Wideband CDMA Radio Transmission Technology

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(ABSTRACT)

Wireless communications is going under explosive growth. The number of mobile users is expected to reach 1 billion by 2010 [2]. In the search for the most appropriate multiple access technology for third-generation wireless systems, a number of new multiple access schemes have been proposed (e.g., wideband CDMA schemes, TDMA-based schemes, and TD-CDMA).

The main goal of the 3rd-generation cellular system is to offer seamless wideband services across a variety of environments, including 2 Mbps in indoor environment, 384 kbps in a pedestrian environment and 144 kbps in a mobile environment [2]. The Japanese 3rd generation system employs wideband code division multiple access (W-CDMA) technology. The International Telecommunications Union (ITU) is also considering W-CDMA technology for a global standard – IMT-2000. The ITU is an international standards body of the United Nations. The system approach is leading to a revolutionary solution instead of an evolutionary solution from the current IS-95 CDMA system. The current IS-95 was designed based on the needs of voice communications and limited data capabilities, but 3rd-generation requirements include wideband services such as high-speed Internet access, high-quality image transmission and video conferencing. The current IS-95 CDMA standard specifies 1.25MHz channel bandwidth and 1.2288Mchips/s chip rate. The relatively narrow bandwidth and low chip rate makes it impossible for IS-95 to meet the data rate requirement of the 3rd-generation. While the cdma2000 system, which supports CDMA over wider bandwidths for capacity improvement and higher data rates, will maintain backward compatibility with existing

IS-95 CDMA systems, the W-CDMA system will use dual-mode terminals to retain the backward compatibility [1].

In this paper, we will provide a comprehensive review of the wideband CDMA scheme, focusing on key technical features of the system. We will also briefly provide a summary of cdma2000 in the United States, and an evaluation of wideband CDMA in Korea.

Introduction and Background

Third-generation mobile radio networks have been under intense research and discussion and will emerge around the year 2000. In the International Telecommunications Union (ITU), third generation systems are called International Mobile Telecommunications-2000 (IMT-2000), and in Europe, Universal Mobile Telecommunications System (UMTS). IMT-2000 will provide a multitude of services, especially multimedia and high-bit-rate packet data [2]. Wideband code division multiple access (W-CDMA) has emerged as the mainstream air interface solution for the third-generation networks. In Europe, Japan, Korea, and the United States, wideband CDMA systems are currently being standardized. The standards bodies include: European Telecommunications Standards Institute (ETSI) in Europe, Association of Radio Industries and Business (ARIB) in Japan, Telecommunications Industry Association (TIA) and T1P1 in the U.S.A., and Telecommunications Technology Association (TTA) in South Korea. The fast development during recent years has been due to the Japanese initiative. In the beginning of 1997, the Association for Radio Industry and Business (ARIB) decided to proceed with detailed standardization of wideband CDMA. The technology push from Japan accelerated standardization in Europe and the United States. During 1997, joint parameters for Japanese and European wideband CDMA proposals were agreed upon [3]. The air interface is now commonly referred to as WCDMA. In January 1998, strong support behind WCDMA led UMTS to choose it as their interface for frequency-division duplex (FDD) frequency bands in ETSI [3]. The selection of wideband CDMA was also backed by Asian and American GSM operators.

Objectives

The objective of this research is to present the wideband CDMA air interface scheme that is currently being developed by the standardization organizations in Europe, Japan, the United States, and Korea for third-generation communication systems. We will discuss the main technical approaches of W-CDMA and present key technical features of the system. We will also briefly summarize the differences between the major proposals given to ITU by the standardization organizations, mainly cdma2000 in the U.S. and wideband CDMA in Korea.

Motivation/Problem Statement

Many research and development projects in the field of wideband CDMA have been going on in Europe, Japan, the United States, and Korea. Investigations into the field of CDMA system as an air interface multiple access scheme for 3rd-generation systems, such as W-CDMA, have been extensively reviewed. It seems that wideband CDMA will be the answer to the emerging requirements for higher rate data services and better spectrum efficiency, which are the main drivers identified for the third-generation mobile systems [3].

Analysis/Implementation

Operating Band Structure:

W-CDMA operates in the 1920-1980MHz band for the uplink and 2110-2170MHz for the downlink. These are the main bands for IMT-2000 and are designated as Band A for the uplink and Band A' for the downlink. These two bands are in the 230MHz global spectrum identified by the ITU World Administration Radio Conference (WARC-92) for a worldwide standard – IMT-2000. Figure 1 shows the frequency plan of the 230MHz global spectrum to be allocated to IMT-2000 [2].

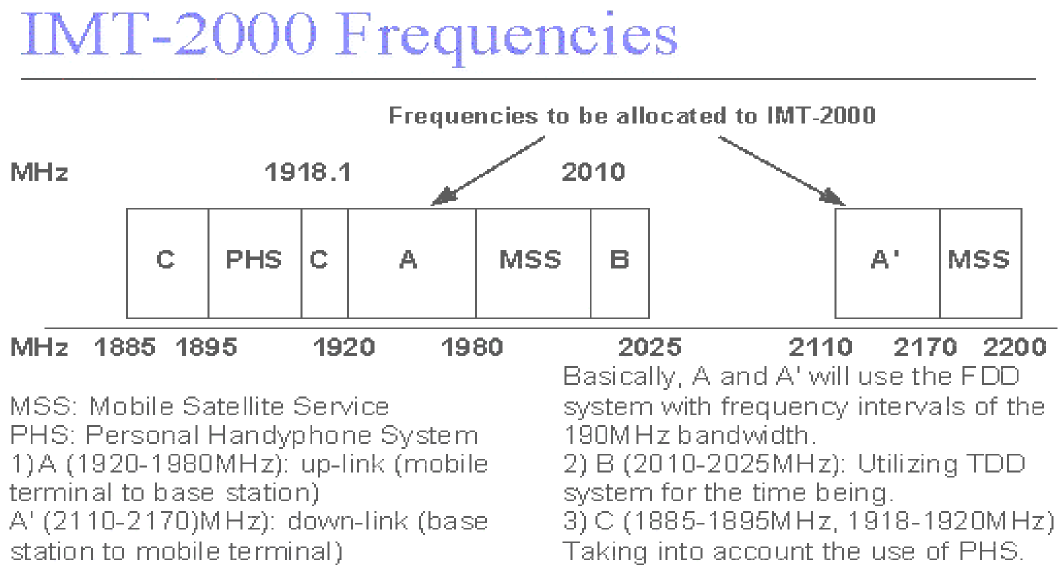

Figure 1. Frequency plan for IMT-2000.

W-CDMA is a frequency division duplex (FDD) system. FDD allows a simultaneous two-way communication by employing two separate frequency channels. The frequency separation between the transmit and receive channel is 190MHz. The lower band (A) carries information from the mobile terminals to the base stations. On the other hand, the upper band (A') carries information from the base stations to the mobile terminals. Both the A and A' bands are 60MHz wide. Both of them are divided into twelve frequency channels. Each frequency channel is 5MHz wide. Figure 2 shows the operating band structure for the mobile terminals [7].

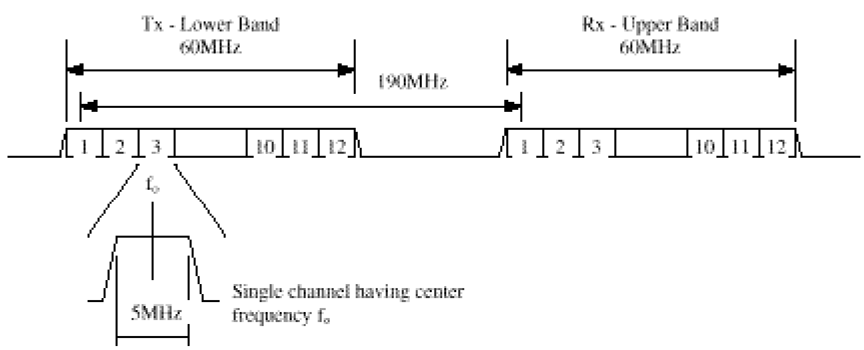

Figure 2. Operating band structure to mobile terminals.

The twelve duplex pairs permit frequency division multiple access (FDMA). FDMA means that a number of two-way communications can be conducted simultaneously by assigning each communication to a different duplex pair. This operating band structure provides for twelve channels in terms of FDMA. Fukasawa [4] showed that the 5MHz channel capacity of the W-CDMA is 82. This is 3.4 times the capacity of current analog cellular systems (AMPS).

W-CDMA Schemes:

Wideband CDMA is a direct sequence spread spectrum (DSSS) system. W-CDMA systems spread the bandwidth of an information stream to a much wider bandwidth and lower the power spectral density (PSD) accordingly. There are two main types of wideband CDMA schemes: network asynchronous and network synchronous [5]. In network asynchronous schemes the base stations are not synchronized, while in network synchronous schemes the base stations are synchronized to each other within a few microseconds. There are three network asynchronous proposals: WCDMA[1] in ETSI and ARIB, and TTA II wideband CDMA in Korea [5]. A network synchronous wideband CDMA scheme has been proposed by TR45.5 (cdma2000) and is being considered by Korea (TTA I) [5]. The ITU radio transmission technology description of different wideband CDMA schemes can be found in [6-12].

The WCDMA scheme has been developed as a joint effort between ETSI and ARIB during the second half of 1997 [6]. The ETSI WCDMA scheme has been developed from the FMA2 scheme in Europe [6] and the ARIB WCDMA from the Core-A scheme in Japan [7]. Table 1 lists the main parameters of the WCDMA scheme [6].

[1] WCDMA is written without a dash when used for the ARIB/ETSI system. For other wideband CDMA proposals it can be written as W-CDMA.

Channel bandwidth	1.25, 5, 10, 20 MHz
Downlink RF channel structure	Direct spread
Chip rate	(1.024)[a]/4.096/8.192/16.384 Mc/s
Roll-off factor for chip shaping	0.22
Frame length	10 ms/20 ms (optional)
Spreading modulation	Balanced QPSK (downlink)
	Dual channel QPSK (uplink)
	Complex spreading circuit
Data modulation	QPSK (downlink)
	BPSK (uplink)
Coherent detection	User dedicated time multiplexed pilot (downlink and uplink); no common pilot in downlink
Channel multiplexing in uplink	Control and pilot channel time multiplexed
	I&Q multiplexing for data and control channel
Multirate	Variable spreading and multicode
Spreading factors	4-256
Power control	Open and fast closed loop (1.6 kHz)
Spreading (downlink)	Variable length orthogonal sequences for channel separation Gold sequences 2^{18} for cell and user separation (truncated cycle 10 ms)
Spreading (uplink)	Variable length orthogonal sequences for channel separation, Gold sequence 2^{41} for user separation (different time shifts in I and Q channel, truncated cycle 10 ms)
Handover	Soft handover Interfrequency handover
[a] In the ARIB WCDMA proposal a chip rate of 1.024 Mc/s has been specified, whereas in the ETSI WCDMA is has not.	

Table 1: Parameters of WCDMA.

Data and Chip Rate:

The full W-CDMA specification allows variable data rates and chip rates at 1.024/4.096/8.192/16.384Mcps [1]. Spreading involves the data and chip sequences. The data sequence is the information stream and the chip sequence is the spreading code. The information stream is a relatively low bit rate sequence, while the spreading code is a relatively high chip rate sequence.

Channel Bandwidth:

The nominal bandwidth for all third-generation proposals is 5MHz. The full W-CDMA specification allows the channel bandwidths of 1.25/5/10/20MHz [1]. The 5MHz bandwidth is the direct result of the choice of the chip rate and the pulse shaping filter. W-CDMA specifies a square root raised cosine pulse shaping filter with roll off factor of

0.22. The use of a pulse shaping filter is to conserve the channel bandwidth. The square root raised cosine filter satisfies the Nyquist criterion such that the introduction of the pulse shaping does not cause intersymbol interference. The choice of a wide channel bandwidth can achieve high data rate. For instance, the 5MHz bandwidth can support a data rate up to 384Kbps. The use of a wide channel bandwidth enables RAKE receivers to resolve more multipaths. This improves the receiver sensitivity and lowers the transmit power requirements for mobile terminals.

Spreading and Modulation:

W-CDMA specifies a two-layered spreading structure. The 1st spreading code is a short code for channelization purposes. The code is derived from a Walsh/Hadamard function. The spreading code for the 2nd layer spreading is a long Gold code for randomization. It is performed in the baseband processor. A detail discussion of the spreading process can be found in [13]. The baseband processor sends the direct (I) and quadrature (Q) spread sequences in digital format to the radio. The radio uses quadrature phase shift keying (QPSK) technique to modulate the sequences on the carrier.

Transmitter Specifications:

The transmitter is specified to have the maximum output power in the range from 29dBm to 33dBm. The output power is controllable over 70dB range – the minimum output power is from –41dBm to –37dBm [13]. The power control step size is 1dB. Transmitter power control (TPC) is essential to direct sequence spreading spectrum (DSSS) systems. It is required to combat the near-far problem. W-CDMA provides TPC on both the uplink and the downlink. There are two types of the TPC: open-loop TPC and closed-loop TPC [7].

Receiver Sensitivity:

W-CDMA employs pilot symbol-aided coherent detection to optimize receiver sensitivity. The pilot symbols associates in both the uplink and downlink as shown in Figure 3 [7].

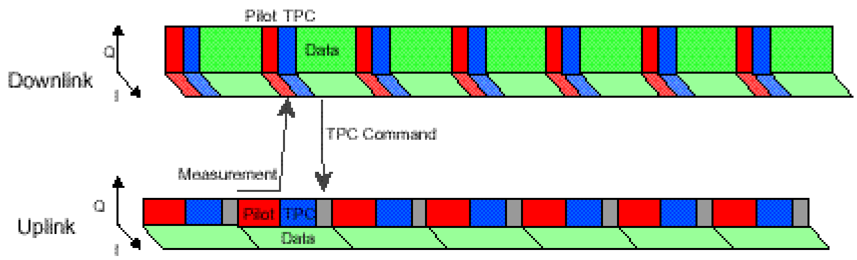

Figure 3. Multiplexing of pilot symbols.

The pilot symbols on the downlink are time multiplexed with the TPC command and the data, while the pilot symbols on the uplink are IQ multiplexed. The pilot symbols are used for channel estimation at the receivers. The estimation allows the coherent detection and automatic frequency control. Detection can achieve 10^{-3} BER at 6dB or less E_b/N_o on the traffic channel [7]. The specified minimum input power is –113dBm at the receiver.

Handover:

W-CDMA employs two receivers in the radio. One is the main receiver and the other is the diversity receiver. The diversity receiver facilitates the inter-frequency handover operation. W-CDMA employs hierarchical cell structures (HCSs) that overlay macrocells on top of smaller micro- or picocells. The HCSs boost system capacity and offer full coverage in urban environments. However, cells of different cell layers will operate on different frequencies. This requires inter-frequency handover ability in the mobile terminals. More discussion on inter-frequency handover can be explored in [7].

Wideband CDMA comparisons:
Below are two tables comparing the different wideband CDMA proposals/schemes.

A Comparison of W-CDMA and cdma2000

	W-CDMA	cdma2000
Chip rate	4.096 Mcps	3.6864 Mcps
Inter BS timing	Asynchronous	Synchronous
Data mod.	QPSK (Fwd) / BPSK (Rev)	QPSK (Fwd) / BPSK (Rev)
Spreading mod.	QPSK	QPSK
Pilot structure	Time Mux (Fwd) / IQ Mux (Rev)	Code Mux (Fwd) / IQ-code Mux (Rev)
Spreading	Direct sequence	Direct sequence or multi-carrier
Interleaving	10/20/40/80 ms	5/20 ms
Rate detection	Variable length rate information	Fundamental channel: Blind
Power steps	0.25 - 1.5 dB	1 dB (0.25, 0.5 dB optional)
Frame length	10 ms	5 or 20 ms

Table 2. Comparison of W-CDMA and cdma2000 [14].

	TTA I	**TTA II**
Channel spacing	1.25 MHz/5 MHz/20 MHz	1.25 MHz/5 MHz/10 MHz/20 MHz
Chip rate	0.9216 Mc/s/3.6864 Mc/s/14.7456 Mc/	1.024 Mc/s/4.096 Mc/s/8.192 Mc/s/16.834 Mc/s
Frame length	20 ms	10 ms
Spreading	Walsh + long codes	Walsh + long codes
Pilot for coherent detection	UL: pilot symbol based	UL: pilot channel based (multiplexed with power control symbols)
	DL: common pilot	DL: common pilot
Base station synchronization	Synchronous	Asynchronous

Table 3. Parameters for Korean wideband CDMA schemes.

Conclusion

A lot of progress has been made in the U.S., Europe, Japan, and S. Korea. Hopefully it will lead to some convergence, thus reducing the number of 3G standards. However, due to the evolution of current systems and the strong commercial interest of their supporters, at the moment there are two wideband CDMA standards: synchronous and asynchronous.

References

[1] Fumiyuki Adachi, Mamoru Sawahashi and Hirohito Suda, "Wideband DS-CDMA for Next Generation Mobile Communications Systems," *IEEE Communications Magazine*, vol. 36, no. 9, pp. 55-69, September 1998.

[2] Michael H. Callendar, "International Mobile Tellecommunications – 2000 Standard Efforts of the ITU," *IEEE Personal Communications*, vol. 4, no. 4, pp. 6-7, August 1997.

[3] Stephen McClelland and Bhawani Shankar, "Mobilizing the Third Generation," *Telecommunications (Americas Edition)*, vol. 31, no. 11, pp. 50-52,54, November 1997.

[4] Atsushi Fukasawa, Takuro Sato, Yumi Takizawa, Toshio Kato, Manabu Kawabe and Reed E. Fisher, "Wideband CDMA System for Personal Radio Communications," *IEEE Communications Magazine*, vol. 34, no. 10, pp. 116-123, October 1996.

[5] Ojanpera and R. Prasad, "Overview of Air Interface Multiple Access for IMT-2000/UMTS," *IEEE Communications Magazine*, vol. 43, no. 7, pp. 78-90, September 1998.

[6] ETSI, "The ETSI UMTS Terrestrial Radio Access (UTRA) ITU-RTT Candidate Submission," June 1998.

[7] ARIB, "Japan's Proposal for Candidate Radio Transmission Technology on IMT-2000: W-CDMA," June 1998.

[8] T1P1, "IMT-2000 Radio Transmission Technology Candidate," June 1998.

[9] TR46, "TR46 RTT Candidate based on the WIMS W-CDMA Proposal," June 1998.

[10] TIA, "The cdma2000 ITU-R RTT Candidate Submission," June 1998.

[11] TTA, "Global CDMA I: Multiband Direct-Sequence CDMA System RTT System Description," June 1998.

[12] TTA, "Global CDMA II for IMT-2000 RTT System Description," June 1998.

[13] Esmael H. Dinan and Bijan Jabbari, "Spreading Codes for Direct Sequence CDMA and Wideband CDMA Cellular Networks," *IEEE Communications Magazine*, vol. 36, no. 9, pp. 48-54, September 1998.

[14] http://www.cina.org/airtouch/sld003.htm