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PERFORMANCE ANALYSIS AND SPECIAL ISSUES OF CODE DIVISION MULTIPLE-ACCESS TECHNIQUES FOR WIRELESS APPLICATIONS

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ABSTRACT

Code Division Multiple Access (CDMA) has gained widespread international acceptance by cellular radio system operators as an upgrade that will dramatically increase both their system capacity and the service quality. CDMA is a "spread spectrum" technology, allowing many users to occupy the same time and frequency allocations in a given band/space. As its name implies, CDMA (Code Division Multiple Access) assigns unique codes to each communication to differentiate it from others in the same spectrum. In a world of finite spectrum resources, CDMA enables many more people to share the airwaves at the same time than do alternative technologies. The core principle of spread spectrum is the use of noise-like carrier waves, and, as the name implies, bandwidths much wider than that required for simple point-to-point communication at the same data rate.

Keywords: *Pseudo-Noise (PN), Low Probability of Intercept (LPI), Orthogonal Variable Spreading Factor (OVSF), Wideband Code Division Multiple Access (W–CDMA), European Telecommunications Standards Institute (ETSI).*

1. INTRODUCTION

CDMA stands for Code Division Multiple Access, but was originally known as IS-95. Qualcomm was the first to created this technology and by 1993 it was adopted by the Telecommunication Industry Association. Later this technology was enhanced and refined by Ericsson.The world is demanding more from wireless communication technologies than ever before as more people around the world are subscribing to wireless. Add in exciting Third-Generation (3G) wireless data services and applications - such as wireless email, web, digital picture taking/sending, assisted-GPS position location applications, video and audio streaming and TV broadcasting - and wireless networks are doing much more than just a few years ago. This is where CDMA technology fits in. CDMA consistently provides better capacity for voice and data communications than other commercial mobile technologies, allowing more subscribers to connect at any given time, and it is the common platform on which 3G technologies are built.

The CDMA air interface is used in both 2G and 3G networks. 2G CDMA standards are branded cdmaOne and include IS-95A and IS-95B. CDMA is the foundation for 3G services: the two dominant IMT-2000 standards, CDMA2000 and WCDMA, are based on CDMA[3][5][8].

1.1 CDMAONE: The Family of IS-95 CDMA Technologies

cdmaOne describes a complete wireless system based on the TIA/EIA IS-95 CDMA standard, including IS-95A and IS-95B revisions. It represents the end-to-end wireless system and all the necessary specifications that govern its operation. cdmaOne provides a family of related services including cellular, PCS and fixed wireless (wireless local loop).

1.2 CDMA2000: Leading the 3G revolution

CDMA2000 represents a family of ITU-approved, IMT-2000 (3G) standards and includes CDMA2000 1X and CDMA2000 1xEV technologies. They deliver increased network capacity to meet growing demand for wireless services and high-speed data services. CDMA2000 1X was the world's first 3G technology commercially deployed (October 2000).

2. SPREAD SPECTRUM COMMUNICATIONS

CDMA is a form of Direct Sequence Spread Spectrum communications. In general, Spread Spectrum communications is distinguished by three key elements[3][4][5]:

1. The signal occupies a bandwidth much greater than that which is necessary to send the information. This results in many benefits, such as immunity to interference and jamming and multi-user access, which we'll discuss later on.

2. The bandwidth is spread by means of a code which is independent of the data. The independence of the code distinguishes this from standard modulation schemes in which the data modulation will always spread the spectrum somewhat.

3. The receiver synchronizes to the code to recover the data. The use of an independent code and synchronous reception allows multiple users to access the same frequency band at the same time.

In order to protect the signal, the code used is pseudo-random. It appears random, but is actually deterministic, so that the receiver can reconstruct the code for synchronous detection. This pseudo-random code is also called pseudo-noise (PN)[21].

There are three ways to spread the bandwidth of the signal:

- Frequency hopping. The signal is rapidly switched between different frequencies within the hopping bandwidth pseudo-randomly, and the receiver knows before hand where to find the signal at any given time.

- Time hopping. The signal is transmitted in short bursts pseudo-randomly, and the receiver knows beforehand when to expect the burst.

- Direct sequence. The digital data is directly coded at a much higher frequency. The code is generated pseudo-randomly, the receiver knows how to generate the same code, and correlates the received signal with that code to extract the data.

2.1 Spread Spectrum Signals

Spread Spectrum uses wide band, noise-like signals. Because Spread Spectrum signals are noise-like, they are hard to detect. Spread Spectrum signals are also hard to Intercept or demodulate. Further, Spread Spectrum signals are harder to jam (interfere with) than narrowband signals. These Low Probability of Intercept (LPI) and anti-jam (AJ) features are why the military has used Spread Spectrum for so many years. Spread signals are intentionally made to be much wider band than the information they are carrying to make them more noise-like[9]-[17].

Spread Spectrum signals use fast codes that run many times the information bandwidth or data rate. These special "Spreading" codes are called "Pseudo Random" or "Pseudo Noise" codes. They are called "Pseudo" because they are not real gaussian noise.

Spread Spectrum transmitters uses similar transmit power levels to narrow band transmitters. Because Spread Spectrum signals are so wide, they transmit at a much lower spectral power density, measured in Watts per Hertz, than narrowband transmitters. This lower transmitted power density characteristic gives spread signals a big plus. Spread and narrow band signals can occupy the same band, with little or no interference. This capability is the main reason for all the interest in Spread Spectrum today.

Since the development of CDMA technology there has been many new releases and platforms. The original CDMA is now referred to as CDMAone. Several different variants of CDMA technology been developed continuously improving quality and data transfer speeds. Third generation CDMA technology, commonly referred to as CDMA2000 encompasses a wide variety of different standards, each continually improving upon the first including; 1X EV, 1XEV-DO, and MC 3X. CDMA2000 is the current standard used by most US carriers today. The first release of CDMA2000 was refereed to as either 3G1X, 1XRTT, or 1X. Designed to provide data transmissions of ten times faster then the previous technology and double the voice capacity of CDMAone[1][2].

As stated above, Verizon Wireless operates on the CDMA network. Depending on the phone you have and its capabilities you will notice symbols in the default screen of your phone reading either 1X, 1XEV-DO or some variation of the two. This symbol defines the CDMA2000 standards your phone is operating on. Newer phones will display EV or EV-DO using the newer faster, more reliable CDMA technology[2]-[7].

Qualcomm the original developer of CDMA owns patents of this technology. They have granted royalty-bearing licenses to over 100 network operators. The **chart** below displays the number of operators, vendors, subscribers and countries each technology is used in.

	CDMA 1X	**CDMA 1X2000 1XEV-DO**	**WCDMA**
Subscribers	33,000,000	193,000,000	56,000,000
Operators	33	98	101
Countries	20	48	44
Vendors	25	57	22

3. TECHNOLOGY

3.1 Multiple-Access

The advantage of CDMA for personal communication services is its ability to accommodate many users on the same frequency at the same time. A specific code is assigned to each user and only that code can demodulate the transmitted signal[9]-[13].

There are two ways of separating users in CDMA:

- Orthogonal Multiple Access
- Non-orthogonal Multiple Access or Asynchronous CDMA

3.1.1 Orthogonal Multiple Access

Each user is assigned one or many orthogonal waveform derived from an orthogonal code. Since the waveforms are orthogonal, users with different codes do not interfere with each other. Orthogonal-CDMA or O-CDMA requires synchronization among the users, since the waveforms are orthogonal only if they are aligned in time.

An important set of orthogonal code is the *Walsh* set. Walsh functions are generated using an iterative process of constructing a Hadamard matrix. starting with $H_1 = [0]$. The Hadamard matrix is built by:

$$H_{2n} = \begin{pmatrix} H_n & H_n \\ H_n & \overline{H_n} \end{pmatrix}$$

For example, here are the Walsh-Hadamard codes of length 2 and 4 respectively:

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

$$H_4 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

From the corresponding matrix, the Walsh-Hadamard codewords are given by the rows. Note that we usually map the binary data to polar form so we can use real numbers arithmetic when computing the correlations. So 0's are mapped to 1's and 1's are mapped to -1.

Walsh-Hadamard codes are important because they form the basis for orthogonal codes with different spreading factors. This property becomes useful when we want signals with different Spreading Factors to share the same frequency channel. The codes that posses this property are called Orthogonal Variable Spreading Factor (OVSF) codes. To construct such codes, it is better to use a different approach than matrix manipulation. Using a tree structure allows better visualization of the relation between different code length and orthogonality between them.

For example, let's see if the second codeword of W_2 which we will denote $W_{2.2}$ and the third codeword of W_4, $W_{4.3}$, are orthogonal. Since they are of different length, we repeat $W_{2.2}$ to match the length of $W_{4.3}$. Hence we get the following two codewords, in polar form:

$W_{2.2}$ => (1 -1 | 1 -1) and $W_{4.3}$ => (1 1 -1 -1)

Computing the orthogonality, we get: (multiplying elements by elements)

$(1 \times 1) + (-1 \times 1) + (1 \times -1) + (-1 \times -1) = 1 - 1 - 1 + 1 = 0$

Hence, $W_{2.2}$ and $W_{4.3}$ are orthogonal.

However, the auto-correlation function of Walsh-Hadamard codewords does not have good characteristics. It can have more than one peak and therefore, it is not possible for the receiver to detect the beginning of the codeword without an external synchronization scheme. The cross-correlation can also be non zero for a number of time shifts and un-synchronized users can interfere with each other. This is why Walsh-Hadamard codes can only be used in synchronous CDMA. Walsh-Hadamard codes do not have the best spreading behavior. They do not spread data as well as PN sequences does because their power spectral density is concentrated in a small number of discrete frequencies.

3.1.2 Non-Orthogonal CDMA

The concept behind this is to give up orthogonality among users and reduce the interference by using spread spectrum techniques. PN sequences are used to spread the spectrum. The family of PN sequences, called *Gold* sequences are in particular popular for non-orthogonal CDMA. Gold sequences have only three cross-correlation peaks, which tend to get less important as the length of the code increases. They also have a single auto-correlation peak at zero, just like ordinary PN sequences.

Gold sequences (codes) are constructed from the modulo-2 addition of two maximum length *preferred* PN sequences. By shifting one of the two PN sequence, we get a different Gold sequence. This property can be use to generate codes which will permit multiple access on the channel.

The use of Gold sequences permits the transmission to be asynchronous. The receiver can synchronize using the auto-correlation property of the Gold sequence.

4. W–CDMA

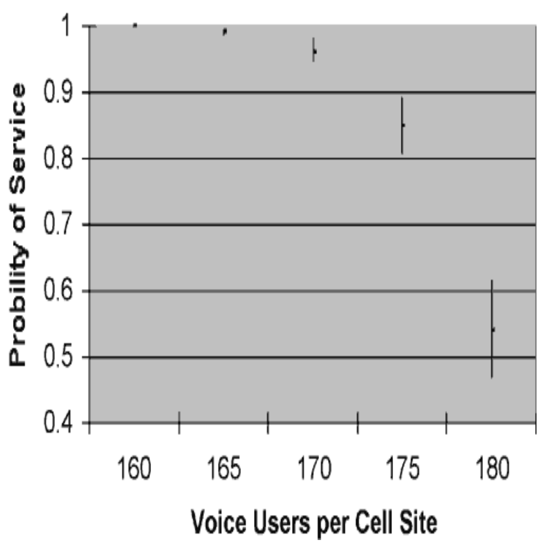
WCDMA technology, standing for Wideband Code Division Multiple access, is the most developed and advanced form of the third generation CDMA2000 technology. It encompasses higher data transfer rates and provides wireless connections in markets world wide. Many existing GSM 2G (GSM/GPRS) operators have slowly began the switch to using WCDMA technology. Wideband code division multiple access (W–CDMA) is a CDMA channel that is four times wider than the current channels that are typically used in 2G networks in North America.In January 1998, European Telecommunications Standards Institute (ETSI) decided to choose the W–CDMA technology to be the multiple access techniques for the third-generation mobile telephone system. For a mobile communication system, a key parameter is the system capacity [9][25].

4.1 W–CDMA Cell Site Loading

Given the limit on spectrum resources, efficient optimization techniques are needed for realizing cost-efficient ways to maximize the capacity in a W–CDMA network. The capacity is essentially interference limited by the overall interference level in the coverage area of each site. A computer simulation for investigating the system capacity was performed that modeled the radio channel in an urban environment. The simulator included many of the CDMA characteristics such as power control and different parameter setting in the hand over algorithm. Given this simulation, antenna characteristics such as sector orientation, number of sectors per site, horizontal beamwidth, and front-to-back ratio were studied. Also studied was the influence of the radio environment, giving rise to different orthogonality factors[2]-[25].

The signal-to-interference ratio typically limits the probability of having service in a dense cell site. As we can see from *Figure 1*, the roll off of service probability for voice traffic is quite quick—from 160 to 180 users per cell site in a typical three-sector configuration compared to about 90 users for omni site configurations. The error bars in the following figures annotate plus or minus one standard deviation about the mean value obtained from the numerical simulations. The numerically obtained results using a set of network statistics for a typical urban setting are shown in *Figure 1*.

Figure 1. Cell Site Loading in a Three-Sector Network Configuration



5. CONCLUSION

One of the main advantages of CDMA systems is the capability of using signals that arrive in the receivers with different time delays. CDMA subscriber units use rake receivers. This is essentially a set of several receivers. One of the receivers (fingers) constantly searches for different multipaths and feeds the information to the other three fingers. Each finger then demodulates the signal corresponding to a strong multipath. The results are then combined together to make the signal stronger. CDMA changes the nature of the subscriber station from a predominately analog device to a predominately digital device. Old-fashioned radio receivers separate stations or channels by filtering in the frequency domain. CDMA receivers do not eliminate analog processing entirely, but they separate communication channels by means of a pseudo-random modulation that is applied and removed in the digital domain, not on the basis of frequency. Multiple users occupy the same frequency band.

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