Seminar Booklet

CDMA Introduction

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CDMA Introduction

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The History of CDMA

In the 1980s, most analog cellular networks in the world reached their subscriber base and call capacity limits. This limited expansion potential and revenue generation for the operators of first generation (1G) analog systems such as AMPS and TACS at a time they were experiencing increased market demands from current, new, and prospective consumers.

This rapid growth of the wireless mobile communications industry put a very high demand on system capacity and drove the development of technologies for low-cost implementation of cellular and PCS systems. By the beginning of the 1990s, several digital technologies had been introduced that would overcome some of the limitations and enhance analog cellular networks by adding many new services and features. These included facsimile and data transmission, together with various call-handling features, such as Caller ID, Voice Messaging, and Paging Alerts. The European Communities developed an 8 slot Time Domain Multiple Access (TDMA) system called GSM. In the USA a 3 slot TDMA system (IS-136/IS-54) was deployed in the late 80's to improve capacity problems and voice quality. Whilst these second generation (2G) systems were a significant improvement over the legacy analog radios they did not entirely fit the bill for 21st century wireless communications.

As the end of 20th century approached, a vision of a ubiquitous telecommunication service known as the PCS (Personal Communications Services) was developed, renewing the interest in commercial applications of Spread Spectrum radio technologies, Code Division Multiple Access (CDMA). The spectral efficiency of this technology offered tremendous improvements in terms of subscriber capacity. CDMA would enable a significant increase in the number of subscribers per Hz and relieve the pressure on governments to allocate more of the scarce frequency spectrum resource to commercial wireless operators. Operators would also have tremendous gains in revenue generation in the frequency bands allocated to them. On paper CDMA offered up to 13 times the subscribers per Hz over the legacy systems. In reality the number is much lower, but it is still a significant gain.

The digital CDMA spread spectrum technology was adopted as a standard in North America. The CDMA system, originally proposed by QUALCOMM for digital cellular phone applications, has been adopted by the Telecommunication Industry Association TR-45 committee as IS-95 standard for cellular and by the Alliance for Telecommunications Industry Solutions committee T1P1 and TIA-TR46 joint standard J-STD-008 for PCS.

In the late 90's the IS-95 system was enhanced by the IS-2000 1XRTT standard that further improved capacity, and provided data speeds approaching those demanded by third generation (3G) wireless communications. In the next few years we will see the commercial launch of 1X-EVDO and 1X-EVDV with data rates exceeding 2 Mbits/sec.

The GSM technology communities are also deploying CDMA through 3G WB-CDMA systems, making CDMA the technology of choice to meet the wireless communications needs of the early 21st century.

The major attributes of CDMA systems are:

System Capacity

The capacity of the CDMA system is much higher than that of analog and TDMA legacy systems due to high spectral efficiency and efficient power control algorithms.

Economies

CDMA is a cost-effective technology that requires fewer, less expensive cells, and no costly frequency reuse pattern.

Quality of Service

CDMA has improved the quality of service by providing robust operation in fading environments and transparent (soft) handoffs.

High Speed Data

Using Packet Data techniques data rates as high as 2 Mbits/sec while stationary or 60 kbits mobile are possible.

Data Services

Provisions for the transport of large data files, real-time location services, and Web Browsing. New applications for mobile data emerge almost daily and are only limited by the applications developers imagination and associated commercial business cases.

Growth of CDMA

The world is on the edge of a wireless revolution. By the year 2000, there are expected to be about 40 million new PCS users worldwide in addition to the present 160 million users.

CDMA users worldwide.

Where is CDMA up and running?

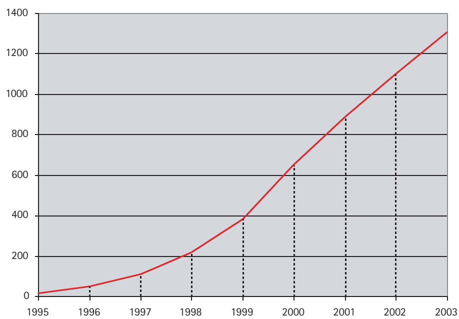
North America:
Installed networks cover all populated areas of USA, Canada and Mexico, initially deployed as IS-95 systems. Recently these have been upgraded to IS2000 1XRTT by both major US operators. There are plans in place to deploy 1X-EV technology upgrades in the 2004 to 2006 time frame. In the last three years the CDMA technology lead in the US has been challenged by the deployment of GSM/GPRS systems by two of the major IS-136 TDMA carriers. Whilst the data speeds of GPRS are not as high as CDMA, they are adequate to meet current applications needs. Eventually these systems will converge to WB-CDMA along with the rest of the worlds GSM communities.

South America:
Installed IS-95 networks in Brazil, Columbia, Chile, Venezuela, Peru and Ecuador. Upgrades to IS-2000 1XRTT are planned for all of these networks. Just like in the US there are challenges to CDMA from GSM/GPRS systems.

Asia-Pacific:
Korea is the primary user of CDMA technologies worldwide with more subscribers than the two US carriers combined. There are also installed networks in China, India, Hong Kong, Indonesia, Australasia and the Philippines. The list of countries deploying CDMA grows almost daily.

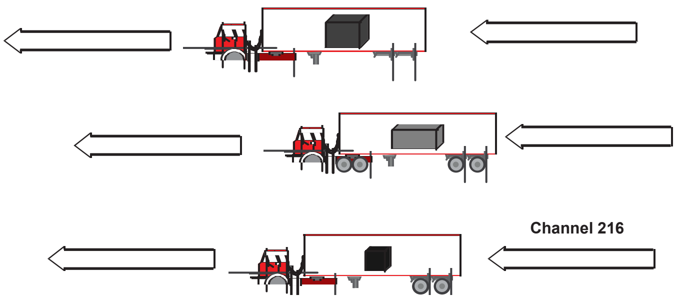
Europe:
Installed networks in Poland, Russia and Ukraine.

Africa:
Installed networks in Nigeria and Zambia.



Differences between FDMA, TDMA and CDMA

FDMA (Frequency Division Multiple Access) means that one carrier frequency can only carry the data for one conversation. In the diagram below you can see that every single connection needs one separate frequency channel, e.g. AMPS. In TDMA (Time Division Multiple Access) systems, such as NADC or GSM, one single carrier can carry up to eight different connections at the "same time". This means up to eight people can be having a conversation on one carrier frequency. In CDMA the number of connections (users) are limited by the effective "noise" floor of the system, and most systems allow for up to 30 users per carrier frequency.

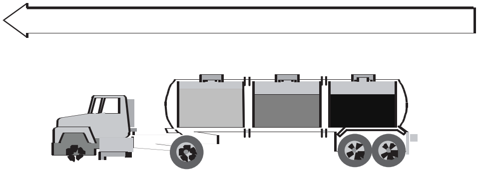


FDMA channel utilization

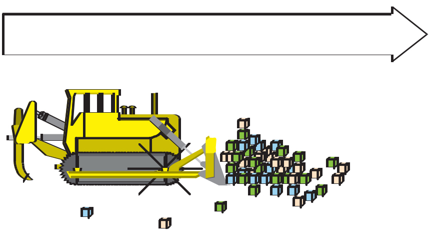
FDMA channel utilization

In TDMA (Time Division Multiple Access) systems, such as NADC, one single carrier can carry up to six different connections at the "same time". This means up to six people can be having a conversation on one carrier frequency.

The GSM TDMA system can carry up to eight users at a time.



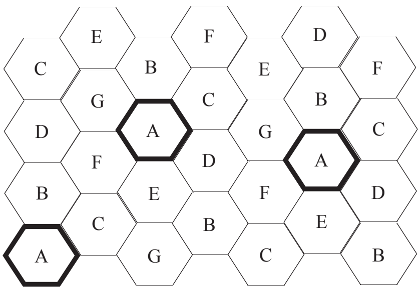
In a CDMA system the user data or voice packages (up to 61 traffic channels on one single CDMA carrier) are transmitted at the same time on the same frequency. CDMA (Code Division Multiple Access) means that the different channels are separated by codes and not by time (as for example in NADC). CDMA is a Spread Spectrum system, which means that its spectrum is very wide, 1.23 MHz for IS-95 and IS-2000, whilst WB-CDMA uses a 5 MHz bandwidth.



Advantages of CDMA

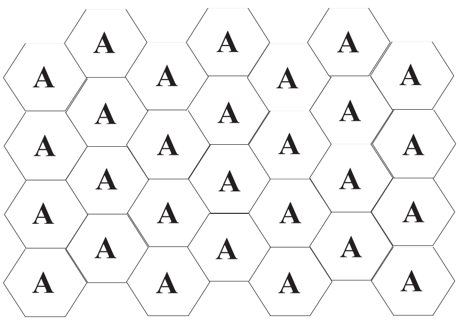
Simplified frequency planning

CDMA does not require expensive and complex frequency reuse pattern planning, as it is possible to reuse the same carrier frequency on every single cell of the network. This is possible due to the fact that everything is separated by codes in CDMA and not by time or frequency.



TDMA frequency planning

Frequency reuse of 7, as in NADC for example (7 different frequencies in one network).



CDMA frequency planning

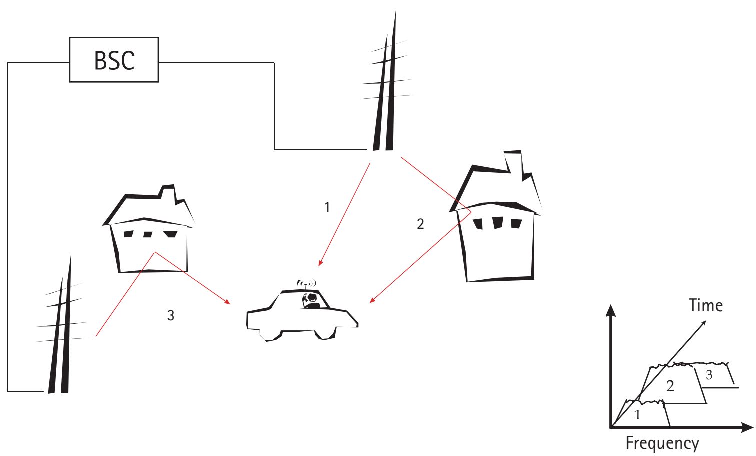
One carrier frequency in the whole network. This eliminates the need to perform extensive frequency reuse planning and to change almost the whole network.

Capacity

The capacity (number of simultaneous phone calls) per channel of CDMA compared to TDMA or FDMA is more then five times higher. In NADC for example only six different time slots per channel are available, whereas CDMA offers up to 61 different traffic channels in one CDMA channel. In reality the gain in subscribers is actually lower than this theoretical capacity and depends on several physical constraints such as interference and power control efficiency. IS-2000 more than doubled the IS-95 capacity by using more efficient coding schemes and better forward/reverse link power control.

Multipath receiving

CDMA mobiles can adjust for differing path delays and phase shifts of the different multipath arrivals due to reflection. The mobile then combines the arrivals coherently and achieves much better signal quality under difficult environments. The Rake Receiver is a unique system which allows a receiver to search for strong multipaths as well as other base stations and slide in time to find their "code". Once found, the receiver element can demodulate the signal, and coherently combine the signal to create a more robust receiver, as well as to allow the radio to "make before break" on handoffs. Mobiles have three and Base Stations four receiver elements (or fingers).



Handoffs

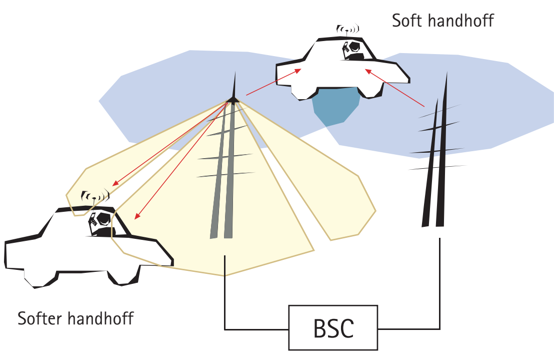
When you use a mobile phone travelling in a car, the mobile phone has to look for the nearest Base Station to send a signal. At some point you will leave the first cell and the mobile phone has to look for the next nearest Base Station. The process of moving from the Base Station in one cell to the next is called "handoff". Handoffs in CDMA are substantially different than in other formats.

There are three different types of handoffs in CDMA:

- Soft handoff
- Softer handoff
- Hard handoff

Soft and softer handoffs

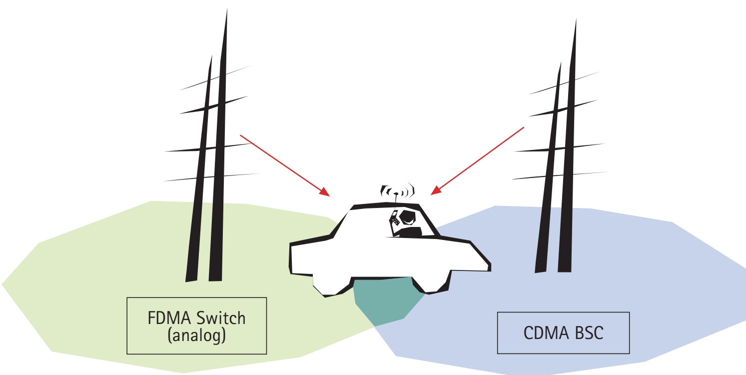
Soft handoffs occur when a Mobile Station (MS) establishes a new link before it breaks the old link. In CDMA, the mobile will continuously look for alternate PN code (see page 13) offsets in order to detect possible handoff candidates. The MS can then request a soft handoff (depending on the SNR [Signal-to-Noise Ratio] of the pilot) and the BSC (Base Station Controller) can direct the soft handoff.
The mobile will receive both signals and coherently combine them. The BSC will receive vocoded frames from both BSs and determine which is most error-free.
A softer handoff involves two sectors of the same BS. Generally, sectors will share hardware from the Walsh encoding, so that one channel element can support multiple sectors.



Hard handoffs

A hard handoff involves a complete disconnection from the serving cell before connecting to the handoff cell. Whenever a mobile crosses from a CDMA network into an FDMA network (IS-95 is a dual standard) a hard handoff must occur. Also, some manufacturers do not support inter-BSC soft handoffs. In the future, hard handoffs may also occur as operators overlay the CDMA principle with FDMA variants: Different base stations or networks may use more than one carrier frequency to increase capacity in high-usage areas.

Hard handoffs typically require much more power to be transmitted initially, this will raise interference levels and often play havoc with capacity. When they do occur, it is essential that they work perfectly, as this is a cause of many dropped calls. During idle state, the mobile will perform soft, softer and hard handoffs as needed. These are known as idle handoffs.



Variable rate vocoder

CDMA uses a variable rate vocoder, which results in high-speech quality, as most of the time there is no need for the highest data rate.

A vocoder is a device which can take analog voice, and using various predictive algorithms, compress and encode this voice data. Currently, there are three vocoders supported in CDMA systems. Originally, the 8 kbps vocoder was to be the main vocoder. This low-rate vocoder was justified because a lower data rate means better system performance (but can sacrifice voice quality). Then carriers decided the degradation in voice quality was not worth the gain in capacity, and so most carriers today support the 13 kbps vocoder.
A new vocoder designed to eliminate noise and optimise call quality has been introduced, called EVRC (Enhanced Variable Rate Coder).

The effective data rate affects the range in which the signal can be decoded, so there is a significant gain by dropping the data rate from the full rate of 13 or 8 kbps to half or even eighth rates. In a normal voice conversation, one person speaks while one person listens. 50% of the time a person speaks, the voice patterns only require high-speed vocoding in a portion of the spoken words. Variable vocoders take advantage of this fact by varying the data rate.

Fast and accurate power control

One very important requirement of CDMA is a fast and accurate power control. This minimises interference to other cellular phones or systems and results in a longer battery life. This is because only the minimum required transmit power is selected to ensure the connection is maintained, consistent with voice quality.

In the reverse link (the link from the MS to the BS), the characteristics are very different. Mobiles closer to the base station may be up to 80 dB higher than a mobile further away, drowning out the far away handset. Each mobile also has a different path, a different loss, and a different fade characteristic. In addition, since in IS-95 there is no pilot, the reverse channel must be demodulated non-coherently, i.e. the BS must take variable path delays into account. This limitation was reduced in IS-2000 by the introduction a reverse pilot signal. This resulted in the use of lower power levels overall in the reverse link, thus reducing the noise floor and increasing effective capacity.

Thus, the reverse link power control is much more extensive. The goal is to have every mobile reach the base station at the same level. This is achieved in two steps: open loop and closed loop power control.

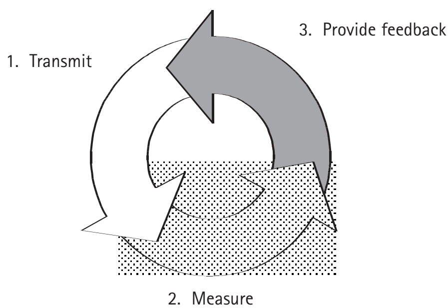
Open loop power control

The initial power control system is the open loop. Before the mobile phone starts transmission, it measures the signal strength that it receives from the base station. The higher the received signal strength in the mobile, the lower initial power it transmits to the base station and vice versa. This mechanism is called open loop control because the mobile does not have any knowledge about how strong its signal is being received by the base station.

Closed loop power control

In closed loop power control, the base station provides level feedback. The base station measures the power level received from each mobile, decides whether it is too high or too low, and orders the mobile to adjust its transmitted power level. This is achieved by transmitting a power control bit on the forward traffic channel every 1.25 ms. Using this bit, the base station tells the mobile to either increase or decrease the power level. Once the power has reached the desired level, this bit will alternate between "up" and "down".

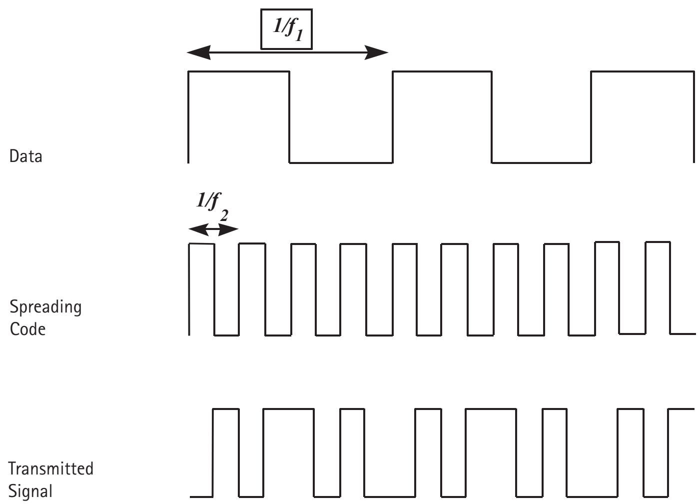
Closed loop power control



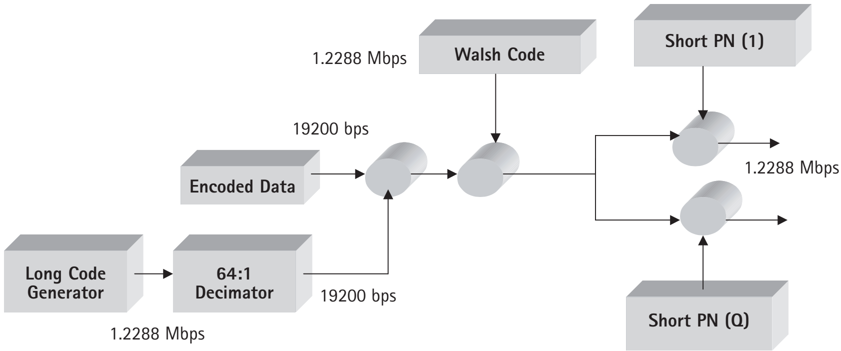
Codes in CDMA

Codes are used in CDMA to distinguish different channels transmitted by a base station, as well as from different base stations. CDMA uses two different types of codes – Walsh codes and PN codes. These different codes are relatively easy to generate because they are built using a recursive algorithm. These codes can be used either to spread the original data (multiply the original data with a higher data rate), or to scramble the data.

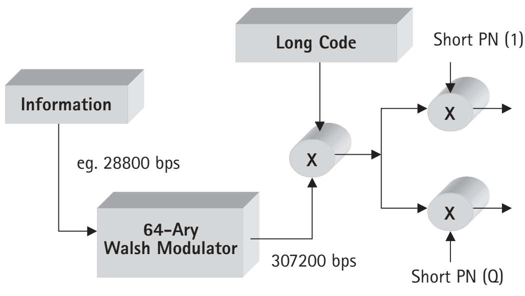
Example of code spreading



The following diagrams show how Walsh Codes and PN Codes are used in the forward and the reverse link.



In the forward channel, user data (e.g. at a rate of 19200 bps) are spread by a Walsh code and possibly scrambled using a Long PN Code. The Short PN Codes have a BS specific PN offset. The resulting I and Q data are then modulated and transmitted.



In the reverse channel, user data (e.g. at a rate of 28800 bps) are spread by a Walsh code at a lower rate, then scrambled using a Long PN Code (resulting in a rate of 1.2288 Mcps). The Short PN Codes are the same as in the forward channel. The resulting I and Q data are then modulated and transmitted.

Walsh Codes

These are used to spread the original signal, i.e. each bit of information is multiplied by 64 bits (called chips) of a certain Walsh code. This multiplication is also called "spreading", which means that by adding more bits, the transfer rate also increases.

CDMA IS-95 uses 64 different Walsh codes, IS-2000 uses 128 codes; each of them is used to carry a different logical channel. All of these codes are orthogonal, i.e. they have no similarity, and if the received signal is multiplied by the wrong Walsh code then the result is close to zero. Therefore instead of multiplying the received signal with the desired carrier frequency to obtain the original baseband signal as in the FDMA world, the received signal is multiplied by the desired Walsh code to obtain the original data.

PN Codes

These pseudo-random codes come in two different flavours: The Short PN Codes are used to differentiate between base stations, whereas the Long PN Code is used in both directions to scramble the signal and for spreading in the reverse channel.

PN codes are binary sequences which have the properties of randomness (i.e. equal numbers of zeros and ones). Both PN code types have a chip rate of 1.2288 Mchips per second (Mcps) and are synchronised worldwide via GPS (the satellite-based Global Positioning System).

Long and Short Codes

The short codes are 215 i.e. 32768 chips in length; two different codes are used to spread or scramble the I and Q signals: PN(I) and PN(Q). At 1.2288 Mcps, the short codes repeat every 26.667 ms. Offsets of 64 chips are used to identify different base stations: As every base station may transmit the same Walsh codes, the short codes are a good means to be able to separate signals from different base stations. All Walsh codes from one base station are the same, but different base stations use different PN offsets. With 32768 chips offset by 64, 512 different PN offsets are available.

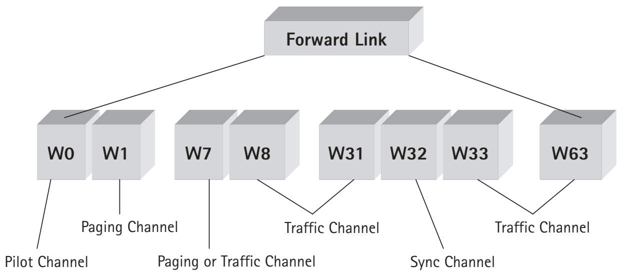
The long code is a sequence of 242 (nearly 4400 billion) chips (repeating every 41.5 days). Like the short code, it is divided into 64 chip long offsets, which can be used to make it more difficult to intercept.

Logical Channels in CDMA

There are 64 code channels in each 1.2288 MHz CDMA carriers. There are two types of overhead channels:

- Forward channel (also known as downlink from BS to MS)
- Reverse channel (also known as uplink from MS to BS)

Forward Channels



The 64 Walsh codes are numbered W0 to W63. On each forward link, there are at least three code domains in use:

- W0 = pilot channel
- W1 = paging channel
- W32 = synchronising channel

Channels W2 to W7 may be present and if so, then they carry either paging or traffic channels. W8 to W31 and W33 to W63 when present, carry traffic channels.

Pilot Channel

The Pilot Channel uses Walsh code 0. It acts as a beacon and has no information on it. Since the data is all zeros, it consists only of the final spreading sequence (the short codes). It is used by all mobiles as a coherent phase reference, as well as a means to identify each cell/sector, and compare strengths for the handoff process. Since the Pilot sequence is just the short code sequence (offset with whatever PN offset designated for that sector), it repeats every 26.667 ms. The pilot contains about 20% of the radiated power.

Paging Channel

Walsh code 1 is always a paging channel, and Walsh codes 2 through 7 may also be paging channels if the system requires more than one paging channel. The Paging Channel is the digital control channel of the forward link. Paging channels are used to page the mobile, transmit overhead information, and assign mobiles to traffic channels.

Messages sent include:

System Parameters Message
Neighbour List
Access Parameters Message
CDMA Channel List Message
Global Service Redirection
.... and more

Each paging channel can handle up to 32 traffic channels. After synchronising to the BS, the mobile monitors this channel.

IS-2000 introduced a Quick Paging channel to improve mobile battery life. This works by the mobile only monitoring a single bit in the Quick Paging channel message stream specific to itself. If the bit is not set the mobile goes back to sleep, if set it decodes the Paging Channel entirely.

Synchronisation Channel

The Synchronisation Channel is always Walsh code 32 and is used by the MS to synchronise with the system. The sync channel is comprised of an 80 ms superframe, divided into three 26.667 ms frames. It transmits the following information: System time, Pilot PN of base station, Long code state 320 ms into the future, system ID, Network ID. Of the three channels (Pilot, Paging and Sync) the Sync has the least power in it.

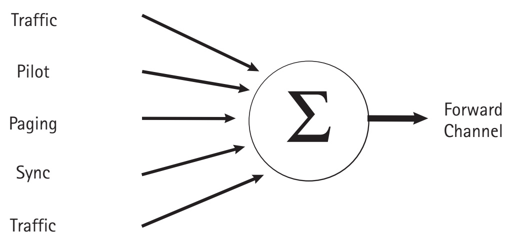
The Forward Traffic Channel

The Forward Traffic Channel, of course, is used to transmit traffic (voice) data, as well as signalling information during a call.

Note that the Long code is used with the user-specific mask to identify each individual user. Once this traffic channel is assigned to a user in an omnicell or sector, it cannot be assigned to another user for the duration of the call.

All the various forward link channels are added onto the same 1.2288 MHz carrier and sent out in the same sector/omnicell with the same PN offset.

To access the system the mobile first finds a pilot channel, and syncs to its PN start and finish (26.67 ms). Next, the mobile is able to read the sync channel message (in which each frame is exactly 26.67 ms) and fully synchronise to the system. The mobile can then monitor the paging channel and read system and access parameters. If a call comes up, the traffic channel becomes active.



The forward link is significantly different than the reverse link. First, all of the code channels take the same path to the mobile, so they all fade together. Thus, at the handset receiver, all of the channels are arriving at the same power levels and do not fade independently – so no one will outshout another.

Secondly the forward link uses better codes (Walsh codes) to separate users. This ideal, perfectly orthogonal separation makes it much easier to pull out the channel's data. Using the Pilot and sync signal, the mobile is able to coherently demodulate using nearly perfect timing and phase information.
IS-2000 introduced forward link power control where a mobile can advise the base station of received signal levels and thus enable the adjustment of power in the coded traffic channel. This reduced overall interference levels and resulted in increased capacity.

Reverse Channel

There are two types of channels in the reverse link (generated in the handset). The access channel and the traffic channel. In the reverse link, handsets are separated by unique offsets of the long code (in the forward link, base stations are identified by unique offsets of the short codes on the I and Q channels, and channels separated by Walsh codes).

Access Channels

- Separated by unique mask on long code
- Used for origination, acknowledging pages and registration
- Also used to set the open loop power control starting estimate

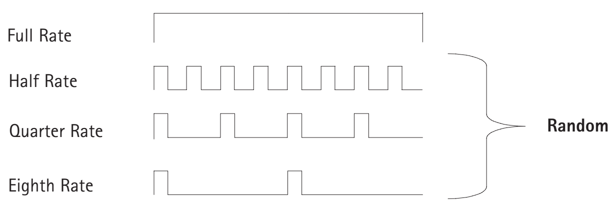
Traffic Channels

- Separated by unique mask on long code (based in phone serial number)
- Voice
- Overhead acknowledgement

The mobile station bursts its power to save power and also lower the noise. The mobile station will burst in a 1.25 ms power control group depending on the current vocoder data rate (the vocoder makes decisions on what data rate to use every 20 ms). The bursting is randomised to spread the transmitted power over time. Also, the transmitted power is lowered 3 dB (halved) for each lower data rate. At full rate, there is no bursting.

Reverse link power bursting

1 power control group = 1.25 ms,
1 frame = 16 pcg



Basic RF Specifications of CDMA

IS-95 is the cellular band standard set by TIA/EIA.
J-STD-008 is the PCS standard.

IS-95

Frequency Range	
uplink	869 MHz to 894 MHz
downlink	824 MHz to 849 MHz
Duplex space	45 MHz
Carrier separation	30 kHz
Carrier numbers	1 to 311, 356 to 644, 689 to 694, 739 to 777 and 1013 to 1023*
Modulation	
uplink	QPSK = Quadrature Phase Shift Keying
downlink	OQPSK = Offset Quadrature Phase Shift Keying

J-STD-008

Frequency Range	
uplink	1930 MHz to 1990 MHz
downlink	1850 MHz to 1910 MHz
Duplex space	80 MHz
Carrier separation	50 kHz
Carrier numbers	0 to 1199
Modulation	
uplink	QPSK = Quadrature Phase Shift Keying
downlink	OQPSK = Offset Quadrature Phase Shift Keying

* The same numbering system is valid for AMPS, NAMPS, TDMA and CDMA, however in CDMA only the above-mentioned channel numbers are valid. The other channel numbers represent guard bands between the two carriers (system A and B).

Glossary

AMPS	=	Advanced Mobile Phone System
bit	=	A single binary digit
BS	=	Base Station
BSC	=	Base Station Controller
CDMA	=	Code Division Multiple Access
Chip	=	Output of a code generator (single binary digit) Typically, many chips are used to represent a single symbol
downlink	=	Forward channel; from BS to MS
Eb/No	=	Bit Energy to Noise Ratio
EVRC	=	Enhanced Variable Rate Coder
FDMA	=	Frequency Division Multiple Access
Forward Channel	=	Downlink; from BS to MS
GPS	=	Global Positioning System
MS	=	Mobile Station
Mcps	=	Mega Chips Per Second
NADC	=	North American Digital Cellular (IS-54, IS-136)
OQPSK	=	Offset Quadrature Phase Shift Keying
PCG	=	Power Control Group

PCS	=	Personal Communication System
PDC	=	Personal Digital Communications
PN	=	Pseudo-random Noise
QPSK	=	Quadrature Phase Shift Keying
Reverse Channel	=	Uplink; from MS to BS
SS	=	Spread Spectrum
RMS	=	Root Mean Square
SNR (S/N)	=	Signal-to-Noise Ratio
Symbol	=	A coded single binary digit (Bit) Typically, several symbols are produced to represent each bit
TDMA	=	Time Division Multiple Access
TIA/EIA	=	Telecommunications Industry Association in association with the Electronic Industries Association
Uplink	=	Reverse Channel; from MS to BS

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