International Journal of Computing and Business Research (IJCBR)
ISSN (Online) : 2229-6166

Volume 3 Issue 3 September 2012

# Multiple Access Interference in Multi-Carrier CDMA

***T. L. Singal***
*Professor,*
*School of Electronics and Electrical Engineering,*
*Chitkara University, Punjab, India*

## ABSTRACT

Multi-carrier code division multiple access (MC-CDMA) technique maintains the original signaling interval while it spreads the signal over wide bandwidth like direct-sequence code division multiple access (DS-CDMA) technique. Low amount of delay spread reduces the guard interval in MC-CDMA and make it power efficient. MC-CDMA is sensitive to frequency offset and small Doppler spread is preferred which enable MC-CDMA scheme to work efficiently. MC-CDMA analyzes nearly all the scattered powers effectively using cyclic prefix insertion technique. Fequency domain equalizers are used for MC-CDMA which performs better than rake receivers used for DS-CDMA. This paper describes the functional requirements to implement MC-CDMA scheme and interleaved division multiple access (IDMA) in which the interleavers employ chip-level interleavers to distinguish different users. Multiple access interference (MAI) comprises of intracell interference and intercell interference. It causes a severe degradation in performance, and may render the system useless for even moderate user loads with equal power received from each user. IDMA is particularly useful for the uplink of next-generation wireless communication networks as well as for an evolution of existing DSSS-CDMA systems. The extension of IDMA to MIMO systems can be easily implemented because the superposition of the different layers at the transmitter side and their separation at the receiver side is possible.

**Keywords:** Code division, Interleaved division multiple access, Multiple access interference, Orthogonal FDMA, Wireless networks.

## 1. INTRODUCTION

Modern digital wireless technologies support a much larger number of mobile subscribers within a given frequency allocation (i.e. higher capacity), provide superior security and voice quality. The user wireless terminal has the potential to become a generic platform for, or gateway to, the complete range of value-added communication services that include voice, data, video and multimedia. [1]. Recent years have witnessed the rapid evolution of commercially available mobile computing environments. The network operators recognize that future revenue streams in competitive and mature markets will be generated from providing sophisticated services with seamless connectivity across the globe. The existing digital wireless standards continue to be developed, particularly as related to value-added services, capacity, bandwidth, coverage, inter-working, and, of course, costs. All major providers of wireless network systems, services and terminals agree that next-generation wireless networks should evolve from the core infrastructures available in today's digital networks [2]. The next significant development in wireless communication will consist of enhancements to the radio access that enable true multimedia services to be delivered at high bit rates. With the advancement in mobile information technologies (such as ultra high-speed transmission, wireless Internet protocol IPv6, user-controllable software defined radios), the potential users would be able to access the Internet as they do in the office – anywhere, anytime but on the move; use cell phone or laptop computer or any other PDA as mobile communication terminal; choose freely the services, applications and service providing networks; and achieve advanced mobile E-commerce applications with higher levels of data security and integrity during transactions.[3].

Multi-carrier direct-sequence code division multiple access (MC-DS-CDMA) and Interleave division multiple access (IDMA) inherits all the advantages of CDMA with the capability to overcome its deficiencies, and is one of the strong competitors for next generation wireless networks. [4], [5]. In present cellular communication networks, CDMA offers numerous features such as robustness to channel impairments and immunity against interference, mitigation of cross-cell interferences, robustness against fading, reuse factor of one, ease of cell planning, dynamic channel sharing, soft capacity, asynchronous transmission, low drop-out rate, large coverage due to soft handover, etc. All these advantages are due to spreading the information signal over a large bandwidth. [6]. However, the performance of conventional CDMA systems is limited by multiple access interference (MAI) as well as intersymbol interference (ISI). Moreover, CDMA multiuser detection has always been a serious concern due to complexity of multiuser detection algorithms and high computational cost.

IDMA is viewed as a new method of digital communication that is very powerful and can approach the Shannon limit. Interleaving operation is usually performed after forward error correction (FEC) coding but prior to spreading. [7]. This technique is very good for multiple user communication as an air interface and is traditionally employed to combat the fading effect. The possibility of employing interleaving for user separation in CDMA systems is possible but the receiver complexity also increases. A conventional random waveform CDMA (RWCDMA) system (such as IS-95) involves separate FEC coding and spreading operations. Theoretical analysis shows that the optimal multiple access channel (MAC) capacity is achievable only when the entire bandwidth expansion is utilized for FEC coding. This suggests combining the FEC coding and spreading operations using low-rate codes to maximize coding gain. But separation of users without spreading operation is not feasible in CDMA. [8].

## 2. MULTI-CARRIER CDMA

Multi-Carrier Code Division Multiple Access (MC-CDMA) is a combination of frequency-domain spreading and orthogonal frequency division multiplexing (OFDM). OFDM is one of multicarrier multiple access schemes which use multiple carrier signals at different frequencies, sending some of the bits on each channel. Multi-carrier direct sequence code division multiple access (MC-DS-CDMA) scheme is a combination of time-domain spreading and OFDM. MC-CDMA maintains the original signaling interval while it spreads the signal over wide bandwidth like DS-CDMA. To transmit 1 Mbps data with the processing gain of 20 dB, the chip rate required in DS-CDMA is 100 Mcps. This necessitates four times faster internal digital front-end processor or at least 100 MHz analogue matched filter. This requirement can be easily achieved by using multi-code assignment for high speed data rate but at the cost of reduced user capacity. MC-CDMA shows high envelope power fluctuation as in OFDM. [9]. For N-subcarrier system, the peak power becomes N times the average power in the worst case and the signal is distorted in the RF power amplifiers, yielding spurious power emission. To reduce the distortion, the operating point in the amplifiers can be backed off, but this may lead to inefficient power usage.

Small delay spread and small Doppler spread enable MC-CDMA scheme to work efficiently. Small delay spread reduces the guard interval in MC-CDMA and make it power efficient. MC-CDMA is sensitive to frequency offset and small Doppler spread is preferred. The difference in the arrival times of multipath signals in indoor wireless environment is typically much less than 1 µs. The multipath resolvability is proportional to the used chip rate. To make the rake receivers to work properly, the chip rate should be much faster than 1 Mcps even when there is no need for high data rate service. In such situation, MC-CDMA scheme is a viable alternative. [10].

When there is a deep frequency selective fading, OFDM loses the corresponding data on corrupted subcarriers. As MC-CDMA spreads an information bit over many subcarriers, it can make use of information contained in some subcarriers to recover the original symbol. MC-CDMA gathers nearly all the scattered powers effectively using cyclic prefix insertion technique. As the received signals are sampled at the original symbol rate in MC-CDMA, the sampling points may not be optimum. In general, the performance of MC-CDMA is equivalent to m-finger rake receiver in DS-CDMA, where *m* is the number of symbols in cyclic prefix of MC-CDMA. Various types of frequency domain equalizers are used for MC-CDMA which perform better than rake receivers used for DS-CDMA. [11].

In MC-CDMA, a good bit error rate (BER) performance can be achieved by using frequency-domain equalization (FDE), since the frequency diversity gain is obtained. On the other hand, conventional MC-DS-CDMA cannot obtain the frequency diversity gain. However, MC-DS-CDMA can obtain the frequency diversity gain by applying frequency domain equalizer (FDE) to a block of a number of OFDM symbols. For broadband multi-path channels, conventional time domain equalizers are impractical because of complexity, very long channel impulse response in the time domain, and prohibitively large tap size for time domain filter. On the other hand, using discrete Fourier transform (DFT), equalization can be done in the frequency domain. Because the DFT size does not grow linearly with the length of the channel response, the complexity of FDE is lower than that of the equivalent time domain equalizer for broadband channel. Most of the time domain equalization techniques such as MMSE equalizer, DFE, turbo equalizer can be implemented in the frequency domain.

Figure 1 depicts the pictorial representation of relationship among SC-FDMA, OFDMA, and DS-CDMA/FDE. [12].

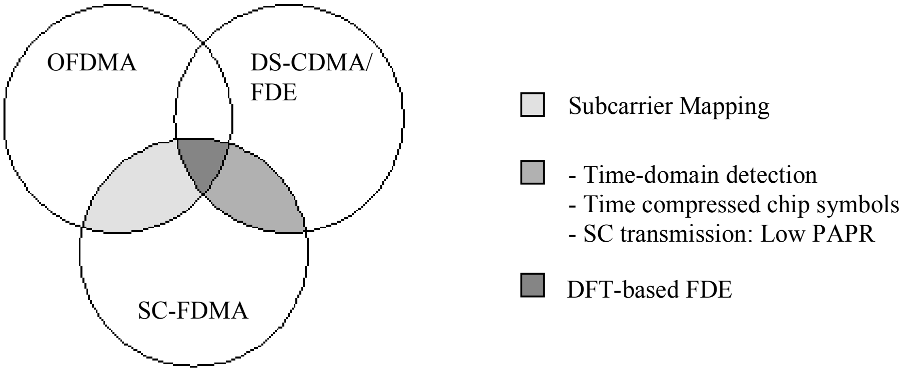

**Figure 1: SC-FDMA, OFDMA, and DS-CDMA/FDE.**

In terms of bandwidth expansion, SC-FDMA is very similar to DS-CDMA system using orthogonal spreading codes. Both spread narrowband data into broader band. Time symbols are compressed into chips after modulation, and spreading gain (processing gain) is achieved. SC-FDE or SC-FDMA delivers performance similar to OFDM with essentially the same overall complexity, even for long channel delay. It has advantage over OFDM in terms of low PAPR, robustness to spectral null, and less sensitivity to carrier frequency offset. Its disadvantage to OFDM is that channel-adaptive subcarrier bit and power loading is not possible. MC-CDMA requires the conventional cell planning in cellular environment by using a PN code. Thus it loses one of the greatest benefits of DS-CDMA, which is the universal frequency reuse. [13].

## 3. INTERLEAVED DIVISION MULTIPLE ACCESS

Interleaved Division Multiple Access (IDMA) technique explores the possibility of employing chip-level interleavers for user separation. Users are solely distinguished by their interleavers, hence the name interleave-division multiple-access (IDMA). The key principle of IDMA is that the interleavers should be different for different users. [14]. In IDMA, FEC encoding and spreading may be done jointly by a single low-rate encoder. Interleaving is done on a chip-by-chip basis. Due to interleaving, the code is nonlinear. Multiple code words can be linearly superimposed in order to enhance the data rate per user. The interleavers are generated independently and randomly, and they disperse the coded sequences so that the adjacent chips are approximately uncorrelated. This facilitates the simple chip-by-chip detection scheme by an iterative sub-optimal receiver structure, which consists of an elementary signal estimator and K single-user a-posteriori probability decoders. This principle has worked well for user separation in coded systems.

For the uplink, IDMA scheme can support a high number of active users, each of them using a different random interleaver suitable for long blocks. As the interleavers work on the spreaded bit sequence, the requirement of long block lengths can be easy satisfied. It is also possible to perform the spreading over multiple sub-carriers to obtain an multi-carrier IDMA system. This can be viewed as an extension of multi-carrier CDMA systems. [15].

For wideband systems, the performance improvement by assigning different interleavers to different users in conventional CDMA has been under extensive research. Chip interleaved CDMA scheme alongwith a maximal-ratio-combining technique to combat Intersymbol interference has shown good results for high spectral efficiency, improved error performance and low receiver complexity. The performance analysis for a conventional CDMA multi-user detection scheme requires the knowledge of the correlation characteristics among code sequences. It can be a quite complicated issue and sophisticated large random matrix theory has been used. IDMA does not involve code sequences, which greatly simplifies the multi-user detection problem. Asynchronous interleave-division multiple-access scheme for spread spectrum mobile communication systems distinguishes the users by different chip-level interleavers instead of by different codes as in a conventional CDMA system. The bandwidth expansion is entirely performed by low-rate coding. It also allows a low complexity multiple user detection techniques applicable to systems with large numbers of users in multipath channels. The IDMA scheme can achieve performance close to the capacity of a multiple access channel and the use of low-rate codes can further enhance the power efficiency of IDMA systems. IDMA system can also exhibit security features of an efficient crypto system. The performance of the IDMA scheme with simple convolutional/repetition codes exhibits overall throughputs of 3 bits/chip with one receive antenna and 6 bits/chip with two receive antennas are observed for systems with as many as about 100 users.

IDMA-based systems can be made highly adaptive in order to guarantee a certain quality of service (QoS) level, defined by a maximum bit error rate, a minimum data rate, and a maximum delay (especially for packet based services), depending on the application. Instead of using adaptive modulation and/or channel coding, IDMA modifies the number of layers and the transmission power. The number of layers used for transmission can be reduced if the data rate is higher than needed or, if the data rate cannot be reduced for QoS reasons, the transmit power can be increased until the target bit-error-rate (BER) is achieved. With a higher number of layers assigned to a user, its data rate is higher. To ensure a certain BER, the power can be adapted as well.

## 4. MULTIPLE ACCESS INTERFERENCE

Multiple Access Interference (MAI) is a type of interference caused by multiple cellular users who are using the same frequency allocation at the same time. With CDMA systems, the same-frequency channel can be reused in the adjacent cell, as long as multiple-access interference is kept below a given threshold level necessary to meet the signal quality requirement. Multiple-access interference can present a significant problem if the power level of the desired signal is significantly lower (due to distance) than the power level of the interfering user. MAI comprises of two types of interference: intracell interference and intercell interference.

(a) Intracell interference is defined as the interference caused by other users operating within the same cell.

(b) Intercell interference is defined as the interference caused at the mobile user in a cell due to reuse of the same CDMA channel in the neighboring cells.

Figure 2 depicts Intracell and Intercell interference in hexagonal cellular architecture.

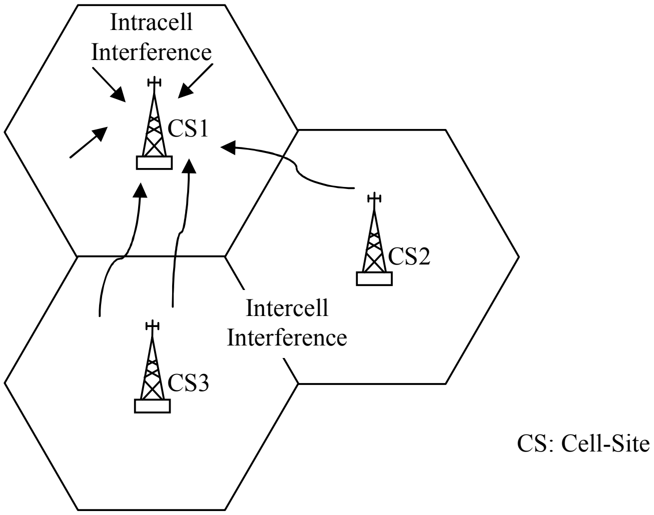

**Figure 2: Multiple-Access interference.**

Intracell interference and intercell interference affect the multiple access performance in a cellular environment for the uplink from a mobile user to a cell site located at the center of the cell. If there is perfect power control on the reverse channel such that the signals from all users are received at equal power at the cell site, then the intracell interference, is given by

$$I_{\text{intracell}} = \left[ \frac{(M - 1)}{Q} \right] \times E_b \quad \text{[Eq. 1]}$$

Where M is number of the number of simultaneous users, Q is number of chips per time period T, and $E_b$ is the common received power level.

Since M » 1, $I_{\text{intracell}} = \left( \frac{M}{Q} \right) \times E_b$ [Eq. 2]

Where M/Q is termed as *channel loading* or capacity.

Most of Intercell interference occur from the first and second tiers of the surrounding cells of the serving cell. The interference from more distant cells suffers more propagation attenuation, and hence can be ignored. The signals causing intercell interference are received at different power levels, because they are power controlled relative to other cell sites. As a consequence, intercell interference depends on the propagation losses from a mobile user to two different cell sites. In general, the relative power from mobile users in other cells will be attenuated relative to the power from the intracell mobile users due to larger distance. [9]. Let σ be the relative intercell interference factor, and is defined as the ratio of intercell interference to intracell interference, that is,

$$\sigma = \frac{I_{\text{intercellular}}}{I_{\text{intracell}}} \qquad \text{[Eq. 3]}$$

It is assumed here that the traffic loading in all cells is the same. The value of intercell interference factor σ ranges from 0.5 to 20, depending upon the number of system parameters and environmental conditions.

The total interference or MAI is the combination of intracell interference and intercell interference, that is

$$I_{MAI} = I_{\text{intracell}} + I_{\text{intercellular}} \qquad \text{[Eq. 4]}$$

$$\Rightarrow \quad I_{MAI} = I_{\text{intracell}} + \sigma\, I_{\text{intracell}} \qquad \text{[Eq. 5]}$$

$$\Rightarrow \quad I_{MAI} = \left(\frac{M}{Q}\right) \times E_b + \sigma \times \left(\frac{M}{Q}\right) \times E_b \qquad \text{[Eq. 6]}$$

$$\Rightarrow \quad I_{MAI} = (1+\sigma)\left[\left(\frac{M}{Q}\right) \times E_b\right] \qquad \text{[Eq. 7]}$$

Thus the MAI is directly proportional to the channel loading or capacity, M/Q. Ultimately, the MAI on a cellular CDMA is more significant at the individual receiver. The *signal-to-interference-plus-noise ratio* (SINR) at the individual receiver is given by

$$\text{SINR} = \frac{E_b}{\left(N_o + I_{MAI}\right)} \qquad \text{[Eq. 8]}$$

$$\text{SINR}= \frac{E_b}{I_{MAI}\left(\frac{N_o}{I_{MAI}}+1\right)} \qquad \text{[Eq. 9]}$$

Cellular CDMA systems are often interference limited; that is, the operating conditions are such that $I_{MAI} > N_0$, typically 6 to 10 dB higher. The $I_{MAI} / N_0$ ratio depends upon the cell size. With large cells and battery-operated mobile phones, most of the transmit power is used to achieve the desired range. Thus large cells tend to be noise limited. Smaller cells tend to be interference limited, and the interference level at the receiver is typically greater than the noise level of the receiver.

$$\Rightarrow \quad \text{SINR}= \frac{E_b}{(1+\sigma)\left[\left(\frac{M}{Q}\right)\times E_b\right]\left(\frac{N_o}{I_{MAI}}+1\right)} \qquad \text{[Eq. 10]}$$

$$\Rightarrow \quad \text{SINR}= \frac{1}{(1+\sigma)\left(\frac{M}{Q}\right)\left(\frac{N_o}{I_{MAI}}+1\right)} \qquad \text{[Eq. 11]}$$

This expression shows the three system design factors that affect the SINR at the receiver, and limit spectral efficiency. The three factors are the intercell interference σ, the channel loading M/Q, and the operating $I_{MAI} /N_0$. The intercell interference depends on the environment as well as on the handover technique; channel loading is clearly a design parameter that needs to be maximized in a commercial cellular system; and, the third factor, $I_{MAI} /N_0$, is related to cell size. There is a trade-off between these three system design parameters. For example, for a constant SINR, moving from a noise-limited system ($I_{MAI} /N_0 = 0$ dB) to an interference-limited system ($I_{MAI} /N_0 = 10$ dB, say) increases the permissible channel loading or capacity. The channel loading must be significantly decreased to support a noise-limited system at the same SINR. Thus, large cells must have lighter load than small cells.

Similarly, for a constant SINR, increasing intercell interference significantly reduces the permissible channel loading. The methods of reducing the required SINR in CDMA systems are use of RAKE receivers and FEC coding. However, soft handoffs are the key design aspect to reducing margins and keeping intercell interference low. On the other hand, reducing the SINR required by the receiver can significantly improve the permissible channel loading.

## 5. CONCLUSION

Interleave-Division Multiple Access fulfils the design issues of fourth-generation wireless systems (4G – target data rates of up to 100 Mbps for high mobility and up to 1 Gbps for low mobility or local wireless access) which includes efficiency (bandwidth as well as power), adaptivity (link adaptation with respect to data rate, data reliability, quality of service, service provisioning), low-complexity transceivers, and ability to operate on frequency selective and fast-fading channels. IDMA is particularly useful for the uplink of new wireless systems, as well as for an evolution of existing DSSS-CDMA systems. Multiple antenna (MIMO) systems are a key technology for 4G. The extension of IDMA to MIMO systems is easy because the superposition of the different layers at the transmitter side and their separation at the receiver side can be implemented.

## REFERENCES

[1]. Suk Yu Hui; Kai Hau Yeung, “Challenges in the migration to 4G mobile systems”, IEEE Communications Magazine, Vol. 41, Issue 12, pp 54 -59, Dece. 2003.
[2]. Varshney, U.; Jain, R., “Issues in emerging 4G wireless networks”, IEEE Computers Magazine, Vol. 34, Issue 6, pp94-96, 2001.
[3]. T. L. Singal, Rajneesh Talwar, “Challenges of Global Connectivity in Next Generation Wireless Communication Networks”, National Conference on Wireless Networks & Embedded Systems (WNES-2006); CIET, Rajpura, Punjab; pp 26-31; July 2006.
[4]. Carl R. Nassar, “Multi-Carrier Technologies for Wireless Communication”, ISBN: 9781441949370, Springer-Verlag Berlin, Heidelberg, 2010.
[5]. V. Nagarajan; P. Dananjayan, “Performance Analysis of MIMO MC-DS/CDMA System Using Chaotic Spreading Sequence”, International Journal of Computer and Electrical Engineering, Vol. 2, No. 2, April, 2010.
[6]. T. L. Singal, “Realization of Seamless Connectivity in 4G Mobile Systems”, ISTE-sponsored National Conference on Latest Trends in Tele-Communication (LTTC 2006); RIEIT, Nawanshahar, Punjab; pp 24-28; August 2006.
[7]. Schmeink, Kathrin; Hoeher Peter A., “Multi-Layer Interleave-Division Multiple Access for Joint Communication and Localization”, 7th International ITG Conference on Source and Channel Coding (SCC), Ulm, Germany, January 2008.

[8]. T. L. Singal, “Analog & Digital Communications”, ISBN: 978-0-07-107269-4, First Edition, Tata-McGraw Hill Education, 2012.

[9]. Andrews J. G., Meng T.H.Y., “Multiple access interference cancellation in fading multipath channels: progress and limitations”, 53rd IEEE Vehicular Technology Conference, Vol. 3, pp 1804-1808, 2001.

[10]. Spencer, Q. H.; Peel, C. B.; Swindlehurst, A. L.; Haardt, M., “An introduction to the multi-user MIMO downlink”, IEEE Communications Magazine, Vol. 42, Issue 10, pp60-67, Oct. 2004.

[11]. Amit Munjal; T. L. Singal, “Improvement in Performance of MC-CDMA System using Iterative LDPC Code”, International Conference on Wireless Networks & Embedded Systems (WECON- 2011), Chitkara University, Chandigarh, India; July 2011.

[12]. T. L. Singal, “Wireless Communications”, ISBN: 978-0-07-068178-1, First Edition, Tata-McGraw Hill Education, 2010.

[13]. J. M. Pereira, "Fourth Generation: Now, It Is Personal," Proceedings of the 11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, London, UK, pp18-21 September 2000.

[14]. Li Ping; Qinghua Guo; Jun Tong, “The OFDM-IDMA approach to wireless communication systems”, IEEE Wireless Communications magazine, Vol. 14, Issue 3, pp18 -24, June 2007.

[15]. Rong Zhang; Hanzo, L., “Three Design Aspects of Multicarrier Interleave Division Multiple Access”, IEEE Transactions on Vehicular Technology, Vol. 57, Issue 6, pp3607 -3617, Nov. 2008.

**Prof. T. L. Singal** graduated from NIT Kurukshetra in 1981, and post-graduated from Punjab Technical University Jalandhar in 2007. He has worked in the field of Wireless and Cellular Communication Systems with leading telecom companies in India, Germany and USA during 1981-2002. In his association with Flextronics International Inc., Dallas (Texas), USA, he held the position of Senior Network Consultant, offering optimization solutions in the domain of GSM and CDMA cellular networks for various clients such as Nokia, AT&T, Nortel, Cingular Wireless, Voice Stream USA during 2000-2002. Since 2003, he has been working with leading engineering institutes in India as Senior Faculty of Electronics and Communication Engineering. He has authored two technical text-books titled `Wireless Communications’, `Analog & Digital Communications’, both published by international renowned publisher Tata McGraw-Hill Education. He has convened international conferences and workshops on Wireless Networks and Embedded Systems, and edited proceedings of conferences. He has coordinated several technical workshop courses under faculty leadership institute programs of Indo US Collaboration of Engineering Education (IUCEE) during 2010-2011. He has presented several technical research papers in international and national journals and conferences.

---------------ooo----------------