

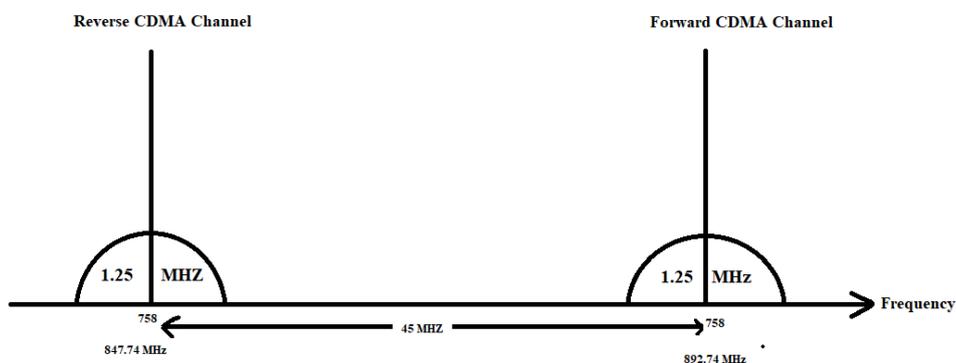
UNIT III

CDMA CHANNELS

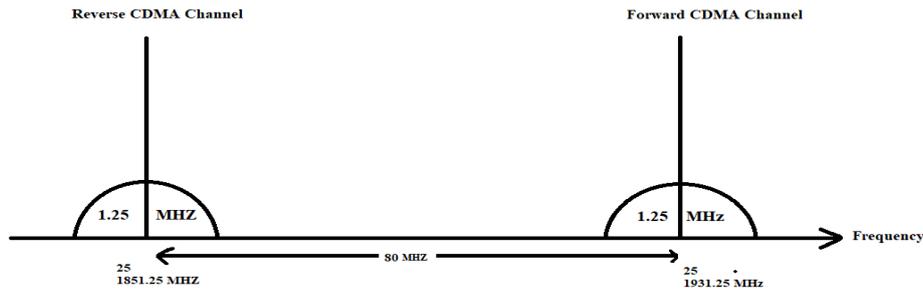
A code channel is a stream of data designated for a specific use or person. This channel may be voice data or overhead control data. In a CDMA system Channels are separated by codes, these channels are broadly categorized as forward and reverse channels. A CDMA channel is a pair of 1.25MHz frequency bands separated by guard-band. The guard-band may be 45 or 80MHz wide. The pair of 1.25MHz band is located either in the 82-893 MHz range in case of cellular CDMA or in the 1850-1989 MHz range in case of PCS CDMA. The guard band used in cellular is 45MHz for PCS for PCS it is 80 MHz. In both the cellular and PCS frequency ranges, CDMA channels have been identified by assigning CDMA channel numbers to the associated center frequencies for the two 1.25 MHz bands used by the channel. The channel numbers lie in the range 0-1023. Out of the two 1.25MHz bands associated with a CDMA channel, the higher frequency one is called the forward CDMA and the lower frequency one the reverse CDMA channel. The terms forward and reverse link are also used to refer to them. The forward link is used for any communication directed by the base station towards mobiles located within its coverage area. The Reverse link is used for any communication directed by the mobiles towards the base station with which they are connected .In general, each cell is assigned a specific CDMA channel which must be used by its base station and the mobiles within the cell. If the base station uses a sectorized antenna, each sector may be assigned a different CDMA channel. Thus sectorized cells may have 3 or 6 channels, instead of just one.

Example:

A CDMA channel in the cellular band(800MHz) is a pair of frequencies 45MHz apart. In this example channel 758 consists of a reverse CDMA channel, centered at 847.74 MHz and a forward CDMA channel centered at 892.74 MHz.



Similarly as defined below, a CDMA channel in the PCS band(1800 MHz) is a pair of frequencies 80 MHz apart. In this example channel 25 has a reverse CDMA channel centered at 1851.25 MHz and a forward CDMA channel centered at 1931.25 MHz.



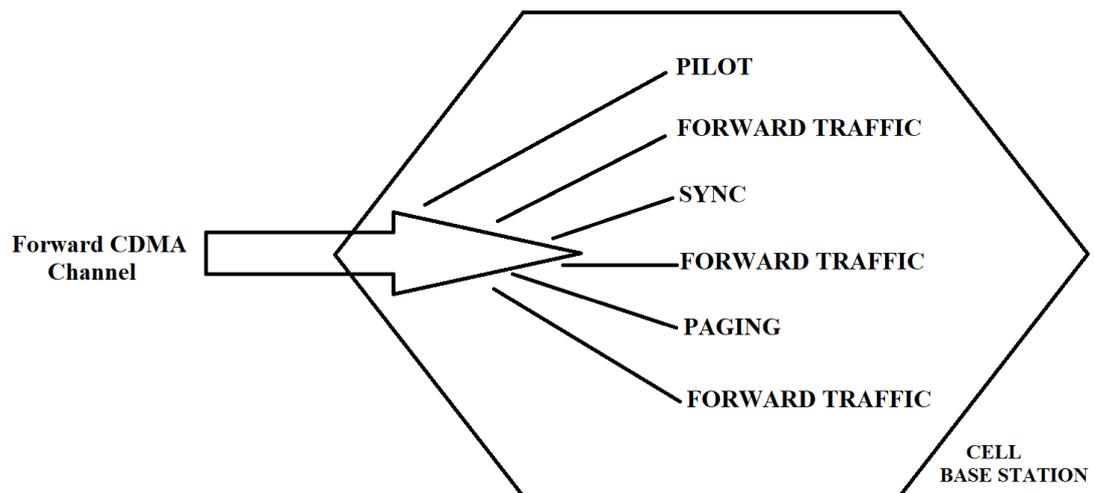
Forward CDMA Channel

The Forward CDMA channel is the cell-to-mobile direction of communication or the downlink path. It consists of four types of channels to transmit voice and control data to the mobile. The types of forward link channels are Pilot, Sync, Paging and Traffic channels.

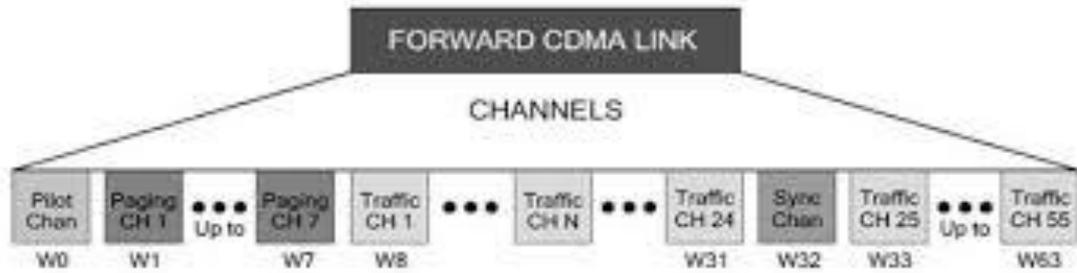
- a) **Pilot Channel:** It is a reference channel which the mobile station uses for acquisition, timing and as a phase reference for coherent demodulation. It is transmitted at all times by each base station on each active CDMA frequency. Each mobile station tracks this signal continuously and uses the pilot signal to monitor and adjust the power needed in order to transmit back to the base station. CDMA system relies heavily on power control. CDMA system can be compared to a room full of students all talking in a different language. So each language forms a code and all of the users are talking at the same time. The base station which understands all the languages can uniquely decode each of the languages. So all the user which are students in the class are using entire bandwidth all the time but using their own code which is the specific language to talk. Now, what is important is the student sitting in the first row must speak softly otherwise they will drown the sound coming from those sitting at the back bench. The users which are closer to the base station must transmit at lower power, those at far away must use a higher power. This has to be decided by some kind of a control channel and pilot channel is used to do that. As we know there is near far problem in CDMA system where there is a threat of our mobile close to the base station drowning the signals coming from a mobile far away from base station. Hence power control is essential for the proper working of CDMA system.
- b) **Sync Channel:** Sync Channel carries a single, repeating message that conveys the timing and system configuration information to the mobile station in the CDMA system. The BTS constantly transmits over the sync channel so that the mobile can synchronize with the base station. Synchronization is of most importance, it provides the mobile with the system time and the identification number of the cell site so it's primarily used for time synchronization. The mobile ignores the sync channel after it is synchronized. So it will transmit a set of known patterns by virtue of which you synchronize basically lock in. Synchronization data includes the PN code for the cell, system time, system ID, Network ID and the data rate used by the paging channels.
- c) **Paging Channel:** The primary purpose is to send out pages, that is, notifications of incoming calls, to the mobile stations. The base station uses them to transmit system

overhead information and mobile station- specific messages. CDMA uses upto 7 paging channels. The paging channel transmits overhead information such as commands and pages to the mobile. The paging channel also sends commands and traffic channel assignment during call setup. It may also be used to inform a mobile, which is already involved in a call to get ready to switch to a traffic channel owned by neighbouring cell, whose coverage area this mobile has entered. Such handoff direction messages are always conveyed using the paging channel. These channels are also used to initiate outgoing calls. Among 7 paging channels some of these are used as traffic channels. Data rate of paging channels is either 4.8kbps or 9.6kbps.

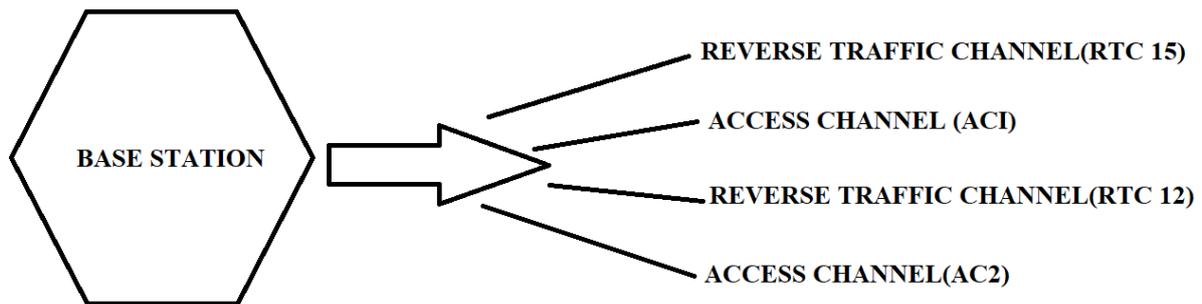
- d) **Traffic channel:** These channels are used to pass incoming voice traffic from the base station to the mobiles. CDMA uses between 55 and 61 forward traffic channels to send both voice and overhead control data during a call. Additionally commands to the mobile about whether to increase or decrease its transmitted power are embedded within the voice traffic and are retrieved and executed by the mobile. A minimum of 55 Forward Traffic Channels are generally supported by a cell or sector. The maximum data transmission rate per channel id 14.4kbps



Forward CDMA channel id divided into 64 code channels using 64 walsh codes as the chip sequence. The forward code channels are grouped into paging(1...7), Forward traffic (1...55), Pilot (1) and Sync(1) channel. Any unused forward channel is used as traffic channels.



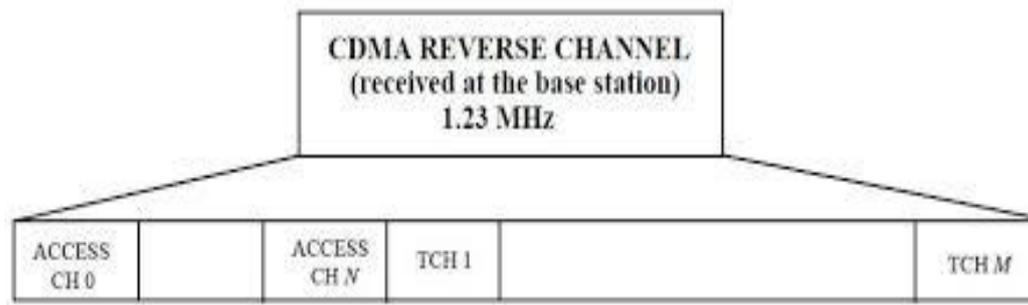
REVERSE CDMA CHANNEL



The Reverse CDMA channel is the mobile-to-cell direction of communication or the uplink path. The reverse link uses two types of channels to transmit voice and control data to the base station. The types of reverse link are Access channel and Traffic channel.

- a) **ACCESS CHANNEL:** The reverse link uses two types of channels to transmit voice and control data to the base station. The mobile uses the access channel when not assigned to a traffic channel. The mobile uses the access channels to:
- It has to register with the network so the moment you switch on the phone in any territory you have to register with the user with the network to tell okay i am here, i can be paged later on. Access channel is also used to originate calls, respond to pages and commands transmit overhead messages to the base station.
 - A set of these channels is generally associated with a specific paging channel on the forward link. These channels are used by the mobile to originate calls, to determine what paging channels it should monitor, respond to pages and to re-register with a new network or system when the mobile has roamed outside its parent network

- b) **TRAFFIC CHANNEL:** The reverse link traffic channel is used only when there is a call. The reverse traffic channel transmits voice data to the BTS, it also transmits the overhead control information during the call. It works in these steps: There is an initialisation and then there is an idle mode. It can go to access mode if there is a call initiated; you go to the traffic mode and then go back to the idle mode once the voice communication is over. The maximum data rate per channel is 14.4 kbps.



WALSH CODES

Numerous access schemes exist to allow multiple users to share a communication medium. One such access scheme is known as Code Division Multiple Access (CDMA). CDMA is a form of multiple access employed by spread-spectrum communication systems. In CDMA systems, a Wide band spreading signal is used to convert a narrowband data sequence to a wideband signal. The spreading signal typically comprises a pseudo noise (PN) sequence that has a chip rate several orders of magnitude higher than the data rate of the data sequence. The resulting wideband signal occupies a bandwidth in excess of the minimum bandwidth required to transmit the data sequence.

Each user has its own PN sequence which is approximately orthogonal to the PN sequences of other users (Orthogonal sequences has zero correlation. Two binary sequences are orthogonal if the result of 'exclusive-or-ing' them results in an equal number of 1's and 0's). The receiver selects the desired signal, which combines in the communication channel with unwanted signals, by performing a correlation operation. That is, the receiver correlates the received signal with the PN sequence of the desired signal. All other signals are spread by the PN sequence and appears as noise to the receiver. The Walsh code is utilized to distinguish the signals corresponding to each mobile station in the cell or sector signals after PN coding.

Orthogonal chip sequences of size 2^n , where $n \geq 1$, may be created using finite number of steps using the well-known walsh method. Walsh Codes are most commonly used in the orthogonal codes of CDMA applications. These codes correspond to lines of a special square matrix called the Hadamard matrix.

For a set of Walsh codes of length N, it consists of n lines to form a square matrix of $n \times n$ Walsh code. The IS-95 system uses 64 Walsh function matrix 64. The first line of this matrix contains a string of all zeros with each of the following lines containing different combinations of bit 0 and 1. Each line is orthogonal and equal representation for binary bits. When implemented with the CDMA system, each mobile user uses one of the 64 sequences

of rows in the matrix as a spreading code. And, it provides zero cross-correlation among all the other users. This matrix is defined recursively as follows –

Where n is a power of 2 and indicates the different dimensions of the matrix W . Further, \bar{n} represents the logic NOT operation on all bits in this matrix. The three matrices W_2 , W_4 , and W_8 , respectively show the Walsh function for the dimension 2, 4, and 8.

Recursion is used to generate higher order matrices from lower order ones; that is,

$$H_{2N} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{bmatrix}$$

where $\overline{H_N}$ contains the same but inverted element of H_N . The seed matrix is

$$H_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

Therefore, to derive a set of four orthogonal Walsh w_0, w_1 and w_3 , we only need to generate a Hadamard matrix of order 4, or

$$H_4 = \begin{bmatrix} H_2 & H_2 \\ H_2 & \overline{H_2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

The four orthogonal sequences in this Walsh code set are taken from the rows of the matrix H_4 ; that is

$$w_0 = [0 \ 0 \ 0 \ 0]$$

$$w_1 = [0 \ 1 \ 0 \ 1]$$

$$w_2 = [0 \ 0 \ 1 \ 1]$$

$$w_3 = [0 \ 1 \ 1 \ 0]$$

By changing the 0s to -1s in each of the four sequences above, that is :

$$w_0 = [-1 \ -1 \ -1 \ -1]$$

$$w_1 = [-1 \ +1 \ -1 \ +1]$$

$$w_2 = [-1 \ -1 \ +1 \ +1]$$

$$w_3 = [-1 \ +1 \ +1 \ -1]$$

We can easily verify that all of the above sequences except w_0 satisfy the orthogonality conditions. In general, the 0th Walsh sequence consists of all -1s and thus cannot be used for channelization.

In commercial CDMA implementation, as depicted in figure, a 64 X 64 matrix comprising 64 walsh codes is used. Each sequence is 64 chips long, and they are pair wise orthogonal with respect to one another, in the same CDMA cell, while sharing the same 1.25 MHZ channel.

	0000000000011111111122222222223333333333444444444455555555556666	
	01234567890123456789012345678901234567890123456789012345678901234567890123	
0	0000 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	0101
2	0011 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	0110
4	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
5	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
6	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
7	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
8	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
9	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
10	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
11	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
12	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
13	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
14	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
15	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
16	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
17	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
18	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
19	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
20	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
21	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
22	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
23	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
24	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
25	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
26	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
27	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
28	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
29	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
30	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
31	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
32	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
33	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
34	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
35	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
36	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
37	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
38	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
39	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
40	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
41	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
42	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
43	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
44	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
45	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
46	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
47	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
48	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
49	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
50	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
51	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
52	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
53	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
54	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
55	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
56	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
57	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
58	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
59	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
60	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000
61	0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101	0101
62	0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011 0011	0011
63	0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110 0110	0110
64	0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0000

WALSH CODE ASSIGNMENT

The 64 Walsh codes are distinguished as two types: one type being assigned to the overhead channels and the other type being assigned to the traffic channels (see Table1). The 0th code is assigned to the pilot channel; the 1st -7th codes are assigned to the paging channels; the 32nd code is assigned to the synchronization channel; and the remaining codes, i.e., the 8th - 31st and the 33rd -63rd codes, are assigned to the traffics. In the case where the 1st code is only utilized for the paging channel, the 2nd -7th codes (i.e., the remaining six codes) can be used as additional traffics. In the existing CDMA DCS (Digital Cellular System) and CDMA PCS (Personal Communication Services), the Walsh codes are serially allocated according to the generated calls or data being transmitted. That is, referring to Table1, if "n" calls occurred in a cell or a sector, the corresponding BCP (Base station Call control Processor) allocates respective "n" Walsh codes to the available codes code-by-code, except for the Walsh codes used for the overhead channels, i.e., the Walsh codes used for the pilot, the paging, and the synchronization channels. Referring to Table1, in the first state (S1), the Walsh codes for the pilot, the paging, and the synchronization are all BUSY (B), and all the Walsh codes for the traffics are IDLE (I). In the CDMA DCS and CDMA PCS system, when a call occurs the Walsh codes are searched serially to determine an IDLE Walsh code, i.e., a Walsh code which does not have a call assigned thereto. This typically involves a long processing time, and, in case of concurrent calls, a caller may have to wait a certain time before his call is assigned to an IDLE Walsh code, thereby, increasing the time required to set up the caller's call.

Table 1

Overhead						Traffic										
	Pilot	Paging			Sync											
W Code	W0	W1	.....	W7	W32	W8	W9	W10	W11	W12	W13	W14	W15	.....	W62	W63
States														...		
S1	B	B		B	B	I	I	I	I	I	I	I		.....	I	I
S2	B	B	.....	B	B	C1	C2	C3	C4	I	I	I	I	.....	I	I
S3	B	B	.....	B	B	C1	C2	C3	C4	C5	C6	C7	C0	.....	I	I
S4	B	B	....	B	B	C1	C2	C3	C4	I	C6	I	C8	.....	I	I
S5	B	B	.....	B	B	C1	C2	C3	C4	C9	C6	C10	C8	.....	I	I

CDMA IS 95

IS95 / cdmaOne was the first cellular telecommunications system to use the CDMA - code division multiple access system. Previous systems had used FDMA - frequency division multiple access or TDMA - time division multiple access. With IS-95 being a second generation - 2G system and all the later 3G systems using CDMA as their access system, this meant that IS95 / cdmaOne was a pioneering system. CDMA arrived on the mobile landscape around 1995 which works completely differently from previous systems. When CDMA was first proposed, the communications industry expressed doubts about its possible success when deployed in real-world, commercial environment. However, through the persistence of single company, Qualcomm, CDMA matured to the point where it was not acceptable, but was viewed as the best technical solution around and the basis for the third-generation mobile systems, competing head-on with D-AMPS. For example, sprint PCS uses CDMA, whereas AT&T wireless uses D-AMPS. CDMA is described in international standard IS-95 and is sometimes referred to by that name.

CDMA is completely different from AMPS, D-AMPS and GSM. Instead of dividing the allowed frequency range into a few hundred narrow channels, CDMA allows each station to transmit over the entire frequency spectrum all time, Multiple simultaneous transmissions are separated using coding theory. The advantage of using CDMA over FDMA and TDMA is that it enables a greater number of users to be supported. The improvement in efficiency is hard to define as it depends on many factors including the size of the cells and the level of interference between cells and several other factors.

Unlike the more traditional cellular systems where neighbouring cells use different sets of channels, a CDMA system re-uses the same channels. Signals from other cells will be appear as interference, but the system is able to extract the required signal by using the correct code in the demodulation and signal extraction process. Often more than one channel is used in each cell, and this provides additional capacity because there is a limit to the amount of traffic that can be supported on each channel.

The CDMA systems use direct sequence spread spectrum (DSSS) for modulation. The idea for using this form of modulation for a multiple access system for mobile telecommunications came from a California based company called Qualcomm in the 1980s. Previously DSSS had been mainly used for military or covert communications systems as the transmissions were hard to detect, jam and eavesdrop.

The system involves multiplying the required data with another data stream with a much higher data rate. Known as a spreading code, this widened the bandwidth required for the transmission, spreading it over a wide frequency band. Only when the original spreading code was used in the reconstruction of the data, would the original information be reconstituted. It was reasoned that by having different spreading codes, a multiple access system could be created for use in a mobile phone system. In order to prove that the new system was viable a consortium was set up and Qualcomm was joined by US network operators Nynex and Ameritech to develop the first experimental code division multiple access (CDMA) system. Later the team was expanded as Motorola and AT&T (now Lucent) joined to bring their resources to speed development. As a result the new standard was published as IS-95A in 1995 under the auspices of the Cellular Telecommunications Industry Association (CTIA) and the Telecommunications Industry Association (TIA). As part of the development of CDMA an organisation called the CDMA Development Group (CDG) was formed from the founding network and manufacturers. Its purpose is to promote CDMA and evolve the technology and standards, although today most of the standards work is carried out by 3GPP2.

It then took a further three years before Hutchison Telecom became the first organisation to launch a system. The IS 95 system was widely deployed in North America, and the Asia Pacific region, but there were also networks in South America, Africa, and the Middle East as well as some in Eastern Europe. With the success of the initial IS 95 format, improvements were made and the standard was upgraded to IS 95B. The main improvement was that this provided for an increased data rate of 115 kbps as data traffic was starting to be carried. The basic CDMA system was later further improved and evolved into a 3G system carrying much higher data rates and introducing new improvements. The 3G migration of IS95 was given the brand name cdma2000, and was available in a variety of flavours including cdma2000 1x, cdma2000 1x ev-do (evolution data only or data optimised) and another version was termed cdma2000 1x ev-dv (evolution data and voice), although this version was never seriously deployed.

Illustration of CDMA using Chip Sequences

In CDMA each bit time is subdivided into m short intervals called chips. Typically there are 64 or 128 chips per bit, but in the example given below we will use 8 chips per bit for simplicity. Each station is assigned a unique m -bit code called a chip sequence. There can be maximum of m such unique sequences, one assigned to each station. Hence a maximum of m stations. To transmit a 1 bit, a station sends its chip sequence. To transmit a 0-bit, it sends the one's complement of its chip sequence. This convention can be reversed, if desired. No other patterns are permitted. Thus, for $m=8$, if station A is assigned the chip sequence 00011011, it sends a 1 bit by sending 00011011 and a 0 bit by sending 11100100.

Increasing the amount of information to be sent from b bits/sec to mb chips/sec can only be done if the bandwidth available is increased by a factor of m , making CDMA a form of spread spectrum communication (assuming no changes in the modulation or encoding techniques). If we have a 1 MHz band available for 100 stations, with FDM each one would have 10kHz and could send at 10Kbps (assuming 1 bit per Hz, since S/N is 1 in free space). With CDMA, each station uses the full 1 MHz, so the chip rate is 1 mega-chip per second. With fewer than 100 chips per bit (100 chip sequences for 100 stations), the effective bandwidth per station is higher for CDMA than FDM, and the channel allocation problem is also solved.

For pedagogical purposes, it is more convenient to use a bipolar notation, with binary 0 being -1 and binary 1 being +1. We will show chip sequence in parenthesis, so a 1 bit for station A now becomes (-1 -1 -1 +1 +1 -1 +1 +1). In the figure given below, (a) we show the binary chip sequences assigned to four example stations. In (b) we show them in our bipolar notation.

A:00011011	A: (-1 -1 -1 +1 +1 -1 +1 +1)
B:00101110	B: (-1 -1 +1 -1 +1 +1 +1 -1)
C: 01011100	C: (-1 +1 -1 +1 +1 +1 -1 -1)
D:01000010	D: (-1 +1 -1 -1 -1 -1 +1 -1)

(a) Binary chip sequences for four station

(b) Bipolar chip sequence

Six Examples:

		ABCD		
	1	--1-	C	$S_1 = (-1 +1 -1 +1 +1 +1 -1 -1)$
	2	-11-	B + C	$S_2 = (-2 0 0 0 +2 +2 0 -2)$
Bit interval	3	10--	$A+B'$	$S_3 = (0 0 - 2 + 2 0 - 2 0 + 2)$
(1 → 6)	4	101-	$A+B' + C$	$S_4 = (-1 +1 -3 +3 +1 -1 -1 +1)$
	5	1011	$A+B+C+D$	$S_5 = (-4 0 -2 0 +2 0 +2 -2)$
	6	1101	$A+B+C' + D$	$S_6 = (-2 -2 0 -2 0 -2 +4 0)$

(c) Six examples of transmissions (transmission of each station during a bit interval/combined transmission during each bit interval)

$$S_1.C = (1 +1 +1 +1 +1 +1 +1 +1)/8=1$$

$$S_2.C = (2 +0 +0 +0 +2 +2 +0 +2)/8=1$$

$$S_3.C = (0 +0 +2 +2 +0 -2 +0 -2)/8= 0$$

$$S_4.C = (1 +1 +3 +3 +1 -1 +1 -1)/8= 1$$

$$S_5.C = (4 +0 +2 +0 +2 +0 -2 +2)/8= 1$$

$$S_6.C = (2 -2 +0 -2 +0 -2 +4 +0)/8= -1$$

(d)Recovery of station C's signal (extracted C's transmission during each bit interval)

Each station has its own unique chip sequence. Let us use the symbol S to indicate the m-chip vector for station S, and S for its negation. All m chip sequences are pair-wise orthogonal(i.e, the ex-or of any pair of sequences results in equal number of 1's and 0's),by which we mean that the normalized product of any two distinct chip sequences (expressed in bipolar notation), S and T(written as S.T) is 0.The technique for generating such sequences known as walsh codes. In mathematical terms, orthogonality of the chip sequence can be expressed as follows:

$$S.T = \frac{1}{m} \sum_{i=1}^m S_i T_i = 0$$

The normalized inner product of any chip sequence with itself is 1:

$$S.S = \frac{1}{m} \sum_{i=1}^m S_i S_i = \frac{1}{m} \sum_{i=1}^m S_i^2 = \frac{1}{m} \sum_{i=1}^m (\pm 1)^2 = 1$$

This follows because each of the m terms in the inner product is 1, so the sum is m, Also S.S=-1.

During each bit time a station can transmit a 1 bit by sending its chip sequence, it can transmit a 0 by sending the negative of its chip sequence,or it can transmit a 0 by sending the negative of its chip sequence,or it can be silent and transmit nothing. For the moment we assume that all stations are synchronised in time, so all chip sequences begin at the same instant.

When two or more stations transmit simultaneously, their bipolar signals add linearly. For example, if in one chip period three stations output +1 and one station outputs -1, the result is +2. One can think of this as adding voltages: three stations outputting +1 volts and 1 station outputting -1 volts gives 2 volts.

In the example(c) above we saw six examples of one or more stations transmitting at the same time.In the first example, C transmits a bit, so we just get C's chip sequence. In the second example both B and C transmit 1 bits, so we get the sum of their bipolar chip sequences, namely:

$$(-1 -1 +1 -1 +1 +1 +1 -1) + (-1 +1 -1 +1 +1 +1 -1 -1) = (-2 0 0 0 +2 +2 0 -2)$$

In the third example, station A sends a 1 and station B sends a 0. The others are silent. In the fourth example, A and C send a 1 bit while B sends a 0 bit. In the fifth example, all four stations send a 1 bit. Finally, in the last example A, B and D send a 1 bit, while C sends a 0 bit. The six sequences S1 through S6 given in the figure represent only one bit time.

To recover the bit stream of an individual station, the receiver must know that station's chip sequence in advance. It does the recovery by computing the normalized inner product of the received chip sequence (the linear sum of all the stations that transmitted) and the chip sequence of the station whose bit stream it is trying to recover. If the received chip sequence is S and the receiver is trying to listen to a station whose chip sequence is C, it just computes the normalized inner product, S.C. To see why this works, just imagine that two stations, A and C, both transmit a 1 bit at the same time that B transmits a 0 bit. The receiver sees the sum, $S=A+B'+C$ and computes

$$S.C=(A+B'+C) \cdot C=A.C+B'.C+C.C=0+0+1=1$$

The first two terms vanish because all pairs of chip sequences have been carefully chosen to be orthogonal, which is the reason why the orthogonality property must be imposed on the chip sequences. An alternative way to think about this situation is to imagine that the three chip sequences all came in separately, rather than summed. Then, the receiver would compute the inner product with each one separately and add the results. Due to the orthogonality property, all the inner products except C.C would be zero. Adding them and then doing the inner product is in fact the same as doing the inner products and then adding those.

To make the decoding process more concrete, let us consider the six examples of transmission shown above. Suppose that the receiver is interested in extracting the bit sent by station C from each of the six sums s_1 through s_6 . It calculates the bit by summing the pairwise products of the received S and the C vector, and then taking 1/8 of the result (since $m=8$ here). As shown earlier the correct bit is decoded each time

Features of IS-95

IS-95 allows each user within a cell to use the same radio channel, and users in adjacent cells also use the same radio channel, since this is a direct sequence spread spectrum CDMA system. CDMA completely eliminates the need for frequency planning within a market. To facilitate graceful transition from AMPS to CDMA, each IS-95 channel occupies 1.25 MHz of spectrum on each one-way link, or 10% of the available cellular spectrum for a U.S. cellular provider (recall, the U.S. cellular system is allocated 25 MHz and each service provider receives half the spectrum or 12.5 MHz). In practice, AMPS carriers must provide a 270 kHz guard band (typically 9 AMPS channels) on each side of the spectrum dedicated for IS-95.

Unlike other cellular standards, the user data rate (but not the channel chip rate) changes in real-time, depending on the voice activity and requirements in the network. Also, IS-95 uses a different modulation and spreading technique for the forward and reverse links. On the forward link, the base station simultaneously transmits the user data for all mobiles in the cell by using a different spreading sequence for each mobile. A pilot code is also transmitted

simultaneously and at a higher power level, thereby allowing all mobiles to use coherent carrier detection while estimating the channel conditions. On the reverse link, all mobiles respond in an asynchronous fashion and have ideally a constant signal level due to power control applied by the base station.

Channel Specifications

IS-95 is specified for reverse link operation in the 824 - 849 MHz band and 869 - 894 MHz for the forward link. A forward and reverse channel pair is separated by 45 MHz. Many users share a common channel for transmission. The maximum user data rate is 9.6 kb/s. User data in IS-95 is spread to a channel chip rate of 1.2288 Mchip/s using a combination of techniques. The spreading process is different for the forward and reverse links. On the forward link, the user data stream is encoded using a rate 1/2 convolutional code, interleaved, and spread by one of sixty-four orthogonal spreading sequences (Walsh functions). Each mobile in a given cell is assigned a different spreading sequence, providing perfect separation among the signals from different users, at least for the case where multipath does not exist. To reduce interference between mobiles that use the same spreading sequence in different cells, and to provide the desired wideband spectral characteristics (not all of the Walsh functions yield a wideband power spectrum), all signals in a particular cell are scrambled using a pseudorandom sequence of length 2^{15} chips.

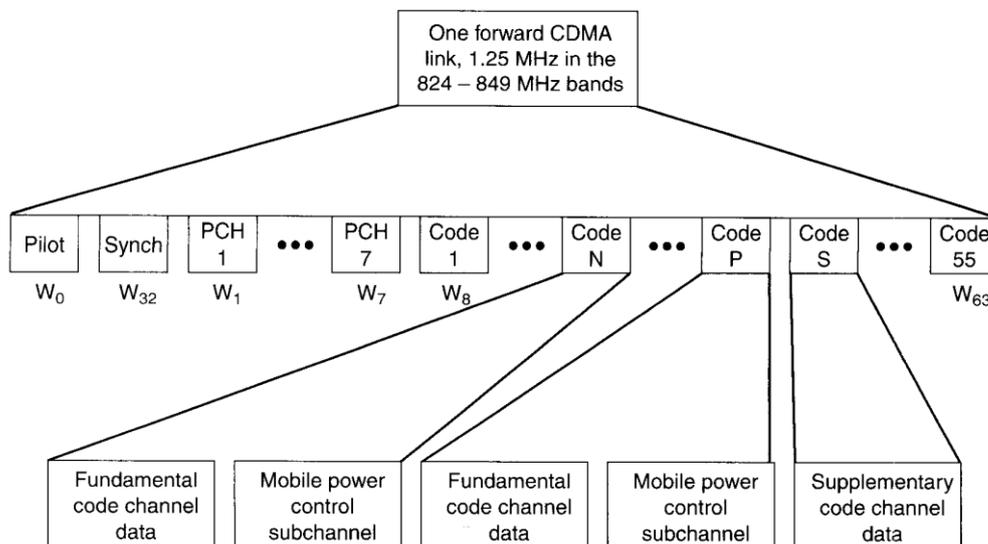
Orthogonality among all forward channel users within a cell is preserved because their signals are scrambled synchronously. A pilot channel (code) is provided on the forward link so that each subscriber within the cell can determine and react to the channel characteristics while employing coherent detection. The pilot channel is transmitted with less power than the user channels. On the reverse link, a different spreading strategy is used since each received signal arrives at the base station via a different propagation path. The reverse channel user data stream is first convolutionally encoded with a rate 1/3 code. After interleaving, each block of six encoded symbols is mapped to one of the 64 orthogonal Walsh functions, providing sixty-four-ary orthogonal signaling. A final fourfold spreading, giving a rate of 1.2288 Mchip/s, is achieved by spreading the resulting 307.2 kchip/s stream by user-specific and base-station specific codes having periods of $2^{42} - 1$ chips and 2^{15} chips, respectively. The rate 1/3 coding and the mapping onto Walsh functions result in a greater tolerance for interference than would be realized from traditional repetition spreading codes. This added robustness is important on the reverse link, due to the non-coherent detection and the in-cell interference received at the base station.

Another essential element of the reverse link is tight control of each subscriber's transmitter power, to avoid the "near-far" problem that arises from varying received powers of the users. A combination of open-loop and fast, closed-loop power control is used to adjust the transmit power of each in-cell subscriber so that the base station receives each user with the same received power. Without fast power control, the rapid power changes due to fading would degrade the performance of all users in the system.

IS-95 CDMA Forward channel

The CDMA forward channel is between the base station and the mobile station. The forward link IS-95 occupies the same frequency spectrum as AMPS. Each carrier of the IS-95 occupies a 1.25 MHz of band, whereas carriers of AMPS and IS-136 each occupy 30kHz of bandwidth. The IS-95 forward channel consists of four types of logical channels- pilot channel, synchronization channel, paging channel and traffic channels. As shown in figure each carrier contains a pilot, a synchronization, up to seven paging, and a number of traffic channels. These channels are separated from one another using different spreading codes. The modulation scheme employed for transmission of spread signal in the forward channel is QPSK. The orthogonal codes are used to isolate the transmission between different channels within a cell, and the PN spreading codes are used to separate the transmissions between different cells.

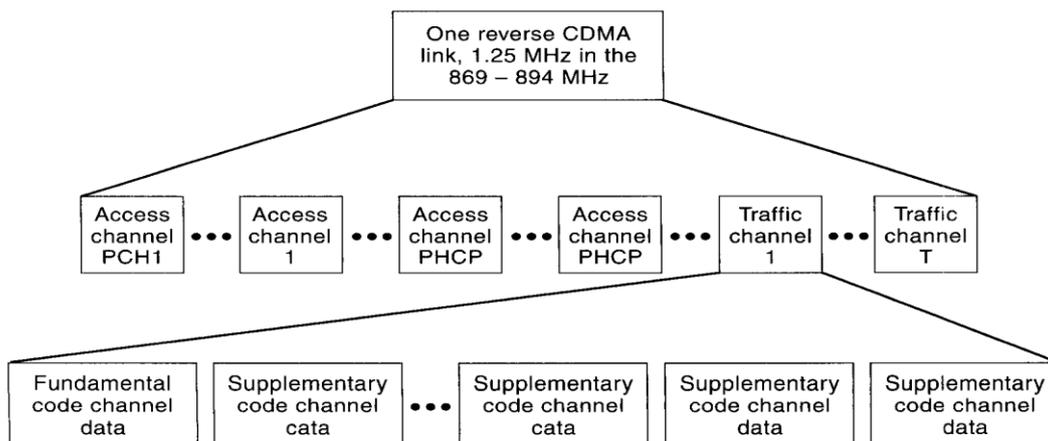
The paging channel is used to page the MS when there is an incoming call, and to carry the control messages for call setup. It employs walsh codes 1 to 7 so that there may be up to seven paging channels. There is no power control for the pilot, sync and paging channels. The traffic channels carry the actual user information (ie. Digitally encoded voice or data). The forward traffic channel has two possible rate sets called RS1 and RS2. RS1 supports data rates of 9.6, 4.8, 2.4 and 1.2 kbps. RS2 supports 14.4, 7.2, 3.6 and 1.8kbps. RS1 has mandatory support for IS-95, and RS2 can be optionally supported. Walsh codes W_2 through W_{31} and W_{33} through W_{63} can be used to spread the traffic channels depending on how many paging channels are supported in the cell.



IS-95 Forward Channel

IS-95 CDMA Reverse channel

The CDMA reverse channel is fundamentally different from the forward channel. It employs OQPSK rather than QPSK used in the forward channel. Compared with the forward channel, there is no spreading of the data symbols using orthogonal codes. Reverse link employs an orthogonal modulation scheme that consumes bandwidth but reduces the error rate performance of the system. There are basically two types of reverse channels in IS-95 the access channels and reverse traffic channels. The reverse traffic channel, like the forward traffic channel, supports voice data at two rate sets- RS1 and RS2.



IS-95 Reverse Channel

Reading Assignment : *Pageno :355-363 section 8.3 to 8.3.2* Principles of wireless networks by Kaveh Pahalvan & Prashant Krishnamurthy

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