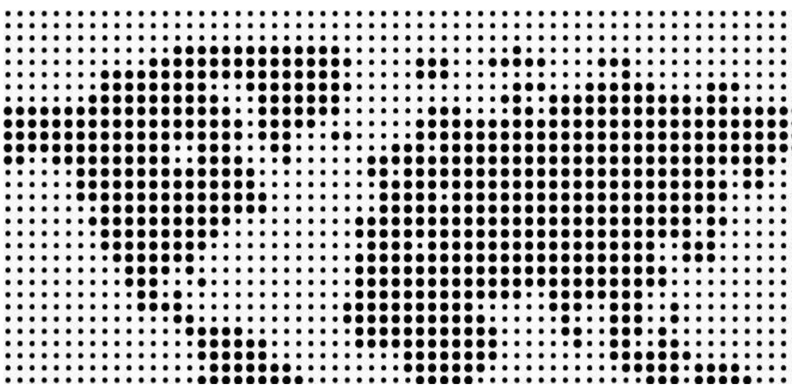

Commonalities between CDMA2000 and WCDMA Technologies

QUALCOMM Incorporated
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Executive Summary

This paper identifies common fundamental techniques underlying cdmaOne[TM], CDMA2000[®] and WCDMA technologies, as well as their family of standards. Furthermore, this paper demonstrates that these technologies predominantly share the same fundamental techniques. Although each family of standards continues to evolve to support high-speed packet data transmission techniques, both standards continue to use similar fundamental methods while enhancing their performance and cost efficiencies to lower the cost of delivering mobile voice, data and multimedia services.

These shared fundamental innovations benefit the entire wireless value chain. They help expedite the standardization and publishing processes, by allowing common techniques among the related standards and the collective knowledge of the cellular industry to be leveraged ultimately resulting in faster time to market for commercial equipment manufacturers. For service providers, these commonalities improve the performance and efficiency of their network resources. For vendors, these commonalities enable a faster time to market, more innovative products and more competitive pricing. For consumers, these commonalities bring lower prices, a better end-user experience and greater customer satisfaction.

The paper is divided into six sections, the key points of which are presented below:

Section 1: Introduction and Background of the Relevant CDMA Standards

- In August 1985, QUALCOMM conceived the first fundamental techniques that are used in Code Division Multiple Access (CDMA) for terrestrial cellular communications.

- Most of the techniques that were conceived, tested, patented and developed by QUALCOMM are fundamental and critical to the proper operation and functioning of all commercial CDMA systems.

- Although the CDMA2000 and WCDMA standards were ratified by different partnership projects (3GPP2 and 3GPP, respectively), they share many of the same fundamental

techniques that were conceived in the late 1980s, commercialized as cdmaOne in the mid 1990s, and later enhanced in the family of CDMA2000 standards.

- As each of these systems evolve to support higher data rate functionalities, they have incorporated similar technologies necessary to implement such high data rate capabilities in a CDMA-based system.

Section 2: Fundamental CDMA Technologies Common to cdmaOne, CDMA2000 and WCDMA

- cdmaOne, CDMA2000 1X and WCDMA standards share the same fundamental technologies.

- Examples of these fundamental technologies are: Direct sequence spread spectrum multiple access, orthogonal channelization codes, random access, fast uplink power control, rake receivers, soft handoff, single frequency re-use and scrambling. These technology solutions and their similarities are discussed in this paper.

Section 3: Similarities in CDMA2000 1X and WCDMA Standards Beyond cdmaOne

- CDMA2000 1X Revision 0, the first commercial iteration of CDMA2000, and WCDMA Release 99 share many of the same new and evolved techniques. These techniques are basic and critical to delivering spectrally efficient (affordable) voice and data services.

- A few of the new and evolved 3G innovations that are shared by CDMA2000 1X and WCDMA standards are: Variable length orthogonal codes, uplink complex spreading, fast downlink power control, data rate configurable channels, dual-event downlink paging and reservation mode random access. These innovations are discussed in this paper.

Section 4: High-Speed Packet-Switched Downlink Technologies Common to CDMA2000 1xEV-DO and HSDPA

- Both CDMA2000 and WCDMA families have evolved to deliver high-speed packet data services and share many of the same fundamental downlink techniques. These new and evolved downlink technologies are critical to delivering broadband data to mobile devices efficiently and affordably.

- A few of the new and evolved high-speed packet downlink technologies that are shared by CDMA2000 1xEV-DO (Evolution-Data Optimized) Release 0 and the High Speed Downlink Packet Access (HSDPA) feature of WCDMA are: Fast and adaptive modulation and coding schemes, fast and adaptive packet data scheduling, fast downlink rate control, fast hybrid ARQ, incremental redundancy feedback for early termination and short transmission time intervals. These technology solutions are discussed in this paper.

Section 5: High-Speed Packet-Switched Uplink Technologies Common to CDMA2000 1X, 1xEV-DO and HSUPA

- Both CDMA2000 and WCDMA families also share the same high-speed packet technologies on the uplink. These new and evolved uplink technologies are critical to sending broadband data from a mobile device to support delay-sensitive services such as voice over Internet protocol (VoIP), push-to-talk, video telephony and multiplayer online gaming.

- A few of the new and evolved high-speed packet uplink technologies common to CDMA2000 1xEV-DO Revision A and the High Speed Uplink Packet Access (HSUPA) feature of WCDMA are: Fast uplink rate control, hybrid ARQ in the uplink and early termination in the uplink. These technology solutions are discussed briefly in this paper.

Section 6: Broadcast and Multicast Service Techniques Common to CDMA2000 and WCDMA

- Mobile broadcasting and multicasting allows service providers to deliver the same multimedia content efficiently and economically to many users on a common channel without clogging up the air interface with multiple transmissions of the same data.

- Novel techniques for broadcasting or multicasting content in an existing cellular environment were developed for CDMA2000 and WCDMA networks, and both CDMA2000 and WCDMA families share the same downlink multicasting technologies.

In summary, this paper identifies the common fundamental technologies shared by both the CDMA2000 and WCDMA families, and emphasizes that the essential fundamental technologies needed to deploy high-capacity voice and high-speed data services on a cellular CDMA network are common to both these CDMA standards although they were standardized by different partnership projects. Both standards continue to evolve by sharing the various innovations to deliver compelling robust voice and high-speed data services from which the entire 3G value chain benefits.

[1] Introduction

The use of Code Division Multiple Access (CDMA) for terrestrial cellular communications was first conceived in 1985 by Dr. Irwin Jacobs, Klein Gilhousen and Dr. Andrew Viterbi, founders of QUALCOMM Incorporated. This pioneering innovation was later standardized as IS-95 in July 1993 by the Telecommunications Industry Association (TIA) and became known commercially as cdmaOne. Early on, these pioneers in digital communications technology knew that CDMA could be made technically feasible and commercially viable because Moore's Law would continue to increase the processing power of semiconductor devices that would be needed to perform their newly envisioned complex CDMA digital signal processing techniques.

In November 1989, the first demonstration of a terrestrial CDMA system proved that CDMA could provide excellent voice quality, increased call capacity, fewer dropped calls, increased caller privacy, and improved data transmission services over any other existing cellular technology.

Based on these encouraging results, QUALCOMM and its key partners took the risk and initiative to begin the rigorous process of standardizing and commercializing CDMA. Only a few network operators and manufacturers believed that QUALCOMM, a small company in San Diego, could be successful in commercializing CDMA. But QUALCOMM was determined to take the risk and show the world a new way to do cellular wireless communication.

"From the beginning, critics warned that the compelling theoretical potential of CDMA would never prove out in the field; dynamic power control in rapidly fading environments would be its Achilles heel; interference would vastly limit capacity; systems under heavy load would be unstable; and power balancing would make infrastructure engineering a nightmare."[1] ***- Bill Frezza***

Against all the odds, in 1995, cdmaOne became the first CDMA system to be commercialized and quickly became one of the fastest growing technologies in the wireless communications world, reaching 100 million subscribers after only six years of commercial deployment[2]. In comparison, GSM took nearly 7 years to achieve a similar milestone[3]. The early adoption of CDMA in Korea, a leading-edge market, enabled local vendors, such as Samsung and LG, with no presence in the wireless telecom market to rise to world-class stature in the global telecommunications industry. Samsung and LG succeeded in becoming two of the leading suppliers of CDMA2000 devices and built on their knowledge of CDMA to become key suppliers of WCDMA devices now, since CDMA2000 and WCDMA technologies are very common in design. Similarly, Motorola, Lucent and Nortel were able to leverage their knowledge and experience of cdmaOne and CDMA2000 into the WCDMA infrastructure arena.

"To claim that a handful of engineers could actually do this was preposterous. But they did it. Fundamentally, they've created something that's amazing.".[4] ***- Ajay Diwan***

The fundamental technologies that were used in cdmaOne became the basis for <u>all</u> CDMA-based third generation (3G) standards, including the family of CDMA2000 and WCDMA standards. Although the CDMA2000 and WCDMA standards were ratified by different standards organizations, many of the same fundamental technologies continued to

1 Wireless Computing Associate, "Succumbing to Techno-Seduction," Network Computing http://www.networkcomputing.com/604/604frezza.html, April 1, 1995
[2] CDMA Development Group (CDG) website: www.cdg.org
[3] Strategy Analytics data base
[4] A wireless analyst at Goldman Sachs Group Inc ."In Touch With a Wireless World," By Peter S. Goodman, Washington Post Staff Writer, February 20, 2000

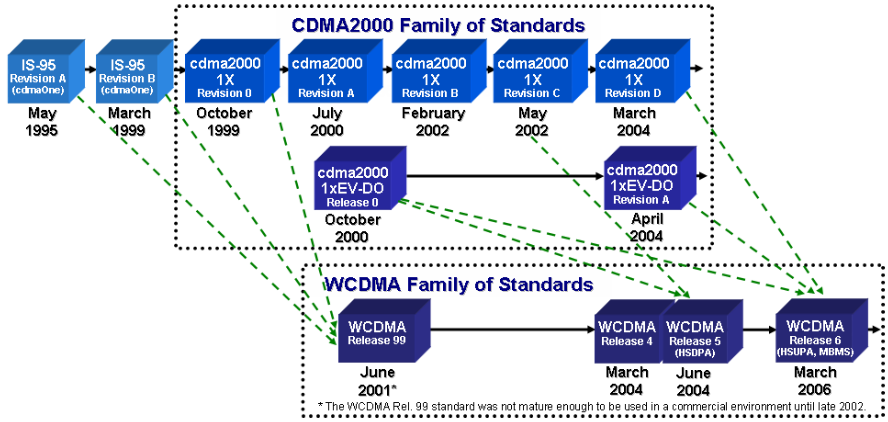
be shared between CDMA2000 and WCDMA technologies and their later revisions.

For the past two decades, QUALCOMM has led the development and delivery of innovative digital wireless communications products and services based on CDMA and other advanced technologies. By recognizing the need to expand an operator's revenue stream beyond voice services, QUALCOMM and its partners developed and standardized many new data transmission techniques to enhance the CDMA2000 and WCDMA standards that would enable deployment of a large selection of revenue-generating mobile data services over CDMA networks.

For example, as far back as October 1998, QUALCOMM demonstrated the "breakthrough" high-speed packet downlink advances that enabled cellular systems to deliver peak data rates above 2 Mbps in a mobile environment. These innovations were published two years later by the TIA as the IS-856 standard—known commercially as CDMA2000 1xEV-DO. Many of these technologies went on to be used in HSDPA, which is a part of Release 5 of the WCDMA standard. In addition, many of the technologies developed to improve uplink performance and standardized in CDMA2000 1xEV-DO Revision A went on to be shared by HSUPA, which is a part of Release 6 of the WCDMA standard.

As of October 2006, 229 CDMA2000 and WCDMA networks have been deployed in 97 countries across six continents, serving more than 273 million people. One hundred ninety eight CDMA2000 and WCDMA devices have been commercialized by 39 vendors in the past 12 months[5]; the wholesale price of CDMA2000 devices has dipped below the US$40[6] price point and the WCDMA devices are now being sold for less than US$150[7].

[5] *3G Today website: www.3Gtoday.com*
[6] *"Aiming Low for Greater Heights: Ultra-Low Cost Device Competition in India", Yankee Group, August 2006.*
[7] *www.GSAcom.com*



Notes:

1. The publication dates for IS-95 and CDMA2000 (3GPP2) standards addendum are shown (Source: 3GPP2).
2. The release of the ASN.1 Radio Resource Control (RRC) dates for WCDMA standards are shown (Source: 3GPP).
3. The standards are considered interoperable and ready for commercial deployment after these dates.

Figure 1. Timeline of CDMA-based standards

In the following sections, many of the fundamental CDMA technologies that were conceived by QUALCOMM—first incorporated into cdmaOne and CDMA2000 standards and later adopted by the family of WCDMA standards (as shown by the green arrows in Figure 1)— are identified and described. We will demonstrate what the commonalities are and why vendors, operators and consumers benefit as a result.

"Although they (CDMA2000 and WCDMA) are developed by different organizations, there are many similarities between these two systems, since both employ key design concepts of IS-95 (cdmaOne)."[8]

- Emre A. Yavuz and Dr. Victor Leung

[2] Fundamental CDMA Technologies Common to cdmaOne, CDMA2000 and WCDMA

In this section various fundamental innovations underlying the CDMA radio air interface technology are described and the key similarities among cdmaOne, CDMA2000 1X and WCDMA Release 99 technologies are identified. A brief overview of these similarities is provided and the

[8] *"A Comparison Study of 3G System Proposals: CDMA2000 vs. WCDMA," University of British Colombia, 1998*

basic techniques used by each CDMA radio air interface technology are compared. It does not include all of the implementation details and parameter settings, which may differ between the systems but do not affect their dependence on the same fundamental techniques.

2.1 Key Similarities between cdmaOne, CDMA2000 1X and WCDMA

The standard for cdmaOne was ratified by the Telecommunications Industry Association (TIA) in the United States. The standard for CDMA2000 was initiated by Lucent, Motorola, Nortel and QUALCOMM and completed by the 3G Partnership Project 2 (3GPP2). Most of the key technologies were contributed by QUALCOMM. While the first version of CDMA2000 was approved in TIA TR45.5, all the later releases were approved by 3GPP2. The standard for WCDMA was initiated by NTT DoCoMo and the European Telecommunications Standards Institute (ETSI) and completed by the 3G Partnership Project (3GPP). Both 3G standards, CDMA2000 and WCDMA, were proposed to the International Telecommunications Union (ITU) to become part of the global family of 3G standards, known as International Mobile Telecommunications 2000 (IMT-2000).

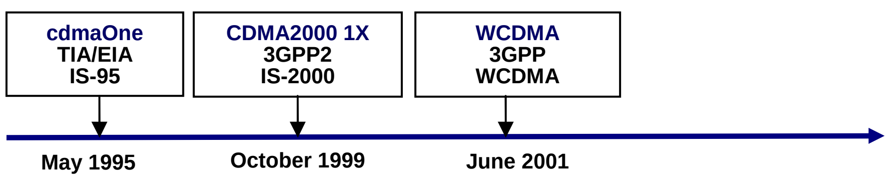


Figure 2. Publication timeline of cdmaOne, CDMA2000 1X and WCDMA Standards

The following is a list of some of the fundamental CDMA technologies that are common to <u>all</u> CDMA systems, including cdmaOne and all of the 3G CDMA-based IMT-2000 systems, most specifically CDMA2000 1X and WCDMA (Release 99).

1. **Direct Sequence Spread Spectrum Multiple Access –** to improve spectral efficiency (system capacity)
2. **Orthogonal Code Channelization** – for user separation on the downlink (mitigates interference)
3. **Random Access –** to efficiently share radio access resources among all users

4. **Fast Uplink Power Control –** to resolve the near-far field effect (reduce interference)
5. **Rake Receivers** – to resolve and benefit from multipath interference and support soft handoffs
6. **Soft Handoff** – to handoff users between base stations
7. **Softer Handoff** – to handoff users between base station sectors
8. **Soft Handoff (SHO) Active Set** – to provide seamless service with increased spectral efficiency
9. **Single Frequency Re-Use** – to increase overall network capacity
10. **Downlink Slotted Paging** – to extend the battery life of mobile devices
11. **Blind Rate Detection** – to enable variable rate decoding without additional overhead
12. **Downlink Reference Channel** – to share a common pilot to increase capacity
13. **Downlink Channel Structure** – to simplify system implementation and efficiency by separating channels with Walsh codes
14. **Scrambling** – to provide randomization so that interference would be uniform. On uplink, serves to provide channelization. Also provides communications privacy
15. **Speech Regulated Vocoders** – to reduce interference and increase system capacity

Table 1 provides a comparison of some of the key similarities between cdmaOne, CDMA2000 1X and WCDMA Release 99. It also demonstrates that all three technologies use many of the same fundamental concepts that were initially developed for cdmaOne.

Feature	**cdmaOne** (IS-95 Revision 0/A/B)	**CDMA2000 1X** (IS-2000 Revision 0/A)	**WCDMA** (WCDMA Release 99)	**QUALCOMM Patents**
Uplink Direct Sequence Spread Spectrum Multiple Access	User-specific PN scrambling	Similar technique	Similar technique	4,901,307 5,103,459 Many others issued and pending
Downlink Orthogonal Code Channelization	Walsh codes used to multiplex the downlink channels	Similar technique	Similar technique	5,103,459 Many others issued and pending

Feature	**cdmaOne** (IS-95 Revision 0/A/B)	**CDMA2000 1X** (IS-2000 Revision 0/A)	**WCDMA** (WCDMA Release 99)	**QUALCOMM Patents**
Uplink Orthogonal Code Channelization	Walsh codes used to multiplex the uplink channels in a mobile device	Similar technique	Similar technique	5,103,459 Many others issued and pending
Random Access	Slotted Aloha random access with power ramping	Similar technique, with a minor difference: - Also supports reserved mode with power control	Similar technique, with minor differences: Access only performed on preamble, but with fast PHY acknowledge-ment (vs. signaling) + subsequent message transmission without power control	5,544,196 6,615,050 6,985,728
Fast Uplink Power Control	- Fast closed loop power control - Open loop power control - Power control bit rate is 800 Hz.	Similar technique for fundamental channels: - Other modes supported for supplemental channels and Enhanced Access Channel	Similar technique, with minor differences: - No open loop power control - Power control bit rate is 1500 Hz	5,056,109 5,257,283 5,265,119 5,267,262
Rake Receivers	Receiver correlates, soft combines, and sums signals from different paths (multipath)	Similar technique	Similar technique	5,109,390

Feature	cdmaOne (IS-95 Revision 0/A/B)	CDMA2000 1X (IS-2000 Revision 0/A)	WCDMA (WCDMA Release 99)	QUALCOMM Patents
Soft and Softer Handoff	- Mobile device receives data from multiple cells or sectors - Includes "OR of the downs" rule for power control command combining	Similar technique	Similar technique	5,101,501 5,267,261 5,640,414 5,625,876 5,933,787
Soft Handoff (SHO) Active Set	Mobile assisted active set management with dynamic thresholds based on all pilots in active set	Similar technique	Similar technique, with minor differences: WCDMA includes additional events/ triggers	6,151,502 And pending application(s)
Single Frequency Re-use	All base stations in network use same frequency	Similar technique	Similar technique	4,901,307 5,103,459 Many others issued and pending
Downlink Flexible Slotted Paging	Flexible slotted paging cycles	Similar technique	Similar technique	5,392,287 5,509,015
Blind Rate Detection	Blind rate detection for low rate services (e.g., voice).	Similar technique	Similar technique, with minor differences: - Downlink only - Format indication is always transmitted in the uplink	5,566,206 5,774,496

Feature	cdmaOne (IS-95 Revision 0/A/B)	CDMA2000 1X (IS-2000 Revision 0/A)	WCDMA (WCDMA Release 99)	QUALCOMM Patents
Downlink Reference Channel	Continuous common pilot channel - BPSK modulation - QPSK spreading	Similar technique, with minor differences: Continuous common pilot channel - Used to demodulate all common and dedicated channels; these channels are transmitted using QPSK modulation.	Similar technique, with minor differences: In addition dedicated reference bits (pilot) are supported in the data channels	4,901,307 5,103,459 Many others issued and pending
Downlink Channel Structure	Dedicated PHY channels (FCH) + auxiliary data channels (SCCH)	Similar technique, with minor differences: Dedicated PHY channels (FCH) + auxiliary data channels (SCH).	Similar technique, with minor differences: Dedicated PHY data channels (DPDCH) + auxiliary data channels (PDSCH/HS-PDSCH).	6,377,809 & pending application(s)
Downlink Scrambling	- PN scrambling for cell identification - Time shift offset of same PN sequence.	Similar technique	Similar technique, with minor differences: Different PN sequences are used instead of time shifts of the same PN sequence	4,901,307 5,103,459 Many others issued and pending

Table 1: Key Similarities between cdmaOne, CDMA2000 1X and WCDMA

QUALCOMM made seminal contributions in the development of these techniques and owns multiple patents directed to most of them. Some of the above fundamental technologies that are essential to the proper operation of <u>all</u> CDMA systems are described in detail within the following paragraphs. Other equally important techniques apply as well, but for the sake of brevity they are not discussed in detail within the context of this paper.

2.1.1 Direct Sequence Spread Spectrum Multiple Access

The basis for all cellular CDMA systems is Direct Sequence Spread Spectrum Code Division Multiple Access, which provides the ability to maintain many calls within one wideband channel by assigning a unique code to each caller. This was a revolutionary technique that was applied to cellular communications and it differed greatly from the TDMA techniques that were previously employed in GSM and IS-54[9] (an enhanced version was designated IS-136) networks at the time.

To better understand CDMA, it is useful to look at the other technologies that were in use when cdmaOne was commercialized in the mid 1990s. Analog systems such as AMPS, TACS, and NMT used frequency division multiple access (FDMA) to divide the available spectrum into frequency channels for each user. Each user is assigned a single channel. Digital time division multiple access (TDMA) systems such as GSM and IS-136 (North American TDMA) further divided each frequency channel into separate timeslots per user. This increased capacity over the previous analog systems by a factor proportional to the number of timeslots available per channel. QUALCOMM designed a completely different multiple access system (CDMA), in which multiple users use the entire channel bandwidth simultaneously to substantially increase the network capacity of a digital cellular system.

In order to achieve this, QUALCOMM first employed direct sequence spread spectrum to spread users' signals over a wide frequency band using pseudorandom noise (PN) codes. The bandwidth of the "code" signal used is much larger than the bandwidth of the "information-bearing" signal, which carries the voice and data packets. The spreading process enlarges (spreads) the spectrum of the transmitted signal (i.e., 1.25 MHz for CDMA2000 and 5 MHz for WCDMA). By doing this, each user appears as wideband noise to

[9] *IS-54 and IS-136 were known as TDMA or North-American TDMA. IS-136 was also called UWC-136.*

every other user. QUALCOMM also assigned orthogonal code (Walsh code) channels to each user, instead of assigning timeslots or frequency channels. The combination of these two spreading techniques enables users to share the same frequency assignment and be distinguished from each other even from within the noise through their unique code assignment. The result is that each user is able to hear his voice communications clearly while sharing a single frequency channel amongst many users, thus increasing voice capacity.

Secondly, to mitigate intra-cell and inter-cell interferences, QUALCOMM employed a collection of tightly related and mutually supportive digital signal processing techniques such as rake receivers, power control, soft handoff and single frequency re-use that significantly increased network capacity. These technologies are described in more detail below.

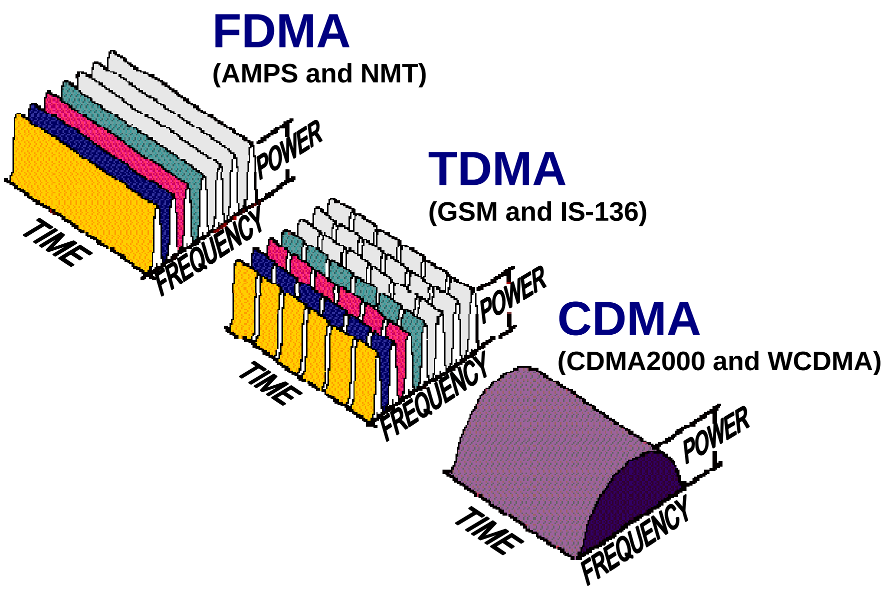


Figure 3. Differences between Time, Frequency and Code Division Multiple Access Techniques

Although both the CDMA2000 and WCDMA standards fundamentally use the direct sequence spread spectrum technique, WCDMA spreads the spectrum across a 5 MHz bandwidth while CDMA2000 spreads the spectrum across a 1.25 MHz bandwidth[10] (the equivalent to that used by cdmaOne systems). However, both WCDMA and CDMA2000 offer comparable capacities when they are normalized within equivalent bandwidths.

2.1.2 Orthogonal Code Division Multiple Access

In CDMA systems, such as CDMA2000 and WCDMA, each user or code channel is assigned a unique orthogonal (i.e., Walsh) code sequence to encode his “information-bearing” signals on the downlink.

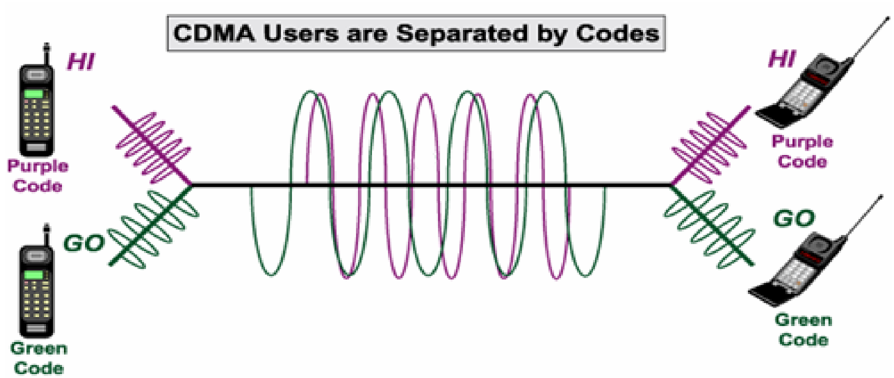


Figure 4. Code Division Multiple Access

The receiver, which knows the user’s unique orthogonal code sequence, de-spreads the received signals using correlation techniques and recovers the original information data. Meanwhile, the other interfering spread-spectrum signals remain spread over the larger bandwidth. Thus, the power within the “information-bearing” signal upon correlation will be larger than the power of the interfering signals plus noise, provided there are not too many interferers and the desired signal can be extracted successfully.

Code orthogonality is critical to maintain minimum interference among several users in a CDMA system and fundamental to enable a large number of users to clearly communicate within a mobile environment. As more callers load the network, this becomes increasingly important.

[10] The exact bandwidth depends upon the definition that is used. The chip rate of WCDMA is 3.84 Mcps; that of cdma2000 is 1.2288 Mcps. WCDMA carriers are typically spaced every 5 MHz; cdma2000 carriers are typically spaced every 1.25 MHz.

2.1.3 Power Control

The biggest challenge that spread spectrum multiple access communication systems, such as CDMA2000 and WCDMA, have to deal with is referred to as the near-far field effect. It is a phenomenon caused by having many users, "near" and "far," wanting to communicate with the same base station. Since the emission power of a radio signal drops off dramatically with distance, the signals from users that are "far" away are usually very weak and the stronger signals from users that are "near" to the base station can drown out or block the "far" away signals.

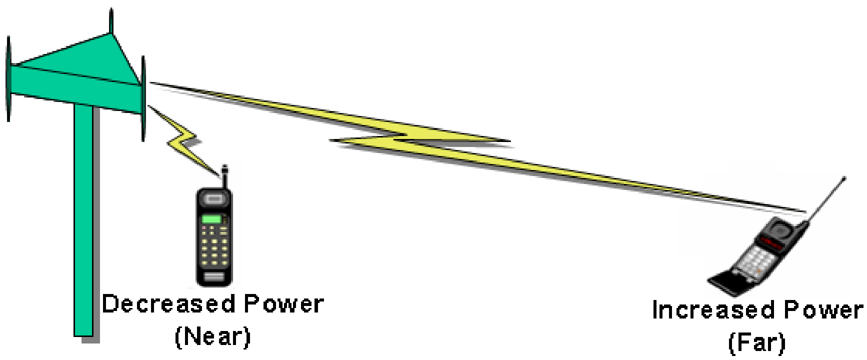


Figure 5. Power control to resolve the "Near-Far" field effect

QUALCOMM resolved the near-far field effect by minimizing the transmission power emitted by the nearby mobile devices through a technique called "power control" in which the transmit power of a user's mobile device was controlled via two closed loops—an outer closed loop and an inner closed loop. A third technique, called open loop, sets the transmit power value based upon the total received power at the handset. Implementing this tight, rapid and accurate power control technique solved the near-far problem by enabling CDMA devices to transmit just enough power to ensure reliable reception. Beyond this, it also served the dual purpose of (1) minimizing interference to other users, and (2) extending the battery life of the mobile device. For consumers, this meant a better end-user experience with less dropped calls and longer battery life.

2.1.4 Rake Receivers

In cellular systems, mobile devices receive multiple versions of the same signal when they arrive on multiple paths with different delays (e.g., a direct signal path and a delayed signal path that bounces off a building or other obstacles). This phenomenon is known as multipath. These signals can often arrive at the receiver out of phase (180 degrees) with each other and can cause destructive interference.

Using rake receivers, CDMA2000 and WCDMA systems actually benefit from the multipath signals in processing of voice signals.

Using a technique called rake receivers, CDMA2000 and WCDMA systems actually benefit from the multipath. The rake receivers are designed to use multiple fingers to receive (rake) the multipath signals that arrive at the receiving antenna with different time offsets, correlate them, and then combine (sum) them into a single (strengthened) coherent signal. This improved the immunity to multipath fading and resulted in significant gains to link margins, with consumers benefiting from improved call quality and better coverage.

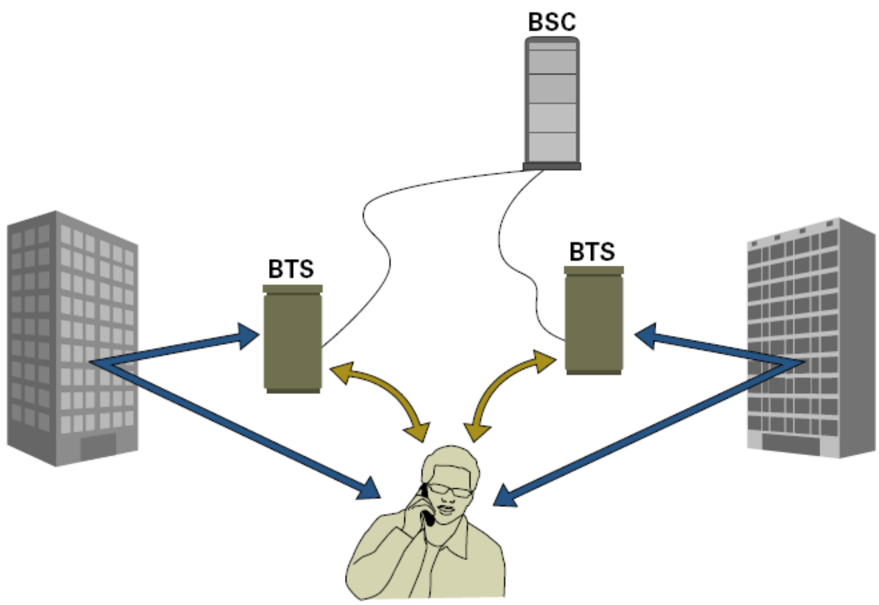


Figure 6. Multipath Effect and Rake Receivers

Rake receivers also support the “soft handoff’ (a handoff process described later in the following sections) of a signal between base stations or among different sectors of the same base station since two or more base stations transmitting the same signal can be received and processed simultaneously using multiple fingers of a rake receiver.

For consumers, the use of rake receivers ensures that the highest signal quality is maintained, and the seamless communications across cell boundaries is enabled and preserved.

2.1.5 Speech Regulated Vocoders

Another means of reducing interference, by better than half, is through the use of a speech regulated vocoder, which reduces transmission bit rates during periods of voice inactivity (quietness) or reduced activity, and hence reduces transmitted power. Conceived by QUALCOMM, this technology allows CDMA to take advantage of inherent non-speech activity (e.g., pauses) common in conversations, resulting in increased network capacity. Note that GSM codecs are on-off type and do not use variable rate. They predate the variable rate codecs used by CDMA2000. Essentially, variable rate codecs allow one to reduce the rate during lesser activity or when there is less speech information to be transferred. The GSM on-off type of codec has to be quite aggressive in when the codec comes on; otherwise, they drop sending important parts of the speech. This is much less critical with a true variable rate codec.

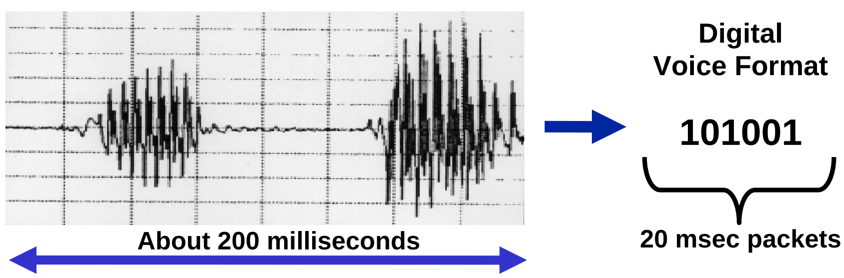


Figure 7. Speech Signal

Speech regulated vocoders enable network operators to support more voice transmissions and allow consumers to enjoy wireless communications free of interruptions (e.g., blocked or dropped calls) and longer battery life on their mobile devices.

2.1.6 Soft and Softer Handoff

Soft handoff is a powerful innovation from QUALCOMM that efficiently manages CDMA calls across cell boundaries before a handover takes place. While the term "soft handoff" characterizes a handoff of a CDMA signal between two base stations, "softer

Soft and Softer handoffs enable a CDMA mobile device to maintain the continuity and quality of the wireless connection while moving across cell boundaries.

handoff" is used to distinguish a soft handover between two sectors within the same base station.

During a soft handoff between CDMA base stations, a mobile device maintains communication with the first base station until after it has begun communicating with the second base station. The mobile device only relinquishes the signal of the first base station after acquiring the signal of the second base station. This is known as a "make-before-break" connection. Softer handoffs work in the same way between the cell sectors.

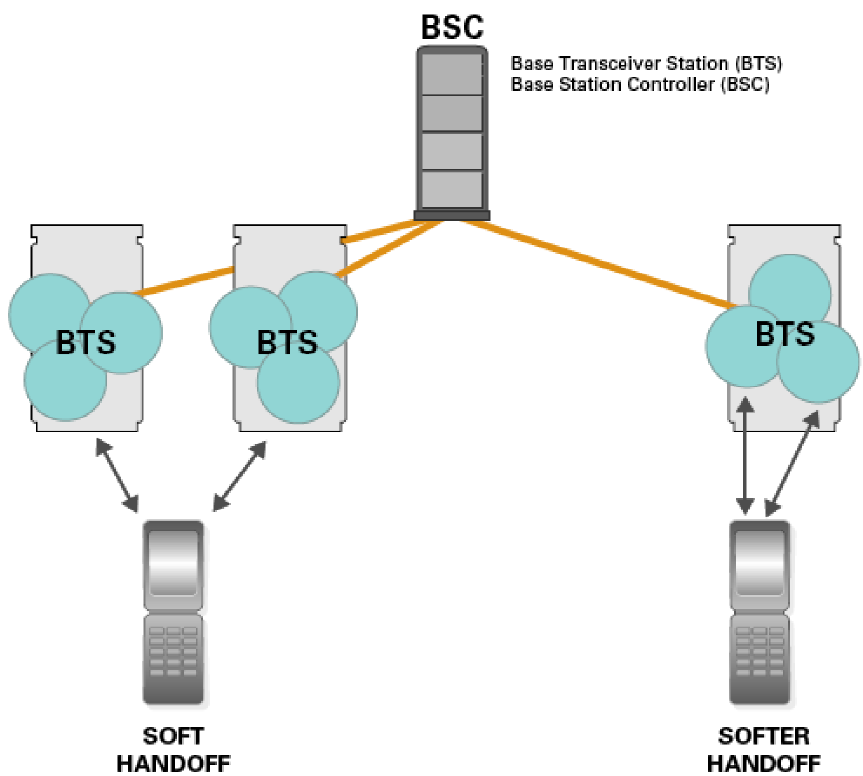


Figure 8. Soft and Softer Handoff

In contrast, a hard handoff (necessary in older networks such as GSM, TDMA and AMPS) is a "break-before-make" connection. The mobile device stops conveying user information (e.g., voice) with the first base station before conveying user information with the second base station. This leads to a higher percentage of dropped calls. For mobile operators, this can mean the difference between retaining a customer and losing a customer due to a poor end-user experience.

Soft and softer handoffs enable significant diversity gain in the link budget at the cell edge of a CDMA network. As a result, CDMA2000 or WCDMA mobile devices can maintain the continuity and quality of the wireless connections while moving from one base station or sector to another.

The signal structure of CDMA, in conjunction with rake receivers, base station power control and the inherent single frequency re-use, enables the successful implementation of soft handoffs in a CDMA receiver.

2.1.7 Single Frequency Re-Use

Single frequency re-use was yet another innovation by QUALCOMM to enable high capacity CDMA networks. QUALCOMM conceived the techniques that allowed all base stations within a CDMA2000 or WCDMA network to use a single frequency—enabling a frequency re-use factor of one (N=1).

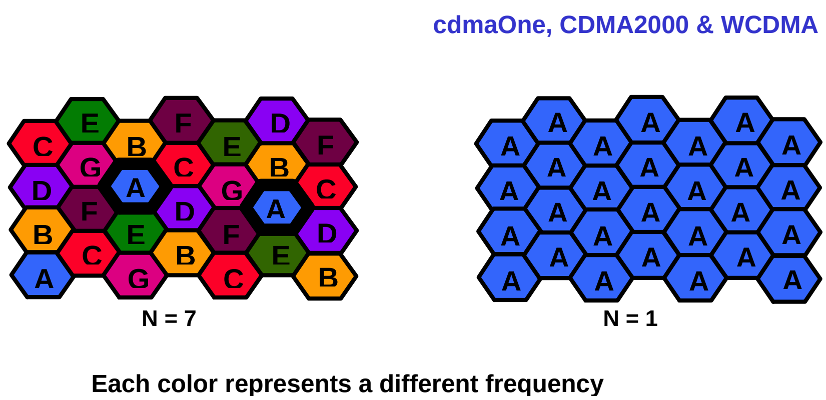


Figure 9. Frequency Re-Use in TDMA/GSM and CDMA Networks

Enabling the same frequency to be used by adjacent CDMA2000 or WCDMA base stations significantly increases the spectral efficiency and the overall network capacity. It also allows two or more base stations to receive the same uplink signal from a mobile device. For service operators, this leads to simpler network plans, lower capital expenditure (CAPEX) and an increase in network capacity.

To summarize, each of the tightly related and integrated technologies described above and many others—which were conceived by QUALCOMM—are fundamental to the proper operation of <u>all</u> commercial cdmaOne, CDMA2000 and WCDMA systems. More importantly, they enabled the following hallmark characteristics of CDMA, which are:

- Greater spectral efficiency
- Greater network capacity
- Better voice clarity
- Extended coverage for each base station
- Enhanced portable battery life

All of these benefits have a direct impact on the end-user experience as they provide service operators with greater opportunity to offer innovative services at progressively lower costs and improve their network performance and cost efficiencies.

[3] New and Evolved Technologies Shared by CDMA2000 and WCDMA Standards

As shown above,, the CDMA2000 and WCDMA families share many of the same fundamental technologies initially developed for cdmaOne. As the CDMA2000 and WCDMA standards have evolved, they continued to share even more innovations and enhancements to these technologies. This section will discuss the newer technologies developed after cdmaOne and shared by CDMA2000 and WCDMA standards, despite being standardized within two separate partnership projects, 3GPP2 and 3GPP.

3GPP developed the WCDMA family of standards while 3GPP2 developed the CDMA2000 family of standards. Both the CDMA2000 and WCDMA proposals, submitted by 3GPP2 and 3GPP respectively, were accepted by the International Telecommunications Union (ITU) to be the basis for a global and unified International Mobile Telecomunications-2000 (IMT-2000) family of standards. The IMT-2000 specification was designed to deliver advanced 3G mobile services such as high-speed data services, video and other feature-rich multimedia applications.

Subsequently, the IMT-2000 standard accommodated five different modes, as shown in Figure 10, three of which were based on CDMA technology. The 5 modes of IMT-2000 are: IMT-2000 CDMA Direct Spread (WCDMA), IMT-2000 CDMA Multi-Carrier (cdma2000), IMT-2000 CDMA TDD (TD-CDMA and TD-SCDMA), IMT-2000 CDMA Single

Carrier (UWC-136), and IMT-2000 FDMA/TDMA (DECT). Note that the names in parenthesis are the common names; the others are the official ITU names.

The fundamental CDMA techniques developed by QUALCOMM are shared by three of five modes —WCDMA, CDMA2000 and the TDD modes consisting of TD-CDMA/TD-SCDMA. The TDD modes have not been widely commercialized, and are therefore not discussed in this paper.

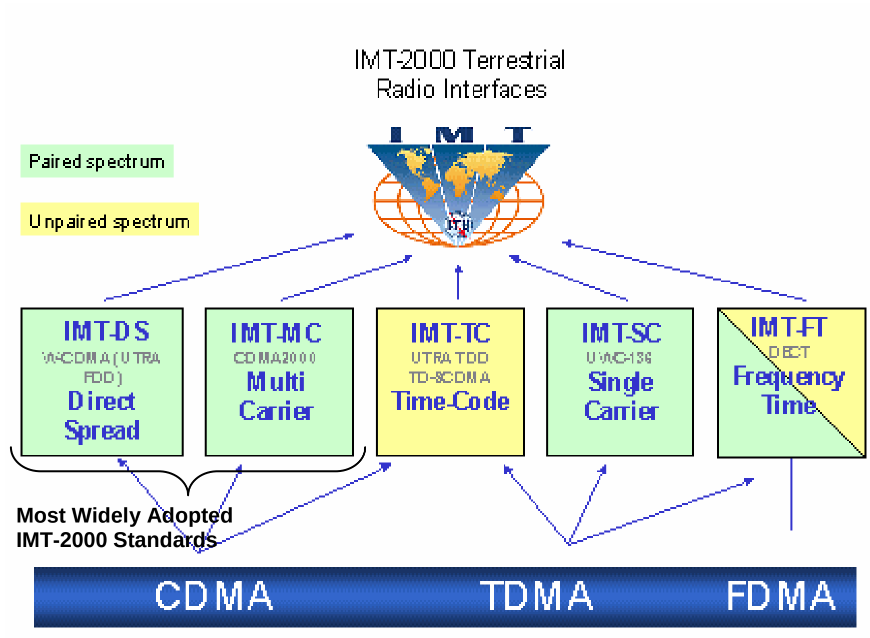


Figure 10. IMT-2000 Terrestrial Radio Interfaces

3.1 Key Similarities between the CDMA2000 1X and WCDMA Standards

A brief overview of the similarities between CDMA2000 1X and WCDMA Release 99 standards (beyond the similarities to cdmaOne) is provided below. Again, this comparison only considers the fundamental core concepts of each of the CDMA air interfaces and does not include all of the details and parameter settings, which typically differ between the systems that are defined by different standards bodies (the differences between these details are generally not as critically important to the successful deployment of the system).

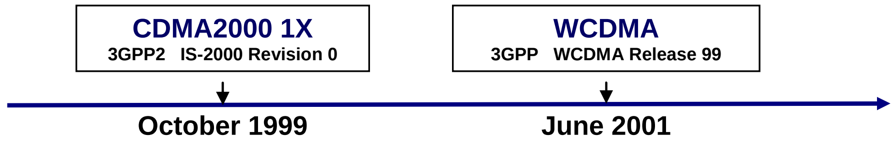


Figure 11. Publication of CDMA2000 1X and WCDMA Standards

CDMA2000 and WCDMA standards incorporate the following non-exclusive list of new evolutionary technologies that are crucial to enhancing the performance of both these standards:

1. **Variable Length Orthogonal Codes** – to support variable data rates
2. **Uplink Complex Spreading –** to increase data rates and network capacity
3. **Fast Downlink Power Control** – to reduce transmit power usage and increase capacity
4. **Data Rate Configurable Channels** –to support a range of applications that use a variety of data rates
5. **Dual-Event Downlink Paging** – to further extend the battery life of mobile devices
6. **Uplink Channel Structure** – to multiplex control and data channels
7. **Reservation Mode Random Access** – to access the network more efficiently
8. **Parallel Turbo Codes** – to improve capacity through more efficient forward error correction
9. **Coherent Uplink Detection** – to improve data rates and coverage
10. **Continuous Uplink Operation** – to increase transmission range and capacity while reducing interference to hearing aids and other devices

Table 2 provides a comparison of the key similarities between the CDMA2000 1X and WCDMA (Release 99) standards.

Feature (Includes only features not in IS-95)	**CDMA2000 1X** (IS-2000 Revision 0/A)	**WCDMA** (WCDMA Release 99)	**Qualcomm Patents**
Downlink Variable Length Orthogonal Codes	Variable length Walsh codes used to multiplex the downlink channels (SF=256 to SF=4)	Similar technique	5,751,761 6,185,246
Uplink Variable Length Orthogonal Codes	Variable length Walsh codes used to multiplex the uplink channels with a mobile device	Similar technique	5,751,761 6,185,246
Uplink Complex Spreading	Complex multiplication of I and Q branches with PN codes	Similar technique	5,926,500 6,549,525 & pending application(s)
Fast Downlink Power Control	- Fast closed loop power control - Quality based set-point control. - Power control bit rate is 800 Hz - Other control bit rates are supported	Similar technique, with minor differences: - Power control bit rate is 1500 Hz	6,396,867 6,757,320 5,461,639 6,035,209 6,317,587 7,013,160 6,137,840 & pending application(s)
Data Rate Configurable Channels	Network determines data rate depending upon application and radio channel conditions	Similar technique	5,751,761 6,185,246 6,377,809 & pending application(s)
Dual-Event Downlink Paging	Quick paging indicator channel for mobile device power saving + message sent on paging channel	Similar technique	6,111,865 6,832,094 & pending application(s)
Uplink Channel Structure	- Uplink includes control and data channels: - CDM for data and control channels - Control consists of TDM pilot and power control on same channelization code - Traffic-to-Pilot gain adjustment	Similar technique, with minor differences: DPCCH also includes transport format bits	6,396,804 6,549,525 5,930,230 & pending application(s)

Feature (Includes only features not in IS-95)	**CDMA2000 1X** (IS-2000 Revision 0/A)	**WCDMA** (WCDMA Release 99)	**Qualcomm Patents**
Uplink Pilot	- Orthogonal and coherent demodulation - RL power control done off the pilot	Similar technique	5,933,781
Reservation Mode Random Access	Mobile transmits short access request and base station grants use of access channel at a time that avoids collision with other mobiles	Similar technique	6,256,301 6,987,982 6,788,937 & pending application(s)

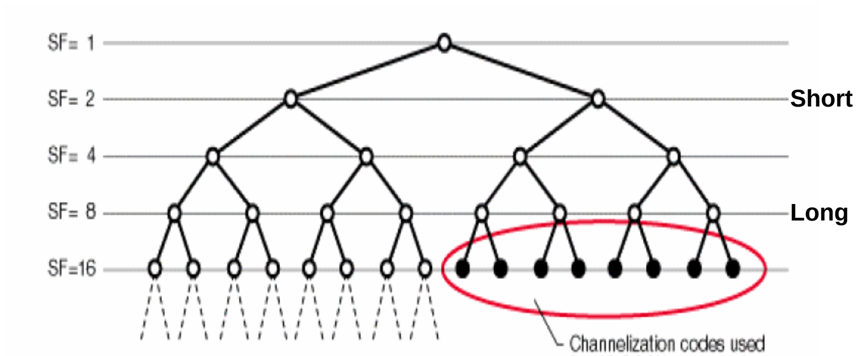
Table 2: Key Similarities between CDMA2000 1X and WCDMA

Again QUALCOMM made seminal contributions in the development of these new techniques and owns multiple patents directed to most of them. Some of these new and evolutionary innovations which are essential to the proper operation of the CDMA2000 1X and WCDMA Release 99 standards are described below.

3.1.1 Variable Length Orthogonal Codes

Both CDMA2000 1X and WCDMA were designed to accommodate both voice and data users. The transmission of voice packets can be accomplished using relatively low data rates of around 8 kbps. The transmission of data packets preferably uses as high a data rate as possible given the channel conditions, in order to minimize delay. Varying the length of the orthogonal code effectively varies the spreading factor and subsequently varies the data rate of the CDMA radio channel. As the orthogonal code rate is usually fixed, it stands to reason that shorter codes permit higher data rates.

If the channel conditions are good, the radio link can support a higher data rate, which is provided by switching to a shorter orthogonal code. However, allocating a given short code renders the longer codes beneath them in the channelization code tree non-orthogonal (unusable). Thus, the allocation and availability of all codes must be dynamically tracked and optimized.



Channelization codes used for packet transmission.
Configurable. Eight codes (example shown).

Figure 12. Variable Length Orthogonal Channelization Codes

QUALCOMM developed the fundamental allocation techniques that allow the effective use of variable length orthogonal codes. Variable length orthogonal codes are a mandatory feature in both the CDMA2000 and WCDMA standards. This is especially important for managing the mix of voice and non-voice services. As non-voice services grow as an important revenue stream for service operators, managing the integrity of the voice network becomes equally critical to provide a satisfying end-user experience.

3.1.2 Uplink Complex Spreading

Since both CDMA2000 and WCDMA mobile devices transmit multiple channels at a time with different orthogonal codes, these code channels can interfere with each other when the phase reference received by the base station is not ideal. As a result, QUALCOMM introduced a complex spreading technique that uses complex multiplication of I and Q branches with PN codes to mitigate the interference generated when different orthogonal codes are demodulated with a non-ideal receiver phase reference. This complex spreading scheme is very different from the earlier spreading and modulation formats that were commonly used by wireless communications systems and shown in Figure 13.

Without complex spreading or scrambling, the I and Q signals would be directly filtered and applied to the I/Q modulator.

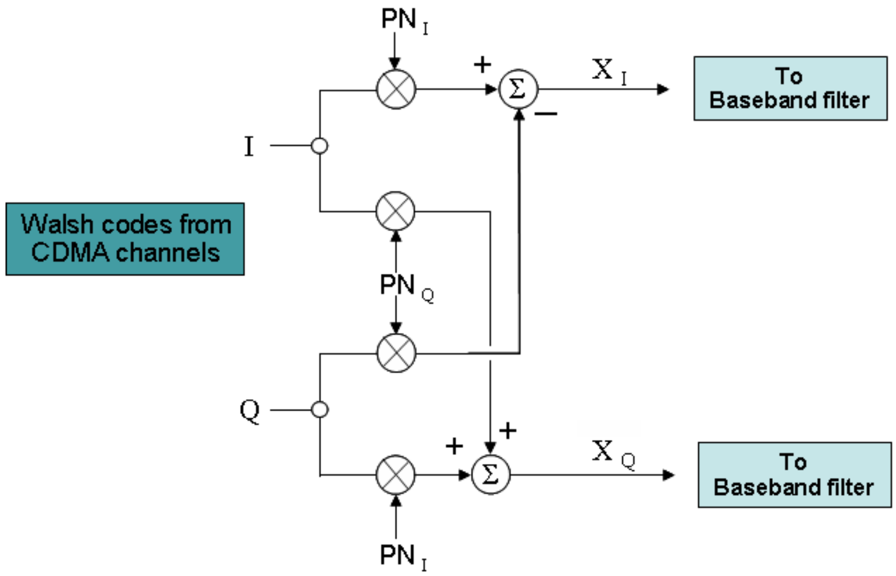


Figure 13. Uplink Channelization Structure with Complex Spreading

3.1.3 Dual-Event Downlink Paging

To preserve battery life, mobile devices sleep (remain in a dormant mode) periodically for short periods of time (in the order of seconds) until they must wake-up and listen for a network page to see if a call needs to be received and processed. In earlier cdmaOne systems, each mobile device "woke up" to listen to the paging message during the paging slot that was assigned to it. The paging message may have informed the mobile device that it was receiving a call. After each paging slot cycle, the mobile device would return to its "sleep mode" to conserve battery power.

QUALCOMM developed an enhancement to downlink paging that sends a brief indicator (e.g., one or two bits) to let the mobile device know whether to "wake up" to listen to a paging message or remain "asleep." The battery power savings provided by this additional feature are significant. Downlink paging is common to all cellular-type air interfaces, including both the CDMA2000 and WCDMA standards. For consumers, the resultant benefits are longer talk times and less frequent battery charging sessions.

3.2 Independent Characteristics of CDMA2000 1X and WCDMA Standards

Table 3 provides a comparison of the characteristics of the CDMA2000 1X and WCDMA standards that are not identical. These characteristics, such as nominal bandwidth and chip rate, impact the system implementation, system parameters and may impact performance characteristics. However, despite these differences, each of these two systems must incorporate the many fundamental common technologies some of which were described in Section 3.1 above.

Feature	CDMA2000 1X (IS-2000 Revision 0/A)	WCDMA (WCDMA Release 99)
Nominal Bandwidth	1.25 MHz (1x) or 5 MHz (3x)	5 MHz
Radio Frequency Channel Configuration	Direct Spread or Multi-carrier	Direct Spread (only)
Chip Rate	1.2288 Mcps (1x) or 3.6864 Mcps (3x)	3.84 Mcps
Network Synchronization	Synchronous	Asynchronous or Synchronous
Core Network	ANSI-41[11]	GSM-MAP

Table 3: Independent Characteristics of CDMA2000 1X and WCDMA

Nominal Bandwidth

The CDMA2000 standard was designed to operate with a channel bandwidth of 1.25 MHz similar to cdmaOne, while WCDMA was designed to operate in a 5 MHz channel. This results in a different peak data rates for each system. However, this has no effect on overall system performance and both technologies will offer similar capacities when normalized within similar bandwidths.

In addition to using the direct sequence spread spectrum technique, CDMA2000 systems can also assign three 1.25 MHz (1X) carriers to a 5 MHz (3X) bandwidth. In this technique, multiple direct spread CDMA2000 waveforms (1.25 MHz carriers) are combined to yield a composite wideband (5 MHz) CDMA signal. The typical carrier separation is 1.25 MHz. This same multicarrier approach can be

[11] *A set of standards were developed which would permit CDMA2000 to use the GSM-MAP core network and WCDMA to use the ANSI-41 core network. Neither of these has been commercially deployed.*

used to assign up to fifteen (15X) CDMA2000 carriers within a 20 MHz bandwidth.

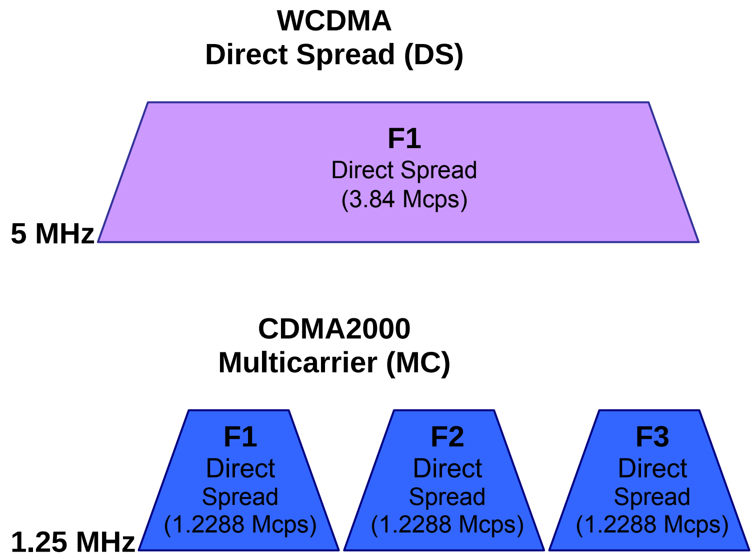


Figure 14. Nominal Bandwidth, Chip Rate and RF Channel Configuration

Chip Rate

Since the nominal bandwidth of WCDMA (5 MHz) is larger than CDMA2000 (1.25 MHz), the corresponding chip rate is also higher. The chip rate of WCDMA was chosen to be 3.84 Mcps while the CDMA2000 standard uses 1.2288 Mcps to enable backward compatibility with cdmaOne systems.

Network Synchronization

cdmaOne and CDMA2000 networks are synchronized, which means that all base stations have a common timing. The easiest way to synchronize base stations is to use a satellite based timing system, such as Global Positioning Satellite (GPS). WCDMA allows its base stations to operate without synchronization (asynchronous), independent of the GPS timing requirement, although these systems also have the option to incorporate synchronous timing.

Vocoder

CDMA2000 devices continue to maintain backward compatibility with existing cdmaOne mobile devices by using a capacity-enhancing variable rate (⅛, ¼, ½, full) vocoder to convert speech into digital communication signals. To maintain backward compatibility with existing GSM vocoders, WCDMA devices use an (On/Off) vocoder.

Core Network

Like previous AMPS, TDMA and cdmaOne systems, CDMA2000 continues to interface into an ANSI-41 core network, plus it added the ability to interface into a GSM-MAP and IP core network. WCDMA only interfaces with GSM-MAP core networks as it was conceived to be evolutionary for GSM networks, although a set of standards were developed to permit WCDMA to use the ANSI-41 core network and CDMA2000 to use the GSM-MAP core networks which have not been commercially deployed.

CDMA2000 core network consists of two parts, one interfacing to external networks such as PSTN and the other interfacing to the IP network. The part of the core network interfacing PSTN supports messages and protocols defined in IS-41 standard. The other part of the core network interfacing the IP network supports the IS-835 wireless IP network standard, and is also referred to as the packet core network (PCN).

[4] High-Speed Packet-Switched Downlink Technologies Common to CDMA2000 1xEV-DO and HSDPA

Since they were initially standardized, both CDMA2000 and WCDMA networks have incorporated high-speed packet-switched transmission technologies on the downlink, and continue to share similar innovations to increase their respective data network capacities and throughputs.

The high-speed packet-switched downlink technologies that enabled cellular networks to deliver peak data rates beyond 2 Mbps in a mobile environment were first conceived, developed and demonstrated by QUALCOMM in 1998. These fundamental innovations formed the basis for the CDMA2000 1xEV-DO Release 0 standard (IS-856), which was published in November 2000, and became the first cellular technology to commercialize the new and evolved packet access techniques.

Many of the same high-speed packet access technologies developed for CDMA2000 1xEV-DO Release 0 were later adopted by 3GPP for the WCDMA standard, which became known as High-Speed Downlink Packet Access (HSDPA) as a part of Release 5. These technologies enhanced the support for high-speed, interactive and streaming multimedia services in the downlink by enabling the CDMA networks to achieve the following improvements in the network performance:

- Significantly higher downlink peak data rates – Beyond 2 Mbps in a mobile environment
- Increased spectral efficiency
- Enhanced data capacity
- Improved resistance to interference
- Enhanced support for multimedia distribution

4.1 Key Similarities between CDMA2000 1xEV-DO Release 0 and HSDPA

This section presents a brief overview of some of the key similarities of the downlink packet access technologies that were developed and currently commercialized as CDMA2000 1xEV-DO Release 0 and HSDPA.

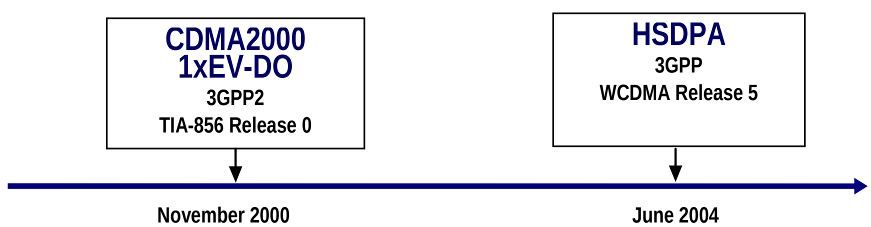


Figure 15. Publication of CDMA2000 1xEV-DO Rel. 0 and HSDPA Standards

3GPP2 IS-856 was published by the TIA in US while the 3GPP2 specifications have also been published in Japan, China, and Korea.

In addition to the basic technologies described in the previous sections that are common to both CDMA2000 and WCDMA systems, their high-speed data enhancements in CDMA2000 1xEV-DO Release 0 and HSDPA share the following fundamental packet data transmission innovations:

1. **High-Speed Packet-Switched Downlink Channelization Structure** – bundling downlink resources into a packet data channel to enable high-speed data rate transmissions by combining all of the available Walsh codes and power

2. **Fast and Adaptive Modulation and Coding Schemes** – to optimize the delivery of packets based on changes in the radio environment
3. **Fast and Adaptive Packet Data Scheduling** – to rapidly adapt to changes in the radio link
4. **Fast Hybrid ARQ** – to acknowledge correct receipt of data and retransmit erroneous data
5. **Incremental Redundancy Feedback in the Downlink** – to increase the effective data rate in the uplink by terminating the transmission of a packet early if it is decoded earlier than expected
6. **Fast Downlink Rate Control** – to rapidly adjust to changes in the radio environment
7. **Uplink Rate Control** – to efficiently control the transmission of mobile devices
8. **Downlink Multiple User Separation** – to efficiently assign the downlink channel to users
9. **Downlink Transmission Signaling** – to indicate the downlink modulation and coding
10. **Closed Loop Uplink Power Control** – to resolve the near-far field effect (reduce interference)
11. **Uplink Rate Detection** – to enable correct decoding of uplink data traffic
12. **Short Transmission Time Intervals (TTI)** – to accelerate the transmission of packets

Table 4 below provides a comparison of some of the key similarities in the downlink between CDMA2000 1xEV-DO Release 0 and HSDPA.

Feature (Includes only new features)	**CDMA2000 1xEV-DO** (TIA-856 Release 0)	**HSDPA** (WCDMA Release 5)	**QUALCOMM Patents**
High-Speed Packet Downlink Channelization Structure	16, SF=16 Walsh codes; time-shared with pilot & MAC	Similar to 1xEV-DO Rel. 0, with minor differences: - 1 to 15, SF=16 Walsh codes; continuous	6,574,211 & pending application(s)

Feature (Includes only new features)	**CDMA2000 1xEV-DO** (TIA-856 Release 0)	**HSDPA** (WCDMA Release 5)	**QUALCOMM Patents**
Fast and Adaptive Modulation and Coding Schemes	Base station selects modulation and coding for sub-packets from one Transmission Time Interval (TTI) to the next based on radio channel conditions	Similar to 1xEV-DO Rel. 0, with minor differences: - Variable timing and modulation/ coding for retransmission	6,496,543 & pending application(s)
Fast and Adaptive Packet Data Scheduling	Base station optimizes scheduling of transmissions to mobiles	Similar to 1xEV-DO Rel. 0, with minor differences: - Rescheduling at each retransmission	6,449,490 Many others issued and pending
Fast Hybrid ARQ in Downlink	Synchronous incremental redundancy interlaced structure	Similar to 1XEV-DO Rel. 0, with minor differences: Asynchronous incremental redundancy interlaced structure	6,694,469 & pending application(s) Re: CDMA2000 Rev D and HSDPA asynch interlaces 2003-067907
Incremental Redundancy Feedback in Downlink	A hybrid ACK bit is sent on the downlink channel to acknowledge packets transmitted in the uplink - Bipolar signaling - On/Off signaling	Similar to 1xEV-DO Rel. 0, with minor differences: - Bipolar or On/Off signaling	6,101,168 6,987,778 & pending application(s)
Fast Downlink Rate Control	- Mobile device continuously reports the data rate based on the measured downlink SNR - Enhanced DRC feedback mechanisms using balance of reliability with latency	Similar to 1xEV-DO Rel. 0, with minor differences: - Mobile device continuously reports the C/I and the BS selects the data rate	6,574,211 & pending application(s) Re: CDMA2000 Rev D and HSDPA enhancements: 6,985,453 2003-0156556

Feature (Includes only new features)	**CDMA2000 1xEV-DO** (TIA-856 Release 0)	**HSDPA** (WCDMA Release 5)	**QUALCOMM Patents**
Fast Uplink Rate Control based on uplink loading of all active sectors	Similar to 1xEV-DO Rel. 0 Downlink, with minor differences: - one up/down commands sent from each base station	Similar to 1xEV-DO Rel. 0 Downlink, with minor differences: - one or more up/down commands sent from each base station - explicit rate assignment message	6,556,549 6,804,210 6,563,810 6,535,523 Re: DO Revs. 0 & A: 6,807,161 Re: EV-DO Rev. 0: 6,965,613 6,567,420
Downlink Multiple User Separation	- Time Division Multiplexing (TDM) - Assigns all resources to one user during each short Time Transition Interval (TTI)	Similar to 1xEV-DO Rel. 0, with minor differences: - Assigns all resources to one or more users during each short TTI	6,574,211 & pending application(s)
Downlink Transmission Signaling	User ID signaling in preamble	Similar to 1xEV-DO Rel. 0, with minor differences: User ID signaling in control channel (HS-SCCH)	6,574,211 & pending application(s)
Uplink Rate Detection	Format indicator (RRI) signals rate	Similar to 1xEV-DO Rel. 0: Note: Also in WCDMA Rel. 99	6,798,736 & pending application(s)
Short Transmission Time Intervals	Very short TTI TTI = 1.67 ms	Similar to 1xEV -DO Rel. 0, with minor differences: TTI = 2 ms	6,574,211 & pending application(s)

Table 4: Key Similarities between CDMA2000 1xEV-DO Rel. 0 and HSDPA

QUALCOMM made seminal contributions in the development of these packet access techniques and owns multiple patents directed to each of them. All the CDMA-based high-speed downlink wireless data standards use many of the same fundamental packet access techniques to support high-speed mobile data applications, some of which are described in more detail below.

4.1.1 High-Speed Packet-Switched Downlink Channelization Structure

The high-speed packet-switched downlink channelization structure created for CDMA2000 1xEV-DO and further refined for HSDPA, represents a significant enhancement to the data transmission capabilities of earlier CDMA2000 1X and WCDMA systems.

QUALCOMM recognized that in order to achieve higher data rates needed to support mobile broadband applications, the CDMA base station needed to transmit the forward physical channels at full power using the entire code space, each occupying a certain fraction of time, rather than sharing the available Walsh code space and power among multiple users/channels. Therefore, Time Division Multiplexed (TDM) slots were introduced in the high-speed packet-switched downlink channelization structure to allocate all of the available resources (code space and power) to a single forward physical channel within each short transmission time interval (TTI). In addition, multiple users could also share Walsh code space by using different subsets of the total channel code set in HSDPA. Fast channel feedback which selects the best MCS and Hybrid-ARQ techniques helped ensure minimal packet loss so that the end-users were able to experience a satisfactory data session. And as networks loaded with increased traffic, more efficient traffic scheduling was also accommodated.

CDMA2000 1X and WCDMA systems use a single orthogonal code to transmit all of the data in a single channel, as shown in Figure 16. The data rate is adjusted by changing the length of the Walsh code in each channel. The users are assigned to each channel and the data rate changes infrequently (only after multiple frames).

The high-speed packet-switched downlink channelization structure created for CDMA2000 1xEV-DO, and further refined for HSDPA, represents significant enhancement to the data transmission capabilities of earlier CDMA2000 1X and WCDMA systems as shown in Figure 17.

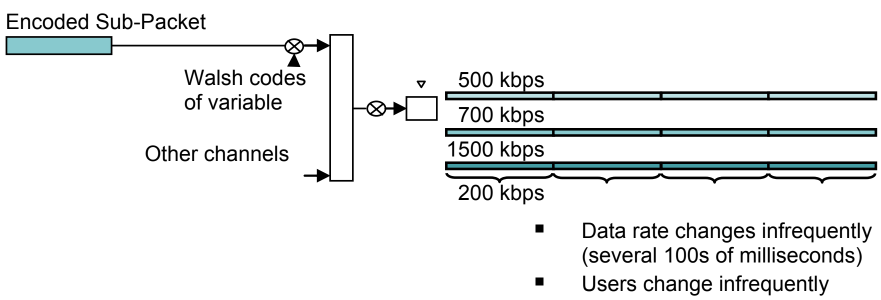


Figure 16. Downlink Channelization Structure of CDMA2000 1X and WCDMA

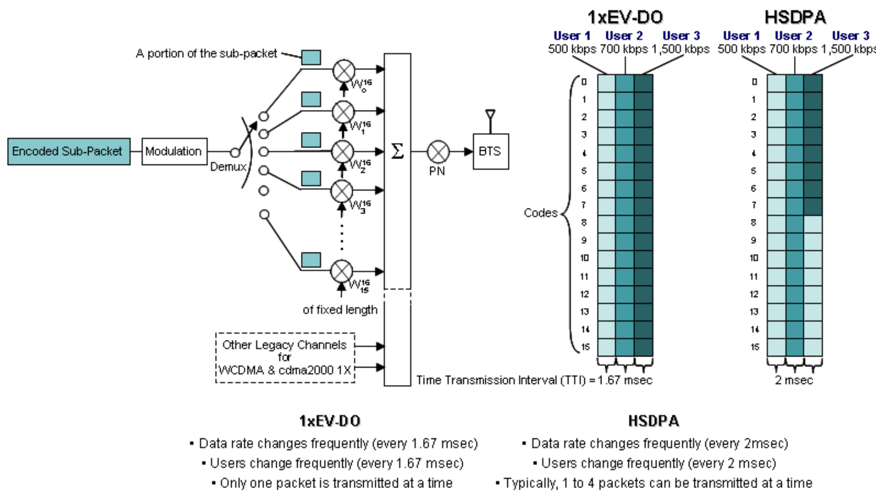


Figure 17. Downlink Channelization Structure of CDMA2000 1xEV-DO Rel. 0 and HSDPA

Channel-dependent scheduling increases the network capacity significantly when compared to a typical round-robin scheduling.

In these new systems, all of the available Walsh codes and channels are used to transmit data to a user (or multiple users). CDMA2000 1xEV-DO base stations transmit encoded sub-packets using all 16 Walsh codes to a single user in each timeslot. HSDPA base stations transmit encoded sub-packets using all available Walsh codes (those that have not been allocated to voice users and overhead) to either a single user or multiple code-shared users, thus using the same fundamental techniques as CDMA2000 1xEV-DO.

4.1.2 Fast and Adaptive Packet Data Scheduling

Fast and adaptive packet data scheduling determines the order of priority in which mobile devices receive packet data transmissions. The objective here is to transmit data to those mobile devices that have favorable radio conditions first while ensuring, to the extent possible, that each user is fairly served. This fundamental concept was first introduced by the CDMA2000 1xEV-DO standard and later adopted by HSDPA.

The scheduler decides when and to which users to be served, and which packet format (modulation and error-correction coding) to be used for each short transmission time interval (TTI), based on

Fast link adaptation is used to instantaneously adjust transmission parameters (modulation, channel coding, etc.) to compensate for rapidly changing radio conditions.

channel quality information. This determines the average data rate that each user experiences.

Channel-dependent scheduling increases the network capacity significantly when compared to a typical round-robin scheduling in which radio resources are allocated to multiple users sequentially. The aim is to transmit to users that have the most favorable instantaneous channel conditions. The gain obtained thus is known as multi-user diversity gain. Many different schedulers can be used; a proportional fair scheduler provides a good mix of capacity versus giving all users satisfactory data rates.

4.1.3 Fast and Adaptive Modulation and Coding Schemes

The radio environment in which a mobile device operates is constantly changing due to user movement, shadowing, fading, interference, distance from the base station, etc. Fast link adaptation is used to instantaneously adjust transmission parameters (modulation, channel coding etc.) to compensate for rapidly changing radio conditions. When the channel conditions permit, fast link adaptation can enable the use of higher-order modulation in conjunction with more robust error-correction coding. This can be performed on a per-timeslot basis.

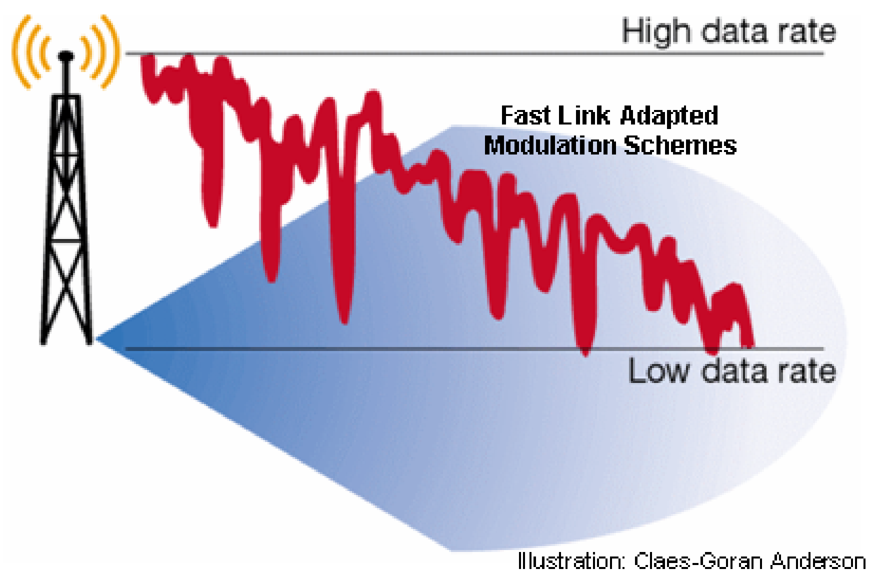


Figure 18. Transmission parameters instantaneously adjusted based on channel conditions

4.1.4 Fast Hybrid ARQ in Downlink

A CDMA mobile device can rapidly request the retransmission of missing data and combine the partial information from the original transmission with that of the later transmission before attempting to decode the message.

A CDMA mobile device can rapidly request the retransmission of missing data and combine the partial information from the original transmission with that of the later transmission before attempting to decode the message. This approach, called "soft combining," increases system capacity and supports more reliable data transmissions. A positive acknowledgement (ACK) is sent when received data is correct at the receiving end and a negative acknowledgement (NACK) is sent when data is erroneous and needs to be resent.

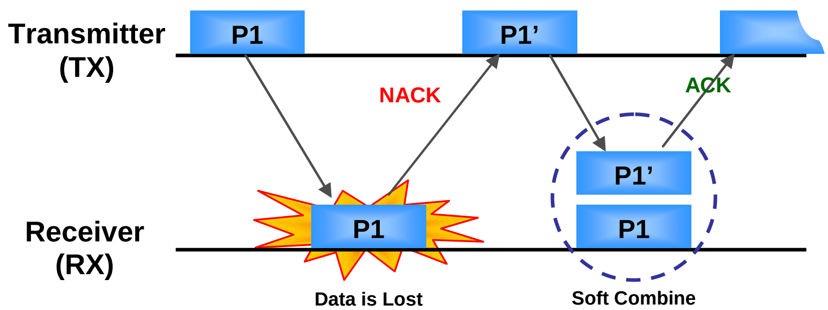


Figure 19. Rapid Request of Retransmission of Missing Data

For consumers, fast hybrid ARQ in the downlink ensures that the packets of data that are transmitted from the mobile device to the base station will be received sooner and without errors, thus reducing latencies significantly.

4.1.5 Short Transmission Time Intervals (TTI)

Use of short Transmission Time Intervals (TTI) reduces the roundtrip time and improves the accuracy of tracking channel variations. Fast link adaptation allows different modulation and channel coding schemes to be allocated dynamically every other millisecond, or hundreds of times per second.

4.2 Independent Characteristics of CDMA2000 1xEV-DO Release 0 and HSDPA

A key distinction between CDMA2000 1xEV-DO and HSDPA is that CDMA2000 1xEV-DO is a standalone system optimized for the delivery of packet data, whereas HSDPA is a packet data enhancement that allows simultaneous support for voice and data within the same WCDMA radio channel. Thus, CDMA2000 1xEV-DO base stations allocate all of their resources (code space and power) to a specific data packet user at any given time. In contrast, HSDPA base stations must first ensure that their respective voice users are served before allocating the remaining Walsh codes to a packet data user. In spite of these differences, CDMA2000 1xEV-DO and HSDPA still adhere to the same fundamental packet transmission technologies.

Table 5 provides a comparison of the characteristics of the CDMA2000 1xEV-DO Release 0 and HSDPA downlinks that are not in agreement:

Feature (Includes only new features)	**CDMA2000 1xEV-DO** (TIA-856 Release 0)	**HSDPA** (WCDMA Release 5)
Downlink Reference Channel	Pilot burst	Same as WCDMA Rel. 99
Downlink Code Sharing with existing voice users	Does not apply	CDM
Downlink Channel Structure	TDM channels: - "Data" channel - "Pilot" channel - "MAC" channel (CDM: PC bits + RL activity control + DRC lock) "ACK" channel	CDM channels: - HS-PDSCH for data info - HS-SCCH for control info - DCH or F-DCH (Rel. 6) for power control and signaling
Downlink Serving Sector Control	Walsh cover on the DRC channel	Upper layer message-based signaling
C/I Feedback	MS determines the C/I and sends desired data rate based upon that C/I back to BS	MS sends the C/I back and the BS selects the data rate

Table 5: Characteristics of CDMA2000 1xEV-DO Rel. 0 and HSDPA That Differ

[5] High-Speed Packet-Switched Uplink Technologies Common to CDMA2000 1xEV-DO and HSUPA

The high-speed packet-switched technologies that enabled CDMA-based wireless devices to deliver peak data rates close to 2 Mbps on the uplink in a mobile environment with very low latencies were first conceived, developed and demonstrated by QUALCOMM in 2004. These fundamental innovations formed the basis for the CDMA2000 1xEV-DO Revision A (TIA-856-A) standard, which was published in April 2004, and the CDMA2000 1X Revision D standard published in March 2004.

These high-speed packet-switched uplink technologies - first conceived, developed and demonstrated by QUALCOMM - support and enhance low-latency services such as VoIP, push-to-talk and richly rendered multiplayer 3D gaming.

CDMA2000 1xEV-DO Revision A is the first CDMA technology commercialized in 2006 with these new and evolved uplink techniques, some of which are based on the innovations employed within the downlink and uplink of CDMA2000 1xEV-DO Release 0. Many of the same high-speed packet access uplink techniques are used by both the CDMA2000 1xEV-DO Revision A standard and the High-Speed Uplink Packet Access (HSUPA) feature in the WCDMA Release 6 standard, which is also known as the Enhanced Uplink (EUL).

These technologies enhance the support for uplink-intensive wireless services requiring symmetric data links and low network latency such as voice over Internet protocol (VoIP), push-to-talk, and richly rendered 3D gaming with multiple players.

EV-DO Revision A was published in April 2004 and major CDMA operators started offering commercial services in late 2006. HSUPA standard was published by 3GPP in March 2006 and expected to be commercialized in 2007.

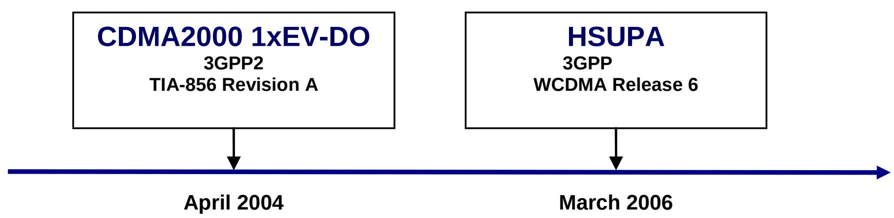


Figure 20. Publication of CDMA2000 1xEV-DO Rev. A and HSUPA Standards

The following fundamental high-speed packet-switched uplink technologies are shared by CDMA2000 1xEV-DO Revision A and HSUPA:

1. **Fast Uplink Rate Control Based on Uplink Loading of all Active Sectors** – to efficiently control the transmission of mobile devices
2. **Fast Hybrid ARQ in Uplink** – to acknowledge correct receipt of data and retransmit erroneous data
3. **Incremental Redundancy Feedback in Uplink** – to increase the effective data rate in the downlink by terminating the transmission of a packet early if it is decoded earlier than expected

4. **Uplink Channelization** – to enable better control of the uplink data flows
5. **Short Transmission Time Interval (TTI)** – to accelerate the transmission of packets

There are many similarities between these two systems, because they employ many of the key uplink packet access design concepts that were developed to increase the peak data rate and reduce the latency in the uplink of CDMA2000 1xEV-DO Revision A and CDMA2000 1X Revision D. These improvements are especially important for VoIP applications, which require low latency to deliver an equivalent voice experience that consumers expect and receive today.

QUALCOMM has made significant contributions in the development of these uplink packet access techniques and owns multiple patents directed to most of them.

[6] Broadcast and Multicast Service Techniques Common to CDMA2000 and WCDMA

Mobile broadcasting and multicasting allows service providers to deliver the same multimedia content efficiently and economically to many users on a common channel without clogging up the air interface with multiple transmissions of the same data.

Many of the same broadcast and multicast service techniques are shared between CDMA2000 and WCDMA. Mobile broadcasting and multicasting allows service providers to deliver the same multimedia content efficiently and economically to many users on a common channel without clogging up the air interface with multiple transmissions of the same data. This allows operators to optimize the delivery of multimedia using their existing 3G networks and provide their subscribers with a better multimedia experience.

To deliver multimedia content simultaneously to multiple users (multicast) within a meaningful proportion of a cell coverage area requires a significant amount of system capacity. The problem is, during multicast transmissions, other one-to-one (unicast) mobile communications in the same coverage area can be saturated. This will impact the end-user experience and the network itself. Therefore, novel techniques for broadcasting or multicasting content in an existing cellular environment were developed for CDMA2000 and WCDMA networks.

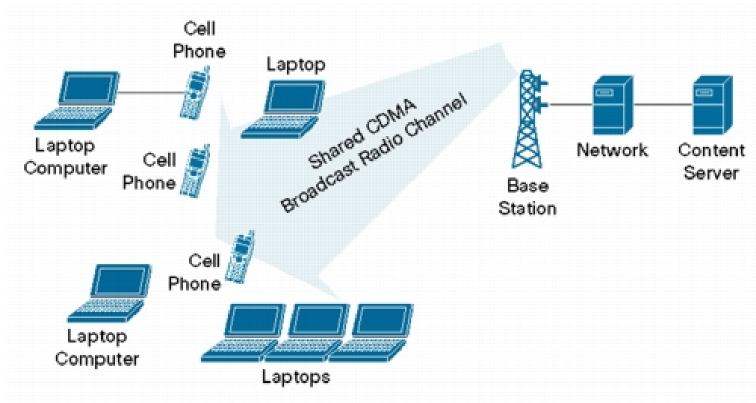


Figure 21. Multicast and Broadcast Traffic

The 3GPP2 standard refers multicasting as "Broadcast and Multicast Services (BCMCS)" while 3GPP standard refers it as "Multimedia Broadcast/Multicast Service (MBMS)". However, the downlink radio access techniques used in enabling BCMCS and MBMS are very similar in nature. They both introduce minor changes to existing radio and core network protocols to support a flexible common radio channel and power-saving multiplexing techniques that are suitable for point-to-multipoint and broadcast traffic.

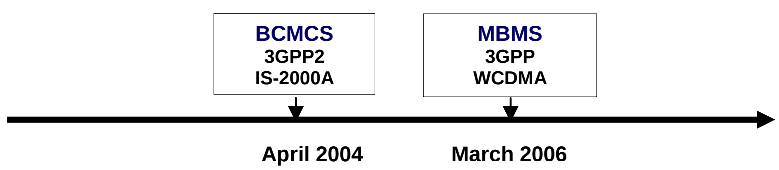


Figure 22. Publishing of BCMCS and MBMS Standards

The following fundamental mobile broadcast and multicast service techniques are shared by the BCMCS and MBMS service features:

1. Broadcast Signal – to deliver content simultaneously to multiple users.

2. Power Saving Features – to reduce mobile device battery consumption.

QUALCOMM has made significant contributions in the development of key techniques for multicasting and owns multiple patents directed to most of them.

[7] Conclusion

cdmaOne™, CDMA2000®, WCDMA and their family of standards, share the same fundamental technologies and innovations. Many of the innovations that were first developed, standardized and commercialized as cdmaOne in the late 1980s and early 1990s have become fundamental to the operation of any commercial cellular system based on CDMA.

Although some of the operating parameters used in these standards may vary, which can have a direct impact on the implementation and performance characteristics of the systems, they still require same fundamental CDMA technologies that were developed initially for cdmaOne and then further enhanced for CDMA2000 and WCDMA. QUALCOMM conceived these fundamental techniques, made seminal contributions in their development, and owns multiple patents directed to most of them.

Beyond sharing the same fundamental technologies, cdmaOne, CDMA2000 and WCDMA standards have continued to share many new innovations that enabled more efficient devices, greater network capacities and higher data throughputs. These include enhanced downlink and uplink packet access techniques. Again, QUALCOMM made significant contributions in the development of fundamental packet access techniques for both downlink and uplink and holds multiple patents directed to most of them. The addition of multicasting technologies to both CDMA2000 and WCDMA standards is yet another significant improvement to both the standards in which QUALCOMM holds important patents.

Increasing the commonality between CDMA2000 and WCDMA benefits these standards by enabling faster adoption and publication, and increasingly utilizes the collective knowledge of the cellular industry. This results in vendors bringing commercial products to market faster at lower costs since most vendors today are producing equipment for both standards. Samsung, Motorola, LG, Lucent, Sony/Ericsson, Nokia, Motorola, Nortel, Panasonic, NEC, Huawei and ZTE serve as prime examples. Ultimately, the consumers benefit by having access to lower cost and higher performing devices, as well as having more desirable and affordable services from the service providers who can operate more efficient and better performing networks with the addition of each new revision of the respective standard.

The commercialization of these CDMA-based systems has had a dramatic impact on the performance, economics and subscriber growth of mobile communications worldwide. Close to 300 million people are using CDMA2000 and WCDMA today from a vast selection of more than 200 mobile devices from more than 40 different suppliers. The wholesale price for CDMA2000 devices are selling below US$40 in the emerging markets and WCDMA devices are now being sold below US$150[12]. It is estimated that by the end of 2010, more than 40% of the total cellular subscriber base will embrace CDMA2000 or WCDMA enabled mobile devices[13].

[12] "Aiming Low for Greater Heights: Ultra-Low Cost Device Competition in India", Yankee Group, August 2006
[13] Strategy Analytics, Worldwide Cellular User Forecasts, 2005-2010, January 2006, EMC WCIS Q1 2006, Yankee Group Global Mobile Market Forecast March 2006, ABI Mobile Subscriber Database April 2006, IGillott Research Worldwide Forecast 2005-2010 April 2006.

[8] APPENDIX: Glossary

Term	Definition
2G	Second Generation digital communications technologies
3G	Third Generation digital communications technologies
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
AMPS	Advanced Mobile Phone Service
BCMCS	Broadcast and Multicast Services
CDG	CDMA Development Group
CDMA	Code Division Multiple Access
cdmaOne™	Trademark of second generation CDMA systems
CDMA2000®	Third generation IMT-2000 standard based on CDMA2000 Systems
CDMA2000 1X	The first release of the CDMA2000 standard
CDMA2000 1xEV-DO	An evolution to the CDMA2000 standard; Evolution-Data Optimized (EV-DO)
DECT	Digital Enhanced Cordless Telecommunications
DS-CDMA	Direct Sequence Code Division Multiple Access
DVB-H	Digital Video Broadcast for Handhelds
EDGE	Enhanced Data for Global Evolution
EIA	Electronic Industries Alliance
ETSI	European Telecommunication Standardization Institute
FPLMTS	Future Public Land Mobile Telecommunication Systems
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HSPA	High Speed Packet Access
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
IMT-2000	International Mobile Telecommunications 2000 standard
IS-2000	Interim Standard 2000 published by the ITU

Term	Definition
IS-95	Interim Standard 95 published by the TIA/EIA
IS-95A	Interim Standard 95 Revision A published by the TIA/EIA
IS-95B	Interim Standard 95 Revision B published by the TIA/EIA
ITU	International Telecommunications Union
MBMS	Mobile Broadband/Multicast Service
Mcps	Mega chips per second
NMT	Nordic Mobile Telephone
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TIA	U.S. Telecommunications Industry Association
PDC	Personal Digital Communications
UMTS	Universal Mobile Telecommunication System
UTRA	UMTS Terrestrial Radio Air interface
UWC	Universal Wireless Communications
WCDMA	Wideband Code Division Multiple Access