CDMA for Cellular and PCS

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Abstract

The Telecommunications Industry Association (TIA) published the North American cellular air interface standard for CDMA cellular communications, IS-95,[1] in 1993 [1]. The Joint Technical Committee (JTC) on Wireless Access, formed between TIA committee TR46 and the Alliance for Telecommunication Solution[2] (ATIS) committee T1, is drafting an IS-95 based standard for Personal Communications Systems (PCS). The IS-95 standard supports data rates up to 9600 bps; the PCS standard under development supports rates to 14400 bps. Extensions to the PCS standard which will support rates up to 76.8 kbps have been proposed [3]. This paper describes the history of CDMA development, various CDMA cellular standards, the PCS standards under development, and the extended PCS system.

1. Introduction

In the Fall of 1989, the first experiments using cellular CDMA at 800 MHz were conducted in San Diego, California. Based upon the success of these experiments, a preliminary common air interface was developed in conjunction with several cellular carriers and manufacturers. During the Fall of 1991, a large scale test was conducted in San Diego. This test showed that a CDMA system could provide high quality and a capacity greater than ten times the capacity of the existing AMPS cellular system. In the Winter and Spring of 1992, the Cellular Telecommunications Industry Association (CTIA) conducted a series of open forums on wideband technologies. The CTIA also requested that the Telecommunications Industry Association (TIA) develop a wideband standard.

The first PCS operation of CDMA was in Munster, Germany in the Spring of 1992 at 1.7 GHz. This system consisted of a microcell embedded inside and on the same frequency as an umbrella macrocell. Since then there have been numerous CDMA PCS trials in the United States.

2. Cellular Standards

In March 1992, the TIA began the development of the IS-95 wideband standard for 800 MHz cellular radio systems by forming TIA subcommittee TR45.5. In July 1993, the TIA published IS-95, titled *Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System.*

When using the traffic channel, IS-95 consists of three protocol stacks (primary traffic, secondary traffic, and signaling traffic) which connect to the multiplex sublayer as shown in Figure 2-1. The multiplex sublayer combines these streams on a per frame basis (20 ms duration) in a manner specified by the multiplex sublayer

[1]For shortness, this paper omits EIA/TIA or TIA/EIA from the front of an interim standard's number. Thus IS-95 is formally written as TIA/EIA/IS-95.

[2]Previously the Exchange Carriers Standards Association.

rules. Signaling for call setup, registrations, short messages, and other overhead functions are handled via a pair of channels called the Paging and Access Channels. IS-95 standardizes the basic foundation of the system, consisting of layer 1 (physical layer), the multiplex sublayer, the traffic channel signaling protocol stack, and the Paging Channel and the Access Channel protocol stack.

The multiplex sublayer provides a set of connections to which various service options can be connected. The first service option that TIA subcommittee TR45.5 developed is called Service Option 1 and is variable rate voice at rates of 8550, 4000, 2000, and 800 bps. This standard is called IS-96 and is titled *Speech Service Option Standard for Wideband Spread Spectrum Digital Cellular System.*

Thus the pair of documents IS-95 and IS-96 form the core standards for a cellular system providing voice service. In scope they are equivalent to other TIA standards, notably EIA/TIA-553 for analog and IS-54-B for TDMA. The TIA subcommittee TR45.5 is completing a data standard, IS-99, which provides for asynchronous data and fax communications over the CDMA system. For asynchronous data, the mobile station resembles a wireline modem which processes standard "AT" commands (see EIA/TIA-602). For fax, the mobile station resembles a group 3, class 2.0 digital fax modem as standardized in EIA/TIA-592. A notebook computer, PDA, or other device can connect to the mobile station via a standard EIA-232 connection or can have CDMA transmission equipment embedded in it, such as in a PCMCIA card. For both asynchronous data and fax, data is transferred digitally over the wireless link between the mobile station and an interworking function (IWF) in the network equipment. The wireline modem is located in the IWF and is allocated to a mobile station on a per call basis.

IS-98 and IS-97 are a pair of companion documents to IS-95 providing minimum performance requirements for mobile stations and base stations respectively. These two documents provide a function similar to TIA standards IS-19 and IS-20 for analog and IS-55 and IS-56 for TDMA. Minimum speech coder performance requirements are specified in IS-125, similar in scope to the IS-85 standard that the TIA developed for TDMA.

A different TIA subcommittee, TR45.2, has responsibility for intersystem operations and has developed the IS-41 series of standards. TR45.2 has recently completed TSB-64[3] containing modifications for CDMA intersystem handoff. These modifications were needed to specify the CDMA channel assignment and to support CDMA mobile assisted handoff.

3. Scope of IS-95

IS-95 analog operation is compatible with base stations conforming to EIA/TIA-553. In addition, IS-95 analog operation supports analog enhancements added into IS-54-B such as calling number identification, authentication, and message encryption.

The basics of the IS-95 physical layer have been described in [2] and, due to space, are not repeated here. Unlike TDMA, the IS-95 standard is being introduced with a full set of digital control channels. A single CDMA frequency can support up to 7 Paging Channels, operating at either 4800 bps or 9600 bps, for communications from the base station to the mobile station. Paging Channels can also be included on different

[3]Technical Standards Bulletin Number 64.

CDMA frequencies. The Paging Channel is divided into slots of 80 ms duration. A mobile station need only listen for pages in its assigned slots. The base station can indicate that it has no more messages for mobile stations operating in the slotted mode, thus allowing these mobile stations, typically portables, to power down early in the slot further increasing battery life. For a mobile station, the period of slot repetition, called the slot cycle, is $0.08 \times 2^{N+4}$ seconds where N is from 0 though 7. The mobile station can select the period of its assigned slots by registering with the value of N that it is using. The mobile station uses a series of three hash functions to select the CDMA frequency to use, the Paging Channel on the frequency, and the slot in its specified slot cycle to monitor. Similarly, the base station performs the hashing to determine the frequency, Paging Channel, and slot in which to send a page.

The control channel used for communications from the mobile station to the base station is called the Access Channel, is slotted, and uses a fixed 4800 bps rate. For each Paging Channel, a system can be configured to support up to 32 Access Channels. Each Access Channel is characterized by a different spreading code. Before making an access, the mobile station pseudo-randomly chooses one of the Access Channels that the base station supports. Multiple mobile stations can transmit into the same slot on the same Access Channel. Since transmissions on the Access Channel having arrival times at the base station separated by more than the anticipated multipath spread can be distinguished by the demodulator, collisions in the Aloha sense are infrequent. In addition, the base station can have mobile stations randomize their timing to further avoid collisions. IS-95 also supports backoff procedures for channel congestion control in cases of overload.

IS-95 supports authentication, message encryption, and voice privacy procedures similar to those used by IS-54-B. As a result, the network's protocols can be identical to those used to support IS-54-B mobile stations.

4. PCS

In the fall of 1993, seventeen PCS air interface standards proposals were submitted to the T1P1.4/TR46.3.3 Joint Technical Committee (JTC) on Wireless Access. Proposals based on IS-95 modifications were submitted by Motorola/QUALCOMM (a joint proposal), AT&T, and OKI. Most of the seventeen original proposals which advocated similar technologies have consolidated into one proposal. At this writing, eight technology ad hoc groups (TAGSs) are working on eight different PCS air interface standards. It is expected that several of these groups will drop out.

The joint Motorola/QUALCOMM proposal advocated a two phased approach to a CDMA PCS air interface. The first phase was to develop a core PCS system. This core system would then be extended to obtain even higher data rates as shown in Table 4-1.

The core system makes several key modifications to the IS-95 system for the 1.8 to 2.2 GHz PCS band. One modification provides support for a 14.4 kbps rate set. This permits use of a voice codec with quality similar to 32 kbps ADPCM. In addition, it allows higher rate data services. Early deployments in the 1.8 GHz to 2.2 GHz band will have to contend with existing microwave systems, called OFS (other fixed services). This is unlike the cellular frequency band where the cellular carriers have exclusive use of their allocated spectrum. The proposed IS-95 based PCS standard has additional capabilities for handling OFS.

Figure 4-1 shows a simplified view of the modulation and coding for a Forward Traffic Channel in IS-95 and the core PCS system–the differences between them occur in the convolutional encoder. For the 1200, 2400, 4800, and 9600 bps rates, a straight rate 1/2 convolutional code is used. For rates lower than 9600 bps, the convolutional encoder repeats symbols so that each symbol appears 8, 4, 2, or 1 times for the 1200, 2400, 4800, and 9600 bps rates respectively. For the 1800, 3600, 7200, and 14400 bps rates, the symbol repetition output is punctured to produced an equivalent of a rate 3/4 code. The output rate of the convolutional encoder for all rates is 19200 symbols per second.

Each forward channel is assigned to one of a set of orthogonal covering codes. The orthogonal covering codes are the set of 64-ary Walsh functions. In the absence of multipath, the transmissions from different forward channels on the same frequency from the same base station do not interfere with each other.

The extended PCS system adds higher rates via a technique called overlay encoding. Overlay encoding adds additional orthogonal channels in phase quadrature to the existing channels and provides a cleaver way of merging orthogonal channels to obtain higher rates. A simplified block diagram of the extended system is shown in Figure 4-2. Note the addition of the overlay encoder block. The overlay encoding process is illustrated in Figure 4-3 for the 1.25 mode (1.23 MHz bandwidth). This shows that as the peak transmission rates increase on the Forward Traffic Channel, then fewer codes are available. For example, there can be 32 Forward Traffic Channels assigned at 38.4 kbps. Some of these 32 channels can also be split; for example, there can be 16 channels assigned at 38.4 kbps and 64 channels assigned at 9600 bps. The information carrying capacity of the channel may limit the actual number of assignments. For example, an IS-95 system can support at least 20 Traffic Channels at 9600 bps using normal voice activities. Assuming the same voice activities, 13 Traffic Channels could be supported using the 1.25 mode at the 14400 bps rate.

The extended system proposes use of a 2.46 MHz spreading bandwidth for the 76.8 kbps rates. To the first order, a spreading bandwidth twice as wide allows for twice the number of users. However, since there are two of the original channels, the net number of users is the same. A larger bandwidth does allow some additional capacity in that the statistical averaging of the voice activity is somewhat better. For the lower transmission rates, there is only a small increase in capacity. However, at higher rates, such as 76.8 kbps, this capacity increase becomes more substantial. For this reason, the extended PCS system shifts to higher a spreading bandwidth for 76.8 kbps. There are also some disadvantages to having a wider spreading bandwidth: First, avoidance of the OFS (microwaves) becomes more difficult. Second, wider spreading bandwidths also make it more difficult or impossible to support private systems such as in office buildings. These first two reasons are particularly true for the 10 MHz (5 MHz for transmit and 5 MHz for receive) wide spectral allocations in the 2.2 GHz band. Third, wider bandwidths also lead to more complex receivers as they must recover additional multipath rays. Finally, in-building multipaths range from about 10 to 100 ns. The FCC has not assigned sufficient bandwidth to PCS to counteract the in-building fading by a higher bandwidth system.

Since the Reverse CDMA Channel is from many mobile stations to a cell, the IS-95 Reverse CDMA Channel has somewhat different modulation and coding. Similar techniques to those described above for the Forward CDMA Channel provide for higher rates on the Reverse CDMA Channel. These techniques and additional information on IS-95 can be found in [1, 3].

5. References

[1] TIA/EIA/IS-95, *Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System*, Telecommunications Industry Association, Washington, D.C., July 1993.

[2] Tiedemann, E. G., Salmasi, A.B., and Gilhousen, K.S., "The Design and Development of a Code Division Multiple Access (CDMA) System for Cellular and Personal Communications," IEEE International Symposium on Personal, Indoor, and Mobile Communications, London, England, pp. 131-136, September 1991.

[3] T1P1.4/TR46.3.3 Joint Technical Committee on Wireless Access, Contribution JTC(AIR)/94.11.01-404, "The CDMA PCS System Common Air Interface Proposal," submitted by QUALCOMM Incorporated and Motorola Incorporated, November 1994.

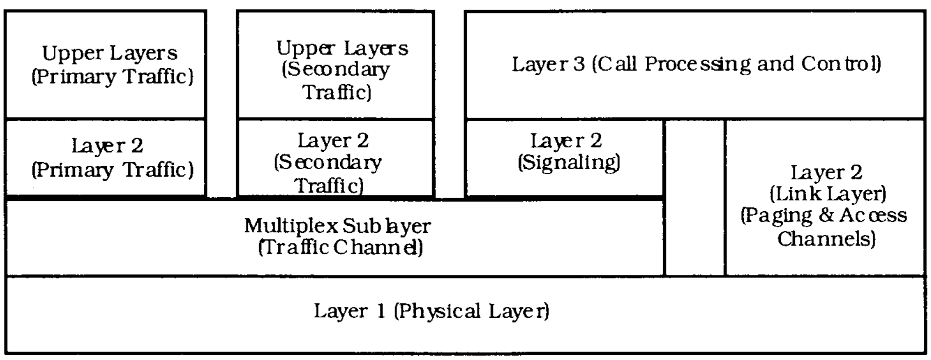

Figure 2-1. Layering in the CDMA Standard

Table 4-1. Summary of the Core and Extended PCS System

Attribute	Core System	Extended System
Bandwidth	1.23 MHz	1.23 MHz (1.25 mode) 2.46 MHz (2.5 mode)
Transmission rates	14400, 7200, 3600, 1800, 9600, 4800, 2400, &1200 bps	1.25 mode: adds 19.2 & 38.4 kbps 2.5 mode: also adds 76.8 kbps
Voice service rates	4, 8, and 13 kbps	adds 16 and 32 kbps
Data service rates	All up to 14.4 kbps	1.25 mode: adds 19.2 & 38.4 kbps 1.25 mode: adds 76.8 kbps

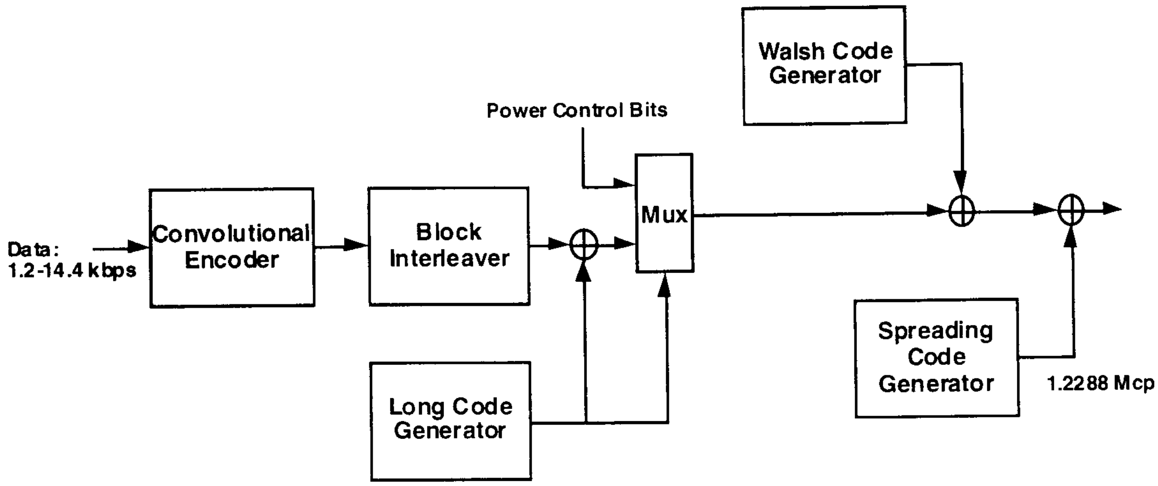

Figure 4-1. Simplified View of the Core System Forward Traffic Channel

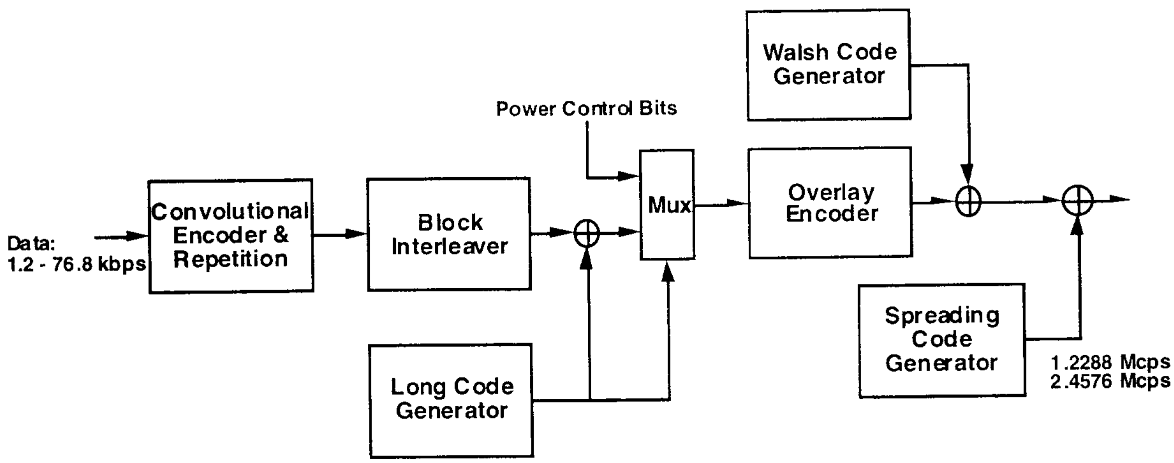

Figure 4-2. Simplified View of the Extended System Forward Traffic Channel

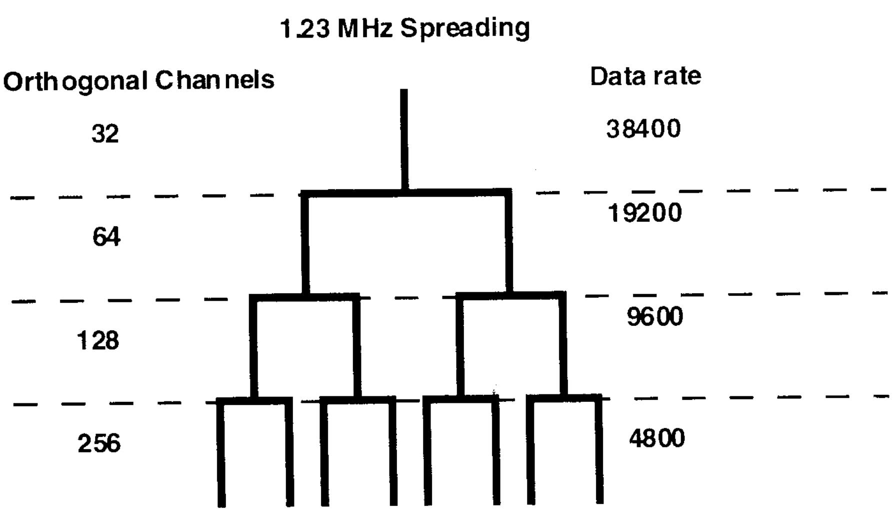

Figure 4-3. Overlay Encoding on the Forward Traffic Channel