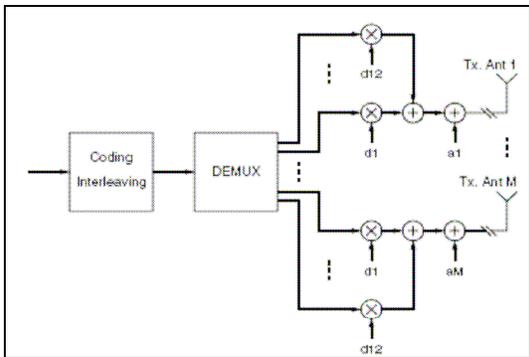


Figure 10: Code Reuse MIMO Architecture for HS-DSCH transmission

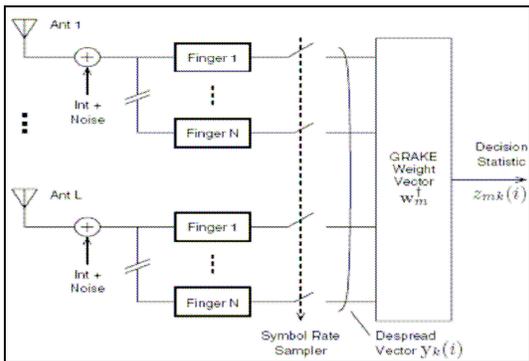


Figure 11: GRAKE multi-antenna receiver

### 8. Major WCDMA Users:

The biggest vendors for turn-key UMTS networks are:

1. Alcatel
2. Ericsson
3. Lucent
4. Motorola
5. Nokia
6. Nortel
7. Siemens/NEC

### Conclusion:

WCDMA technology is growing and expanding very fast, over 50 countries have merged to the third generation of UMTS. This upgrade is what is giving us the privilege to have video games, check emails, send and receive images and pictures over the phone, access the broadband network at a very efficient speed. Even though 3G seems very satisfying, major companies are already pushing to upgrade to the fourth generation which will give us all these privileges plus a lot more. The question is? Will there be enough space for more new bandwidth or we have to use the old generations and just merge them with the new ones as we already see happening in the United States, which led in a slow upgrade due to the existing old technologies.

## References:

- [1] Barkat, Mourad, Signal Detection and Estimation 2<sup>nd</sup> Edition, Boston Artech House, 2005
- [2] Holma, H. and A. Toskala, WCDMA for UMTS Radio Access for Third-Generation Mobile Communications, John Wiley & Sons, Inc., 2005
- [3] Harte, Lawrence, Introduction to Code Division and Multiple Access (CDMA): Network, Services, Technologies, and Operation, Althos Publishing, 2004
- [4] Aziz, Ahsan, Channel Estimation for a WCDMA Rake Receiver, Application Note AN2253, 2004
- [5] Souto, N. Carlos Silva, J. Cercas, F. Dinis, R. Rodrigues, A. Correia, A. Non-Uniform Constellations for Broadcasting and Multicasting Services in WCDMA Systems, Instituto Superior Tecnico, Lisboa, Portugal.
- [6] <http://www.altera.com/end-markets/wireless/cellular/wcdma/wir-wcdma.html>
- [7] 3G & Spectrum Allocation: Sharing Ericsson's Experience. [www.ericsson.com](http://www.ericsson.com)
- [8] White Paper, WCDMA Evolved, The first step-HSDPA, Ericsson Application note: 284 23-2958, 2004
- [9] Vandendorpe, Luc, WCDMA for UMTS, UCL Communications and Remote Sensing Lab, University Catholique de Louvain
- [10] Zhang G. Chin F, Multi-Antenna WCDMA Receiver Design with CORDIC, Institute of infocomm research, Singapore
- [11] Molnar, K. Grant, S. Krasny, L, Improved Packed data Performance for WCDMA Using Multi-Antenna Techniques, Ericsson Inc, 2003