IS-95 North American Standard –
A CDMA Based Digital Celluar System

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ABSTRACT

This paper provides an introduction to the IS-95 Standard. The first important issue is on explaining the key aspects of IS-95 technology used for information transmission in a cellular mobile environment. Then we focus on the description of system architecture, which serves as an reference of thorough details. A calling process example is shown for practical system inference. Finally, primary benefits of this technology and some of its drawbacks are also discussed in this paper.

1 Introduction

1.1 IS-95 and CDMA Technology

Interim Standard 95 (IS-95) is a North American digital cellular standard base on the Code Division Multiple Access (CDMA) Technology. It is formally adopted by the U.S. Telecommunication Industry Association (TIA) on July 16, 1993, and was revised in May of 1995 with minor improvements. The IS-95 system is designed to be compatible with the exiting U.S. analog cellular system (Advanced Mobil Phone System, AMPS) frequency band, hence mobile and base stations can be economically produced for dual mode operation. The first commercial product, developed by Qualcomm, Inc., was available in 1994[1].

Code Division Multiple Access (CDMA) is a class of multiple access technology that uses specialized codes to provide multiple communication channels in a designated segment of the electromagnetic spectrum[2]. It was proposed by A. J. Viterbi in 1985[3]. CDMA is based on the Spread Spectrum communication technology which has been used in military communications for over half a century, primarily for two purposes: to overcome the effects of strong intentional interference (jamming), and to hide the signal from the eavesdropper (covertness)[4]. For commercial wireless applications, the spread spectrum technology achieves much higher bandwidth efficiency for a given wireless spectrum allocation, and hence serves a far large population of multiple access users, than analog or other digital technologies.

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. This universal frequency reuse increases the efficiency of spectrum usage and eliminates the chore of planning for different frequency allocation for neighboring users or cells.

The fast and accurate power control method used in IS-95 ensures a high level of transmission quality, and hence a low level of interference to other user terminals. In 1991, Gilhousen et al. proved that CDMA indeed is only interference limited[5]. That means that any reduction in interference converts directly and linearly into an increase in capacity.

At both the base station and the mobile in IS-95, RAKE receivers are used to resolve and combine multipath components, thereby reducing the degree of fading. A RAKE receiver exploits the multipath time delays in a channel and combines the delayed replicas of the transmitted signal[1]. Another major benefit with IS-95 is the soft handoff technique used among multiple cell base stations, which provides improved cell-boundary performance and prevents dropped call.

1.2 Other Celluar Standards

Celluar mobile radio differs from previous mobile radio designs in two critical areas: *frequency reuse* and *cell splitting*[6]. With conventional mobile radio systems, the objective is to have each fixed base station cover as large an area as possible by using antennas mounted in high towers and the maximum affordable power. Each base station is assigned a group of disjoint channels. With celluar systems, the power radiated by the base stations is kept to a minimum and the antennas are located just high enough to achieve the desired coverage. These procedures enable cells to use the same set of frequencies. By splitting an area into small cells, therefore, the number of customers that can be served in a given area increases because each channel serves more customers in different cells.

In the late 1970s, AT&T Bell Laboratories developed the first U.S. celluar system called the Advanced Mobile Phone Service (AMPS). The AMPS is an analog, cellular system which uses frequency modulation (FM) for radio transmission. Frequency Division Multiple Access (FDMA) is used for multiple access. In the U.S., transmissions from mobiles to base stations (reverse link) use frequencies between 824 MHz and 849 MHz, while base stations transmit to mobiles (forward link) using frequencies between 869 MHz and 894 MHz. A similar system, the European Total Access Communication System (ETACS), was developed in Europe in the mid 1980s[1].

Digital celluar systems emerged during the late 1980s. They offer large improvements in capacity and system performance[8]. In 1990, the first digital celluar system, Interim Standard 54 (IS-54), was approved by TIA. IS-54 system was designed to share the same frequencies, frequency reuse plan, and base stations as AMPS. It is also known as Digital AMPS (D-AMPS) or United States Digital Cellular System (USDC). IS-54 is a Time Division Multiple Access (TDMA) system which offers as much as six times the capacity of AMPS.

Global System for Mobile (GSM) was developed in Europe and was first introduced into the market in 1991. GSM is the world's first cellular system to specify digital modulation and network level architectures and services. GSM services follow ISDN guidelines and are classified as either *teleservices* or *data services*. Teleservices include standard mobile telephony and mobile-originated or base-originated traffic. Data services include computer-to-computer communication and packet-switched traffic. GSM uses a combination of TDMA and Frequency Hopping (FH) schemes to provide simultaneous multiple access.

Japanese Digital Cellular Standard (JDC), also known as Personal Digital Cellular (PDC), was developed in 1991 to provide for needed capacity in congested cellular bands in Japan[9]. It is somewhat similar to the IS-54 standard.

1.3 Structure of Paper

In Section 1, we have briefly introduced the IS-95 Standard and CDMA technology. We have also shown other existing standards that are competitors to the IS-95. Section 2 and Section 3 are general description of IS-95. In Section 2, we discuss, at first, an important issue: "how can I transmit a message via IS-95". We start this problem by describing a general radio communication system and depict the technology used in IS-95. In Section 3, we discussion the problems involved in a celluar environment and show how IS-95 deals with them. In Section 4, the detailed IS-95 Architecture will be shown. The purpose of this section is to provide readers a detailed description of IS-95. An operational example of IS-95 is in Section 5. Section 6 includes a series of discussion about the performance of IS-95 system. Finally, we will make a conclusion in Section 7.

2 IS-95 Technology I: Radio Communication System

In the following two sections, we will discuss the technology used in an IS-95 System. A through IS-95 system includes several techniques that are mutually related. However, those techniques may be roughly classified as belonging to two parts: *Communicaiton System* and *Celluar Environment.* At first, we focus our discussions on the wireless communication system techniques that are used in IS-95. A general communication system concerns about how to transmit information from users at one place to users at another. Discussion issues in a digital communication system generally include: *Coding*, *Ciphering*, *Multiplexing*, and *Modulation.* We will discuss them later in this section. The second category includes the issues generally concerned in a celluar environment. In such an environment, some practical problems such as Propagation Loss, Fading, Multipath, Frequency Reuse, Power Control, Handoff Strategies, etc.. Such issues and their related technology will be discussed in Section 3.

2.1 Digital Wireless Communication System

Regardless of the particular application and configuration, all information transmission systems invariably involve three major subsystems - a transmitter, the channel, and a receiver[10]. To transmit digital information from a transmitter to a receiver, four steps are usually concerned in such a system: *Coding*, *Ciphering*, *Multiplexing*, and *Modulation.* Coding is used for two purposes: representing the data more efficiently and/or generating codes that are more resistant to noise. Ciphering is used for deferring unauthorized access to the information transmitted. Multiplexing is a technology that allows a communication system serve many users simultaneously. The final stage, Modulation, is the method of switching frequency bands for trasmitting signals via electromagnetic waves.

In a mobile radio system, there is a fixed *base station* located at the center or on the edge of a coverage region and consist of radio channels. There are transmitter and receiver antennas mounted on a tower. Many *mobile stations* in the coverage region communicate to other terminals

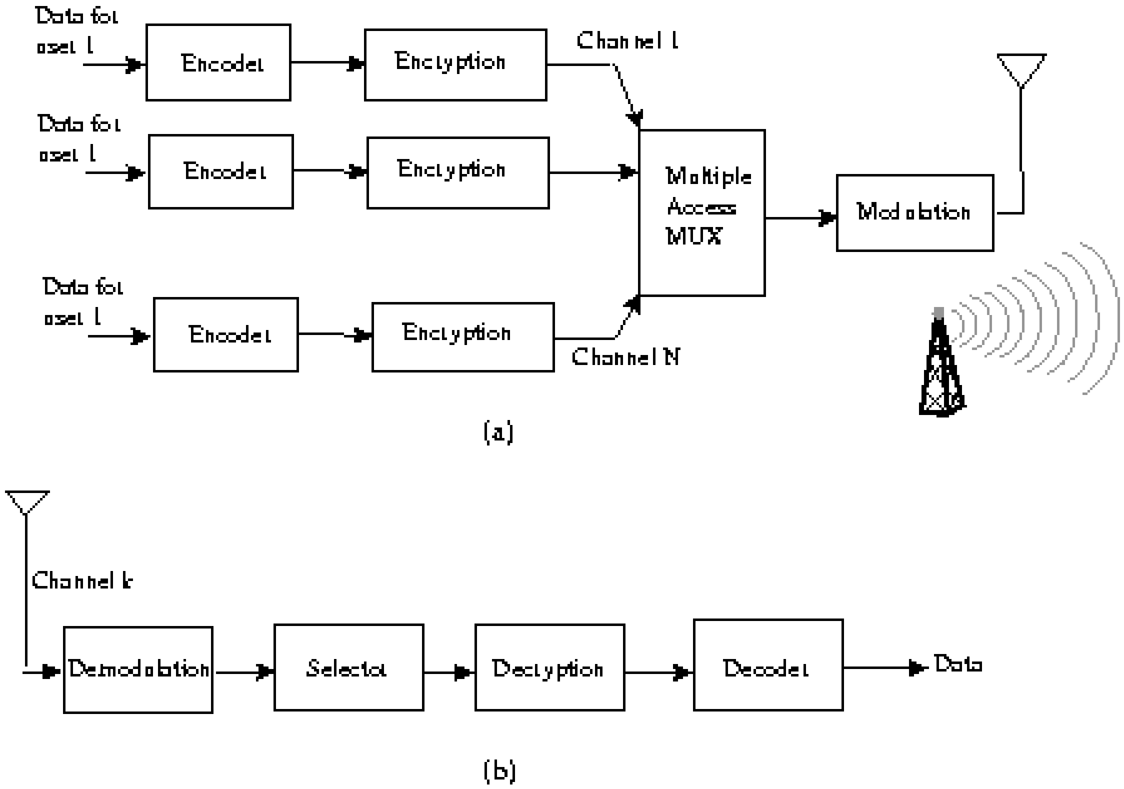


Figure 1: General Wireless Communication System I: (a) Transmission Process from Base Station, (b) Receiving Process at Mobile.

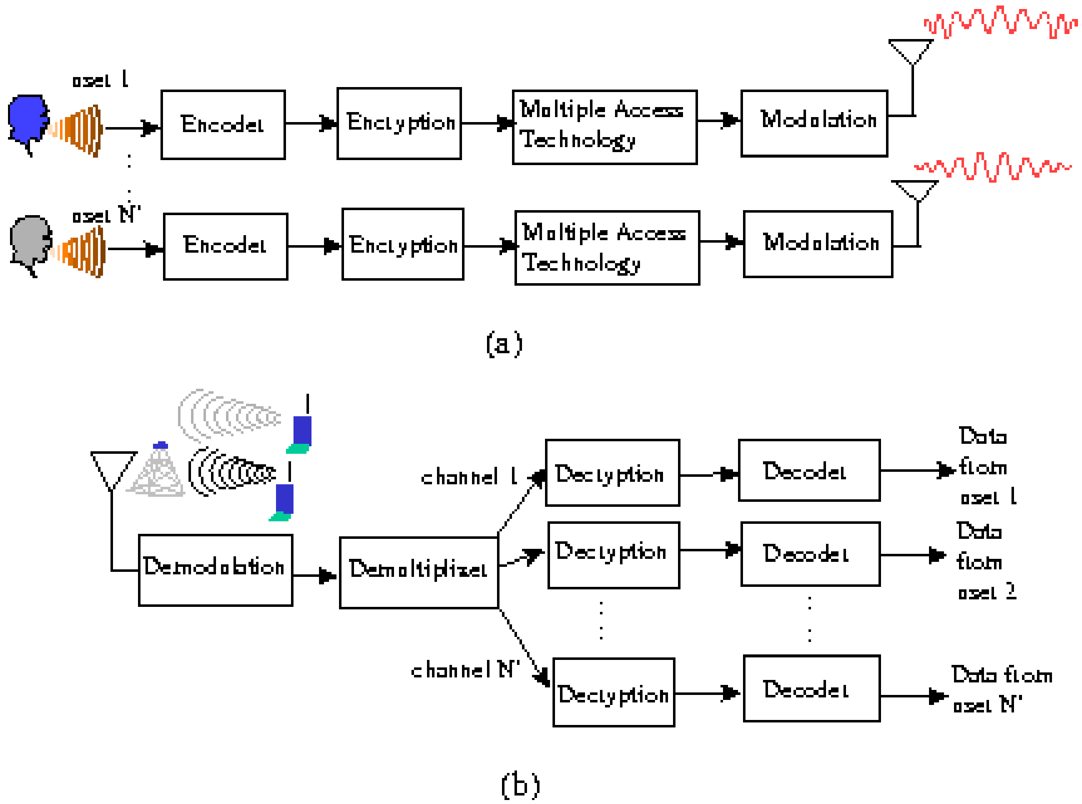


Figure 2: General Wireless Communication System II: (a) Transmission Process from Mobile, (b) Receiving Process at Base Station.

in the world through the base station. All communications are made between the base station (BS) and mobile stations (MS). No direct communications exist between mobiles. Fig. 1 represents the transmission process from the base station to the mobiles. It is generally called as *forward link* or *downlink*. Fig. 2 is the process for the mobile-to-base-station transmission. It is known as *reverse link* or *uplink*.

In the following four subsections, we will show the techniques used in IS-95 standards. We only discuss their concepts in this section and leave their details discussed in Section 4.

2.2 Multiple Access Method in IS-95 – CDMA

In a communication system, the task of multiple access technology is to transmit messages from many users simultaneously without mutual interference. Traditionally, signals are considered from two approaches: *time* and *frequency*. Therefore, it is nature that there are two basic strategies whereby resources are seperated to serve multiple users: Frequency Division Multiple Access (FDMA), where each user is assigned to a different frequency, and Time Division Multiple Access (TDMA), where each user is assigned to a different time slot.

A completely different approach, suggested at least in part by the principles of Shannon's information theory, does not attemp to allocate disjoint frequency or time resources to each user. Instead this approach spreads the message from each user to longer codes. Codes from different users are mutually statistically uncorrelated, i.e., orthogonal. Therefore, a correlator with the property of the codes of a specific user can extract the information from him/her even though all users' codes are mixed. This method is called as Code Division Multiple Access (CDMA).

CDMA allocates all resources to all simultaneous users. The required power transmitted by each is, therefore, controlled to the minimum to maintain a given signal-to-noise ratio for the required level of performance. CDMA takes advantage of multipath fading to enhance communications and voice quality because fading causes a substantial degradation of signal quality in narrowband systems such as FDMA and TDMA. In other words, a CDMA system attributes mainly on *System Capacity*, *Economics*, and *Quality of Service*.

In IS-95 standard, the CDMA operations are slightly different in uplink and downlink. In downlink, the base station use Walsh codes to generate orthogonal codes. There are 64 Walsh codes used in a base station, and they are deterministic, strictly orthogonal, and most efficient. In uplink, each mobile use a long "Pseudo-Noise (PN) Codes" to spread the message. The PN sequence generator is seeded with data received in messages sent from the base station[11]. The same seed is used in both directions.

2.3 Modulation Method in IS-95 – QPSK in Downlink and OQPSK in Uplink

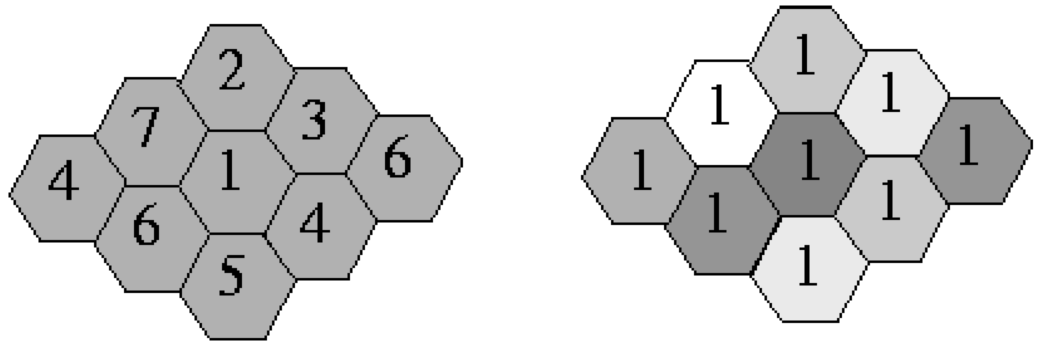
Quadrature Phase-Shift Keying (QPSK) digital modulation technique is derived from Binary Phase-Shift Keying (BPSK). In BPSK, the phase of a constant cmplitude carrier signal is switched between two values according to the two possible signals m_0 and m_1 corresponding to binary 1 and 0, respectively. Normally, the two phases are separated by $\frac{\pi}{2}$. QPSK modulation can be viewed as two independent BPSK modulations. In QPSK, the binary input waveform is split into two orthogonal waveforms that are denoted as the in-phase component (I) and quadrature component (Q). Then, these two components are modulated by BPSK, seperately, and their outputs are summed as the RF signal transmitted.

In IS-95, the stage of waveform splitting process is conducted by two short PN Sequence. Adjacent cells distinguish one another by using different time offsets on the short codes in this stage. Therefore, adjacent cells can share the same spectrum without confliction.

Modulation methods are not exactly the same in uplink and in downlink. In downlink, the QPSK method described above is used. In uplink, Offset-QPSK (OQPSK) modulation method is used. With OQPSK, for the quadrature channel (Q), a delay of $\frac{1}{2}$ of a PN symbol is added before BPSK modulation.

2.4 Coding Method in IS-95 – CELP Vocoder & Interleaver

IS-95 uses a a code-excited linear prediction (CELP) voice-encoding system at 8 kbps and optionally at 13 kbps. CELP systems model the operation of the human vocal tract to code speech efficiently, whcih is one kind of Vocoder[12]. Vocoders are a class of speech coding systems that analyze the voice signal at the transmitter, transmit parameters derived from the analysis, and



FDMA Reuse

CDMA Reuse

Figure 3: Cellular Frequency Reuse Patterns: (a) FDMA Reuse, adjacent use different frequencies, (b) CDMA Reuse, adjacent cell use the same frequencies but different QPSK spreading codes

then synthesize the voice at the receiver using those parameters. Vocoders are in general much more complex than the waveform coders and achieve very high economy in transmission bit rate.

For IS-95, the data bits can be voice, data, or signaling. They are multiplexes before a convolutional encoder. The data bits are then repeated, and interleaved by frames. By interleaving the data, no two adjacent bits are transmitted near to each other, and the data errors are randomized. These process are used to enhance the transmitted data to be more robust to the noise.

2.5 Ciphering Method in IS-95 – Stream Cipher

In IS-95, following the interleaver in the coding process, the data is scrambled by the use of a long code, which serves only as a privacy mask. A simple Stream Cipher method is used for data scrambling. With this method, in the encryption process, a stream of bits, which is called a keystream, is XORed with a stream of plaintext bits to produce the stream of ciphertext bits. In the decryption process, the ciphertext bits is then XORed with the keystream used in the encryption to reproduce the original plaintext bits.

In downlink, a long code which is generated by a pseudorandom binary sequence the is generated as a keystream. Only the mobile with the corresponding seed can generate the same keystream, and decrypt the ciphertext. In uplink, there is no sepearate operation for ciphering because similar functions have been included in the Walsh functions and spreading process.

3 IS-95 Technology II: Cellular Mobile Environment

3.1 Frequency Reuse in IS-95

Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region. Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a *cell*. Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. Adjacent cells use different frequency band in FDMA and TDMA based systems. However, in IS-95, adjacent cells use the same frequency band. As we discussed in the last section, different cells use different time offsets on QPSK to distinguish channels. The *frequency reuse* (or called as *frequency planning*) in FDMA and CDMA is shown in Fig. 3.

3.2 Power Control in IS-95 – Open Loop and Closed Loop

Control of the mobile station power is essential for IS-95 to work. If one mobile station were to be received at the base station with too much power, it raises unnecessarily the amount of interference experienced by other users, and could jam them[2].

The goal is to have the signal of all mobile stations arrive at the base station with exactly the same and adequate power. Two forms of power control are used: *open-loop* and *closed-loop.* Open-loop power control is based on the similarity of loss in the forward and reverse paths. The received power at the mobile station is used as a reference. For example, if it is low, the mobile station is presumed to be far from the base station, therefore it transmits with high power. The product of the two powers is a constant. Closed-loop power control is used to force the power from the mobile station to deviate from the open-loop setting. This is done by an active feedback system from the base station to the mobile station.

Because the IS-95 mobile station transmits only enough power to maintain a link, the average transmitted power is much lower than that required for an analog system. An analog cellular phone always transmits enough power to overcome a fade, even though a fade does not exist most of the time. The IS-95's advantage in transmitting with lower power has the potential of longer battery life and smaller, lower-cost output amplifier design.

3.3 Handoff in IS-95 – Soft Handoff

The IS-95 cellular system provides a unique handoff capability that can not be provided with other wireless systems – *soft handoff.* Soft handoff is a make-before-break system in which two cell sites maintain a link with one mobile simultaneously. Unlike channelized wireless systems that assign different radio channels during a handoff (called a *hard handoff*), spread spectrum mobiles share the same channel in every cell. When a call is in a soft handoff condition, a mobile user is monitored by two or more cell sites and the transcoder circuitry compares the quality of the frames from the two receive cell sites on a frame-by-frame basis. The system can take advantage of the moment-by-moment changes in signal strength at each of the two cells to pick out the best signal. This ensures that the mobile station may actually decide which version of the user's signal is best at any moment in time.

3.4 Diversity Techniques in IS-95

Diversity is a commonly used technique in mobile radio systems to combat signal fading[14]. IS-95 makes use of multiple forms of diversity: *spatial diversity, frequency diversity,* and *time diversity.*

The traditional form of spatial diversity, using multiple antennas, is used for the cell site receiver. Another form of spatial diversity is used is the *soft handoff* technique mentioned in the last subsection.

Frequency diversity is provided in the bandwidth of the transmitted signal. A multipath environment will cause fading, which looks like a notch filter in the frequency domain. The width of the notch can vary, but typically will be less than 300 kHz. While this notch is sufficient to impair ten analog channels, it only removes about 25% of the CDMA signal[2].

Multipath signals are used to advantage, providing a form of time diversity. The multiple correlative receiver elements can be assigned to different, time delayed copies of the same signal. These can be combined in what is called a RAKE receiver which has multiple elements called *fingers*. The term RAKE refers to the original block diagram of the receiver which includes a delay line with multiple taps. By weighting the signal at each tap in proportion to its strength, the time-diverse signals are combined in an optimal manner.

Another form of time diversity is the use of forward error correcting codes followed by interleaving, which we have discussed in Section 2.

4 IS-95 Architecture

4.1 IS-95 Forward Channels

4.1.1 Frequency Plan & Forward Channels

The FORWARD CHANNEL is the cell-to-mobile direction of communication. The forward link consists of up to 64 logical channels (code channels) that are separated by Walsh Codes. Those channels include: a pilot channel, asynchronization channel, up to 7 paging channels, and remaining forward traffic channels.

The base station transmit frequency is 45 MHz above the mobile station transmit frequency in the cellular service (IS-95A). Permissible frequency assignments are on 30 kHz increments in cellular.

4.1.2 Forward Link Encoding

Coding & Interleaving

The fundamental data rate of the channel is 9600 bps. The data is packetized into 20-ms blocks and has forward error correction applied by use of a convolutional encoder. This is done at half rate, while yields two bits out for every bit in. The data is then interleaved.

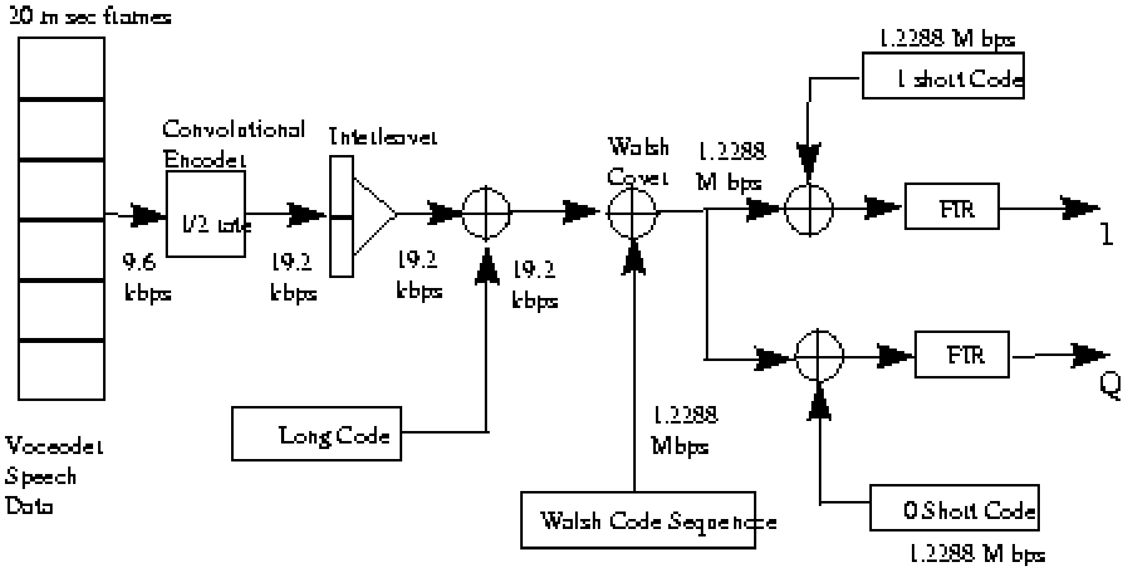


Figure 4: IS-95 Forward Link Physical Layer

Data Scrambling

The data is scrambled by a stream cipher following the interleaver. A PN long code, keystream, is generated by a 42-bit-long shift register. This register is also used as the master clock of the system, and is synchronized to the limit of propagation delays among all base stations and mobile stations. A mask is applied to the generator that selects a combination of the available bits. These are added modulo two by way of exclusive-OR gates to generate a single bit stream at 1.2288 MHz. For the forward link, a data rate of only 19.3 kbps is needed, so only 1 of 64 bits get used. The long code generated in this way is XORed with the data from the interleaver.

Spread Spectrum & Walsh Code

The resulting data is then encoded using the Walsh matrix. One row of the Walsh matrix is assigned to a mobile station during call setup. If a 0 is presented to the Walsh cover, then the 64 bits of the assigned row of the Walsh matrix are sent. If a 1 is presented, then the NOT of the Walsh matrix row is sent. This has the effect of raising the data rate by a factor 64, from 19.2 kbts to 1.228 Mbps.

The Walsh codes are based on the Walsh matrix, a square matrix with binary elements that always have its dimensions as powers of two. It has the property that every row is orthogonal to every other row. Orthogonal means that the inner product of any two rows is zero. Between any two rows exactly half the bits match and half the bits do not match. The CDMA system uses a 64 by 64 bit Walsh matrix[2].

Because only whole periods of the Walsh functions occur in each code symbol, the effect of the Walsh cover is to make the channels completely separable in the receiver, at least in the absence of multipath. Moreover, The orthogonality not only means that there is no co-mingling of channels, it means there is no interference between users in the same cell, again in the absence of multipath.

This has a substantial beneficial effect on the forward link capacity.

RF Modulation

QPSK is used for modulation. The data is split into I and Q channels and the data in each channel is XORed with a unique PRBS short code. In the case of the short codes, there are two shift registers, each 15 bits long, with feedback taps that define specific sequences. These run at 1.2288 MHz. After the data is XORed with the two short code sequences, the result is two channels of data at 1.2288 Mbps. Each channel is low-pass filtered digitally using an FIR filter. The filter cutoff frequency is approximately 615 kHz. A typical FIR filter implementation might output 9-bit-wide words at 4.9152 MHz. The resultant I and Q signals are converted to analog signals and are sent to a liner I/Q modulator. It should be noted that adjacent cells use different time offset on the short codes to identify themselves and reuse the 64 Walsh codes.

4.1.3 Channels

Pilot Channel

The goal for building pilot channel is to send pilot signal which can aid in clock recovery at the mobile station. This channel is always assigned to code channel 0. It is both a demodulation reference for the mobile receivers, and for handoff level measurements, and thus must be present in every station. It carries no information. It is pure short code, with no additional cover or information content.

All stations use the same short code, and thus have the same pilot waveform. They are distinguished from one another only by the phase of the pilot. The short period of the short code, facilitates rapid pilot searches by the mobiles.

Sync Channel

The sync channel is transmitted by a base station to enable the MS to obtain frame synchronization of the CDMA signal. The CDMA system uses a data rate of 1.2 kbps for the sync channel and then convolutionally encodes the data with a rate one-half code. The Sync Channel carries a single, repeating message that conveys the timing and system configuration information to the mobile station. The mobile station can derive accurate system time, to within a fraction of a spreading chip (833 ns) by synchronizing to the short code. The short code synchronization and the pilot offset, which is part of the sync message, fix system time modulo 26.667 ms. The code period ambiguity is then resolved by the long code state and system time fields that are also part of the sync message.

Paging Channel

The paging channel is the vehicle for communicating with mobile stations when they are not assigned to a traffic channel. As the name implies, its primary purpose is to convey pages, that is, notifications of incoming calls, to the mobile stations. It carries the responses to mobile station accesses, both page responses and unsolicited originations. Successful accesses are normally followed

Channel	Sync	Paging		Traffic			
Data rate	1200	4800	9600	1200	2400	4800	9600
Code repetition (bps)	2	2	1	8	4	2	1
Modulation symbol rate (sps)	4800	19200	19200	19200	19200	19200	19200
PN chips/modulation symbol	256	64	64	64	64	64	64
PN chips/bit	1024	256	128	1024	512	256	128

Table 1: Forward Link Channel Parameters, Rate Set 1

Channel	Traffic			
Data rate	1800	3600	7200	14400
Code repetition (bps)	8	4	2	1
Modulation symbol rate (sps)	19200	19200	19200	19200
PN chips/modulation symbol	64	64	64	64
PN chips/bit	682.67	341.33	170.67	85.33

Table 2: Forward Link Channel Parameters, Rate Set 2

by an assignment to a dedicated traffic channel. Once on a traffic channel, signaling traffic between base and mobile can continued interspersed with the user traffic.

The paging channel was maximumly assigned to the code channel 1 to 7 (inclusive) in sequence. Several of the modulation step are similar to the sync channel. Both systems convolutionally encode the data with a rate one half code. After encoding, the signal is processed by s symbol repetition stages are identical to those used for sync channel the traffic channel as well.

Each base station must have at least one paging channel per sector, on at least one of the frequencies in use. All paging can be done on one frequency, or it can be distributed over multiple frequencies.

Traffic Channel

Traffic channels are assigned dynamically, in response to mobile station accesses, to specific mobile stations. The mobile station is informed, via a paging channel message, which code channel it is to receive.

The traffic channel always carries data in 20 ms frames. Frames at the higher rates of Rate Set 1, and in all frames of Rate Set 2, include CRC codes to help assess the frame quality in the receiver.

Traffic channels carry variable rate traffic frames, either 1, 1/2, 1/4, or 1/8 of the maximum rate. In IS-95A only a 9600 bps rate family is currently available in the standard. The Rate Set 2 will be added in a future revision of IS-95.

The rate variation is accomplished by 1, 2, 4, or 8-way repetition of code symbols. Transmission is continuous, with the amplitude reduced at the lower rates so as to keep the energy per bit

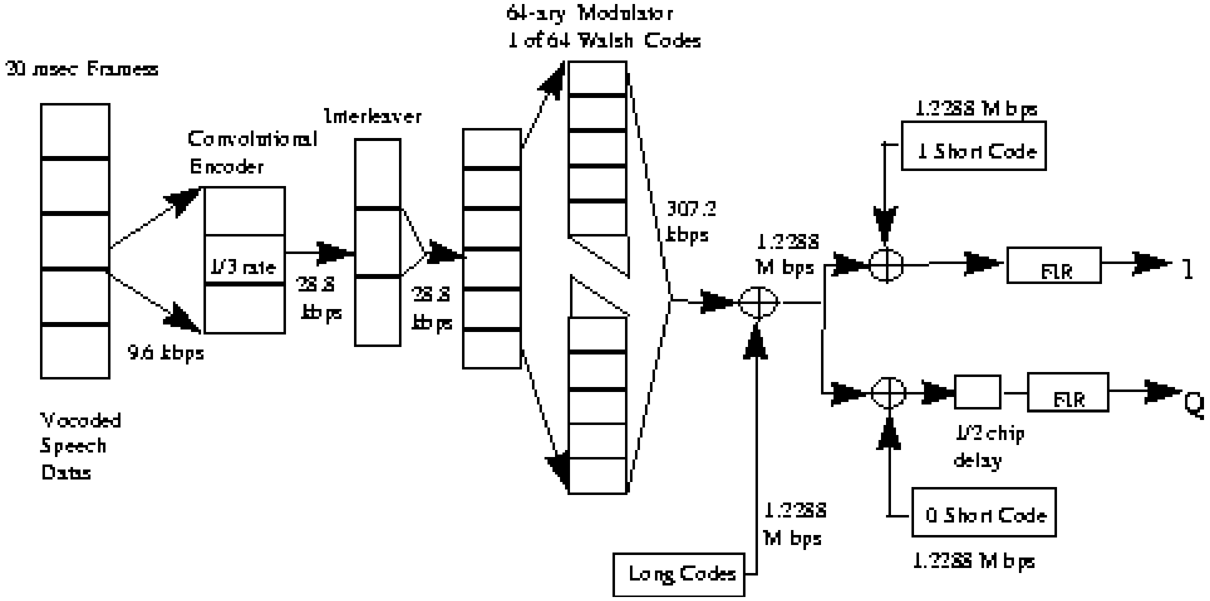


Figure 5: IS-95 Reverse Link Physical Layer

approximately constant, regardless of rate. The rate is independently variable in each 20 ms frame.

Power Control Subchannel

The 800 bps reverse link power control subchannel is carried on the traffic channel by puncturing 2 from every 24 symbols transmitted. The punctured symbols both carry the same power control bit, so they can be coherently combined by the receiver. Each base station participating in a soft handoff makes its own power control decision, independent of the others, unless they are different sectors of the same cell, in which case they all transmit a common decision. This special circumstance is made known to the mobile when the handoff is set up.

Timing

All base stations must be synchronized within a few microseconds for the station identification mechanisms to work reliably and without ambiguity. Any convenient mechanism can be used for this purpose, but the system was designed under the assumption that the Global Positioning System (GPS) would be used. This is a family of low-earth-orbit satellites that broadcast a spread-spectrum signal and ephemeris information from which a sophisticated Kalman filter algorithm in a receiver can derive both a very accurate position and a very accurate time.

4.2 IS-95 Reverse Channels

The REVERSE CHANNEL is the mobile-to-cell direction of communication. It carries traffic and signaling. The access channel is used to make originations are established, all communication

Channel	Access	Traffic							
Data rate (bps)	4,800	1,200	2,400	4,800	9,600	1,800	3,600	7,200	14,400
Code Rate	1/3	1/3	1/3	1/3	1/3	1/2	1/2	1/2	1/2
Symbol Rate before Repetition (sps)	14,400	3,600	7,200	14,400	28,800	3,600	7,200	14,400	28,800
Symbol Repetition	2	8	4	2	1	8	4	2	1
Symbol Rate after Repetition (sps)	28,800	28,800	28,800	28,800	28,800	28,800	28,800	28,800	28,800
Transmit Duty Cycle	1	1/8	1/4	1/2	1	1/8	1/4	1/2	1
PN Chips / Modulation Symbol	256	256	256	256	256	256	256	256	256
PN chips transmitted / bit	256	128	128	128	128	256/3	256/3	256/3	256/3

Table 3: Reverse Link Channel Parameters

occur on the reverse traffic channel. On I-95 the mobile stations accessing a base station over an access or traffic channel share the same CDMA frequency assignment using direct sequences CDMA techniques. Each channel is identified by a distinct access channel long code sequence.

On the other hand, The designer of the CDMA system assumed that the recovery of the pilot signal from the mobiles would be difficult. so an asymmetric channel modulation method is used. On the reverse channel. Walsh functions are not used, but PN functions are used to distinguish the signals from different mobile transmitters.

4.2.1 Frequency Plan

The mobile station transmit frequency is 45 MHz below the base station transmit frequency in the IS-95 cellular service. Permissible frequency assignments are on 30 kHz increments in cellular.

Transmission Parameters

The IS-95A Reverse CDMA Channel currently supports a 9,600 bps rate family in the Access Channel and Traffic Channels, as shown in the table. The transmission duty cycle varies with data rate. In all cases the FEC code rate is 1/3, the code symbol rate is always 28,800 symbols per second after there are 6 code symbols per modulation symbol, and the PN rate is 1.2288 MHz. The modulation is 64-ary orthogonal, using the same Walsh functions that are used in the forward link for channelization. Each period of the Walsh function is repeated for four chips of the PN code. The Walsh symbol rate is thus 1.2288 MHz/(4 chips per Walsh chip)/(64 Walsh chips per Walsh symbol) = 4,800 modulation symbols per second. Note that 1.2288 MHz = 128*9,600 bps.

Parameter	Function	Notes
Frequency	Divides the spectrum into several 1.23-MHz frequency allocations.	Forward and reverse links are separates by 45 MHZ
Wallsh Codes	Separate forward link user of the same cell	Assigned by cell site. Walsh code 0 is always the sync channel.
Long Code	Separates reverse link user of the same cell.	Depends on time and User ID. Th Long code is composed of a 43-bit-long PRBS generator and a user specific mask.
Short Codes	Separates cell sites or sector of cells.	The I and Q codes are different but are based on 15-bit-long PRBS generators. Both codes repeat at 26.667 ms intervals Base stations are differentialed by time offsets of the short sequences.

Table 4: CDMA Channelization Functions.

4.2.2 Channels

Access Channel

The reverse access channel is used by the MS to access the CDMA system to response to pages, make call originations, and process other message between the MS and the base station. There is only one type of overhead channel in the Reverse CDMA Channel: the Access Channel. It is used to respond to pages, make call originations and process other messages between the MS and the base station.

Traffic Channel

Each station has a unique Long Code Mask, based on its electronic serial number. Whenever the mobile is assigned to traffic, it uses its specific long code mask.

The primary traffic channel, the secondary traffic channel, and the signaling channel are multiplexed together and processed by the same convolutional encoder, symbol repetition, interleaver, and 64-ary orthogonal modulator.

Traffic channels carry variable rate traffic frames, either 1, 1/2, 1/4, or 1/8 of the maximum rate. In IS-95A only a 9600 bps rate family is currently available in the standard. The traffic channel always carries data in 20 ms frames.

4.2.3 Comparisons to Forward Channels

Separation of Users

The reverse CDMA Channel, in contrast to the Forward CDMA Channel, does not use strict orthogonality in any sense to separate logical channels. Rather, it uses a very long period spreading code, in distinct phases. The correlations between stations are not zero, but they are acceptably small.

Orthogonal Modulation

Reverse link data modulation is 64-ary orthogonal, and is applied prior to the spreading. Groups of six code symbols select one of 64 orthogonal sequences. The 64-ary orthogonal sequences are the same Walsh functions that are used in the Forward CDMA Channel. However, they are used for a totally different purpose here. Each period of the Walsh sequence (a Walsh Chip) is four PN chips in duration. The modulation symbol rate is thus always 4,800 sps.

RF Modulation

The two coded, covered, and spread streams are vector-modulated on the RF carrier. The Q-axis modulation is delayed by 1/2 chip. The spreading modulation is thus offset QPSK. Offset modulation was chosen in an effort to reduce the envelop modulation of the RF signal and reducing performance requirements on the power amplifiers in the subscriber station.

The spectrum shaping of the reverse link is carefully prescribed in the IS-95A air interface and the IS-98 performance specification. The latter is in terms of the so-called Rho meter, a measurement of the correlation between the actual transmitter output with the ideal transmitter output. The air interface also specifies a slightly nonlinear phase characteristic the purpose of which is partial pre-equalization of the mobile receiver.

Each base station must service at least one Access Channel, on at least one of the frequencies in use. The Long Code Mask for the Access Channel is derived from the station identity, the paging channel number with which the access channel is associated, and Access Channel number within that base station.

5 Operational Example

When the mobile station first turn on, it knows the assigned frequency for CDMA service in the local area. It will tune to that frequency and search for pilot signals. It is likely that multiple pilot signals will be found, each with different time offest. The time offset is the means of distinguishing one base station from another. The mobile station will pick the strongest pilot, and establish a frequency reference and a time reference from the signal. It will then start demodulation of Walsh number 32, which is always assigned to sync channel. The sync channel message contains the future contents of the 42-bits long code shift register. These are 320 ms early, so the mobile station has time to decode the message, load its register, and become synchronized with the base station's system time.

The mobile station may be required to register. This would be a power-on registration in which the mobile station tells the system that it is available for calls and also tells the system where it is. It's anticipated that a service area will be divide into zones, and if the mobile station crosses from one zone to another while no call is in progress, it will move this registration location by use of an idle state handoff. The design of the zones is left to the service provides and is chosen to

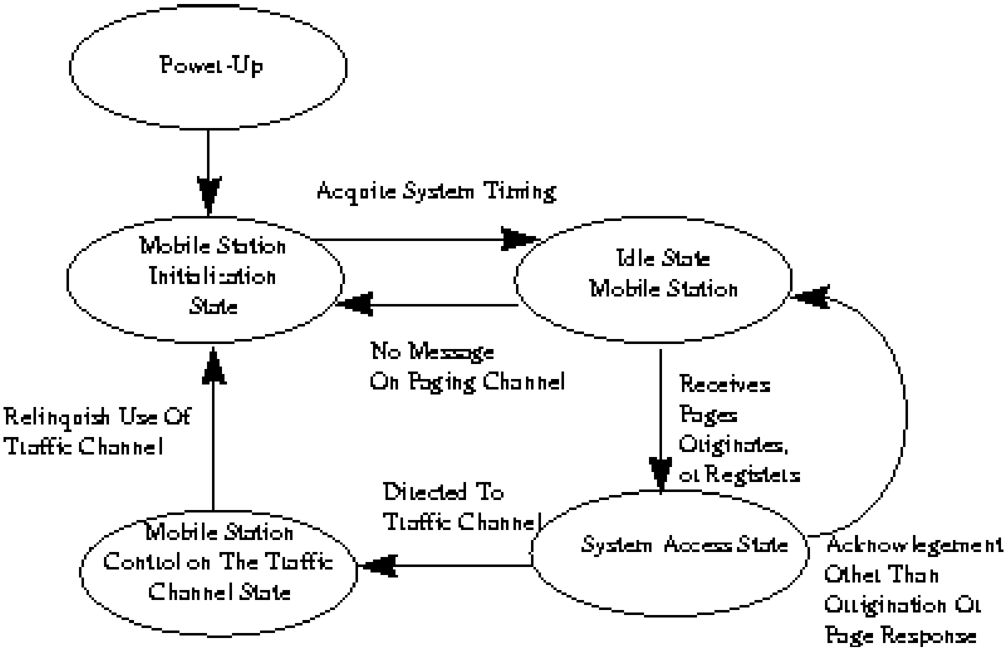


Figure 6: Mobile call processing states

minimize the support messages. Small zones result in efficient paging but a large number of idle state handoffs. Large zones minimize idle state handoffs, but require paging messages to be sent form a large number of cells in the zones.

At this point the user makes a call by entering the digits on the mobile station keypad and hitting the send button. The mobile station will attempt to contact the base station with an access probe. A long code mask is used that is based on cell site parameters. It's possible that multiple mobile station may attempt to link on the access channel simultaneously, so collisions can occur. If the base station does not acknowledge (on the paging channel) the access attempt. After making contract, the base station will assign a traffic channel with its Walsh number. At this point, the mobile station changes its long code mask to one based on its serial number, receives on the assigned Walsh number, and starts the conversation mode.

It's common for a mobile sation communicating with one cell to detect another cell's pilot that is strong enough to be used. The mobile station will then request soft handoff. When this is set up, the mobile station will be assigned different Walsh numbers and pilot timing and use these in different correlative receiving element. It's capable of combining the signals form both cells. Eventually, the signal from the first cell will diminish and the mobile station will request from the second cell that soft handoff be terminated.

At the end of that call, the channel will be freed. When the mobile station is turned off, it will generate a powerdown registration signal that tells the system that it is no longer available for the incoming calls.

Fig. 6 represents the mobile call processing states and their mutual operations[15].

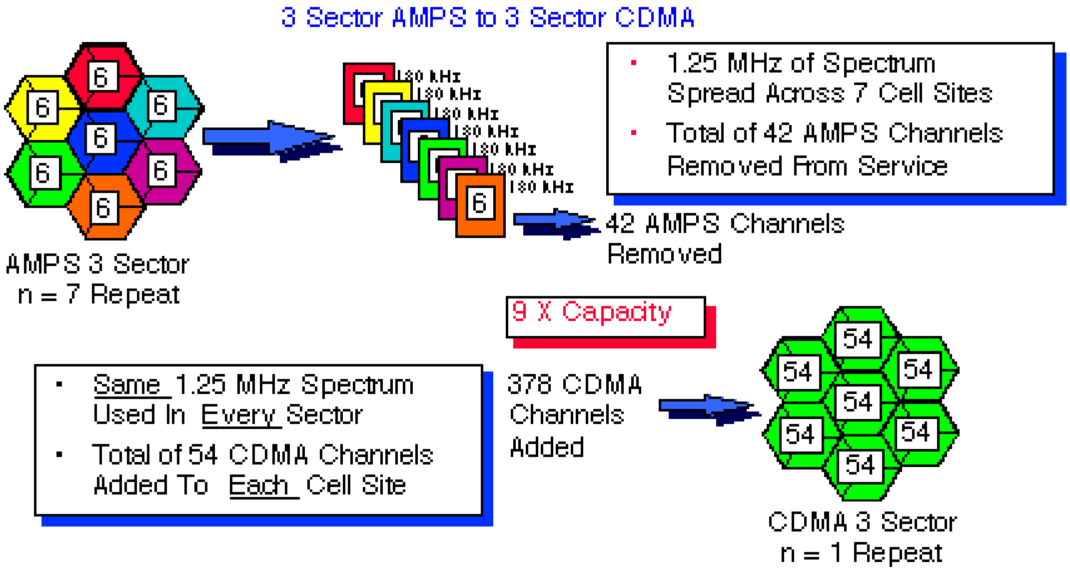


Figure 7: Comparisons of Basic Capacity on CDMA, TDMA and FDMA

6 Attributes of IS-95

6.1 Improved Capacity

The great attraction of CDMA technology from the beginning has been the promise of extraordinary capacity increase over narrowband multiple access wireless technologies. Simple models suggest that the capacity improvement may be more than 20 times that of the existing narrowband cellular standards, such as AMPS in North America, NMT in Scandinavia, TACS in the United Kingdom.

6.2 Improved Power Control

In a CDMA system, the base station continually measures the received signal from the mobile, compares it to the desired power level, to achieve the requirement.

Anyhow, despite of the complexity of power control the improved power control that the base station communicates to the mobile station, instructing the mobile to adjust its power up or down. The mobile station transmits only enough power to maintain a link, so the average transmitted power is much lower than that required for an analog system.

By contrast, most narrowband systems, have very slow and course power control capabilities. This means the subscriber unit cannot adjust power quickly enough to compensate for fades. As a result, the handset must always transmit at a power level several dB higher than optimum to account for possible fading. As would be expected, this leads to shorter battery life.

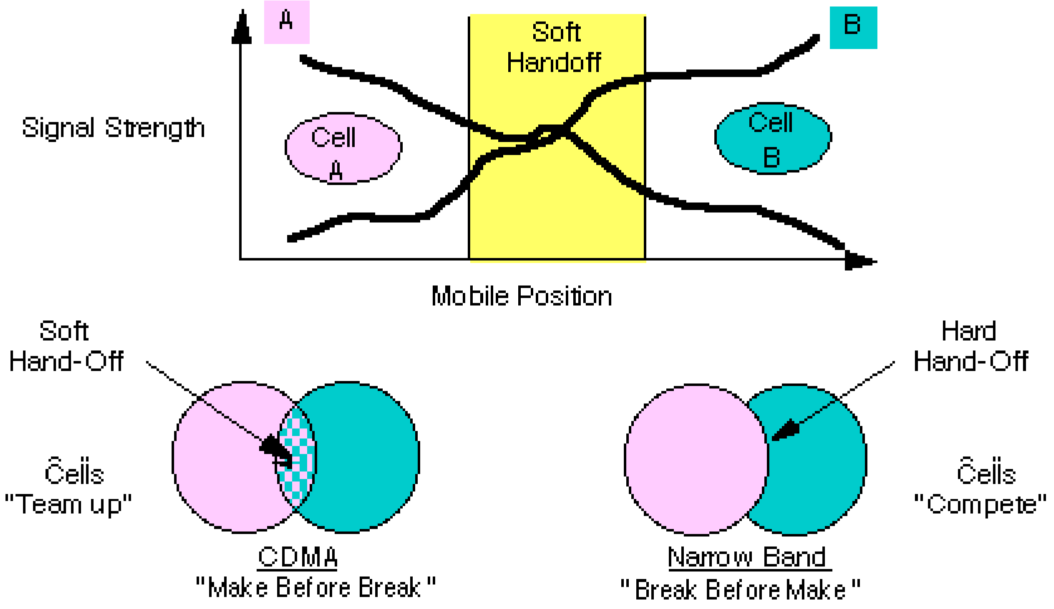


Figure 8: Make-Break v.s. Break-Make

6.3 Improved Call Quality

6.3.1 Soft Handoff

IS-95 can improve the quality of service by providing robust operation in fading environments and transparent (or soft) handoffs. By using a RAKE receiver and other improved signal-processing techniques, each mobile station selects the three strongest multipath signals and coherently combines them to produce an enhance signal. Thus, the fading multipath nature of the channel is used to an advantage in IS-95[?].

Soft handoff contributes to high call quality by providing a make before break connection. This eliminates the short disruption of speech one hears with non-CDMA technologies when the RF connection breaks from one cell to establish the call at the destination cell during a handoff. Narrow band technologies ”compete” for the signal, and when Cell B wins over Cell A, the user is dropped by cell A (hard handoff). In CDMA the cells team up to obtain the best possible combined information stream. Eventually, Cell A will no longer receive a strong enough signal from the mobile, and the transcoder will only be obtaining frames from Cell B. The handoff will have been completed, undetected by the user. CDMA handoffs do not create the ”hole” in speech that is heard in other technologies.

Some cellular systems suffer from the ping pong effect of a call getting repetitively switched back and forth between two cells when the subscriber unit is near a cell border. At worst, such a situation increases the chance of a call getting dropped during one of the handoffs, and at a minimum, causes noisier handoffs. CDMA soft handoff avoids this problem entirely.

And finally, because a CDMA call can be in a soft handoff condition with up to three cells at the same time, the chances of a loss of RF connection (a dropped call) is greatly reduced. CDMA also provides for softer handoffs. A ”softer” handoff occurs when a subscriber is simultaneously communicating with more than one sector of the ”same cell.”

6.3.2 Advanced Error Detection and Error Correction

The IS-95 CDMA air interface standard specifies powerful error detection and correction algorithms. In IS-95, convolutional encoding, bits repetition, block interleaving techniques are used. Corrupted voice data can be detected and either corrected or manipulated to minimize the impact of data errors on speech quality[24].

6.3.3 Sophisticated Vocoder

The IS-95 vocoder increases call quality by suppressing background noise. Any noise that is constant in nature, such as road noise, is eliminated. Constant background sound is viewed by the vocoder as noise which does not convey any intelligent information, and is removed as much as possible. This greatly enhances voice clarity in noisy environments, such as the inside of cars, or in noisy public places.

6.3.4 Multiple Levels of Diversity

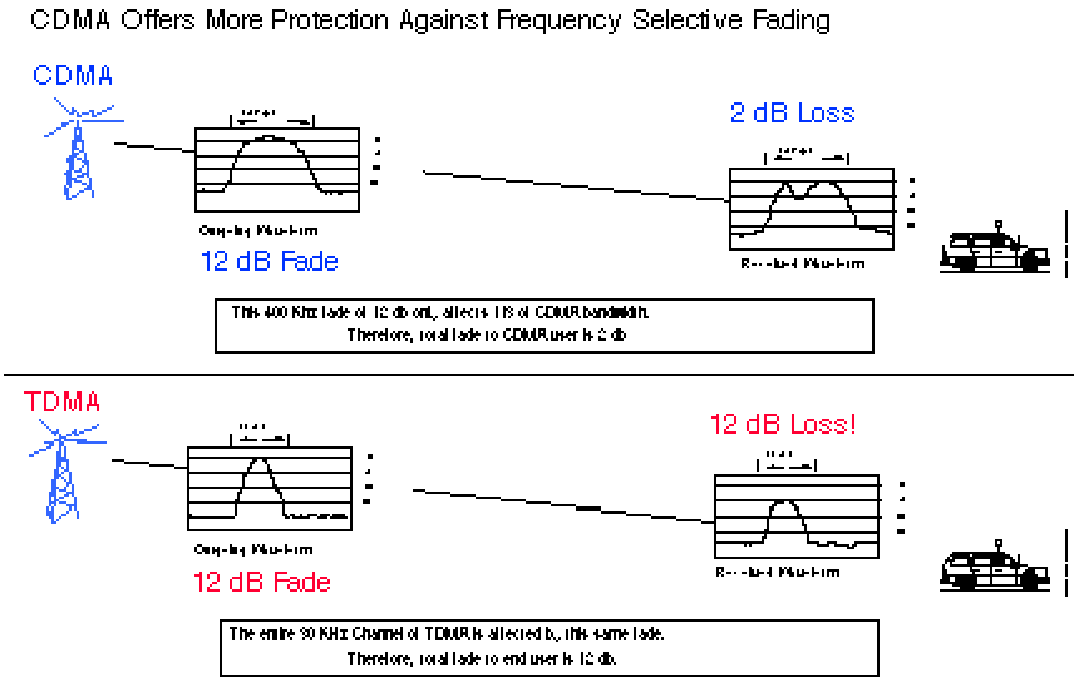
CDMA takes advantage of a number of types of diversity, all of which lead to improved speech quality. The four types are frequency diversity, spatial diversity, path diversity and time diversity.

Frequency Diversity

With radio, fades or holes in frequency will occur. Fades occur in a multi-path environment when two or more signals combine and cancel each other out. Narrow band transmissions are especially prone to this phenomenon. For wide band signals such as CDMA, this is much less of a problem. The wide band signal is, of course, also subjected to frequency selective fading, but the majority of the signal is unaffected and the overall effect is minimal.

CDMA is more resistant to interference or “jamming” In a typical narrow band technology such as AMPS or TDMA, if this narrow band jammer was at the same frequency as the signal of interest, and was of sufficient magnitude, it would totally disrupt the information signal.

However, a narrow band jammer has little effect on a CDMA signal. In the CDMA despreading process, when the received signal is combined with the original spreading code, the signal of interest correlates with the spreading code and the desired signal jumps out of the noise. A narrow band jammer is a random signal, so it will not correlate with any spreading code. Therefore, in the CDMA despreading process the energy of the narrow band jammer is spread across the spectrum and does not interfere with the desired signal of interest. This fundamental immunity to interference is one of the most attractive benefits of CDMA.



This 400 KHz fade of 12 db only affects 1/3 of CDMA bandwidth.
Therefore, total fade to CDMA user is 2 db

The entire 30 KHz Channel of TDMA is affected by this same fade.
Therefore, total fade to end user is 12 db.

Figure 9: Comparisons of Interference in Narrowband and Wideband System

Spatial Diversity

Spatial Diversity refers to the use of two receive antennas separated by some physical distance. The principle of spatial diversity recognizes that when a mobile is moving about, it creates a pattern of signal peaks and nulls. When one of these nulls falls on one antenna it will cause the received signal strength to drop. However, if a second antenna is placed some physical distance away, it will be outside of the signal null area and thus receive the signal at an acceptable signal level.

Path Diversity

With radio communications, there is usually more than one RF path from the transmitter to the receiver. Therefore, multiple versions of the same signal are usually present at the receiver. However, these signals, which have arrived along different paths, are all time shifted with respect to each other because of the differences in the distance each signal has traveled. This "multipath" effect is created when a transmitted signal is reflected off of objects in the environment (buildings, mountains, planes, trucks, etc.). These reflections, combined with the transmitted signal, create a moving pattern of signal peaks and nulls.

When a narrow band receiver moves through these nulls there is a sudden drop in signal strength. This fading will cause either lower, more noisy speech quality or, if the fading is severe enough, the loss of signal and a dropped call.

Although multipath is usually detrimental to an analog or TDMA signal, it is actually an advantage to CDMA, since the CDMA rake receiver can use multipath to improve a signal. The CDMA receiver has a number of receive "fingers" which are capable of receiving the various multipath signals. The receiver locks onto the three strongest received multipath signals, time shifts them, and then sums them together to produce a signal that is better than any of the individual signal components. Adding the multipath signals together enhances the signal rather than degrading it.

Time Diversity

CDMA systems use a number of forward error correcting codes, followed by interleaving.
Error correction schemes are most effective when bit errors in the data stream are spread more evenly over time. By separating the pieces of data over time, a sudden disruption in the CDMA data will not cause a corresponding disruption in the voice signal. When the frames are pieced back together by the decoder, any disrupted voice data will have been in small pieces over a relatively longer stretch of the actual speech, reducing or eliminating the impact on the voice quality of the call.

Interleaving, which is common to most digital communication systems, ensures that contiguous pieces of data are not transmitted consecutively. Even if you lose one small piece of a word, chances are great that the rest of the word will get through clearly.

6.4 Other Attributes

6.4.1 Simplified System Planning

All users on a CDMA carrier share the same RF spectrum. This N=1/S reuse of frequencies (where S = number of sectors per cell) is one factor which gives CDMA its greater capacity over AMPS and other technologies, but it also makes certain aspects of system planning more straightforward. Engineers will no longer have to perform the detailed frequency planning which is necessary in analog and TDMA systems.

Because frequency planning is unnecessary, that element of engineering work formerly required as part of an initial system design is eliminated. Even more significantly, frequency re-tunes for expansion of a system are also eliminated. If a customer wants to add cell sites or channels, it will no longer require an entirely new frequency plan to do so.

Note that when CDMA is added as an overlay on an existing analog system, frequency planning would be required to clear spectrum for the CDMA carriers.

6.4.2 Improved Coverage

At the startup of a new system, there are fewer subscribers, so fewer cells are required to handle the traffic. However, there is still the need to provide wide initial geographic coverage.

A CDMA cell site has a greater range than a typical analog or digital cell site. Therefore fewer CDMA cell sites are required to cover the same area. Depending on system loading and interference, the reduction in cells could be as much as 50% when compared to GSM. CDMA's greater range is due to the fact that CDMA uses a more sensitive receiver than other technologies.

6.4.3 Increased Portable Talk Time

Because of precise power control and other system characteristics, CDMA subscriber units normally transmit at only a fraction of the power of analog and TDMA phones. This will enable portables to have longer talk and standby time.

6.4.4 Bandwidth on Demand

A wideband CDMA channel provides a common resource that all mobiles in a system utilize based on their own specific needs, whether they are transmitting voice, data, facsimile, or other applications. At any given time, the portion of this "bandwidth pool" that is not used by a given mobile is available for use by any other mobile. This provides a tremendous amount of flexibility - a flexibility that can be exploited to provide powerful features, such as higher data rate services. In addition, because mobiles utilize the "bandwidth pool" independently, these features can easily coexist on the same CDMA channel.

7 Conclusion

We have shown that IS-95 CDMA based system is a superior system that provides several benefits, espeically the capacity, economics, and quality of service, over other existing systems. IS-95 system has been established in more than 30 more countries in the world, especially in U.S., Canada, South America, Russia, China, Japan, German, Great British, etc.[25]. An additional specification, TSB-74, has been published that describes interaction between an IS-95A system and PCS CDMA systems that extends its compatiblity to wireless networking services[26]. The popularity of CDMA based digital cellular systems is anticipated.

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