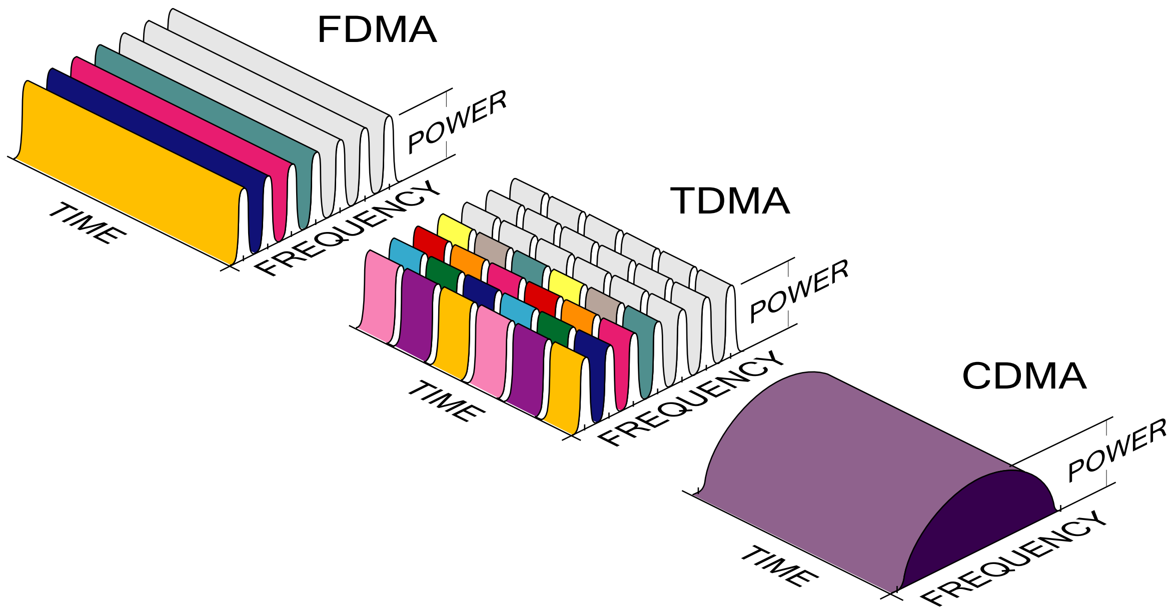
QUALCOMM cdma university | **Multiple Access Methods** | CDMA2000 1x RC1 & RC2 Section 1-7

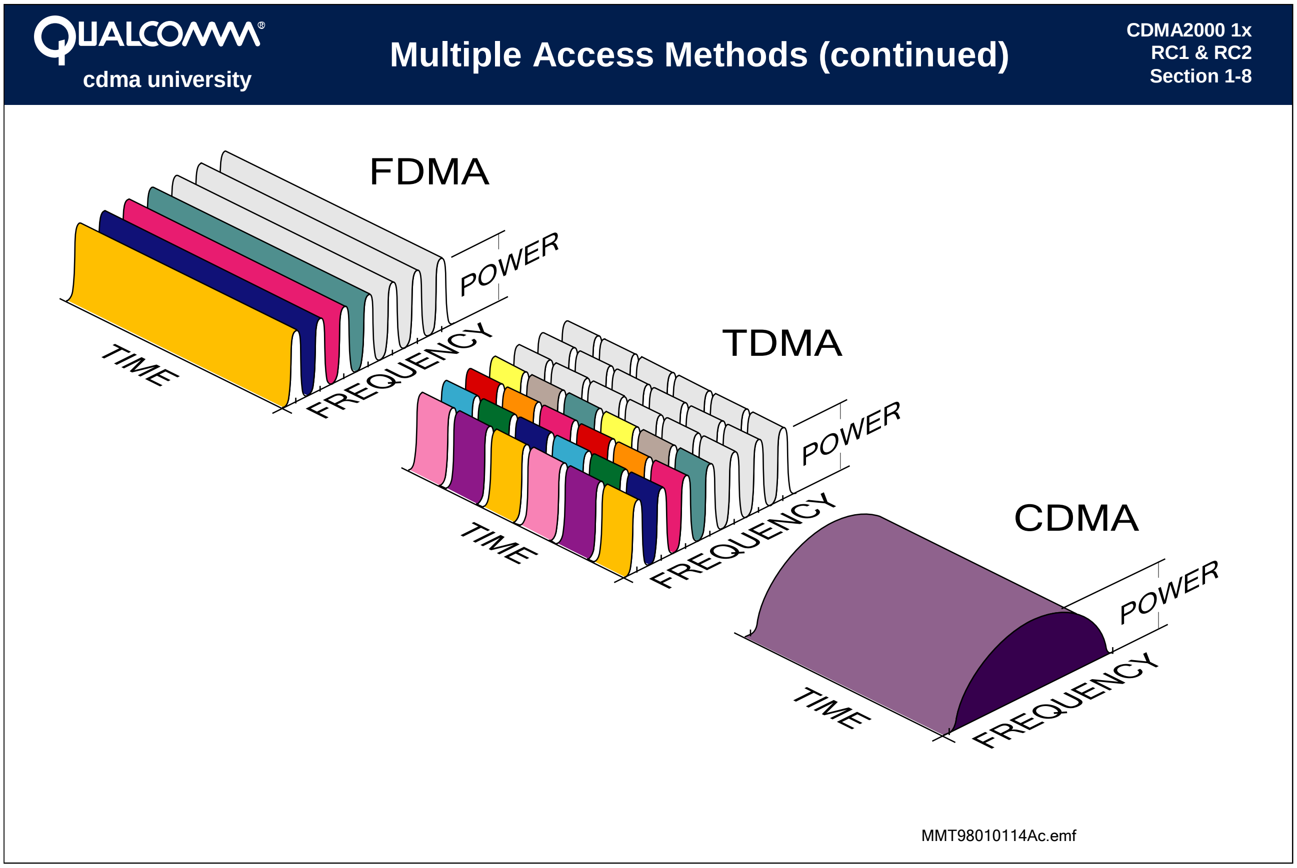


FDMA: Frequency Division Multiple Access

FDMA is a multiple access method in which users are assigned specific frequency bands. The user has sole right of using the frequency band for the entire call duration.

TDMA: Time Division Multiple Access

TDMA is an assigned frequency band shared among a few users. However, each user is allowed to transmit in predetermined time slots. Hence, channelization of users in the same band is achieved through separation in time.



CDMA: Code Division Multiple Access

CDMA is a method in which users occupy the same time and frequency allocations, and are channelized by unique assigned codes. 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.

In December of 1991, QUALCOMM presented to CTIA the results of some of the first CDMA field trials. Following these presentations, the CTIA Board of Directors unanimously adopted a resolution requesting that the Telecommunications Industry Association (TIA), prepare structurally to accept contributions regarding wideband cellular systems.

In March of 1992, a new subcommittee within the TR45 Committee was formed to develop spread spectrum cellular standards. That subcommittee published the first CDMA cellular standard, IS-95, in July 1993. CDMA systems based on the IS-95 standard and related specifications are referred to as *CDMAOne*™ systems. CDMAOne is a trademark of the CDMA Development Group (CDG).

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Overview of CDMA

CDMA2000 1x
RC1 & RC2
Section 1-9

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The CDMA "Cocktail Party"

The CDMA concept is analogous to the situation encountered at a party. At the "CDMA Cocktail Party," all subscribers are talking in the same room together simultaneously. Imagine that every conversation in the room is being carried out in a different language that you do not understand. They would all sound like noise from your perspective.

If you "knew the code," the appropriate language, you could imagine filtering out the unwanted conversations and listening only to the conversation of interest to you. A CDMA system must filter the traffic in a similar way.

Even with knowledge of the appropriate language, the conversation of interest may not be completely audible. The listener can signal the speaker to speak more loudly and can also signal other people to speak more softly. A CDMA system uses a similar power control process.

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CDMA2000

CDMA2000 1x
RC1 & RC2
Section 1-10

CDMA2000

CDMA2000.jpg

Code Division Multiple Access (CDMA)

The frequency spectrum, in a practical sense, is a finite resource. To effectively support a large number of users, some technique for sharing the spectrum is required to minimize mutual interference. Several common techniques have focused on the use of directional antennas to carefully restrict propagation, the use of separate frequency slots, or time sharing. Code Division Multiple Access (CDMA) is a digital technique for sharing the frequency spectrum. CDMA is based on proven Spread Spectrum communications technology. There are several CDMA implementations that are currently deployed or under development.

CDMAOne

The first commercial and most widely deployed CDMA implementation is CDMAOne. The foundation of CDMAOne is the TIA/EIA IS-95 standard. The term CDMAOne intended to represent the end-to-end wireless system and all of the necessary specifications that govern its operation. CDMAOne technology provides a family of related services including cellular, PCS, and fixed wireless (wireless local loop).

CDMA2000

CDMA2000 is an improvement on TIA/EIA-95. It provides a significant improvement in voice capacity and expanded data capability, and is backward-compatible with IS-95 handsets.

QUALCOMM cdma university | TIA/EIA-95 | CDMA2000 1x RC1 & RC2 Section 1-11

TIA/EIA-95 =

IS-95A + TSB-74 + J-STD-008

- Analog Details

+ Corrections

+ New Capabilities

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Contents of TIA/EIA-95-B

The new revision, TIA/EIA-95-B, combined IS-95A and B, TSB-74, and ANSI J-STD-008 into a single document and eliminated much of the redundancy among the three documents. Most of the analog information was deleted and the standard referenced the existing analog standard IS-553A when applicable. Lastly, TIA/EIA-95-B added technical corrections and new capabilities.

TIA/EIA-95-B is Protocol Revision 5.

The 2000 Family of Standards

CDMA2000 1x RC1 & RC2 Section 1-12

CDMA2000 has multiple releases:

- **TIA/EIA-95**
  (covered by CDMA2000 radio configurations 1 & 2)
- **CDMA2000 Release 0**
  Uses TIA/EIA-95 Paging and Access Channels and new Traffic Channels
- **CDMA2000 Release A**
  New overhead channels
- **CDMA2000 Release B**
  Minor revisions plus rescue channel
- **CDMA2000 Release C**
  1x EVDV support

CDMA2000 Releases

The first revision of CDMA2000 was Release 0, developed by the Telecommunications Industry Association (TIA) standards body. The TR45 Committee completed the revision in July 1999.

Release A of CDMA2000 was developed by Third Generation Partnership Product 2 (3GPP2), a consortium of five standards bodies:

- TIA in North America
- Telecommunications Technology Association (TTA) in Korea
- Association of Radio Industries and Businesses (ARIB) and Telecommunications Technology Committee (TTC) in Japan
- China Wireless Telecommunication Standards Group (CWTS) in China.

Release A was completed in March 2000.

Release B of CDMA2000 was completed by 3GPP2 on April 19, 2002.

Release C of CDMA2000 was completed by 3GPP2 on May 28, 2002.

Note that the discussion of CDMA2000 in this course assumes CDMA2000 revision A unless otherwise stated.

QUALCOMM cdma university | CDMA2000 Physical Layer | CDMA2000 1x RC1 & RC2 Section 1-13

New Concepts in the CDMA2000 Physical Layer

- Spreading Rate 1 (1x) and Spreading Rate 3 (3x)
- Logical Channels
- Radio Configurations
- Many new Physical Channels
- Transmit Diversity Pilot Channels
- Enhanced Access Channel Procedures
- Reverse Link Pilot Channel

CDMA2000 Physical Layer

Spreading rates for CDMA2000 include 1x (the same as TIA/EIA-95 with a code rate of 1.2288 Mcps) and the new 3x rate which is three times faster, or 3.6864 Mcps.

The CDMA2000 standard has been written in layers to simplify the system design, so the signaling has been divided into Logical Channels and Physical Channels.

The new spreading rates and FEC rates require different hardware configurations, so there are many new Radio Configurations in CDMA2000.

New Physical Channels have been added to improve performance (transmit diversity), to improve capacity (Reverse Pilot) and call set up times (new overhead channels and access channels).

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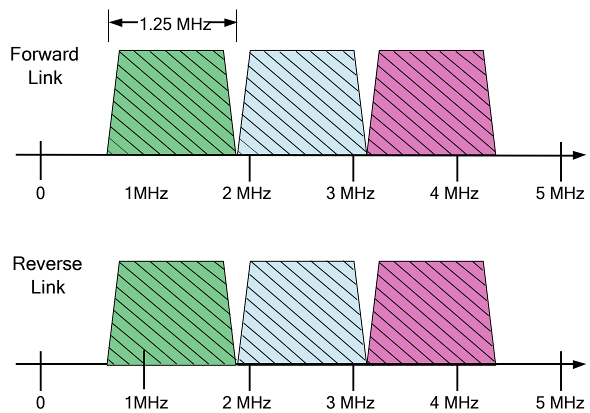
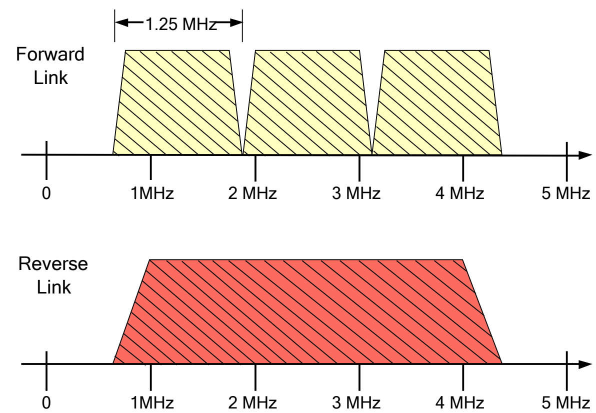
Spreading Rate 1 and Spreading Rate 3

CDMA2000 1x
RC1 & RC2
Section 1-14



Spreading Rate 1



Spreading Rate 3

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Spreading Rates

CDMA2000 supports two different spreading rates:

- **Spreading Rate 1 —** also called “1x”
  - Both Forward and Reverse Channels use a single direct-sequence spread carrier with a chip rate of 1.2288 Mcps.
- **Spreading Rate 3 —** also called “3x” or MC (Multi-Carrier)
  - Forward Channels use three direct-sequence spread carriers each with a chip rate of 1.2288 Mcps.
  - Reverse Channels use a single direct-sequence spread carrier with a chip rate of 3.6864 Mcps.

Radio Configurations

RC1 ad RC2 are exactly backward-compatible to TIA/EIA-95-B Rate Set 1 and Rate Set 2.

The new Radio Configurations are RC3 and up, and these use new modulations, new FEC rates, and 1x or 3x spreading rates.

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Radio Configurations – Forward Link

CDMA2000 1x RC1 & RC2 Section 1-16

Radio Configuration	Spreading Rate	Max Data Rate* (kbps)	Effective FEC Code Rate	OTD Allowed	FEC Encoding	Modulation
1	1	9.6	1/2	No	Conv	BPSK
2	1	14.4	3/4	No	Conv	BPSK
3	1	153.6	1/4	Yes	Conv and Turbo	QPSK
4	1	307.2	1/2	Yes	Conv and Turbo	QPSK
5	1	230.4	3/8	Yes	Conv and Turbo	QPSK
6	3	307.2	1/6	Yes	Conv and Turbo	QPSK
7	3	614.4	1/3	Yes	Conv and Turbo	QPSK
8	3	460.8	1/4 or 1/3	Yes	Conv and Turbo	QPSK
9	3	1036.8	1/2or 1/3	Yes	Conv and Turbo	QPSK

* Maximum data rate for a single Supplemental Channel

Forward Link Radio Configurations

Radio Configurations 1 and 2 correspond to TIA/EIA-95-B Rate Set 1 and Rate Set 2, respectively. These are backward-compatible Radio Configurations.

Radio Configurations 3, 4, and 5 use Spreading Rate 1, while Radio Configurations 6, 7, 8, and 9 use Spreading Rate 3. Turbo coding or convolutional coding may be used. RC3, RC4, RC6, and RC7 are based on Rate Set 1 (multiples of 9.6 kbps), while RC5, RC8 and RC9 are based on Rate Set 2 (multiples of 14.4 kbps).

Max Data Rate refers to the maximum data rate for a single Supplemental Channel. Since up to two Supplemental Channels may be used for a single Traffic Channel, the total maximum data rate is twice the value shown in the table.

Radio Configurations – Reverse Link

Radio Configuration	Spreading Rate	Max Data Rate* (kbps)	Effective FEC Code Rate	FEC Encoding	Modulation
1	1	9.6	1/3	Conv	64-ary ortho
2	1	14.4	1/2	Conv	64-ary ortho
3	1	153.6 (307.2)	1/4 (1/2)	Conv or Turbo	QPSK
4	1	230.4	3/8	Conv or Turbo	QPSK
5	3	153.6 (614.4)	1/4 (1/3)	Conv or Turbo	QPSK
6	3	460.8 (1036.8)	1/4 (1/2)	Conv or Turbo	QPSK

*** Maximum data rate for a single Supplemental Channel**

Reverse Link Radio Configurations

Radio Configurations 1 and 2 correspond to TIA/EIA-95-B Rate Set 1 and Rate Set 2, respectively. These are backward-compatible Radio Configurations.

Radio Configurations 3 and 4 use Spreading Rate 1, while Radio Configurations 5 and 6 use Spreading Rate 3. Turbo or convolutional coding may be used.

RC3 and RC5 are based on Rate Set 1, while RC4 and RC6 are based on Rate Set 2.

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Where are the Standards?

CDMA2000 1x RC1 & RC2 Section 1-18

Up-to-date copies of the standard can be viewed and downloaded as PDF's from:

www.3gpp2.org

Where are the Standards?

3gpp2 is a collaborative third generation (3G) telecommunications standards-setting project comprising North American and Asian interests, developing global specifications for ANSI/TIA/EIA-41 "Cellular Radio Telecommunication Intersystem Operations network evolution to 3G," and global specifications for the radio transmission technologies (RTTs) supported by ANSI/TIA/EIA-41.

Questions?

If you have a question about CDMA2000, send email to:

CDMA.HELP@QUALCOMM.COM

Notes

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What We Learned in This Section

CDMA2000 1x
RC1 & RC2
Section 1-20

- ✓ TIA/EIA-95 is a subset of CDMA2000.
- ✓ New Physical Channels for CDMA2000.
- ✓ Many new Radio Configurations.
- ✓ CDMA2000 standards are available from *3gpp2*.

Notes

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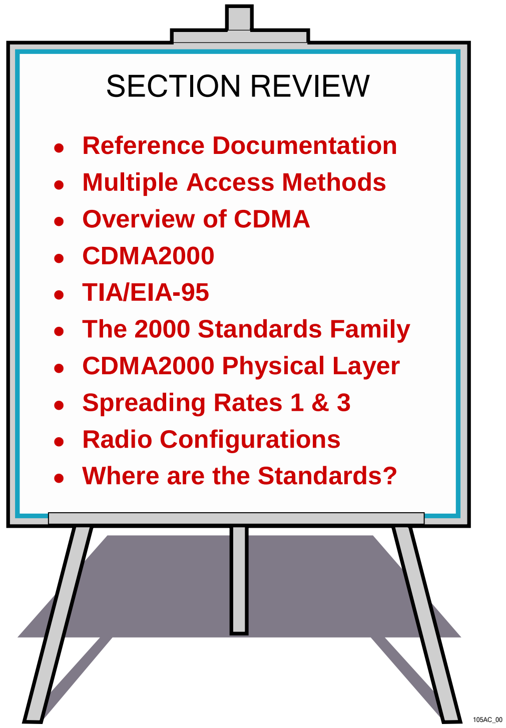
RC1 & RC2 Introduction – Review

CDMA2000 1x
RC1 & RC2
Section 1-21



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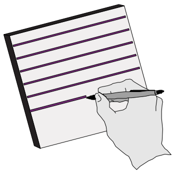

Comments/Notes

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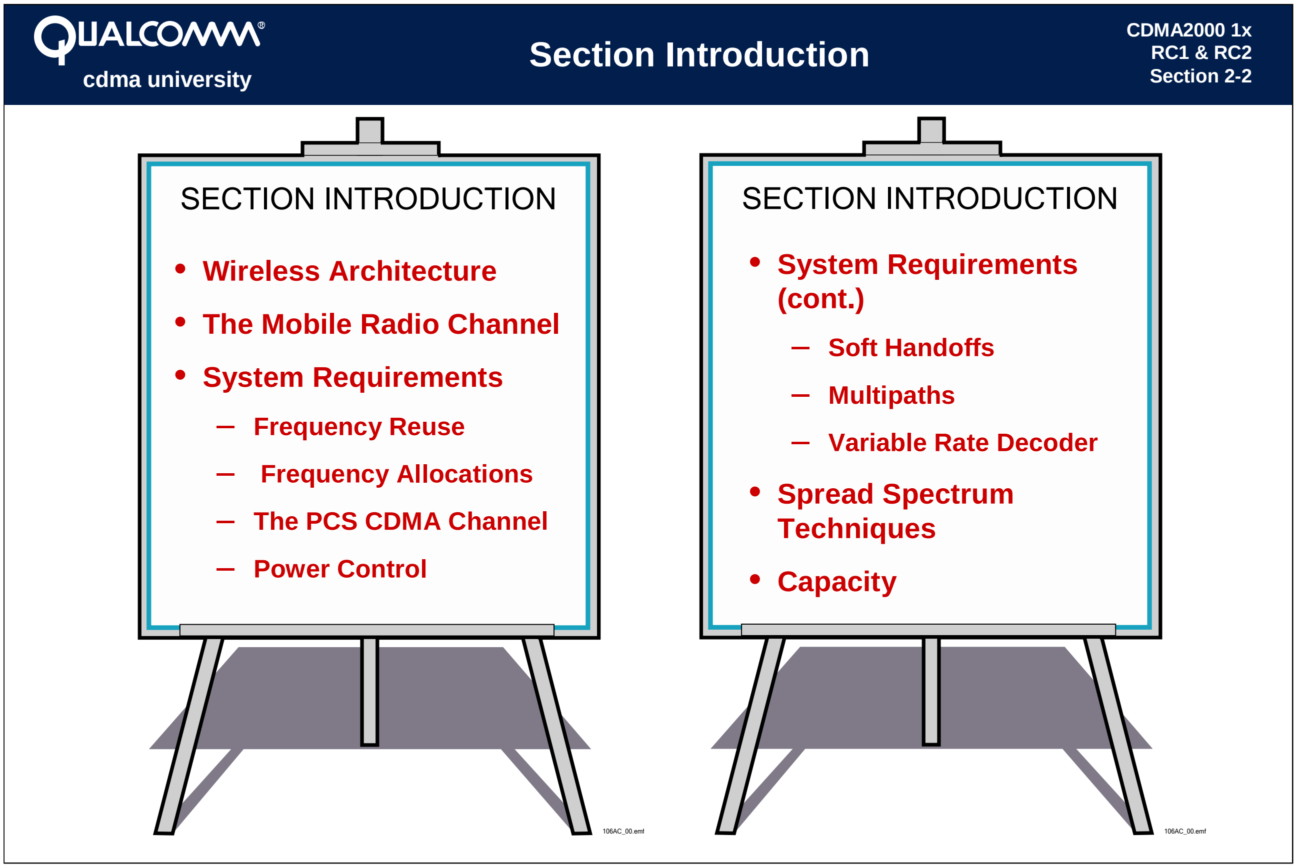
Section 2: Design Considerations

CDMA2000 1x RC1 & RC2 Section 2-1

SECTION 2

Design Considerations

Notes



Section Introduction

The design of a wireless system requires the consideration of many factors. This section examines some of the important factors that influenced the design of the IS-95 CDMA system.

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Section Learning Objectives

CDMA2000 1x RC1 & RC2 Section 2-3

Given instructor lecture and appropriate documentation, you will be able to:

- Identify the elements of a wireless architecture.
- Describe the characteristics of the mobile radio channel.
- List the mobile subscribers' requirements.
- List the limitations of conventional approaches to mobile communications.
- Describe the basic principles of spread spectrum communications.

Notes

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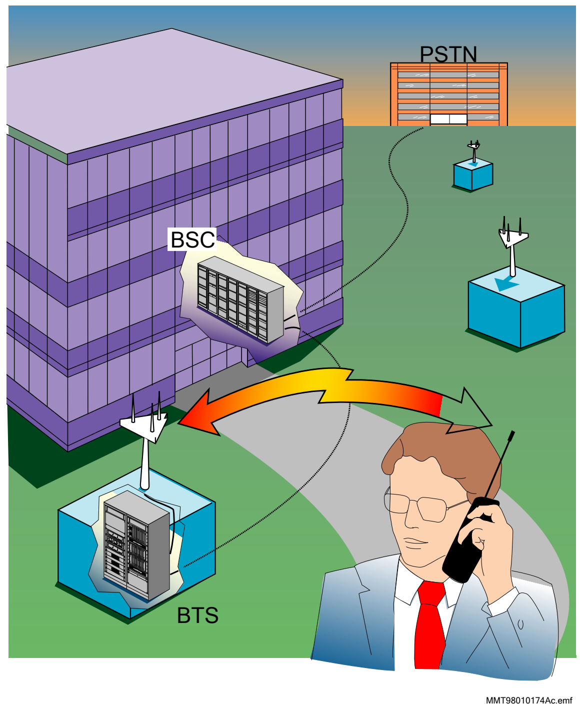
Wireless Architecture

CDMA2000 1x
RC1 & RC2
Section 2-4



Mobiles (Subscriber Units)

Mobiles (sometimes called mobile stations or subscriber units) encode the user's voice, generate the Reverse CDMA Channel waveforms, and demodulate the Forward CDMA Channel.

Base Transceiver Subsystem (BTS)

The BTS generates the Forward CDMA Channel and demodulates the mobile transmissions, producing vocoded frames.

Base Station Controller (BSC)

The BSC converts the landline voice signals into vocoded frames, then sends them to an appropriate BTS. The BSC also receives vocoded frames from the BTSs and converts these frames into PCM signals.

Public Switched Telephone Network (PSTN)

The PSTN links the BSC and the BTSs in the system. It also interfaces the land phone system with the wireless system.

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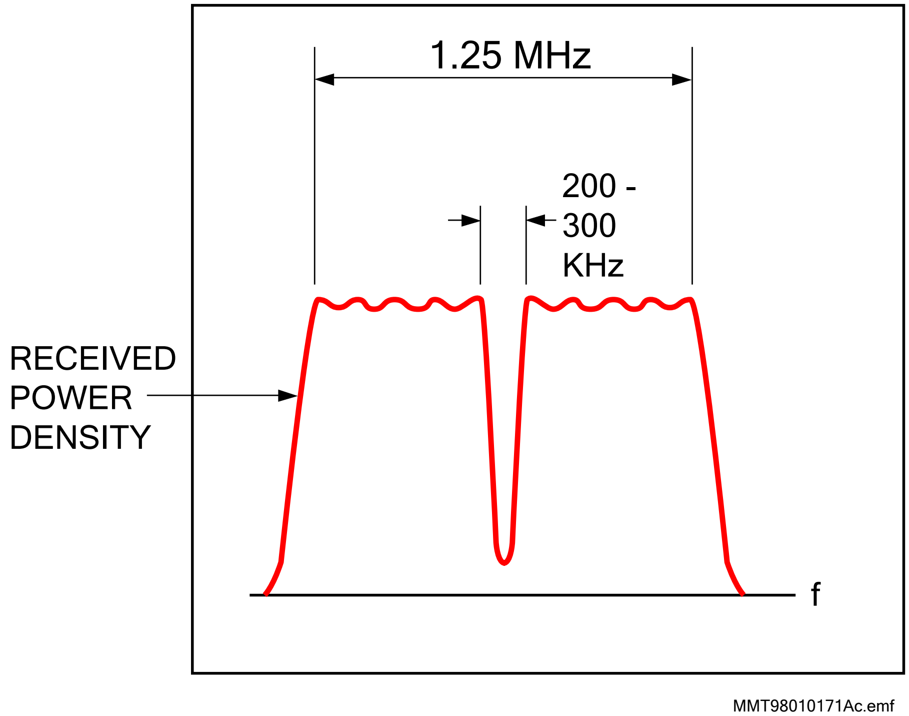
The Mobile Radio Channel – Fading

CDMA2000 1x RC1 & RC2 Section 2-5



Frequency Selective Fading

In the frequency domain, a fade can appear as a notch that moves back and forth across the spectrum as channel conditions change. The width of the notch is proportional to the difference in the arrival times of the multipath signals. For a bandwidth of 1.23 MHz, only those multipaths arriving less than 1 microsecond apart can cause the signal to experience a deep fade. The figure is a simple illustration. In practice, several notches can exist with varying levels of depth.

Flat Fading

Flat fading is a fade of the entire bandwidth. This is far less likely to occur in the wideband CDMA system than in narrowband systems. This kind of fading can happen when there is substantial multipath interference arriving too close together in time to be distinguishable.

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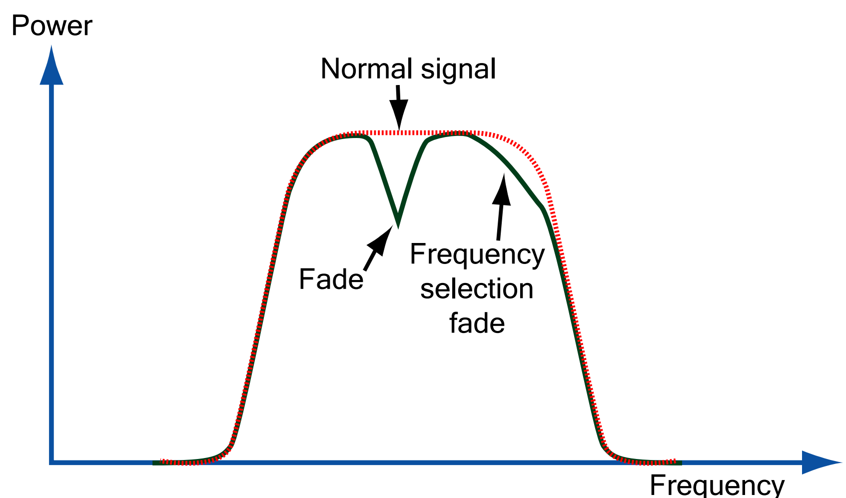
The Mobile Radio Channel – Flat Fading and Frequency Selective Fading

CDMA2000 1x RC1 & RC2 Section 2-6

When the coherence bandwidth is ***greater than or equal** to* the transmitted signal's bandwidth, the received signal will undergo **flat fading**.

When the coherence bandwidth is ***less than*** the transmitted signal's bandwidth, the received signal will undergo **frequency selective fading**.



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Frequency Selective Fading

Flat Fading and Frequency Selective Fading

When the symbol energy duration of a transmitted signal is greater than the delay spread of a channel that the transmitter uses to transmit the signal, the receiver will experience flat fading. This delay is inversely proportional to bandwidth.

One of the key factors that differentiates third-generation CDMA from second-generation CDMA is the wider bandwidth. In addition to the ability to provide wideband services, the increased bandwidth makes it possible to resolve more multipath components in a mobile radio channel.
If the transmission bandwidth is wider than the coherence bandwidth of the channel, the receiver can separate multipath components. This brings more diversity and higher capacity.

Diversity and capacity will be discussed later in this section.

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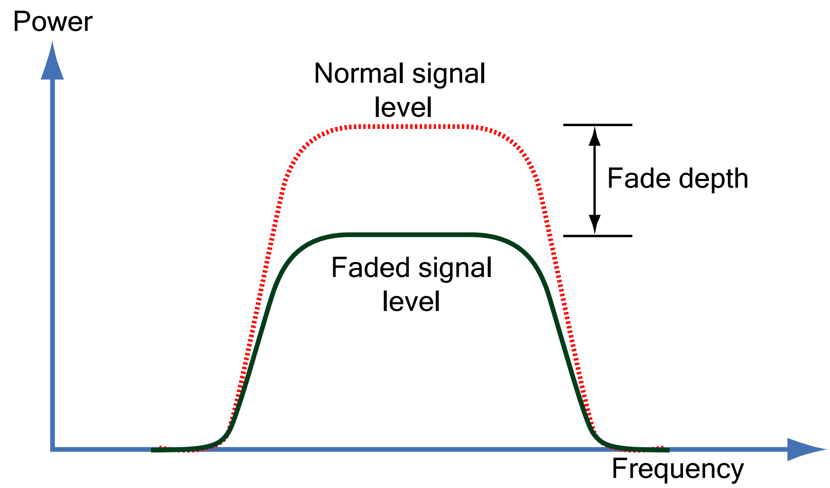
The Mobile Radio Channel – Multipath-Associated Problems: Flat Fading

CDMA2000 1x RC1 & RC2 Section 2-7

If multipath delays are less than one CDMA spreading chip, the receiver will experience **flat fading**. In flat fading, the amplitude of the signal changes with time, but the spectral characteristics of the transmitted signal are preserved at the receiver.



Flat Fading

What is the effect of the flat fading?

The answer is complex and is different in the Forward and Reverse links. It also depends on the fading rate, which in turn depends on the velocity of the mobile. Generally, fading increases the average signal-to-noise ratio needed for a particular error rate. The increase can be as much as perhaps 6 dB.

In both the Reverse link and Forward links of a CDMA2000 system, power control mitigates the effects of fading at low speed; at high speed it has little effect. At high speed, and in both links, the Forward Error Correction (FEC) coding and interleaving become more effective as the characteristic fade time becomes less than the interleaver span.

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System Requirements

CDMA2000 1x RC1 & RC2 Section 2-8

- Frequency Reuse
- Frequency Allocations
- The PCS CDMA Channel
- Power Control
- Soft Handoffs
- Multipaths
- Variable Rate Vocoder

Notes

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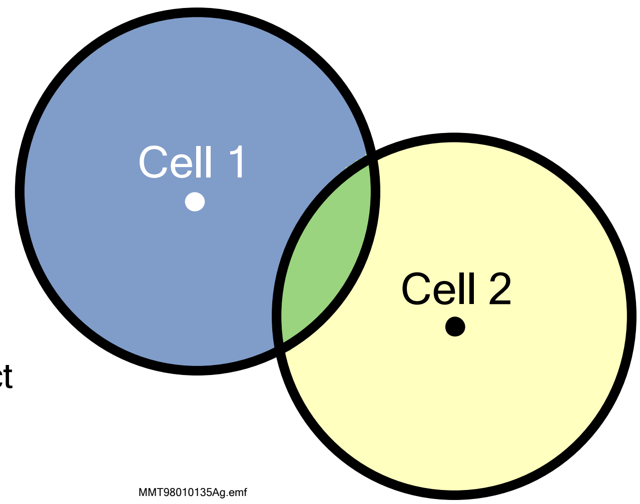
Frequency Reuse – FDMA and TDMA Systems

CDMA2000 1x
RC1 & RC2
Section 2-9

If Cell 1 and Cell 2 were both on the same frequency in conventional cellular systems, the overlap area would have a frequency conflict



Frequency Reuse in FDMA and TDMA Systems

When multiple access is achieved by providing disjoint slots in frequency and time, users in adjacent cells must also be provided disjoint slots; otherwise their mutual interference would become intolerable. This leads to limited frequency reuse, where typically a slot is used only once in a certain geographic area.

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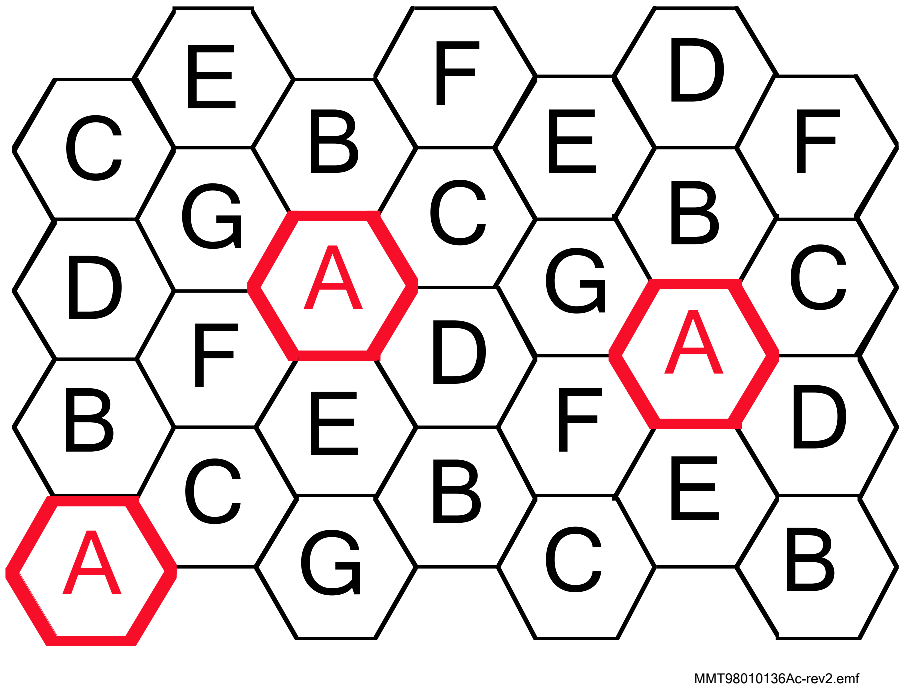
Frequency Reuse – Reuse Pattern of 7

CDMA2000 1x RC1 & RC2 Section 2-10



Frequency Reuse Pattern of 7

A reuse pattern of 7 is common in cellular systems. Only 1/7 of a carrier's frequency allocation is used in any one cell.

In sectorized cells, a reuse pattern of 21 is common (3 sectors per cell x 7 cells). When a new cell is introduced, a revision of the frequency plan is required.

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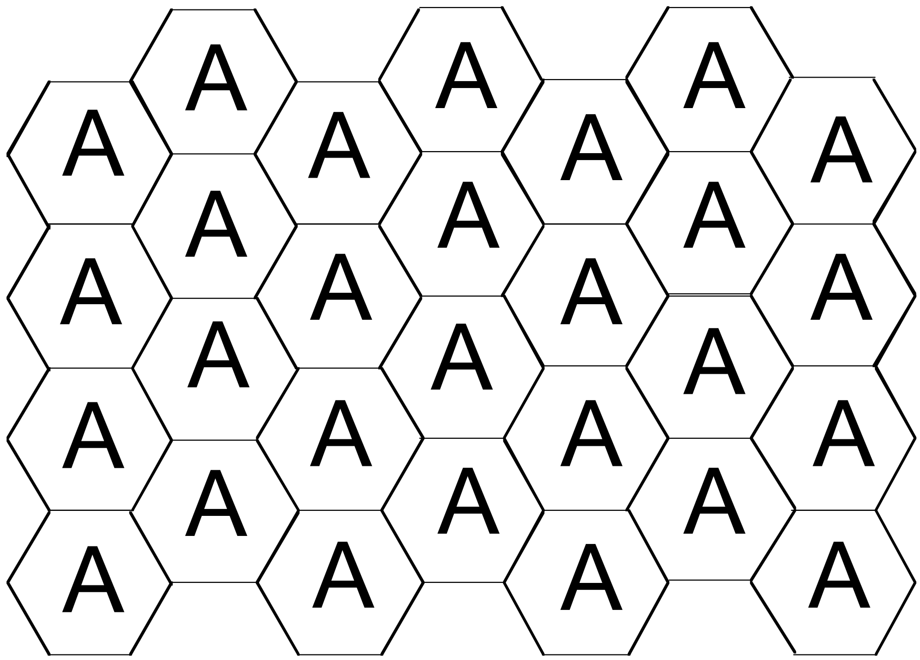
Frequency Reuse – CDMA

CDMA2000 1x
RC1 & RC2
Section 2-11



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Universal Frequency Reuse — CDMA

The principal attribute of a CDMA System is that *all subscribers can use the same frequency*. This underlies all other attributes.

With spread spectrum, universal frequency reuse applies not only to users in the same cell, but also to those in all other cells. The advantage here is that complicated reuse patterns are not necessary.

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Frequency Allocations – Analog System Constraints

CDMA2000 1x RC1 & RC2 Section 2-12

System	Valid CDMA Frequency Assignments	Analog channel Count	CDMA Channel Number	Transmitter Frequency Assignment (MHz)	
				Mobile	Base
A" (1 MHz)	/////////	22	991 1012	824.040 824.670	869.040 869.670
	CDMA	11	1013 1023	824.700 825.000	869.700 870.000
A (10 MHz)	CDMA	311	1 311	825.030 834.330	870.030 879.330
	/////////	22	312 333	834.360 834.990	879.360 879.990
B (10 MHz)	/////////	22	334 355	835.020 835.650	880.020 880.650
	CDMA	289	356 644	835.680 844.320	880.680 889.320
	/////////	22	645 666	844.350 844.980	889.350 889.980
A' (1.5 MHz)	/////////	22	667 688	845.010 845.640	890.010 890.640
	CDMA	6	689 694	845.670 845.820	890.670 890.820
	/////////	22	695 716	845.850 846.480	890.850 891.480
B (2.5 MHz)	/////////	22	717 738	846.510 847.140	891.510 892.140
	CDMA	39	739 777	847.170 848.310	892.170 893.310
	/////////	22	778 799	848.340 848.970	893.340 893.970

Analog System Constraints

For the cellular allocation at 800 Mhz, the frequency allocation for CDMA is the same as for Analog. Some channels are not valid for CDMA because the out-of-band emissions from the CDMA waveform would cause interference in a neighboring band. One CDMA channel occupies the same bandwidth as about 42 Analog channels.

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Frequency Allocations – U.S. PCS Allocations

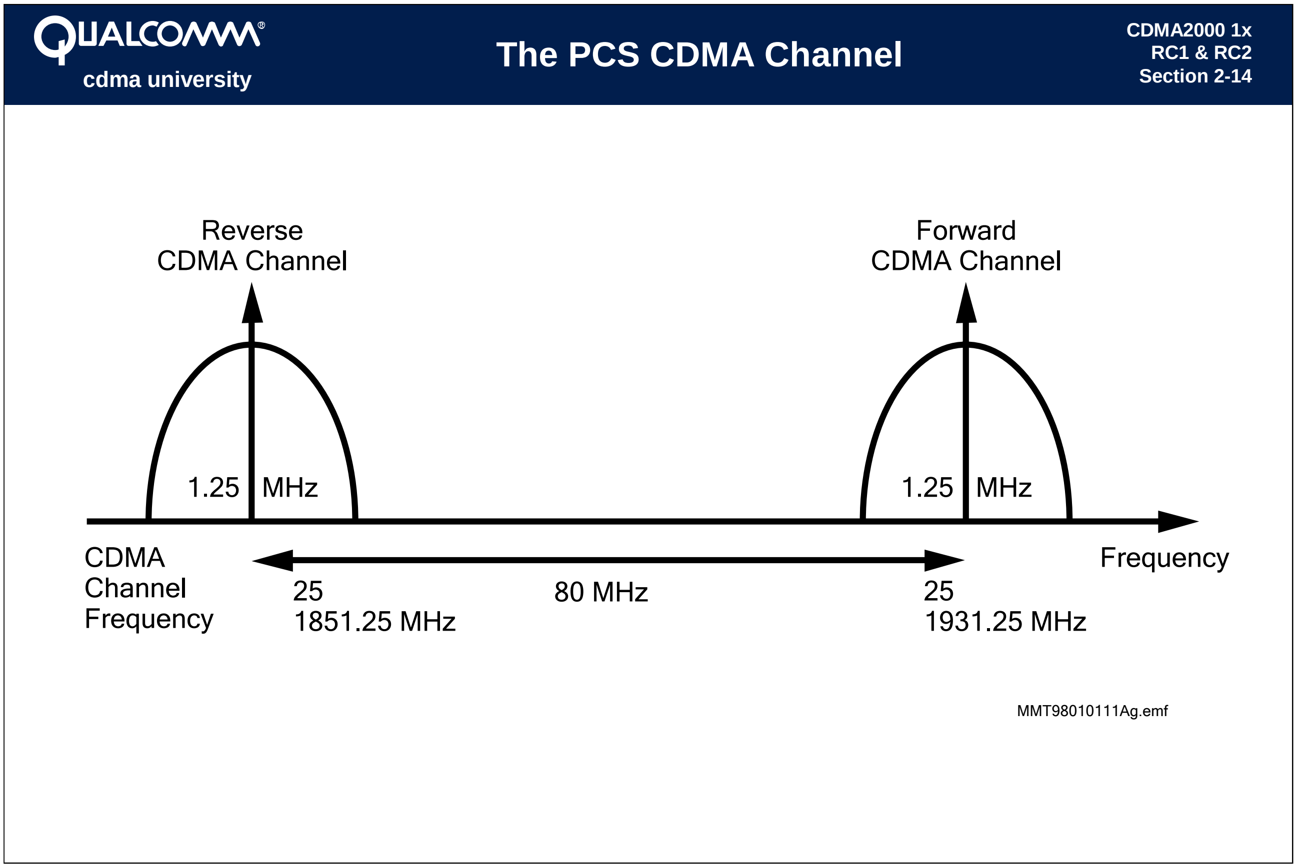
CDMA2000 1x RC1 & RC2 Section 2-13

Block Designator	Valid CDMA Frequency Assignments	CDMA Channel Number	Transmitter Frequency Band (MHz) Personal Stations	Transmitter Frequency Band (MHz) Base Station
A (15 MHz)	Not Valid	0-24	1850.000-1851.200	1930.000-1931.200
	Valid	25-275	1851.250-1863.750	1931.250-1943.750
	Cond. Valid	276-299	1863.800-1864.950	1943.800-1944.950
D (5 MHz)	Cond. Valid	300-324	1865.000-1866.200	1945.000-1946.200
	Valid	325-375	1866.250-1868.750	1946.250-1948.750
	Cond. Valid	376-399	1868.800-1869.950	1948.800-1949.950
B (15 MHz)	Cond. Valid	400-424	1870.000-1871.200	1950.000-1951.200
	Valid	425-675	1871.250-1883.750	1951.250-1963.750
	Cond. Valid	676-699	1883.800-1884.950	1963.800-1964.950
E (5 MHz)	Cond. Valid	700-724	1885.000-1886.200	1965.000-1966.200
	Valid	725-775	1886.250-1888.750	1966.250-1968.750
	Cond. Valid	776-799	1888.800-1889.950	1968.800-1969.950
F (5 MHz)	Cond. Valid	800-824	1890.000-1891.200	1970.000-1971.200
	Valid	825-875	1891.250-1893.750	1971.250-1973.750
	Cond. Valid	876-899	1893.800-1894.950	1973.800-1974.950
C (15 MHz	Cond. Valid	900-924	1895.000-1896.200	1975.000-1976.200
	Valid	925-1175	1896.250-1908.750	1976.250-1988.750
	Not Valid	1176-1199	1908.800-1909.950	1988.800-1989.950

U.S. PCS Allocations

For the US PCS allocations, some channels at the band edge are either Not Valid or Conditionally Valid:

- The *Not Valid* channels lie on the edge of the spectrum allocation, and out-of-band emissions would always fall into a different (non-cellular) service, so these allocations are never allowed.
- The *Conditionally Valid* channels are dependent on the holder of the spectrum license. For example, if a licensee owns both E and F bands, then the channels 776–824 would be valid for service, but the channels 700-724 and 876–899 would not be valid because they could cause interference in channels that the licensee does not own.



The PCS CDMA Channel

The Channel Number (25 in the picture above) uniquely identifies both a Forward link frequency (Base Station to mobile) and a Reverse link frequency (mobile to Base Station).

For PCS operation the channels are always separated by 80 MHz. For operation in the Cellular band at 800 Mhz the separation is always 45 MHz.

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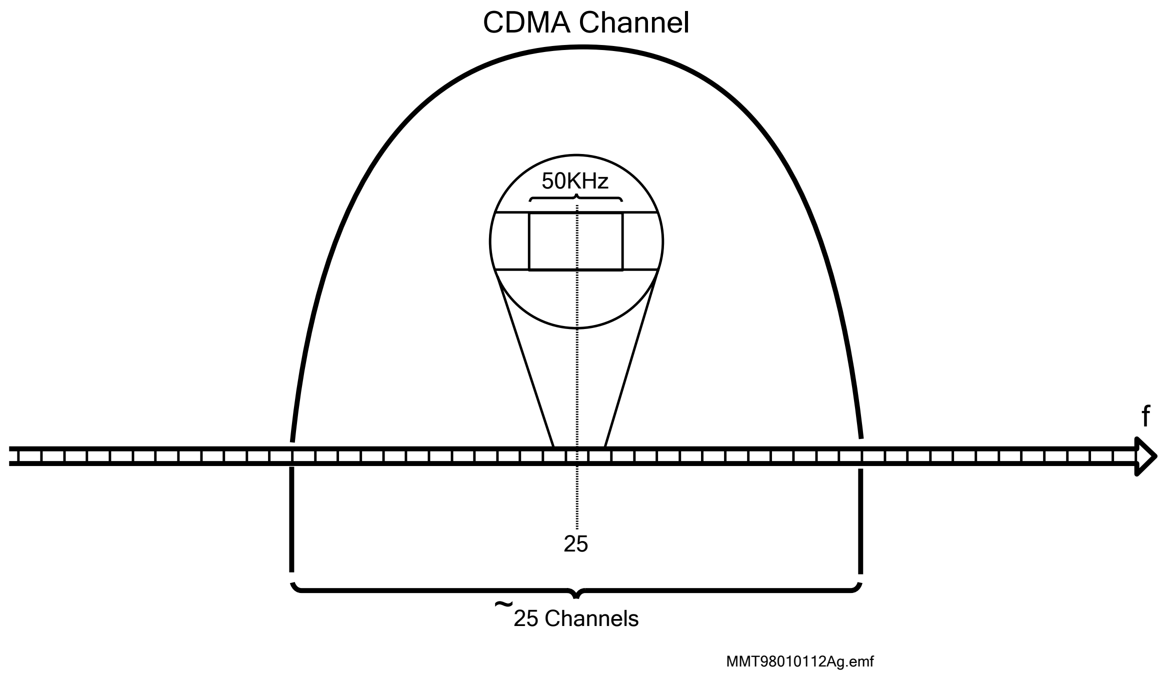
The PCS CDMA Channel (continued)

CDMA2000 1x
RC1 & RC2
Section 2-15



PCS Spectrum

The PCS spectrum in the US is channelized in 50 KHz increments to be fair to all radio technologies. The 50 KHz channel is much smaller than the CDMA waveform and the channel number identifies only the center of the CDMA waveform.

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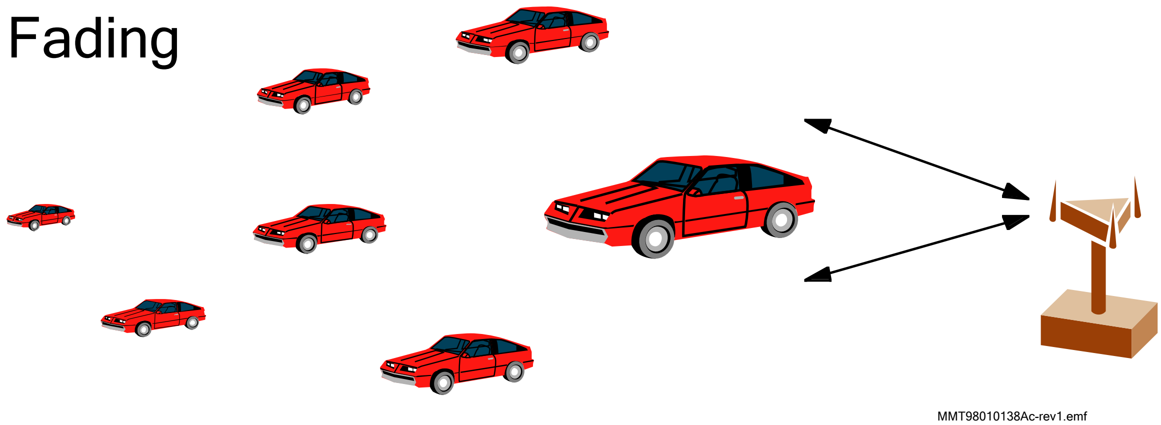
Power Control – Effective Power Control is Required

CDMA2000 1x RC1 & RC2 Section 2-16

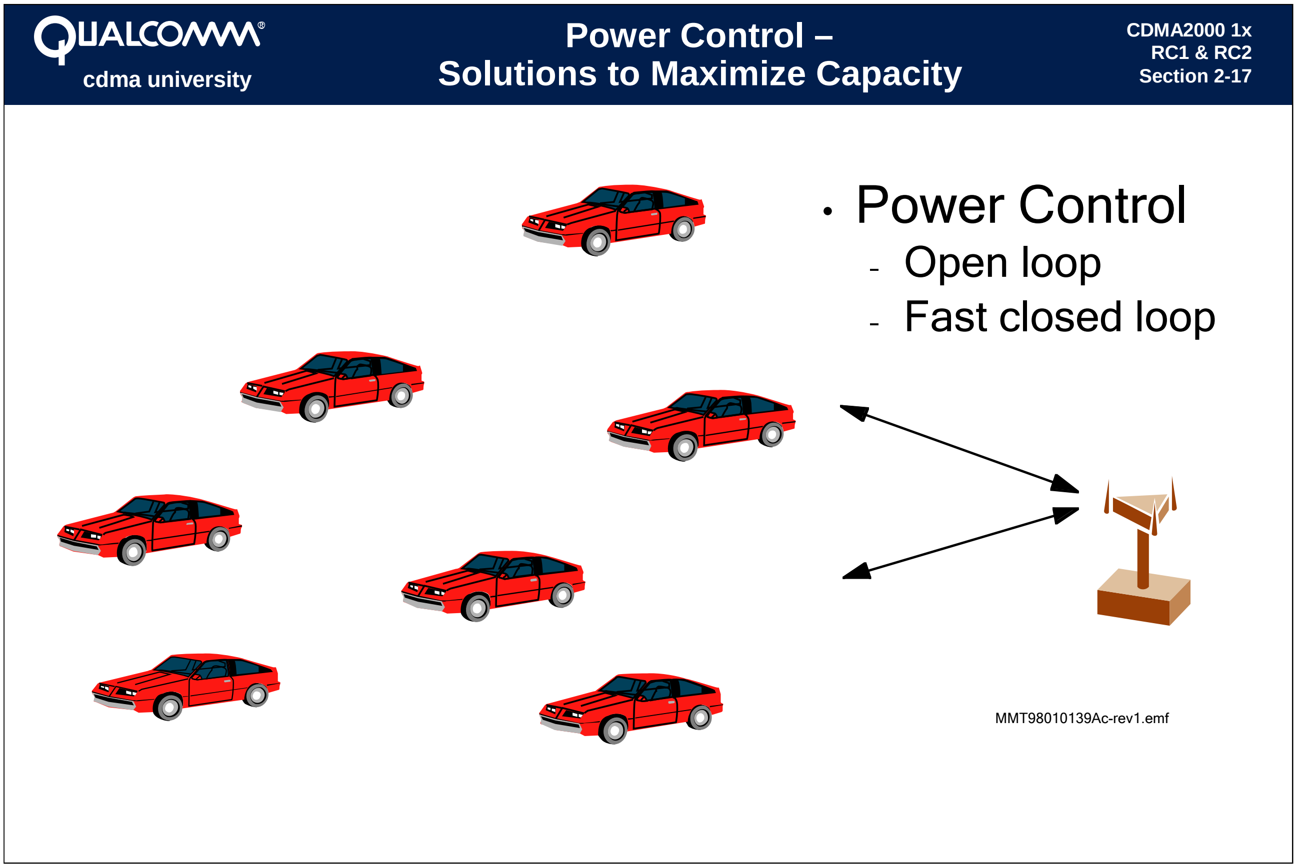
- Near-Far Problem
- Path Loss
- Fading



Power Control and the Near-Far Problem

CDMA will not work without an effective power control, because of the *near-far problem*. The near-far problem arises when a mobile user near a cell jams a user that is distant from the cell (assuming both are transmitting at the same power). This problem may be present despite high processing gain. An effective method to eliminate the near-far effect is therefore necessary.

Other factors such as varying path loss and fading also result in the need to control the mobile's transmission power.



The Power Control Solution

It can be shown that capacity is maximized if all users are controlled so that their signals reach the Base Station at approximately the same power level.

CDMA2000 systems use a two-step approach to achieve this:

- An original estimate is made by the mobile (***open loop power control***).
- A faster correction is made to this estimate, based on instructions provided to the mobile by the Base Station (***closed loop power control***).

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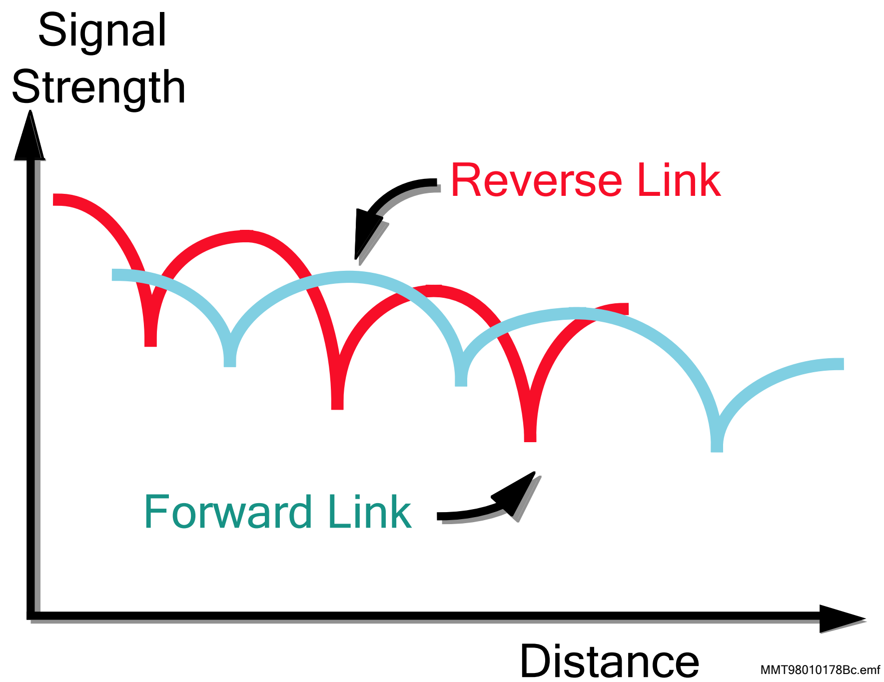
Power Control –
Small Scale Path Loss: Fast Fading

CDMA2000 1x RC1 & RC2 Section 2-18



Small Scale Path Loss and Fast Fading

Large changes in path loss can occur over very small distances or very short time intervals. This effect is called *fast fading*. Fast fading is a function of the strength and delay of the multipath waves and the bandwidth of the transmitted signal.

In the mobile environment, signals are reflected and scattered by obstacles in their path. These obstacles can be buildings, hillsides, trees, and vehicles. The result is multiple copies of the same signal arriving at the receive antenna. These multiple copies, however, took different paths and so arrive at the receive antenna offset in time. This offset can cause the signals to add in a destructive way at one moment and reinforce each other in the next. This is *fast fading*.

Such fading in narrowband systems causes fluctuations in received signal by 20-30 dB while the mobile travels a distance of only 1 meter. The use of a wideband CDMA signal can significantly reduce the impact of fast fading.

Forward and Reverse Channels are Not Correlated

An additional complication results from the frequency separation between the Forward and Reverse links (45 MHz for cellular systems; 80 MHz for PCS systems). This amount of separation is usually great enough to decouple any dependency between fast fading in the two directions. Fast fading in the Forward direction, then, is often different than the fading seen in the Reverse direction.

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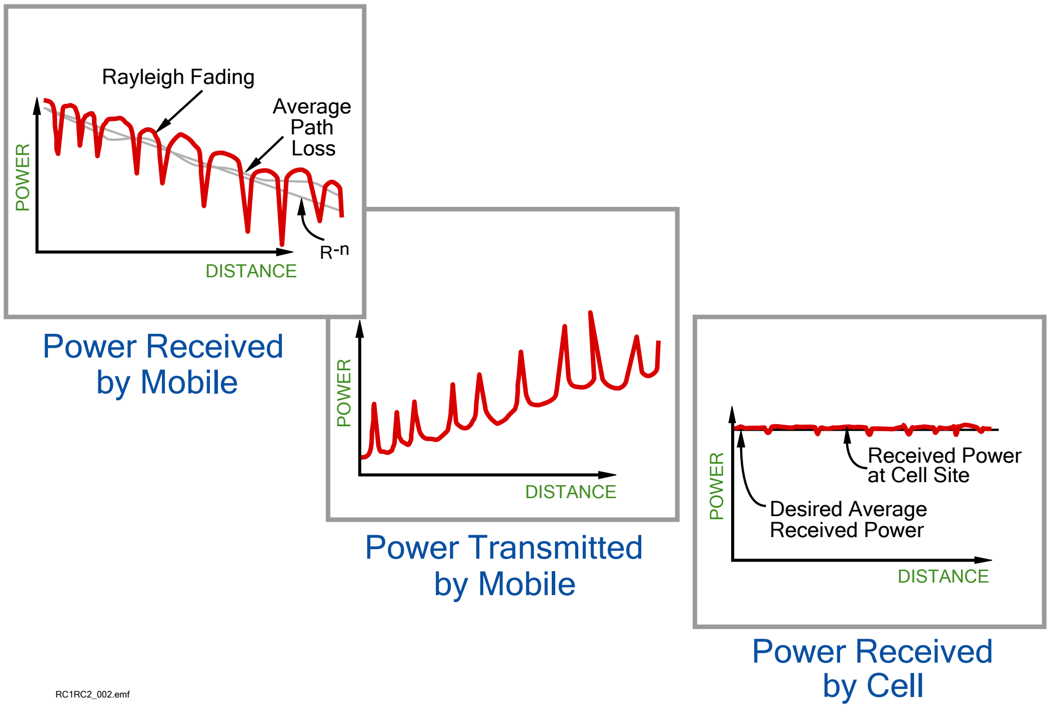
Power Control – From the Reverse Link

CDMA2000 1x RC1 & RC2 Section 2-19



From the Reverse Link

The Power received by the mobile is a function of the path loss and the fast fading.

The power transmitted by the mobile is also a function of the path loss and the fast fading.

The power received at the Base Station is nearly constant, only limited by the rate at which Closed Loop power control can correct the fast fading.

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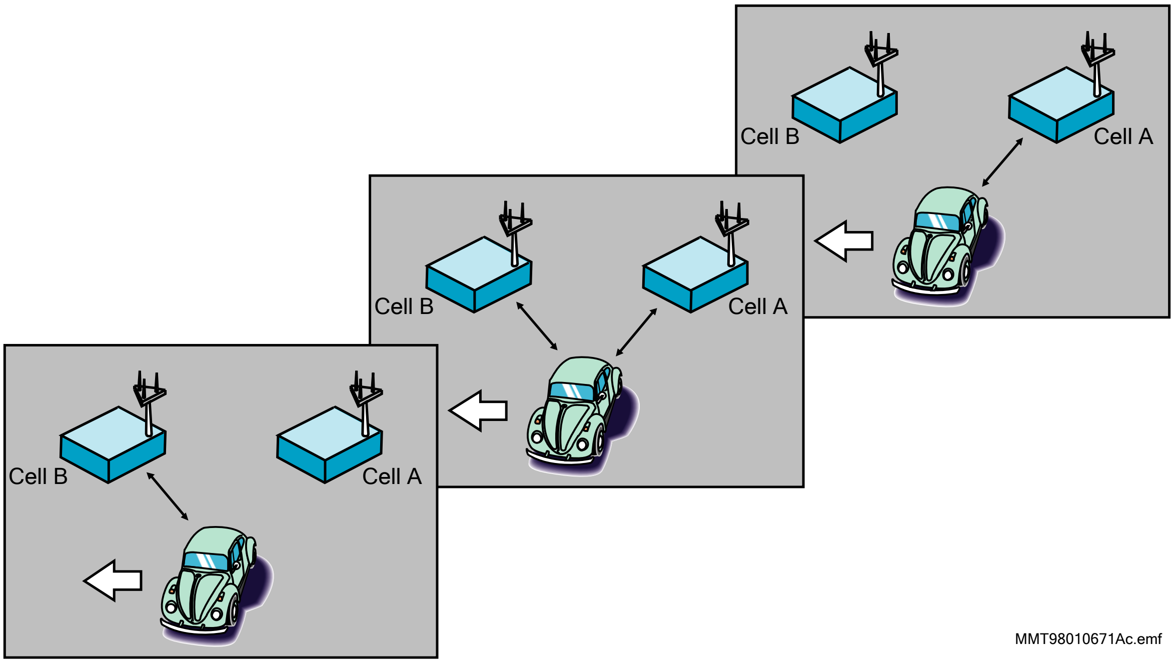
Soft Handoffs

CDMA2000 1x
RC1 & RC2
Section 2-20



Soft Handoffs

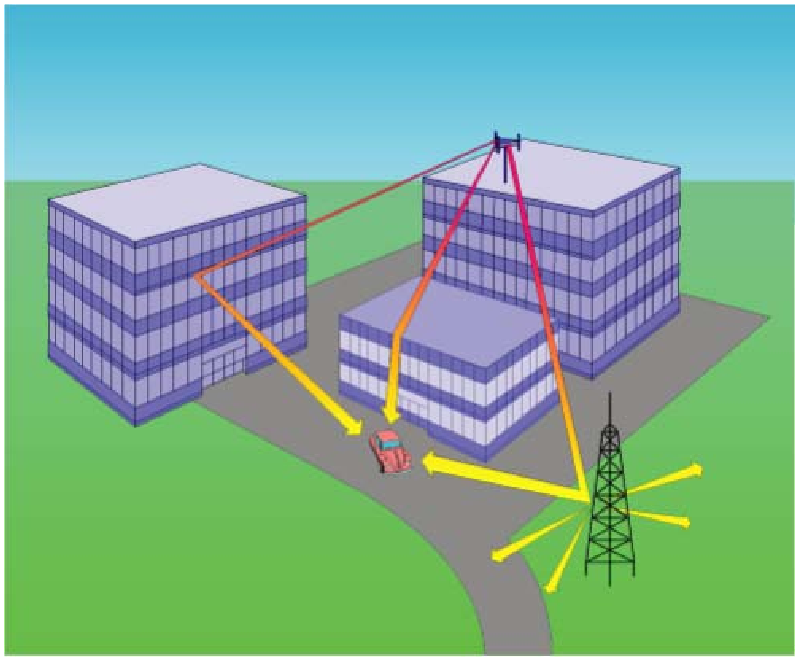
Soft handoff refers to the state where the mobile is in communication with multiple Base Stations at the same time. Soft handoff is a *make-before-break* type of handoff, whereby a mobile acquires a target code channel before breaking an existing one.

Soft handoff is a special attribute of CDMA and is enabled by universal frequency reuse.

Soft handoff has several advantages:

- Fewer dropped calls.
- Soft handoffs in general require less mobile transmit power.
- Increases capacity.
- Improved call quality.

QUALCOMM cdma university | Multipaths | CDMA2000 1x RC1 & RC2 Section 2-21



Multipaths

Propagation in relatively small congested cells is dominated by diffraction, scattering, and reflection caused by the structures and objects surrounding both the cell site and the mobile antennas. The multipaths formed by the scatterers and reflectors add up at the receive antenna to produce the received signal.

Diffraction occurs when the radio path is blocked by an object that has sharp irregularities.

Scattering occurs when the wave strikes objects that are small compared to a wavelength. Foliage, lampposts, and street signs produce scattering.

Reflection occurs when a propagating electromagnetic wave impinges upon an object that has very large dimensions when compared to the wavelength of the propagating wave (Rappaport, page 78).

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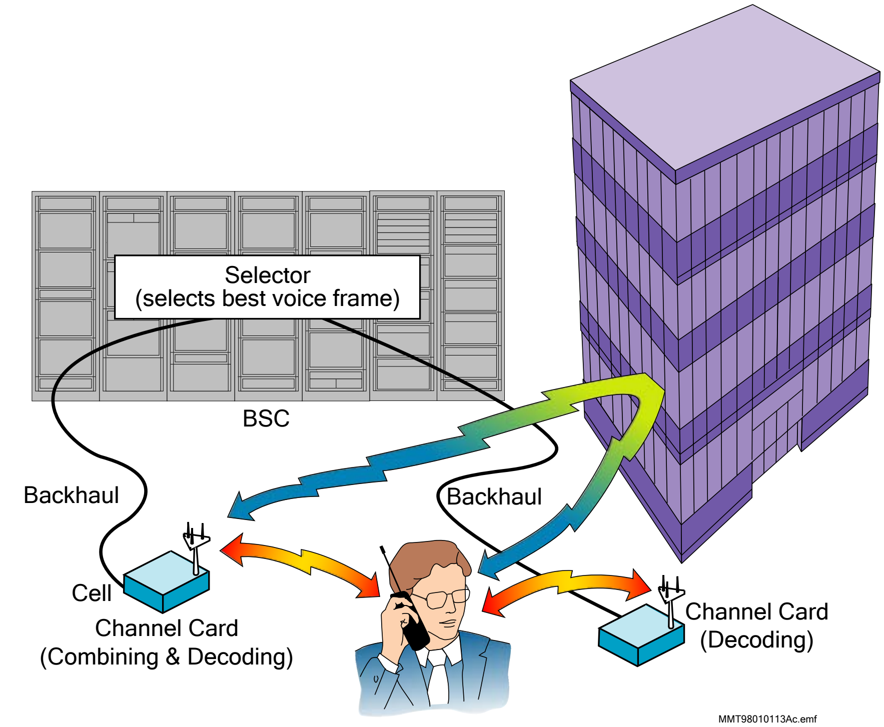
Multipaths (continued)

CDMA2000 1x
RC1 & RC2
Section 2-22

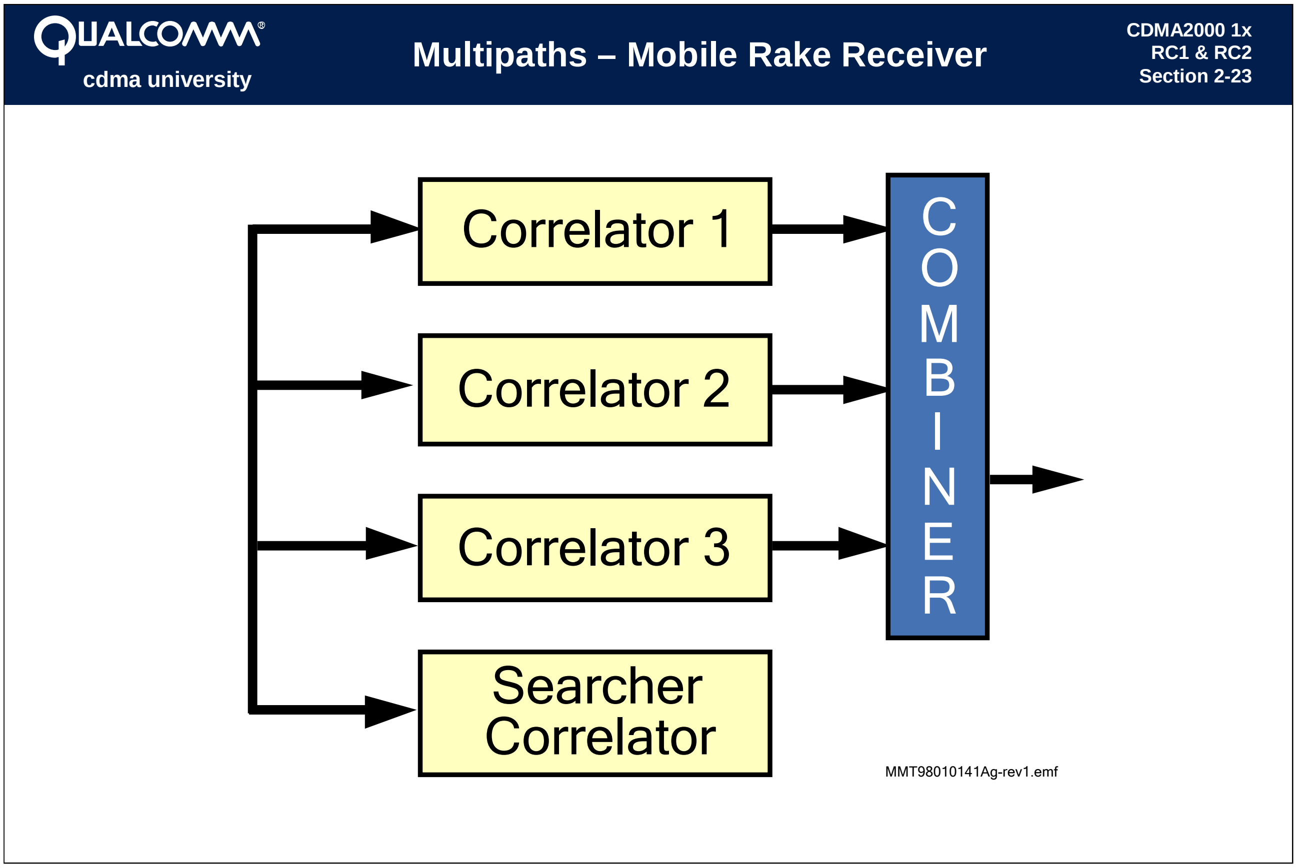


Better Use of Multipath

One of the main advantages of CDMA systems is the capability of using signals that arrive in the receivers with different time delays. This phenomenon is called *multipath*.

FDMA (analog cellular) and TDMA, which are narrowband systems, cannot discriminate between the multipath arrivals, and resort to equalization to mitigate the negative effects of multipath.

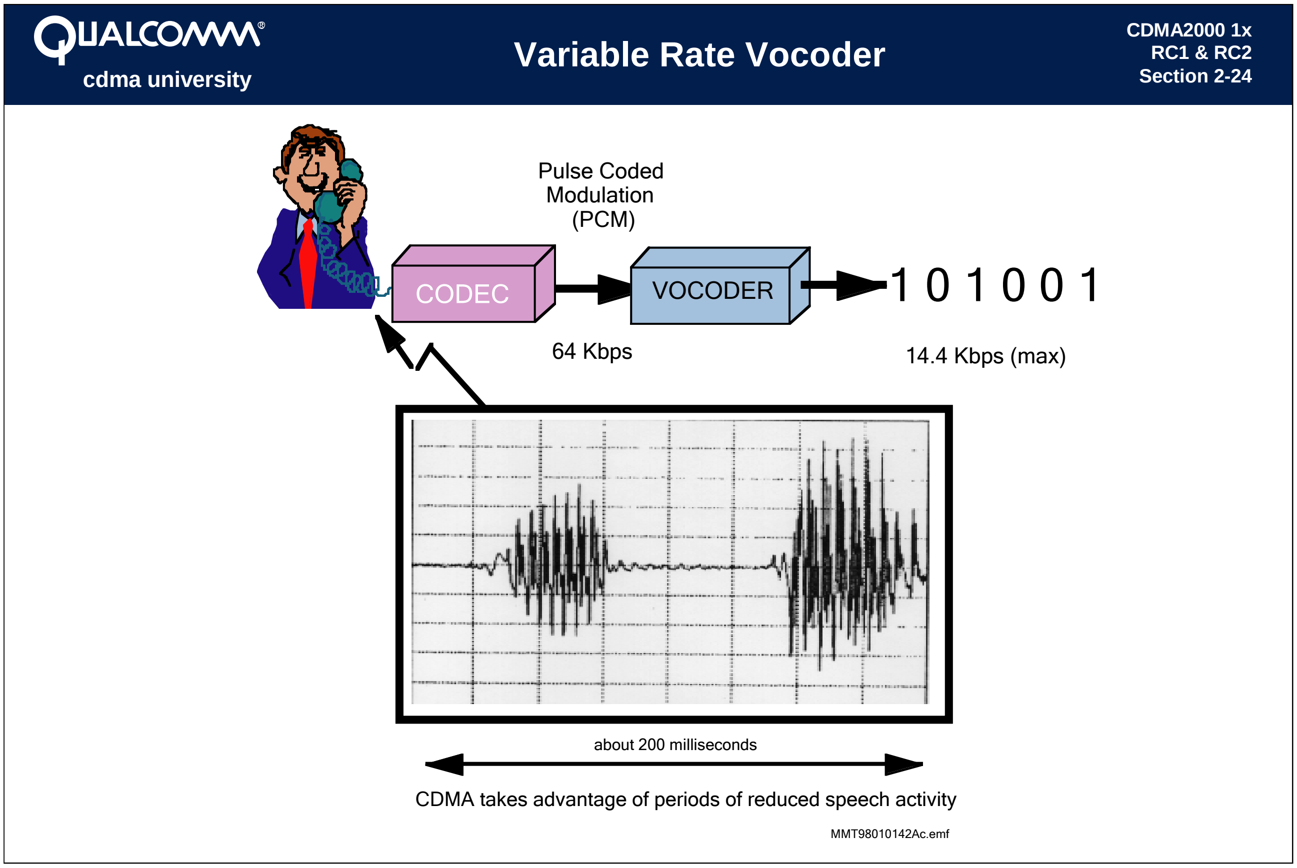
Due to its wide bandwidth and rake receivers, CDMA uses the multipath signals and combines them to make an even stronger signal at the receivers.



Rake Receivers

CDMA mobiles use *rake receivers*. The rake receiver is essentially a set of four or more receivers (or *fingers*).

One of the receivers constantly searches for different multipaths and helps to direct the other three fingers to lock onto strong multipath signals. Each finger then demodulates the signal corresponding to a strong multipath. The results are combined to make the signal stronger.



Codec

A *codec* is an analog-to-digital and digital-to-analog converter.

The figure depicts the codec as an analog-to-digital converter whose output is a wideband PCM signal (bit rate = 64 kbps).

Variable Rate Vocoder

The vocoder compresses the output of the codec to a lower bit rate to reduce bandwidth. The *variable rate vocoder* takes advantage of low speech activity and transmits at lower rates, thus reducing the average transmission to about 4 kbps. The vocoder outputs frames at full, half, quarter, and eighth rates.

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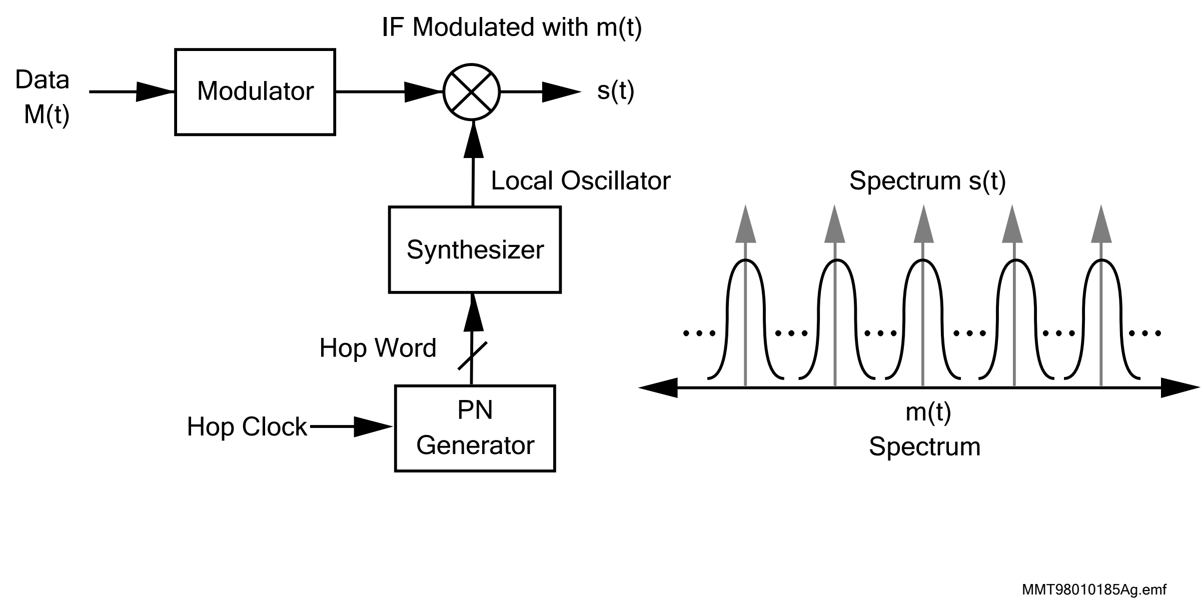
Spread Spectrum Techniques – Frequency Hopped Spread Spectrum

CDMA2000 1x
RC1 & RC2
Section 2-25



Frequency Hopped Spread Spectrum

Spreading can also be achieved by hopping the narrowband information signal over a set of frequencies. This type of spreading can be classified as Fast or Slow depending on the rate of hopping to the rate of information:

- Fast hopping — the hopping rate is larger than the bit rate.
- Slow hopping — more than one bit is hopped from one frequency to another.

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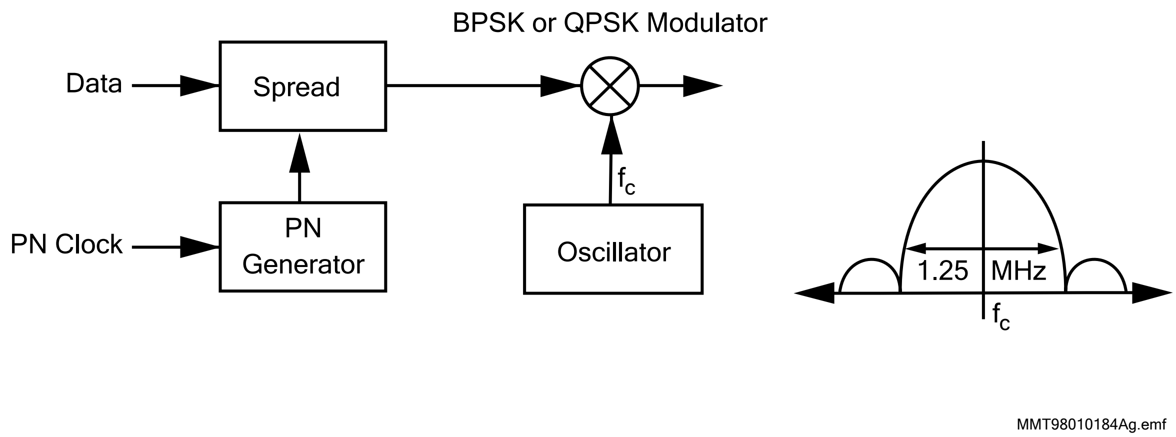
Spread Spectrum Techniques – Direct Sequence Spread Spectrum

CDMA2000 1x RC1 & RC2 Section 2-26



Direct Sequence Spread Spectrum

The information signal is inherently narrowband, on the order of less than 10 KHz. The energy from this narrowband signal is spread over a much larger bandwidth by multiplying the information signal by a wideband spreading code.

Direct sequence spread spectrum is the technique used in the IS-95 CDMA cellular system. The details on how this spreading is accomplished are discussed in Section 4, CDMA Physical Layer.

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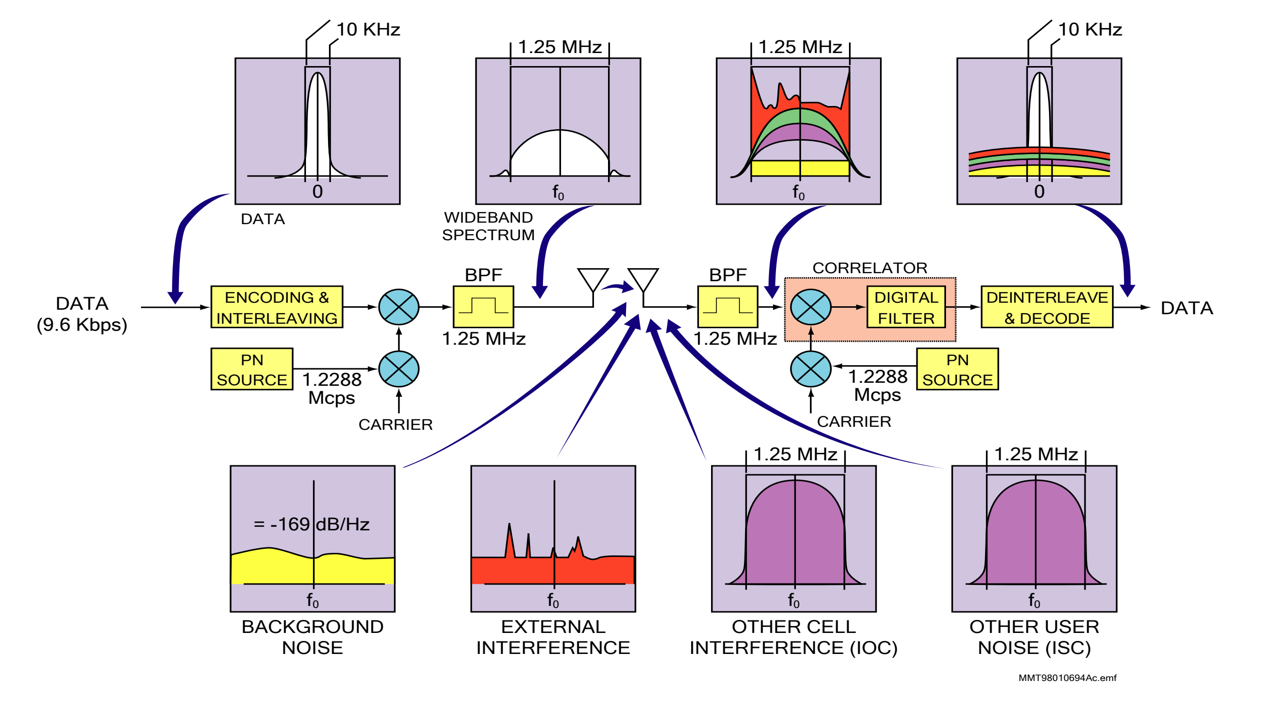
Spread Spectrum Techniques – View of the CDMA Concept

CDMA2000 1x RC1 & RC2 Section 2-27



View of the CDMA Concept

This view shows the narrowband data, spreading of the data, the receiver gathering the transmitted signal plus the various forms of interference, the despreading of the data, and how the modulator rejects the wideband interference and passes the narrowband information.

The data to be transmitted is much smaller than the spreading bandwidth. In this case, the data occupies a 10 Khz bandwidth.

The RF carrier frequency is multiplied by the PN code with a chip rate (bit rate) of 1.2288 Mcps which results in a RF signal that is wideband.

This wideband RF/PN signal is then used to multiply the data signal, which results in a wideband signal. This wideband signal is then transmitted over-the-air to the receiver.

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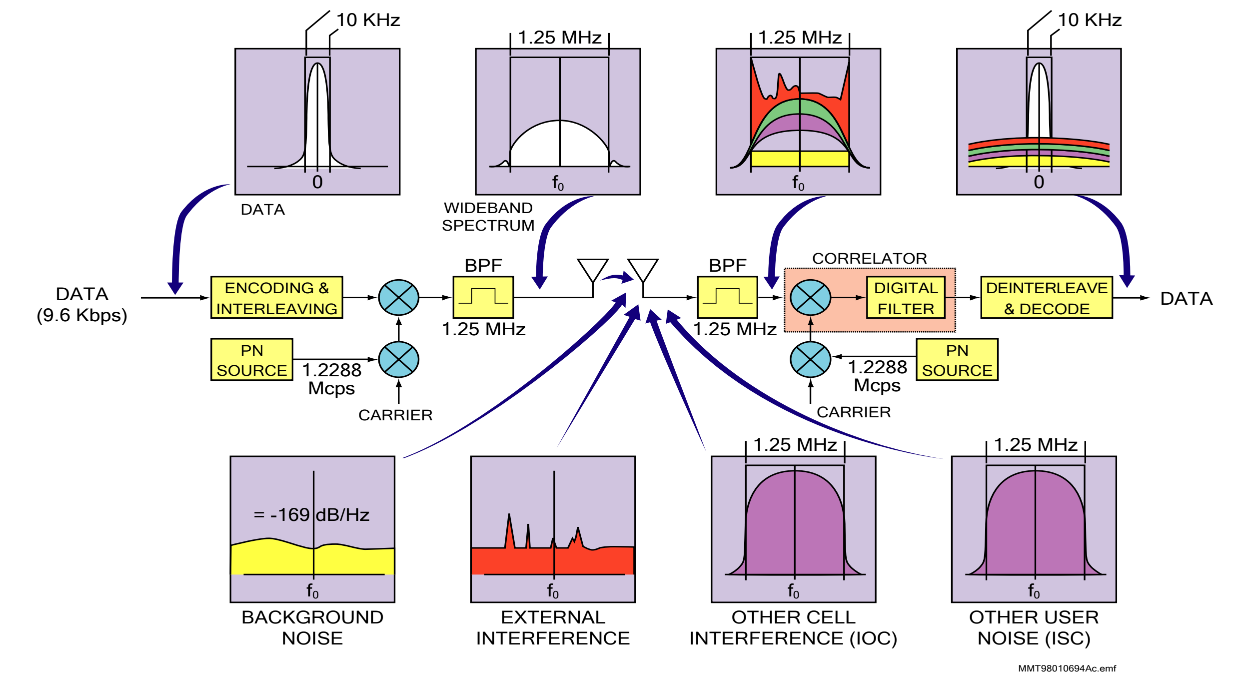
Spread Spectrum Techniques – View of the CDMA Concept (continued)

CDMA2000 1x RC1 & RC2 Section 2-28



The Receiver

The receiver antenna receives the transmitted signal, thermal noise, and other interference.

To generate a wideband spreading signal that is identical to the transmit spreading signal, the receiver uses two components:

- An RF carrier of exactly the same frequency as the transmitter.
- A PN generator that generates the same PN and is exactly synchronized to the transmit PN (including the propagation delay from transmitter to receiver and the delay through the radio circuits).

When the received signal is multiplied by the receiver carrier/PN, the wideband signal is exactly un-modulated back to the original narrowband signal. The thermal noise (and other interference) is also multiplied by this carrier/PN signal and, since these signals are not correlated, their product is a wideband signal.

The demodulator then uses a narrowband filter to pass the data signal to the demodulator and reject most of the energy of the wideband interference signals. This ratio of the data bandwidth to the interference bandwidth is the Processing Gain of the spread spectrum receiver.

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Capacity – Reverse Capacity Estimate

CDMA2000 1x RC1 & RC2 Section 2-29

$$\#\text{ of users} \approx \frac{\left(\frac{W}{R}\right) G_A\, G_V}{\left(\frac{E_b}{I_o}\right)(1+f)}$$

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A Reverse Capacity Estimate

The equation in the figure is an estimate of Reverse Traffic Channel capacity. It is based on the following assumptions:

1. Each user's transmitted power is controlled so that all are received at the Base Station at equal power levels. If the received signal power of each user is S watts, and the background noise is negligible, the total interference power, I, presented to each user's demodulator is: $I = [N_{users} - 1]S$.

2. The digital demodulator for each user can operate against Gaussian noise at a bit energy-to-noise density level of E_b/I_0. This parameter is the figure of merit of the digital modem and varies typically between 3 dB and 9 dB depending on its implementation, use of error-correcting coding, channel impairments such as fading, and, of course, error rate requirements.

(continued on next page)

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Capacity – Reverse Capacity Estimate (continued)

CDMA2000 1x RC1 & RC2 Section 2-30

$$\# \text{ of users} \approx \frac{\left(\frac{W}{R}\right) G_A \, G_V}{\left(\frac{E_b}{I_o}\right)(1+f)}$$

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3. Suppose further that two additional processing features are added to the spread spectrum multiple access system to diminish interference. The first is to stop transmission, or at least reduce its rate and power, when voice (or data) activity is absent or reduced. Since for a uniform population this reduces the average signal power of all users and consequently the interference received by each user, the capacity is increased proportional to this overall rate reduction, provided the user population is large enough that the weak law of large numbers guarantees that the interference is nearly at its average value most of the time. We denote this factor as the voice activity gain, G_V. By numerous measurements on two-way telephone conversations, it has been established that voice is active only about 2/5 of the time so that $G_V = 2.5$.
4. Similarly, if we assume that the population of users is uniformly distributed in area over the single isolated cell, employing a sectored antenna reduces the interference and hence increases capacity by the antenna gain factor, G_A. Note that if the users are uniformly distributed in area, this is the classical definition of (two-dimensional) antenna gain, which is the received energy in the direction of the transmitter divided by the mean received energy, averaged over the circle. For a three sectored antenna, this gain factor is less than three. If we take the loss from ideal gain to be 1 dB, $G_A = 2.4$.
5. Finally, since all users in all cells employ the common spectral allocation of W Hz, it is necessary to evaluate the interference introduced into each user's demodulator in the given cell by all users in all other cells.

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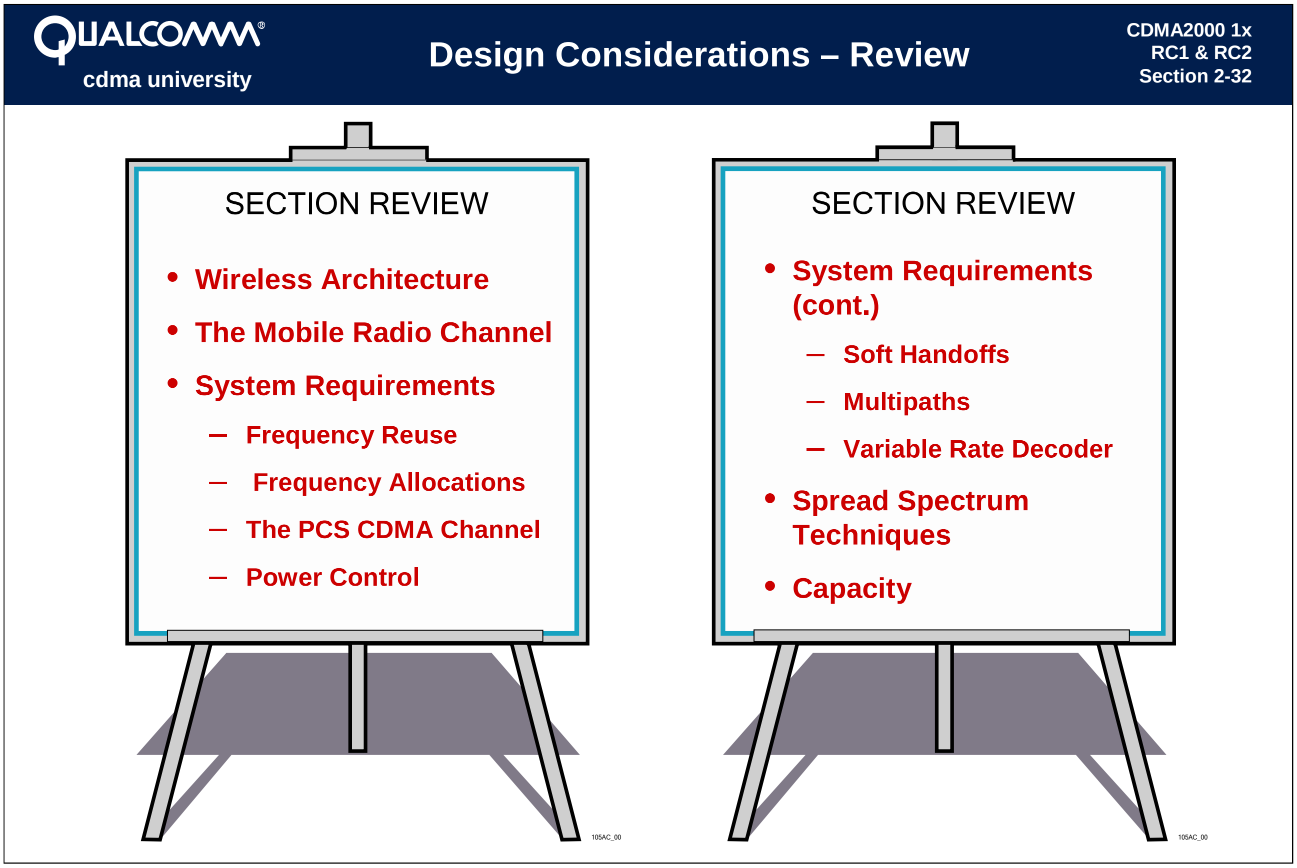
What We Learned in This Section

- ✓ The elements of a wireless architecture.
- ✓ The characteristics of the mobile radio channel.
- ✓ The mobile subscribers' requirements.
- ✓ The limitations of conventional approaches to mobile communications.
- ✓ The basic principles of spread spectrum communications.

Notes



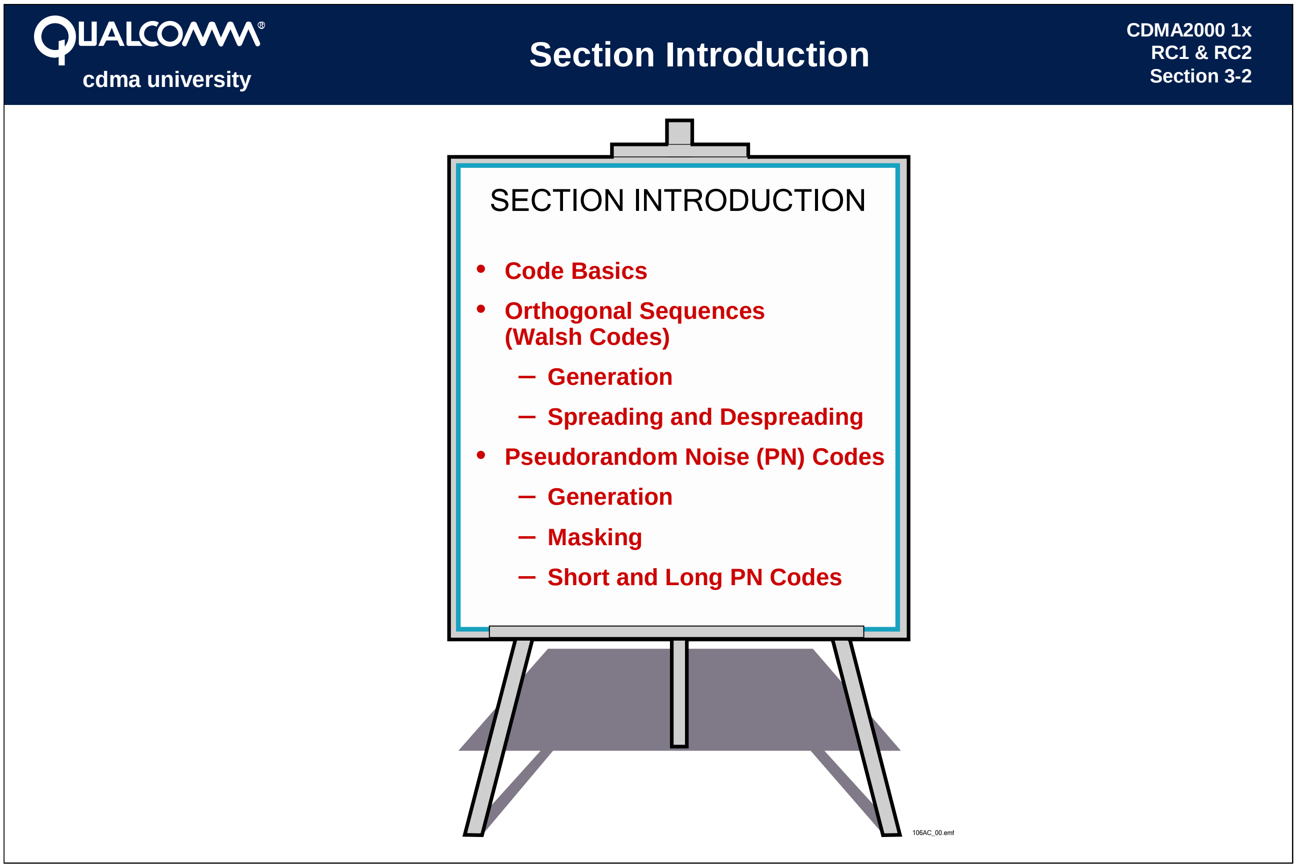
Review

This section addressed several factors that influenced the design of the IS-95 system.

SECTION 3

Codes in CDMA

Notes



Section Introduction

CDMA2000 systems use two types of code sequences:

- Orthogonal sequences (Walsh codes).
- Pseudorandom noise (PN) sequences.

This section examines the basic properties of both codes.

Section Learning Objectives

- List the two types of code sequences used in CDMA2000 systems.
- List and describe the properties of orthogonal and PN codes.
- Describe how these two code sequences are generated.
- Describe the process of spreading and despreading using these two codes.
- Describe the process of time-shifting a PN code sequence.

Notes

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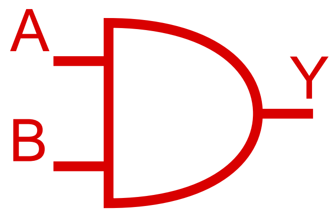
Code Basics – AND Function

CDMA2000 1x RC1 & RC2 Section 3-4



A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

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AND Function

The figure depicts a two-input AND gate and its corresponding truth table. A and B denote the inputs to the gate, while Y denotes its output. The AND operation (or function) is simply defined by the equation:

$$Y = \mathrm{A} \bullet \mathrm{B}$$

The AND gate outputs a logic "1" only when both inputs A and B are logic "1" as well. The output of the AND gate is zero if any of its inputs assumes the logic "0" state.

Understanding AND gate operation will prove useful in the discussion that follows.

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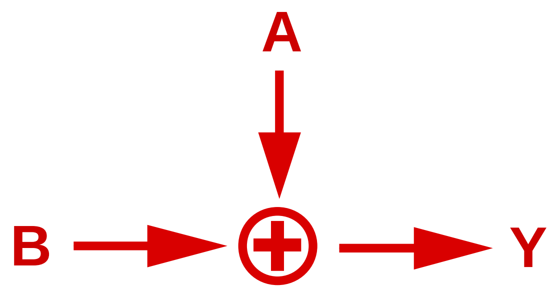
Code Basics – XOR Function

CDMA2000 1x RC1 & RC2 Section 3-5



A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

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XOR Function

The figure depicts a two-input XOR gate and its corresponding truth table. A and B denote the inputs, while Y denotes its output. The XOR operation (or function) is simply defined by the equation:

$$Y = A \oplus B = \overline{A} \bullet B + A \bullet \overline{B}$$

The XOR gate produces a one when the two inputs are at opposite levels. When the total number of ones at the inputs is odd, the result of XORing them is "1".

This operation is also needed for the upcoming discussion of codes.

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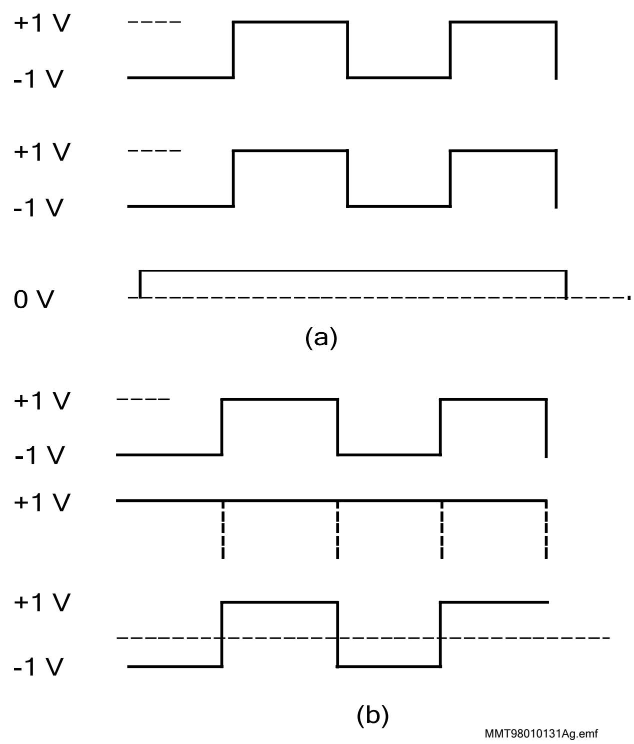
Code Basics – Correlation

CDMA2000 1x
RC1 & RC2
Section 3-6

(a)
Complete Correlation

(b)
No Correlation



Correlation

Correlation is a measure of similarity between any two arbitrary signals. It is computed by multiplying the two signals and then summing (integration) the result over a defined time window. For example:

- Figure (a) — the two signals are identical and therefore their correlation is 1 or 100%.
- Figure (b) — the two signals are uncorrelated and therefore knowing one of them does not provide any information on the other.

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Orthogonal Sequences – Orthogonal Functions

CDMA2000 1x RC1 & RC2 Section 3-7

Orthogonal functions have ZERO CORRELATION. Two binary sequences are orthogonal if the process of "XORing" them results in an equal number of 1's and 0's:

EXAMPLE:

```
 0000
 0101
------
 0101
```

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Orthogonal Functions

Orthogonal functions (that is, signals or sequences) have zero cross-correlation. Zero correlation is obtained if the product of two signals, summed over a period of time, is zero.

For the special case of binary sequences, the values 0 and 1 may be viewed as having opposite polarity. Thus when the product (XORing in this case) of two binary sequences results in an equal number of 1’s and 0’s, the cross-correlation is zero.

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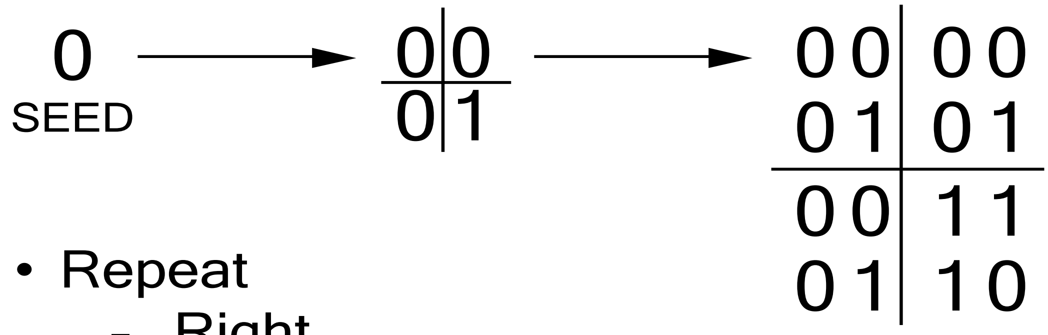
Orthogonal Sequences – Generating Orthogonal Codes

CDMA2000 1x RC1 & RC2 Section 3-8



- Repeat
  - Right
  - Below
- Invert (diagonally)

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Generating Orthogonal Codes

Orthogonal codes are easily generated by starting with a seed of 0, repeating the 0 horizontally and vertically, and then complementing the 0 diagonally. This process is continued with the newly-generated block until the desired codes with the proper length are generated.

Sequences created in this way are referred to as *Walsh codes*.

	0123	4567	1 8901	1111 2345	1111 6789	2222 0123	2222 4567	2233 8901	3333 2345	3333 6789	4444 0123	4444 4567	4455 8901	5555 2345	5555 6789	6666 0123
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
1	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101	0101
2	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011	0011
3	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110	0110
4	0000	1111	0000	1111	0000	1111	0000	1111	0000	1111	0000	1111	0000	1111	0000	1111
5	0101	1010	0101	1010	0101	1010	0101	1010	0101	1010	0101	1010	0101	1010	0101	1010
6	0011	1100	0011	1100	0011	1100	0011	1100	0011	1100	0011	1100	0011	1100	0011	1100
7	0110	1001	0110	1001	0110	1001	0110	1001	0110	1001	0110	1001	0110	1001	0110	1001
8	0000	0000	1111	1111	0000	0000	1111	1111	0000	0000	1111	1111	0000	0000	1111	1111
9	0101	0101	1010	1010	0101	0101	1010	1010	0101	0101	1010	1010	0101	0101	1010	1010
10	0011	0011	1100	1100	0011	0011	1100	1100	0011	0011	1100	1100	0011	0011	1100	1100
11	0110	0110	1001	1001	0110	0110	1001	1001	0110	0110	1001	1001	0110	0110	1001	1001
12	0000	1111	1111	0000	0000	1111	1111	0000	0000	1111	1111	0000	0000	1111	1111	0000
13	0101	1010	1010	0101	0101	1010	1010	0101	0101	1010	1010	0101	0101	1010	1010	0101
14	0011	1100	1100	0011	0011	1100	1100	0011	0011	1100	1100	0011	0011	1100	1100	0011
15	0110	1001	1001	0110	0110	1001	1001	0110	0110	1001	1001	0110	0110	1001	1001	0110
16	0000	0000	0000	0000	1111	1111	1111	1111	0000	0000	0000	0000	1111	1111	1111	1111
17	0101	0101	0101	0101	1010	1010	1010	1010	0101	0101	0101	0101	1010	1010	1010	1010
18	0011	0011	0011	0011	1100	1100	1100	1100	0011	0011	0011	0011	1100	1100	1100	1100
19	0110	0110	0110	0110	1001	1001	1001	1001	0110	0110	0110	0110	1001	1001	1001	1001
20	0000	1111	0000	1111	1111	0000	1111	0000	0000	1111	0000	1111	1111	0000	1111	0000
21	0101	1010	0101	1010	1010	0101	1010	0101	0101	1010	0101	1010	1010	0101	1010	0101
22	0011	1100	0011	1100	1100	0011	1100	0011	0011	1100	0011	1100	1100	0011	1100	0011
23	0110	1001	0110	1001	1001	0110	1001	0110	0110	1001	0110	1001	1001	0110	1001	0110
24	0000	0000	1111	1111	1111	1111	0000	0000	0000	0000	1111	1111	1111	1111	0000	0000
25	0101	0101	1010	1010	1010	1010	0101	0101	0101	0101	1010	1010	1010	1010	0101	0101
26	0011	0011	1100	1100	1100	1100	0011	0011	0011	0011	1100	1100	1100	1100	0011	0011
27	0110	0110	1001	1001	1001	1001	0110	0110	0110	0110	1001	1001	1001	1001	0110	0110
28	0000	1111	1111	0000	1111	0000	0000	1111	0000	1111	1111	0000	1111	0000	0000	1111
29	0101	1010	1010	0101	1010	0101	0101	1010	0101	1010	1010	0101	1010	0101	0101	1010
30	0011	1100	1100	0011	1100	0011	0011	1100	0011	1100	1100	0011	1100	0011	0011	1100
31	0110	1001	1001	0110	1001	0110	0110	1001	0110	1001	1001	0110	1001	0110	0110	1001
32	0000	0000	0000	0000	0000	0000	0000	0000	1111	1111	1111	1111	1111	1111	1111	1111
33	0101	0101	0101	0101	0101	0101	0101	0101	1010	1010	1010	1010	1010	1010	1010	1010
34	0011	0011	0011	0011	0011	0011	0011	0011	1100	1100	1100	1100	1100	1100	1100	1100
35	0110	0110	0110	0110	0110	0110	0110	0110	1001	1001	1001	1001	1001	1001	1001	1001
36	0000	1111	0000	1111	0000	1111	0000	1111	1111	0000	1111	0000	1111	0000	1111	0000
37	0101	1010	0101	1010	0101	1010	0101	1010	1010	0101	1010	0101	1010	0101	1010	0101
38	0011	1100	0011	1100	0011	1100	0011	1100	1100	0011	1100	0011	1100	0011	1100	0011
39	0110	1001	0110	1001	0110	1001	0110	1001	1001	0110	1001	0110	1001	0110	1001	0110
40	0000	0000	1111	1111	0000	0000	1111	1111	1111	1111	0000	0000	1111	1111	0000	0000
41	0101	0101	1010	1010	0101	0101	1010	1010	1010	1010	0101	0101	1010	1010	0101	0101
42	0011	0011	1100	1100	0011	0011	1100	1100	1100	1100	0011	0011	1100	1100	0011	0011
43	0110	0110	1001	1001	0110	0110	1001	1001	1001	1001	0110	0110	1001	1001	0110	0110
44	0000	1111	1111	0000	0000	1111	1111	0000	1111	0000	0000	1111	1111	0000	0000	1111
45	0101	1010	1010	0101	0101	1010	1010	0101	1010	0101	0101	1010	1010	0101	0101	1010
46	0011	1100	1100	0011	0011	1100	1100	0011	1100	0011	0011	1100	1100	0011	0011	1100
47	0110	1001	1001	0110	0110	1001	1001	0110	1001	0110	0110	1001	1001	0110	0110	1001
48	0000	0000	0000	0000	1111	1111	1111	1111	1111	1111	1111	1111	0000	0000	0000	0000
49	0101	0101	0101	0101	1010	1010	1010	1010	1010	1010	1010	1010	0101	0101	0101	0101
50	0011	0011	0011	0011	1100	1100	1100	1100	1100	1100	1100	1100	0011	0011	0011	0011
51	0110	0110	0110	0110	1001	1001	1001	1001	1001	1001	1001	1001	0110	0110	0110	0110
52	0000	1111	0000	1111	1111	0000	1111	0000	1111	0000	1111	0000	0000	1111	0000	1111
53	0101	1010	0101	1010	1010	0101	1010	0101	1010	0101	1010	0101	0101	1010	0101	1010
54	0011	1100	0011	1100	1100	0011	1100	0011	1100	0011	1100	0011	0011	1100	0011	1100
55	0110	1001	0110	1001	1001	0110	1001	0110	1001	0110	1001	0110	0110	1001	0110	1001
56	0000	0000	1111	1111	1111	1111	0000	0000	1111	1111	0000	0000	0000	0000	1111	1111
57	0101	0101	1010	1010	1010	1010	0101	0101	1010	1010	0101	0101	0101	0101	1010	1010
58	0011	0011	1100	1100	1100	1100	0011	0011	1100	1100	0011	0011	0011	0011	1100	1100
59	0110	0110	1001	1001	1001	1001	0110	0110	1001	1001	0110	0110	0110	0110	1001	1001
60	0000	1111	1111	0000	1111	0000	0000	1111	1111	0000	0000	1111	0000	1111	1111	0000
61	0101	1010	1010	0101	1010	0101	0101	1010	1010	0101	0101	1010	0101	1010	1010	0101
62	0011	1100	1100	0011	1100	0011	0011	1100	1100	0011	0011	1100	0011	1100	1100	0011
63	0110	1001	1001	0110	1001	0110	0110	1001	1001	0110	0110	1001	0110	1001	1001	0110

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Generating Orthogonal Codes (continued)

The orthogonal sequences currently used in terrestrial CDMA2000 systems are Walsh codes of length 64.

- In the Forward CDMA link, Walsh codes are used to separate users. In any given sector, each Forward Channel is assigned a distinct Walsh code.
- In the Reverse CDMA link, the 64 Walsh sequences are used as a signaling set by the Baseband Orthogonal Modulator.

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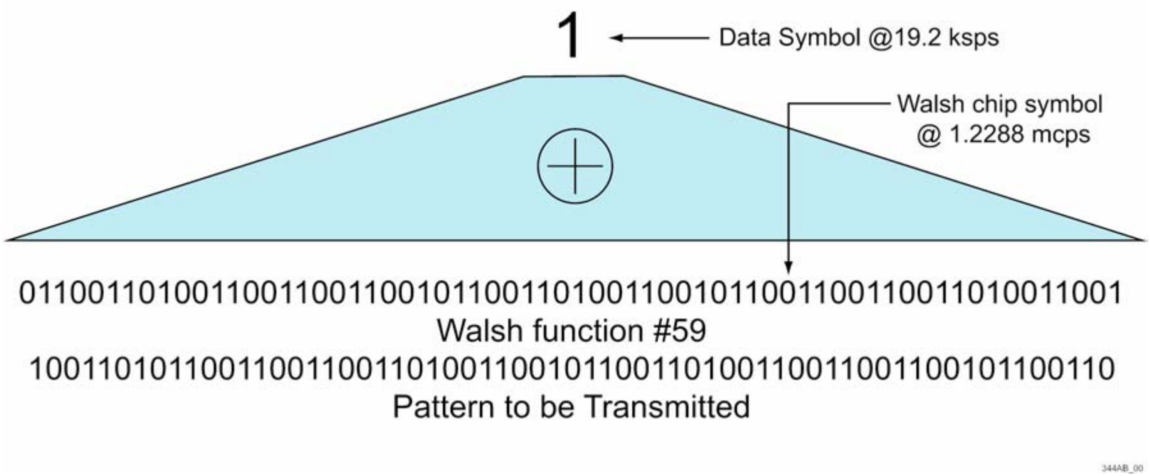
Orthogonal Sequences – Orthogonal Spreading

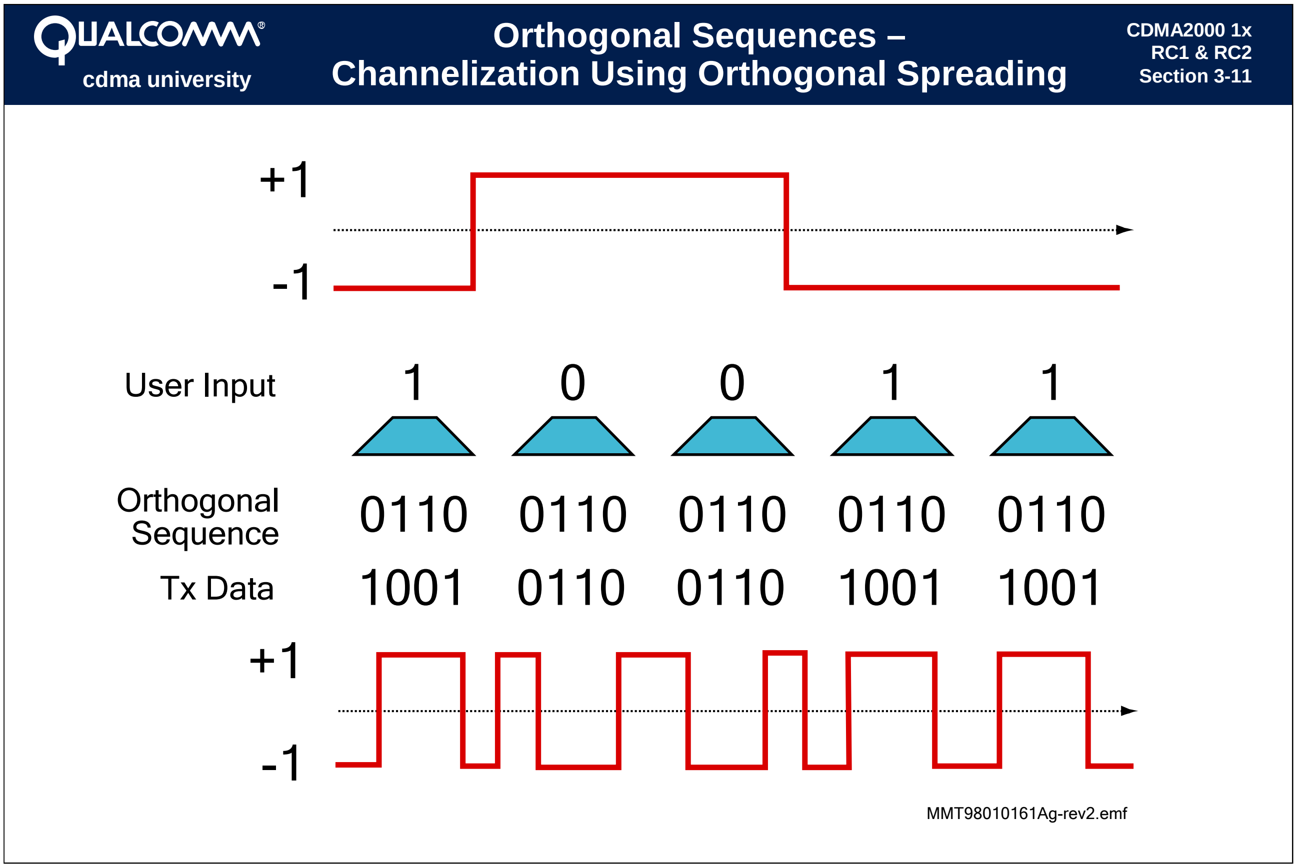
CDMA2000 1x RC1 & RC2 Section 3-10



Orthogonal Spreading

The principle behind spreading and despreading is that when a symbol is XORed with a known pattern and the result is again XORed with the same pattern, the original symbol is recovered. In other words, the effect of an XOR operation if performed twice using the same code is null.

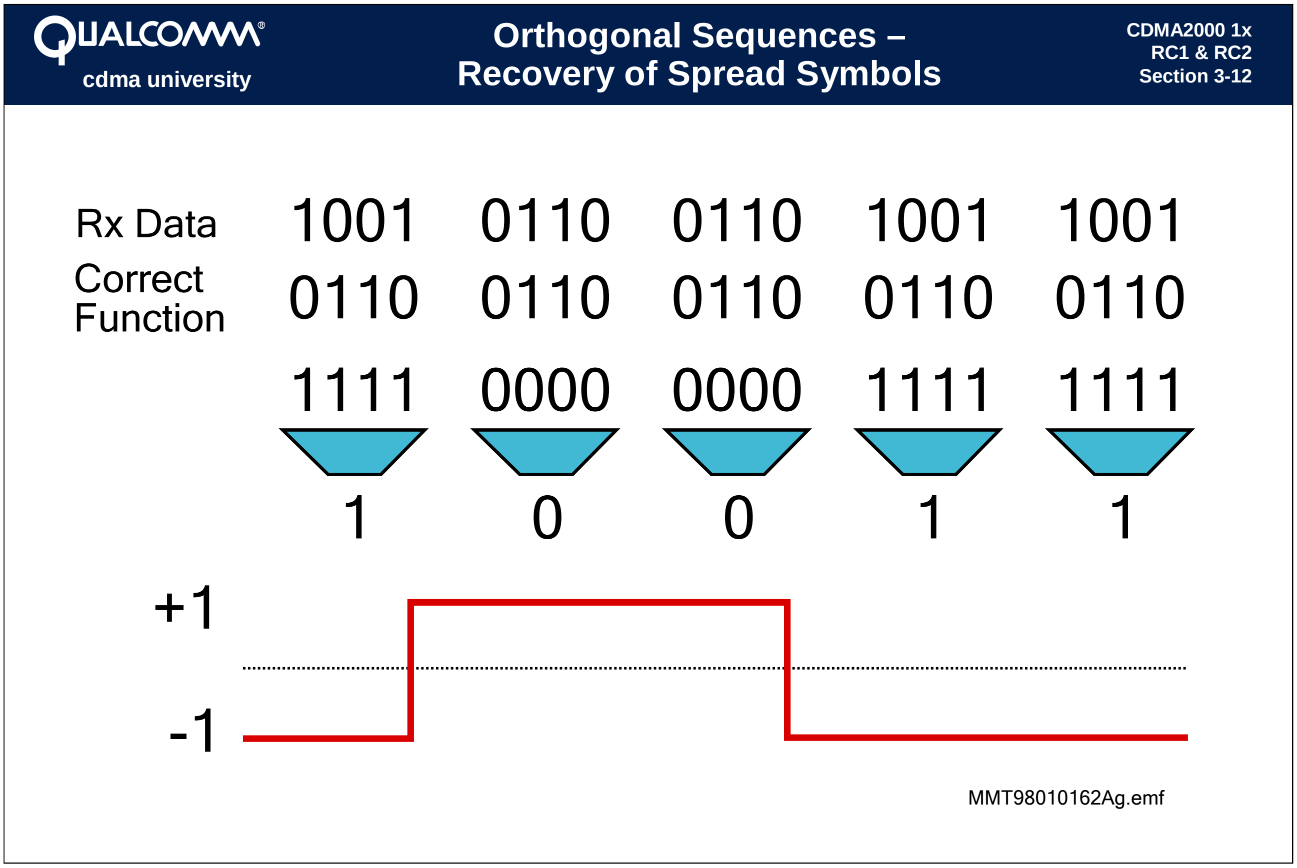
In orthogonal spreading, each encoded symbol is XORed with all 64 chips of the Walsh code. For example, in the figure a symbol of value “1” is orthogonally spread with Walsh code 59, thus yielding a 64-chip representation of the symbol.



Example of Channelization Using Orthogonal Spreading

By spreading, each symbol is XORed with all the chips in the orthogonal sequence (Walsh sequence) assigned to the user. The resulting sequence is processed and is then transmitted over the Physical Channel along with other spread symbols.

In this figure, a 4-digit code is used. The product of the user symbols and the spreading code is a sequence of digits that must be transmitted at 4 times the rate of the original encoded binary signal.



Recovery of Spread Symbols

The receiver despreads the chips by using the same Walsh code used at the transmitter. Notice that under no-noise conditions, the symbols or digits are completely recovered without any error. In reality, the channel is not noise-free, but CDMA2000 systems employ Forward Error Correction (FEC) techniques to combat the effects of noise and enhance the performance of the system.

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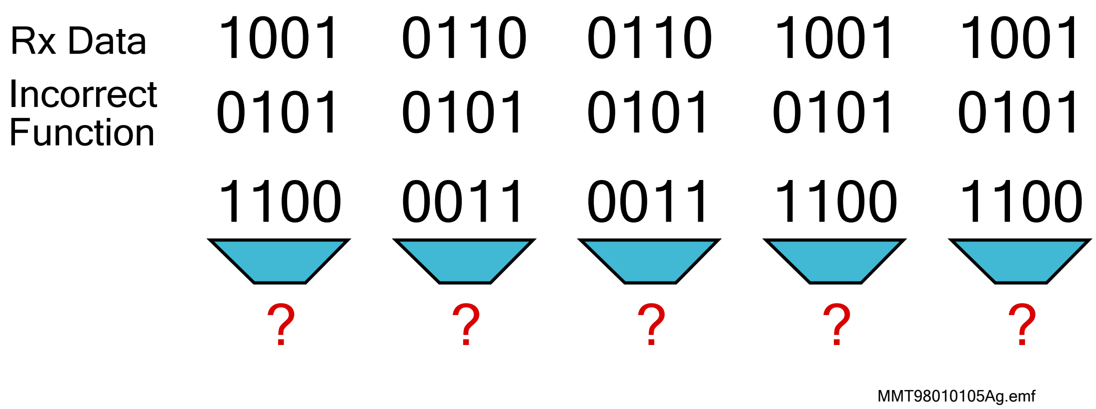
Orthogonal Sequences – Recovery of Spread Symbols using Wrong Function

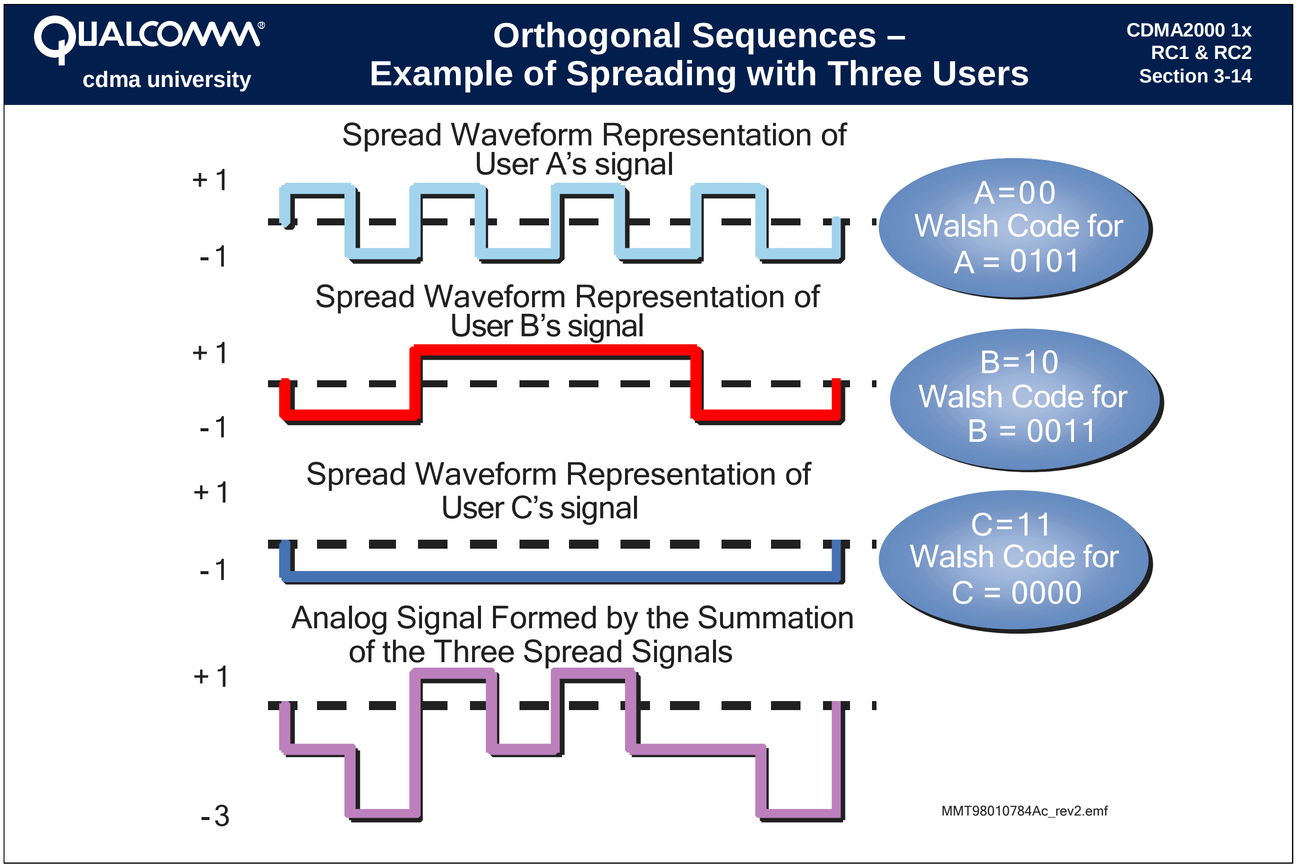
CDMA2000 1x RC1 & RC2 Section 3-13



Recovery of Spread Symbols using Wrong Function

When the wrong Walsh sequence is used for despreading, the resulting correlation yields an average of zero. This clearly demonstrates the advantage of the orthogonality property of the Walsh codes.

Whether the wrong code is mistakenly used by the target user or by other users attempting to decode the received signal, the resulting correlation is always zero because of the orthogonality property of the Walsh sequences.

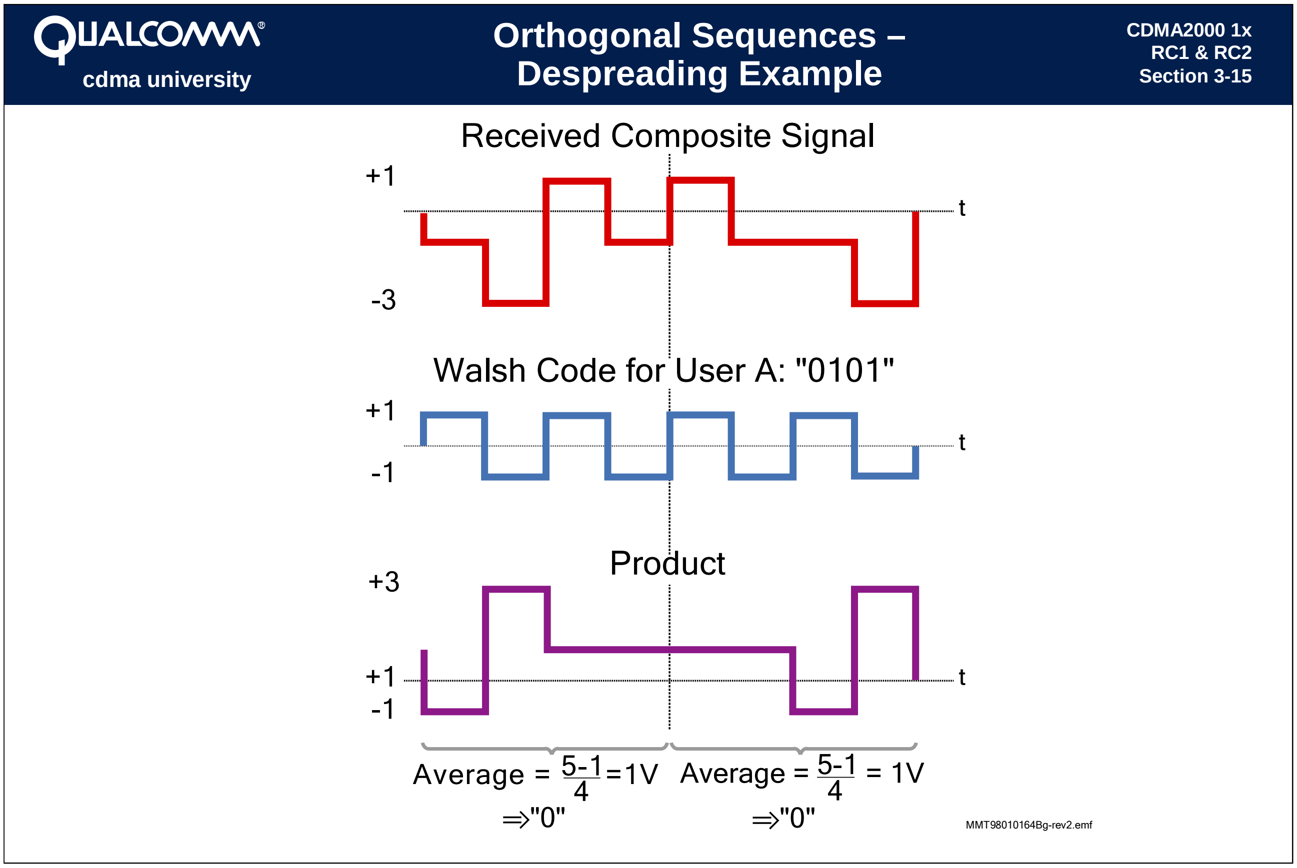


An Example of Spreading with Three Subscribers

In this example, three users, A, B, and C are assigned three orthogonal codes for spreading purposes:

- User A signal = 00, Spreading Code = 0101
- User B signal = 10, Spreading Code = 0011
- User C signal = 11, Spreading Code = 0000

The analog signal shown on the bottom of the figure is the composite signal when all of the spread symbols are summed together.



Despreading Example

At the receiver of user A, the composite analog signal is multiplied by the Walsh code corresponding to user A and the result is then averaged over the symbol time. This process is called correlation. Note that the average voltage value over one symbol time is equal to 1. Therefore, the original bit transmitted by A was “0”.

You may try to decode the symbols for users B or C in the same manner. This process occurs in the CDMA mobile for recovering the signals.

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Orthogonal Sequences – Walsh Usage

CDMA2000 1x RC1 & RC2 Section 3-16

- RC1 and RC2 use Walsh 64.
- RC3 through RC9 use variable length Walsh functions.
  - 1x typically uses 64 and 128 length.
- Length is a function of data rate.
- For 1x the Walsh chip rate is always 1.2288 Mcps.

Walsh Usage

Since RC1 and RC2 are the TIA/EIA-95 mode, only Walsh 64 is used.

RC3 through RC9 use variable length Walsh functions to handle different data rates. For RC3, voice calls use Walsh 64, while for RC4 voice calls use Walsh 128.

The higher the data rate, the shorter the Walsh function used. This is because the chip rate for the Walsh function is constant (1.2288 Mcps for 1x), and the full length of the Walsh function must be employed for each data bit.

Orthogonal Sequences – Walsh Space

Capacity of new Traffic Channels (RC3 and up) can exceed Walsh 64 space.

- Use RC4 with Walsh 128 space.
- Use QOF (Quasi Orthogonal Functions).
- With variable data rates and higher capacity Walsh space planning is more difficult for RC3 and up.
- Release A has many new physical channels; each requires a unique Walsh code.

Walsh Space

With the increased capacity of CDMA2000, environments exist where the capacity may exceed 64 channels. In this case RC4 could be employed since it uses Walsh 128, or the QOF functions could be employed to augment the smaller Walsh 64 space. Quasi Orthogonal Functions are not perfectly orthogonal, so they do create some interference in the Forward link signal.

The use of the higher data rates requires shorter Walsh functions, and these shorter functions are the seed function for longer functions. Thus when a high data rate channel is employed using a short Walsh function, this precludes using Walsh functions of longer length that have the short function as seed.

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PN Codes

PN Codes:

Maximum Length Pseudorandom Binary Sequences

Properties:

- Balance
- Run-Length
- Shift and Add
- Autocorrelation

Pseudorandom Noise (PN) Codes

Maximum Length Pseudorandom Binary Sequences

- **Pseudorandom:** Of, relating to, or being random numbers generated by a *deterministic* process.
- **Binary:** Takes on one of two values.
- **Maximum Length:** Maximum achievable period of a generated sequence – not arbitrary.

Properties

- **Balance property:** The output sequence will have an almost equal number of zeros and ones (2^{r-1} ones and $2^{r-1} - 1$ zeros).
- **Run-length property:** In any period, half of the runs of consecutive zeros or ones are of length one, one-fourth are of length two, one-eighth are of length three, etc.
- **Shift and add property:** The chip-by-chip sum of the output sequence C_k and any shift of itself C_{k+t}, τ ¼ 0 is a time-shifted version of the same sequence.
- **Autocorrelation property:** This property will be discussed in a later slide in this section.

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PN Codes – PN Balance

CDMA2000 1x RC1 & RC2 Section 3-19

Maximal Length PN codes have almost the same number of ones and zeros.

The number of ones is *one* greater than the number of zeros.

PN Balance

Maximal Length PN codes have one more one than zeros. Not all PN codes have this good behavior.

This balance of ones and zeros gives the PN code good noise-like properties that are important to CDMA2000.

PN Codes – One-Zero Distribution

The number of runs of each length is a decreasing power of 2 as the run length increases.

Distribution of Runs for a $2^7 - 1$ Bit *m*-Sequence

Run Length (bits)	Number of Runs: Ones	Number of Runs: Zeros	Number of Bits Included
1	16	16	32
2	8	8	32
3	4	4	24
4	2	2	16
5	1	1	10
6	0	1	6
7	1	0	7
			127 total

Adapted from R.C. Dixon, *Spread Spectrum Systems*

One-Zero Distribution

With the Run Length distribution as shown in the above slide, the power spectral density of the PN code is flat with frequency (or “white”) which means that when it is used for spreading, the energy of the spread waveform is evenly spread across the wideband signal.

PN Codes – Code Isolation

Each Base Station is assigned a unique PN code offset that is modulated on top of the Walsh code.

- Each sector of a Base Station is unique.
- Necessary because each Base Station uses the same Walsh code set.

Code Isolation

The Short PN is used as the final step in the spread spectrum modulation, and this makes the Forward link from each sector a unique waveform, since every sector has a different Short PN offset.

The entire set of Walsh functions is reused in each sector.

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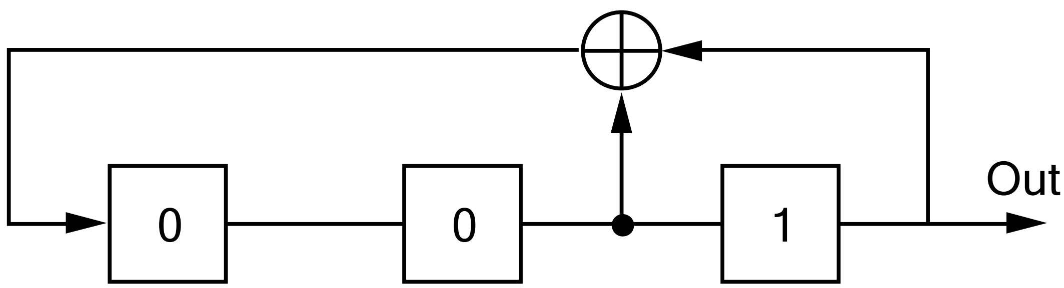
PN Codes – Generation

CDMA2000 1x
RC1 & RC2
Section 3-22



- Seed Register with 001
- Output will be a 7-digit sequence that repeats continually: 1001011

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PN Code Generation

PN codes are generated from prime polynomials using modulo 2 arithmetic. The state machines generating these codes are very simple and consist of shift registers and XOR gates.

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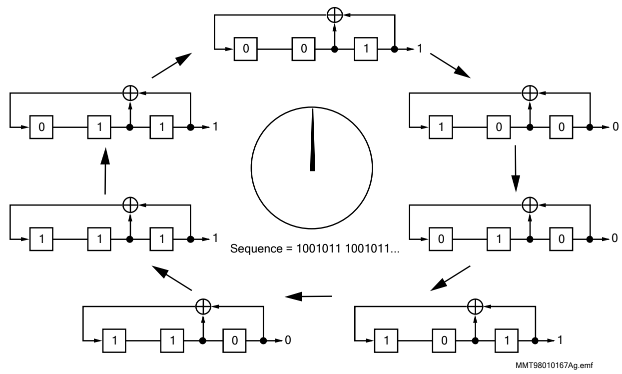
PN Codes – Generation (continued)

CDMA2000 1x RC1 & RC2 Section 3-23



Clock Pulse	D3	D2	D1
0	0	0	1
1	1	0	0
2	0	1	0
3	1	0	1
4	1	1	0
5	1	1	1
6	0	1	1
7	0	0	1

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Shift Registers

PN codes are maximum length. In general, if there are N shift registers (N = number of shift registers), the length of the PN code is equal to 2^N-1.

In this example, the number of distinct states in the shift registers is 2^3-1=7.

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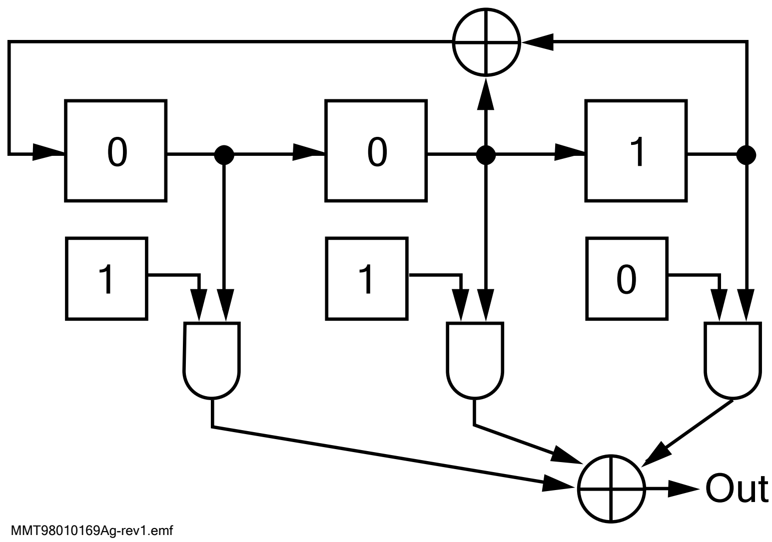
PN Codes – Masking

CDMA2000 1x
RC1 & RC2
Section 3-24

Masking will cause the generator to produce the same sequence, but offset in time.



PN Offset (Masking)

Masking provides the shift in time for PN codes. Different masks correspond to different time shifts. In CDMA2000 systems, Electronic Serial Numbers (ESN) are used as masks for users on the Traffic Channels.

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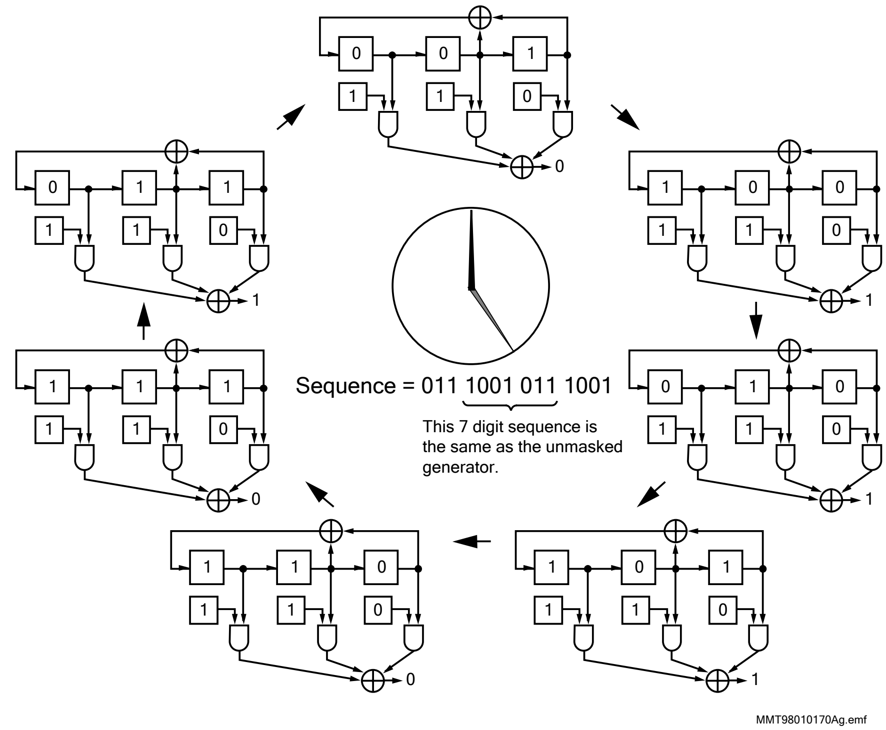
PN Codes – Masking (continued)

CDMA2000 1x
RC1 & RC2
Section 3-25



Sequence Produced by a Masked Generator

This example illustrates how a mask produces the same original sequence shifted in time.

The content of the 3-digit mask determines the offset of the sequence. Masking is used to produce offsets in both the short codes and the long code. The offsets of the short PN codes are used to uniquely identify the Forward channels of individual sectors or cells. The offsets of the Long PN code are used to separate code channels in the Reverse direction.

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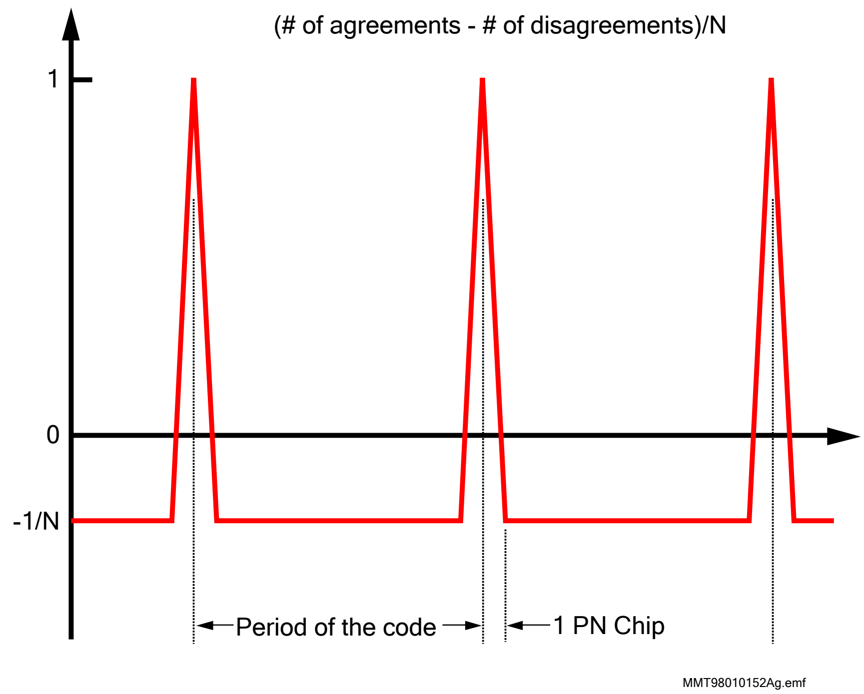
PN Codes – Autocorrelation of a PN Code

CDMA2000 1x
RC1 & RC2
Section 3-26



Autocorrelation of a Pseudorandom Noise Code

PN sequences have an important property: time-shifted versions of the same PN sequence have very little correlation with each other.

Autocorrelation is the measure of correlation between a PN code and a time-shifted version of the same code. The figure shows the autocorrelation function, and it is clear that it is a two-valued function. As long as the time shift is greater than the chip time, correlation is very small.

The channelization of users in the Reverse link is accomplished by assigning them different time-shifted versions of the long code, thus making them uncorrelated with each other. This property is then exploited to separate subscribers' signals in the BTS receivers.

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PN Codes – Short and Long

CDMA2000 1x RC1 & RC2 Section 3-27

- Two Short Codes (2^{15} = 32,768)
  - Termed "I" and "Q" codes (different taps)
  - Used for Quadrature Spreading
  - Unique offsets serve as identifiers for a Cell or a Sector
  - Repeat every 26.67 msec (at a clock rate of 1.2288 Mcps)
- One Long Code (2^{42} - 1 = 4400 Billion)
  - Used for spreading and scrambling
  - Repeats every 41 days (at a clock rate of 1.2288 Mcps)

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Short and Long PN Codes

The two short codes and one long code used in CDMA systems are time-synchronized to midnight, January 6, 1980 (GPS time). In CDMA2000 systems, all Base Stations and all mobiles use the same three PN sequences.

The two short codes are the same length, but are different codes. The codes are different patterns of ones and zeros because the feedback used to make the PN generator is tapped at different shift register outputs

A true Maximal Length PN code has a length of 2^N –1 bits. The short codes used in CDMA2000 have been modified by adding an extra zero to increase the length to an even number of bits. This makes the system design and hardware design easier to implement.

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PN Codes – Short PN

CDMA2000 1x
RC1 & RC2
Section 3-28

Short PN Code

The short PN code repeats every 26.667 ms, with length 2^{15} chips. Each sector of a Base Station uses the same short code phase to spread all the signals from that sector. Each sector uses a unique time offset.

The mobile can discern these unique offsets and thus identify the different sectors of the cellular system. It is desirable to have many unique offsets to make system planning easy.

With 512, or 2^9, unique offsets, then offsets occur every 64 chips, or 2^6.

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PN Codes – Chips vs. Distance

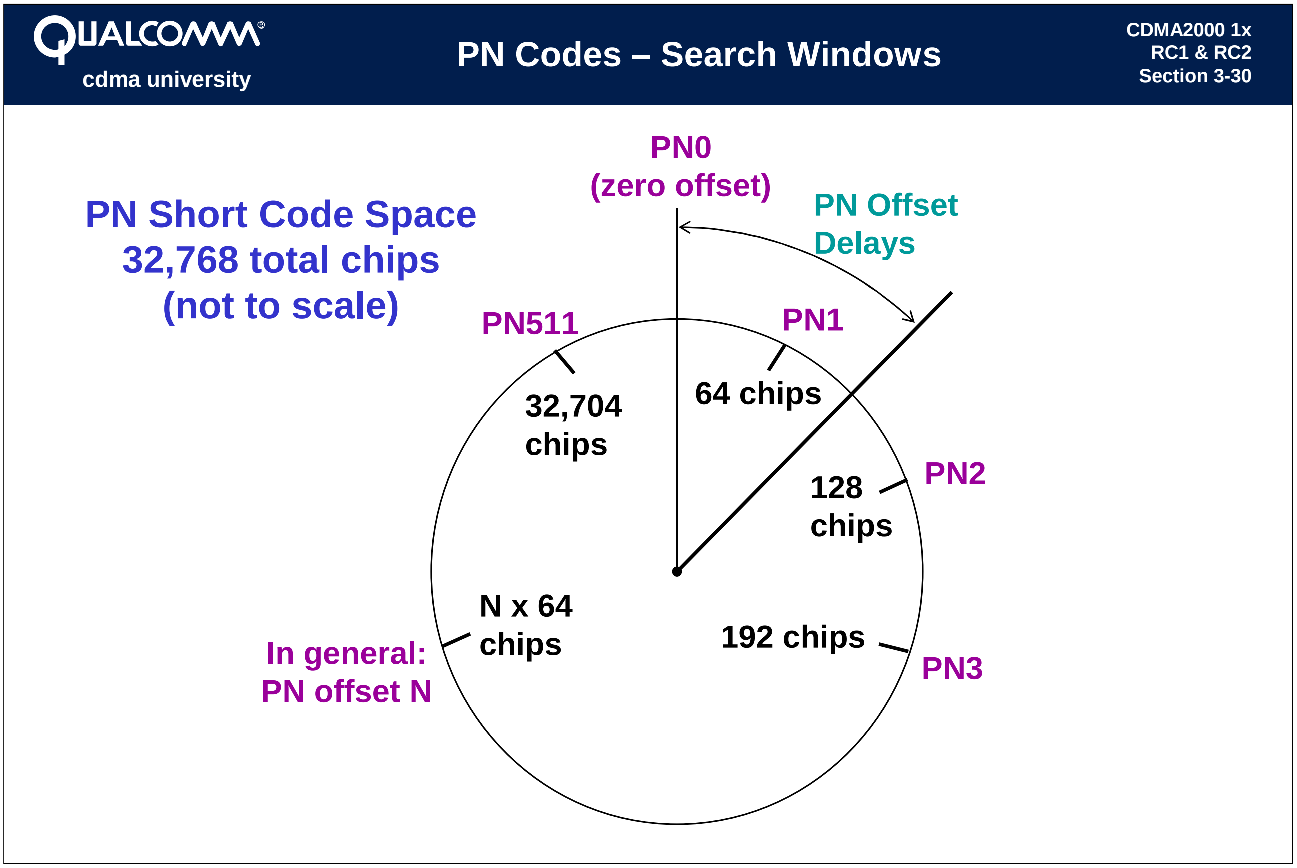
CDMA2000 1x RC1 & RC2 Section 3-29

With the speed of light at 3E8 m/sec, and 1 chip of PN at 814nS:

- In one chip time the speed of light (or the speed of the radio wave) moves 244 m.
- Or about 4 chips per Km, 6 chips per mile.

Chips vs. Distance

The Base Stations radiate the Short PN code at the correct time, and due to the speed of radio waves, these signals arrive at the mobile at a later time. The mobile does not know the distance to the Base Station, so the mobile timing is offset from the true system time by the one-way path delay.



Search Windows

The Short PN is offset in groups of 64 bits because the delay ambiguity of the mobile can be many chips in a real system due to the speed of light.

Most commercial networks use a PN increment of 4, resulting in an offset between sectors of 256 chips.

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What We Learned in This Section

CDMA2000 1x
RC1 & RC2
Section 3-31

- ✓ The two types of code sequences used in CDMA2000 systems.
- ✓ The properties of orthogonal and PN codes.
- ✓ How these two code sequences are generated.
- ✓ The process of spreading and despreading using these two codes.
- ✓ The process of time-shifting a PN code sequence.

Notes

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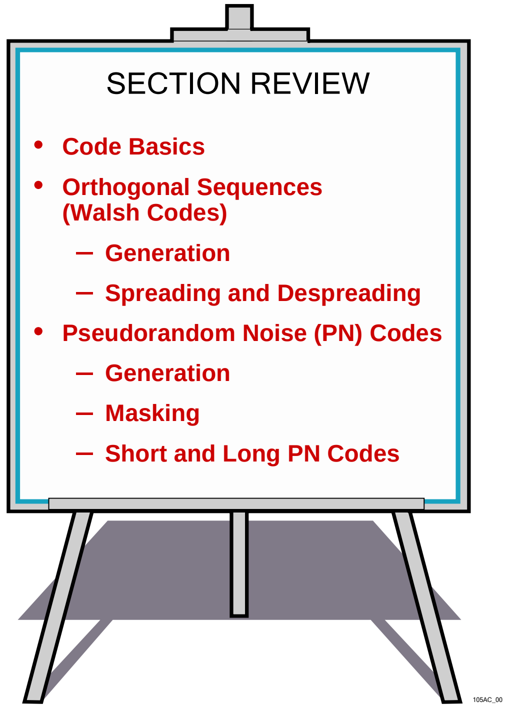
Codes in CDMA – Review

CDMA2000 1x
RC1 & RC2
Section 3-32



Notes

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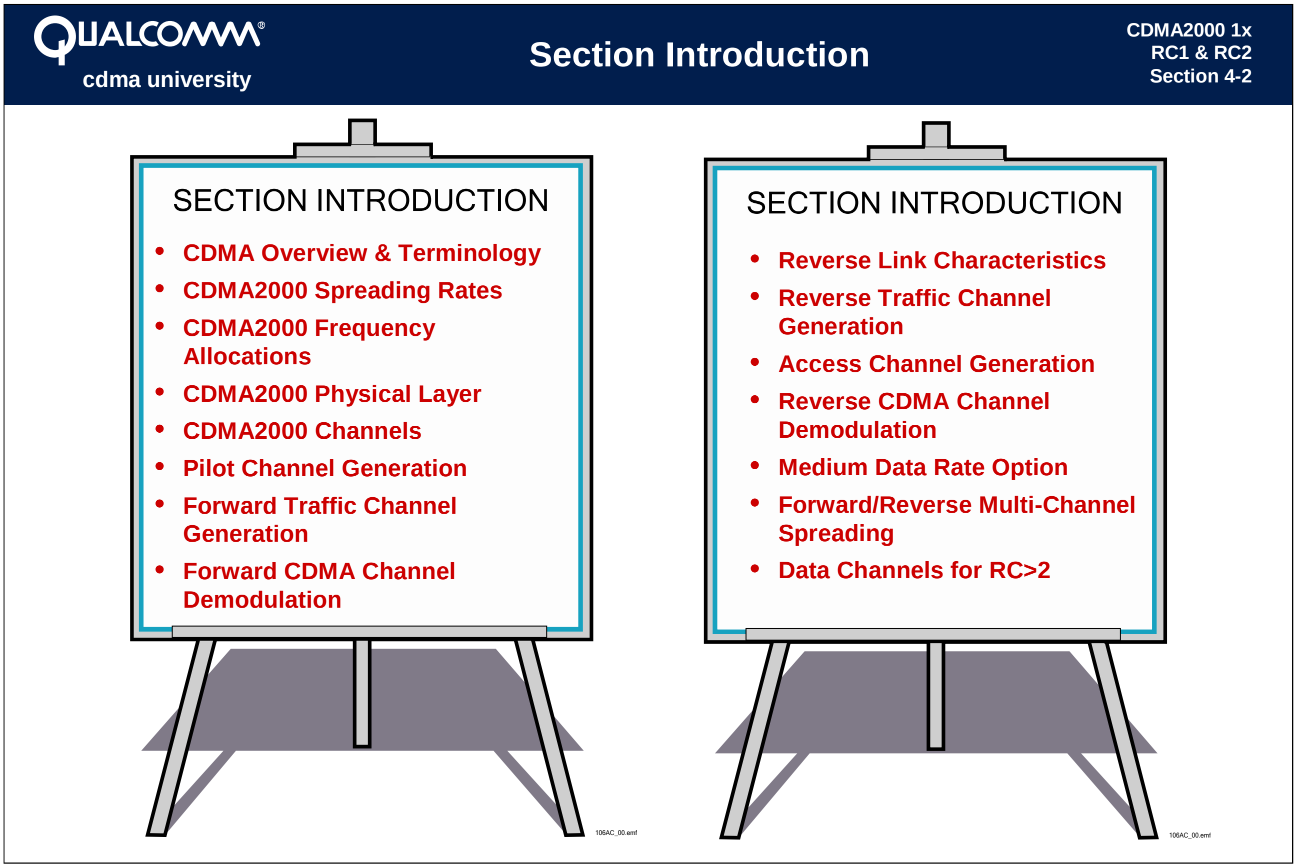
Section 4: CDMA Physical Layer

CDMA2000 1x
RC1 & RC2
Section 4-1

SECTION
4

CDMA Physical Layer

Notes



Section Introduction

TIA/EIA-95 and CDMA2000 provide a detailed specification for the generation of spread spectrum signals. This section carefully discusses these details, along with the rationale for many of the design decisions.

The standard, however, contains no details on demodulation. Consequently, this section provides only a brief overview of the structure and processes performed in the demodulators.

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Section Learning Objectives

CDMA2000 1x RC1 & RC2 Section 4-3

- Describe the generation of the CDMA waveforms in both the Forward and Reverse directions.
- List the CDMA code channels.
- List the steps in the generation of each code channel.
- Explain the rationale for each step.
- Describe the demodulation of the Forward and Reverse CDMA channels.

Notes

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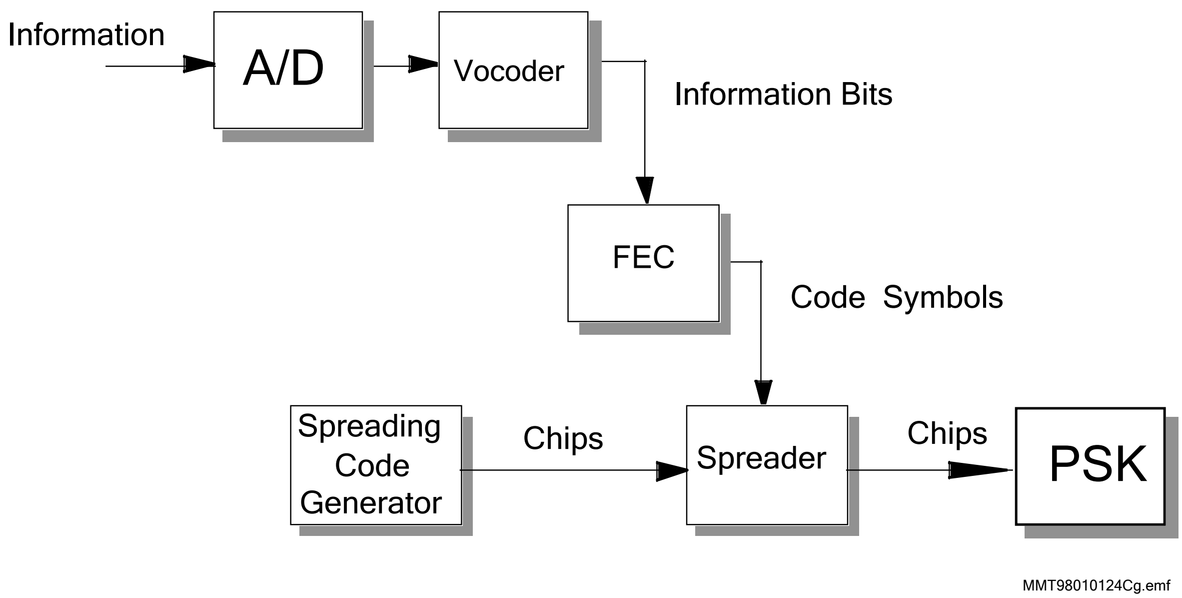
CDMA Overview & Terminology – Bits, Symbols, and Chips

CDMA2000 1x
RC1 & RC2
Section 4-4



An Overview of CDMA2000 Modulation

CDMA2000 systems convert the analog voice signal into a digital signal for transmission. There are several steps in the digital transmission process. Many of these steps are common to digital wireless schemes. After each step in digital processing, the signal conveys a different meaning and several terms are used to refer to the signal at different stages in the process.

The Bit

A *bit* is the fundamental unit of information: a single binary digit. Analog information is encoded into a sequence of binary digits (A/D conversion). Both user data and error detection code digits are considered bits. The *bit rate* (bits per second) is a measure of the volume of information being transmitted.

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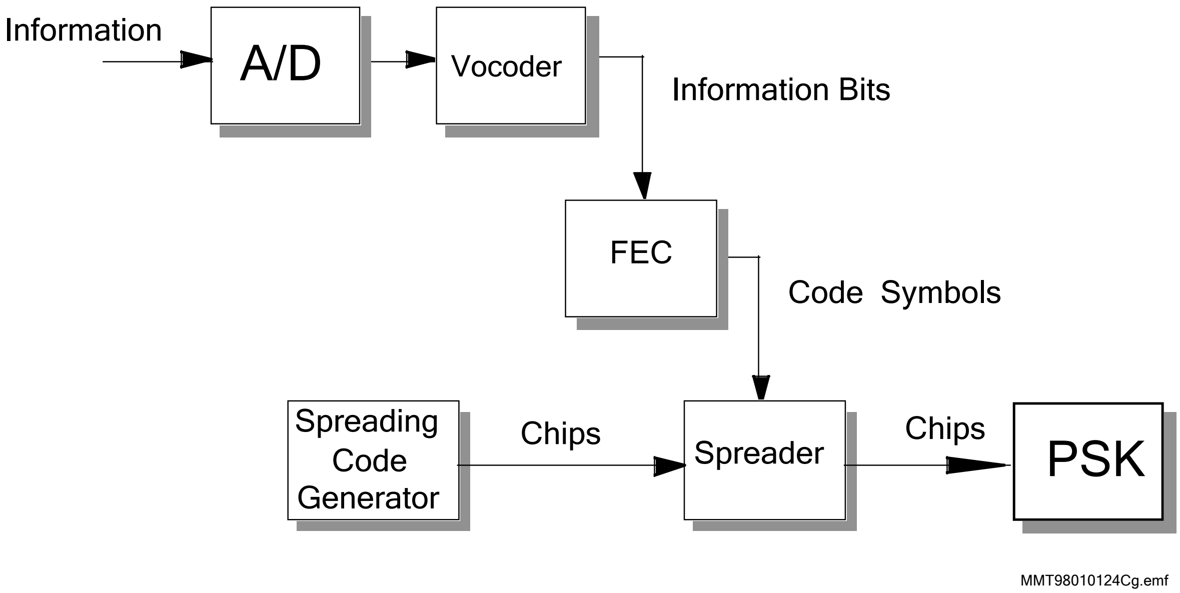
CDMA Overview & Terminology – Bits, Symbols, and Chips (continued)

CDMA2000 1x
RC1 & RC2
Section 4-5



The Code Symbol

In CDMA2000 systems, a *code symbol* is the output of the coding process (Forward Error Correction [FEC]). Each bit produces several code symbols. The symbol rate is a measure of the redundancy introduced by the FEC scheme. Each symbol is also a single binary digit.

The Chip

The output digits of a spreading code generator are commonly termed *chips*. A chip is also a single binary digit. Several chips are used to spread a single code symbol. The *chip rate* is a measure of the amount of spreading performed.

Bits, symbols, and chips all look the same: a single binary digit. What distinguishes one from another is their relationship to the information signal.

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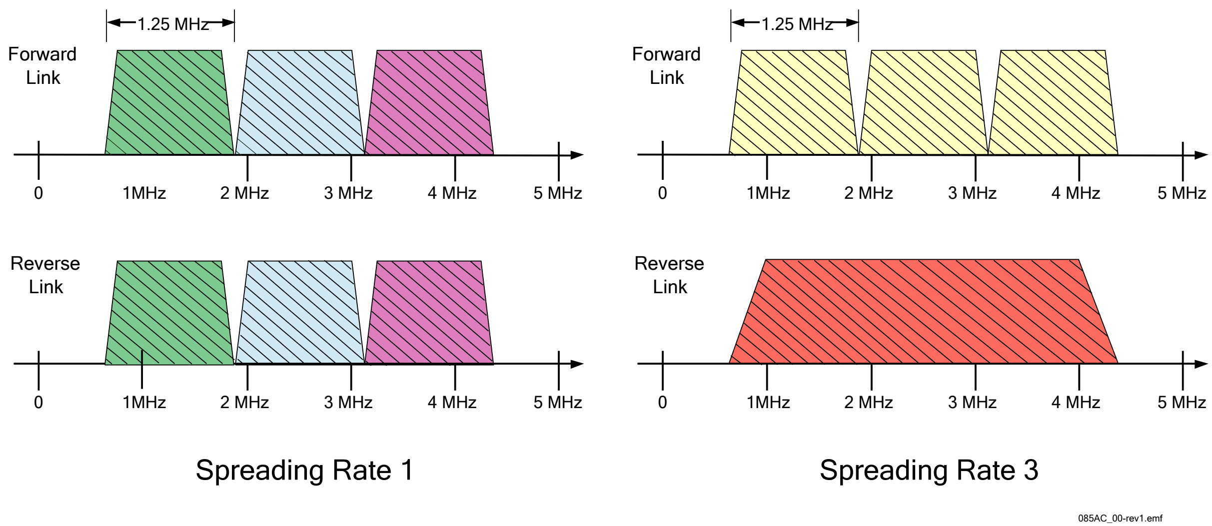
CDMA2000
Spreading Rate 1 and Spreading Rate 3

CDMA2000 1x RC1 & RC2 Section 4-6



Spreading Rates

CDMA2000 supports two different spreading rates:

- **Spreading Rate 1 —** also called "1x"
  - Both Forward and Reverse Channels use a single direct-sequence spread carrier with a chip rate of 1.2288 Mcps.
- **Spreading Rate 3 —** also called "3x" or MC (Multi-Carrier)
  - Forward Channels use three direct-sequence spread carriers each with a chip rate of 1.2288 Mcps.
  - Reverse Channels use a single direct-sequence spread carrier with a chip rate of 3.6864 Mcps.

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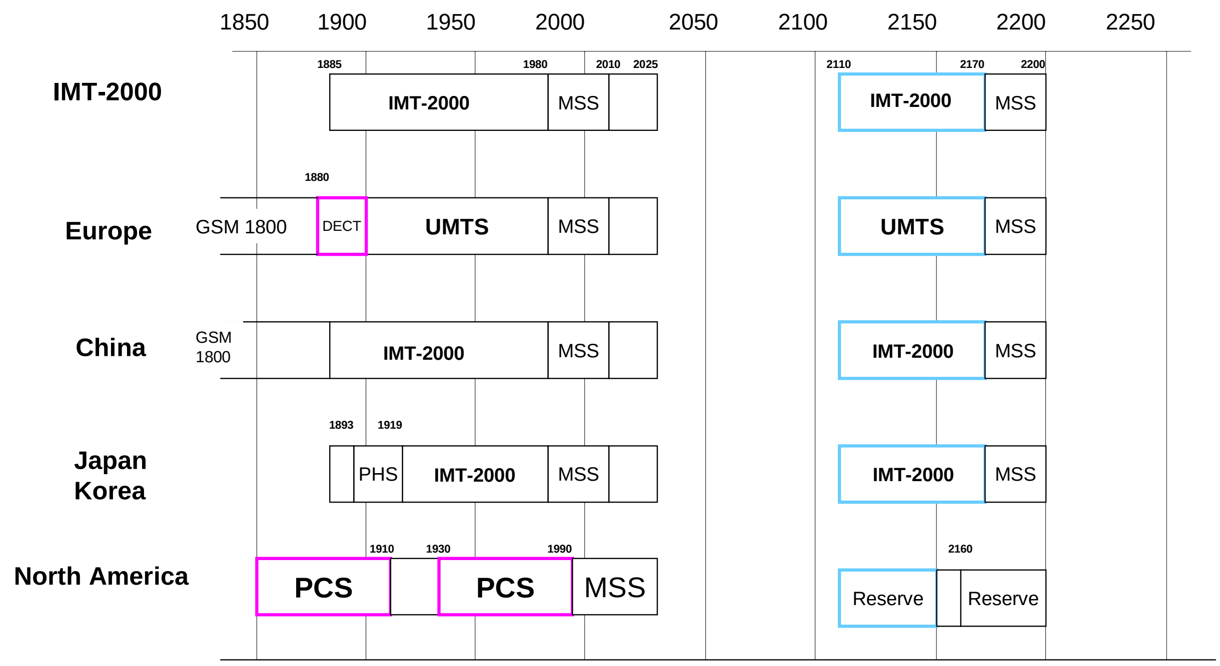
CDMA2000 Frequency Allocations

CDMA2000 1x
RC1 & RC2
Section 4-7



CDMA2000 Frequency Allocations

It would be desirable to have a universal frequency allocation for all CDMA2000 systems. Unfortunately, spectrum allocations are controlled by individual regulatory agencies, and no universally clear spectrum was available. The chart above shows the desired spectrum allocations for CDMA2000 (called International Mobile Telecommunications [IMT]-2000).

In China, the entire spectrum is available.

In Europe, Japan, and Korea, portions of it are available (Europe calls it Universal Mobile Telecommunications System [UMTS]).

In North America, CDMA2000 systems are supported in the the Personal Communications System (PCS) and cellular bands.