BER and PAPR Analysis of OFDMA based Multiple Access Techniques

Anu Gandhi[1] *Deepak Kedia*[2]
Department of Electronics and Communication Engineering
Guru Jambheshwar University of Science & Technology, Hisar (Haryana), INDIA

Abstract--*This paper presents a comprehensive performance analysis of various orthogonal frequency division multiple access (OFDMA) based schemes. We investigate the basic principle and different subcarrier allocation schemes of OFDMA i.e., interleaved OFDMA and localized OFDMA. Another multiple access scheme obtained from the combination of CDMA technique with multicarrier transmission namely multi-carrier code division multiple access (MC-CDMA) is also described. Through computer simulation, we present the Bit error rate (BER) and peak-to-average power ratio (PAPR) performance of OFDM, MC-CDMA, and OFDMA along with subcarrier allocation schemes.*

Keywords – Bit error rate (BER), Interleaved Orthogonal Frequency Division Multiple Access (I-OFDMA); Localized OFDMA (L-OFDMA), Multi-Carrier Code Division Multiple Access (MC-CDMA), Orthogonal Division Multiple Access (OFDMA), Peak-to-average power ratio (PAPR).

I. Introduction

Long Term Evolution (LTE) of the Universal Mobile Telecommunication System (UMTS) is being developed by the 3rd Generation Partnership Project (3GPP) for improved services, high data rate, as well as higher spectral efficiency. LTE [1] establish as the latest step towards the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile communications. LTE a cellular wireless communication standard based on orthogonal frequency-division multiplexing (OFDM). OFDM is a multicarrier transmission technique and its principle is to convert a serial high-rate data stream onto multiple parallel low-rate sub-streams. Each sub-stream is modulated onto different subcarrier. Since the symbol rate on each subcarrier is much less than the initial serial data symbol rate, the effect of delay spread i.e., inter symbol interference (ISI), significantly decreases, thus reducing the complexity of the equalizer. Recently, OFDM based multiple access schemes and its Multiple Access (MA) [2] derivative, Orthogonal Frequency Division Multiple Access (OFDMA) are attracting much attention for uplink physical layer protocols in high-speed wireless networks. Where OFDM assigns one block (in time) to one user, OFDMA assigns different groups of subcarrier (in frequency) to different users. This way more than one user can access the air interface at the same time. Multicarrier based multiple access (MA) schemes like OFDMA [3], avoids ISI by the application of a guard interval, and the orthogonality of different users' signal is maintained even for transmission over time-dispersive channels. Thus OFDMA can take advantages of frequency diversity and multiuser diversity.

In cellular applications, a big advantage of OFDMA is its toughness in the presence of multipath signal propagation [4]. The immunity to multipath derives from the fact that an OFDMA system transmits information on M orthogonal frequency carriers, each operating at 1/M times the bit rate of the information signal. On the other hand, the OFDMA waveform exhibits very pronounced envelope fluctuations resulting in a high peak-to-average power ratio (PAPR). Signals with a high PAPR require highly linear power amplifiers to avoid redundant intermodulation distortion. To accomplish this linearity, the amplifiers have to operate with a large backoff from their peak power. The result is low power efficiency (measured by the ratio of transmitted power to dc power dissipated), which places a significant burden on portable wireless terminals. To overcome the disadvantage of high PAPR in OFDMA, 3GPP is exploring a modified form of OFDMA for uplink transmissions in the LTE of cellular systems. The modified version of OFDMA, referred to as single carrier FDMA (SC-FDMA) [5] which is realized by the application of Discrete Fourier transform (DFT) preceding OFDMA. SC-FDMA utilizes single-carrier modulation at the transmitter and frequency domain equalization at the receiver and typically achieves lower PAPR which makes it popular in uplink transmission in LTE.

Other interesting MA schemes can be obtained from the combination of techniques from single- and multicarrier transmission. One concept is the combination of multicarrier modulation and spread-spectrum technique that results in Multicarrier Code Division Multiple Access (MC-CDMA) also known as OFDM-CDMA. OFDM based system, in particular MC-CDMA [6] is the most promising candidate for fourth-generation broadband mobile communication networks. The principle of MC-CDMA [7] is to map the chips of a spread data symbol in frequency direction over several parallel sub-channels. In MC-CDMA, a data stream from each active user is divided into low rate parallel data streams each being spread by its own chip of the spreading sequences [8] and sent via its own subcarrier. MC-CDMA inherits merits of OFDM and direct sequence CDMA, which has a fine performance but has higher peak-to-average power ratio (PAPR) because of the multicarrier structure from OFDM. In [9], it has been shown that MC-CDMA has high PAPR. BER performances of MC-CDMA are shown in [10]. Further, there are two subcarrier allocation schemes for OFDMA known as Interleaved and Localized subcarrier allocation. By employing some specific subcarrier allocations, we can avoid the inter user interference (IUI). However, simulation results in [11] show the user by user bit error rate (BER) performance of the interleaved and localized OFDMA system with the conventional receiver. Interleaved subcarrier allocation schemes provide better system performance than the localized subcarrier allocation scheme.

In this paper, we introduce the basic principle of OFDMA and MC-CDMA. Furthermore, we discuss different subcarrier allocation schemes for OFDMA i.e., interleaved subcarrier allocation, and localized subcarrier allocation. Through computer simulation, we first present the PAPR characteristics using the complementary cumulative distribution function (CCDF) and secondly the BER performance for OFDM, MC-CDMA, and OFDMA along with interleaved and localized subcarrier allocation is analyzed.

The remainder of the paper is organized as follows: In section II, basic principle of OFDMA and MC-CDMA system are introduced. Then we describe the basic concept of subcarrier allocation schemes i.e. interleaved scheme and localized scheme in section III, and performance analysis of OFDM, MC-CDMA, localized OFDMA and interleaved OFDMA system via computer simulation in section IV. Finally, concluding remarks are presented in section V.

II. System Model

In this section, we present detailed overview of the OFDMA system and MC-CDMA system. The first subsection gives a brief introduction to the transmitter and receiver structure of OFDMA system. The second one provides the overview of transmitter structure and signal generation of MC-CDMA.

A. Overview of OFDMA

OFDMA is one of the most promising multiple access technique that can possibly meet all those requirements through efficient radio spectrum utilization. We take OFDMA as basic framework in next generation wireless communication system design. In OFDMA instead of sequentially assigning OFDM symbols in time to different users, the system directly assigns subcarriers in frequency to different users. Thus, subcarriers do overlap in frequency, but as far as the recovery of data symbols is concerned, they do not interfere with one another. Thus low computational effort at the receiver for compensation of the channel and for user separation is achieved, which enables high data-rate transmission. Moreover, OFDMA provides low computational complexity [3] due to efficient implementation using the Fast Fourier Transforms (FFT) algorithm and high spectral efficiency due to the concept of overlapping but mutually orthogonal narrowband subcarriers.

Figure 1 portrays the block diagram [4] of the OFDMA system. In the simplest OFDMA scheme (one subcarrier per user) each user signal is a single-carrier signal. The transmitter of an OFDMA system converts a binary input signal to a sequence of modulated subcarriers. At the input to the transmitter, first random bit generator generates the binary bit sequence. Further, a baseband modulator transforms the binary input to a multilevel sequence of complex numbers in one of several possible modulation schemes including quadrature PSK (QPSK), 16 level quadrature amplitude modulation (16-QAM) and 64-QAM. After that serial-to-parallel converter assigns the high-rate stream into low-rate substreams. In doing so, the serial-to-parallel converter assigns successive data symbols (at its input) to separate low-rate substreams (at its output). The system accommodates the modulation format, and thus so the transmission bit rate, to match the current channel state of each terminal. The transmitter next cluster the modulation symbols into blocks each containing M symbols via suitable subcarrier mapping. An M-point inverse DFT (IDFT) then transforms the subcarrier amplitudes to a complex time domain signal. Each signal then modulates a single frequency carrier and all the modulated symbols are transmitted sequentially through parallel to serial converter. To do so, it performs the signal processing operation. Signal processing is repeated in a few different time intervals. Resource allocation takes place in transmit time intervals (TTIs) [4]. In 3GPP LTE, a typical TTI is 0.5ms. The TTI is besides divided into time intervals mentioned as blocks. A block is the time used to transmit all of subcarrier once.

The transmitter accomplishes another signal processing operations prior to transmission. It insert a set of symbols referred to as a cyclic prefix (CP) in order to provide a guard time to prevent inter-block interference (IBI) due to multipath propagation. In general, CP is a copy of the last part of the block, which is affix at the start of each block for a couple of reasons. First, CP behaves as a guard time between successive blocks. If the length of the CP is longer than the maximum delay spread of the channel, or harshly,

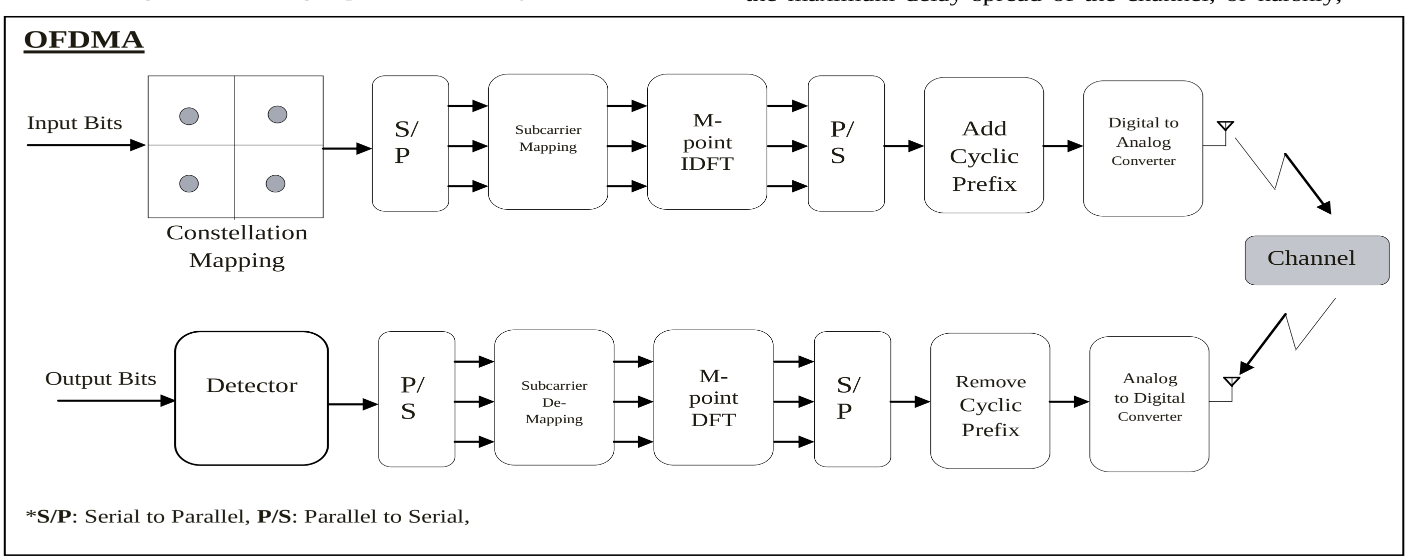

Figure 1 Transmitter and receiver structure of OFDMA system.

the length of the channel impulse response, afterwards there is no IBI. Second, since CP is a copy of the last part of the block, it transforms a discrete time linear convolution into a discrete time circular convolution. Therefore, transmitted data propagating through the channel can be sampled as a circular convolution between the channel impulse response and the transmitted data block [4], where transmitted data block is in the frequency domain, is a point-wise multiplication of the DFT frequency samples. Therefore, to remove the channel distortion, the DFT of the received signal can simply be divided by the DFT of the channel impulse response point-wise and frequency domain equalization technique can be implemented. At the base station (e.g., fixed wireless access or interactive DVB-T) of the received signal, being the sum of K users' signals, behave as an OFDM signal due to its multi-point to point nature. Unlike conventional FDMA which requires K demodulators to handle K synchronous users, OFDMA requires only a single demodulator, followed by an M-point DFT. Since OFDMA is preferably used for the uplink in a multiuser environment, low-order modulation such as QPSK is preferred. However, high-order modulation (e.g., 16- or 64-QAM) can also be applied. Various approaches to mapping transmission symbols to OFDMA subcarriers are currently under deliberation. These are divided into two categories namely interleaved and localized and are explained further in section III. In addition to advantages of low-complexity modulation and better spectral efficiency, OFDMA offers two more important advantages [3]:

- OFDMA can take advantage of frequency diversity through distributed subcarriers for a single user. Distributing a user's subcarrier pseudorandomly throughout the band means some of the user's subcarriers likely to experience fading.

- OFDMA can take advantage of multiuser diversity through contiguous subcarriers. Multiuser diversity occurs because different users at different locations would likely experience different channel responses, thus the system can improve a particular user's link by assigning to that user a set of contiguous subcarriers that experiences the best channel condition.

Additionally, OFDMA has the advantage of simple decoding at the receiver side due to the absence of inter carrier interference (ICI). Other benefits of OFDMA include better granularity and improved link budget in the uplink communications. The OFDMA is broadly adopted in various communication standards like worldwide interoperability for microwave access (WiMAX), mobile broadband wireless access (MBWA), evolved UMTS terrestrial radio access (E-UTRA) and ultra-mobile broadband (UMB). The OFDMA is also a strong candidate for the wireless regional area networks (WRAN) and the long term evaluation advanced (LTE-Advanced) [19].

B. Overview of MC-CDMA

Spread spectrum systems have been developed since the mid-1950s [7]. The initial applications have been military anti-jamming tactical communications, guidance systems, and experimental anti-multipath systems. The success of the spread spectrum techniques for second-generation mobile radio and OFDM for digital broadcasting and wireless LANs motivated many researchers to explore the combination of both techniques. The combination of DS-CDMA and multi carrier modulation was proposed in 1993 [12]. The realization of multiple access exploiting multi-carrier spread spectrums is referred to as MC-CDMA. OFDM scheme is robust to frequency selective fading; still, it has severe disadvantages such as hard in subcarrier synchronization and sensitivity to frequency offset and nonlinear amplification, which outcome from the fact that it is composed of a lot of subcarriers with their overlapping power spectra and exhibits a non-constant nature in its envelope. Accordingly, the Multicarrier CDMA schemes unavoidably have the same drawbacks. Anyway, the union of OFDM signaling and CDMA scheme has one major advantage that it can lower the symbol rate in each subcarrier so that a longer symbol duration makes it easier to quasi-synchronize [12] the transmissions. In this scheme, the different users share the same bandwidth at the same time and separate the data by applying different user specific spreading codes, i.e., the separation of the user's signals is carried out in the code domain. Moreover, this scheme applies multi-carrier modulation to reduce the symbol rate and thus, the amount of ISI per sub-channel is reduced. This ISI [7] reduction is significant in spread spectrum systems where high chip rates occur. The principle of MC-CDMA is to map the chips of a spread data symbol in frequency direction over several parallel sub-channels. MC-CDMA transmits a data symbol of a user simultaneously on

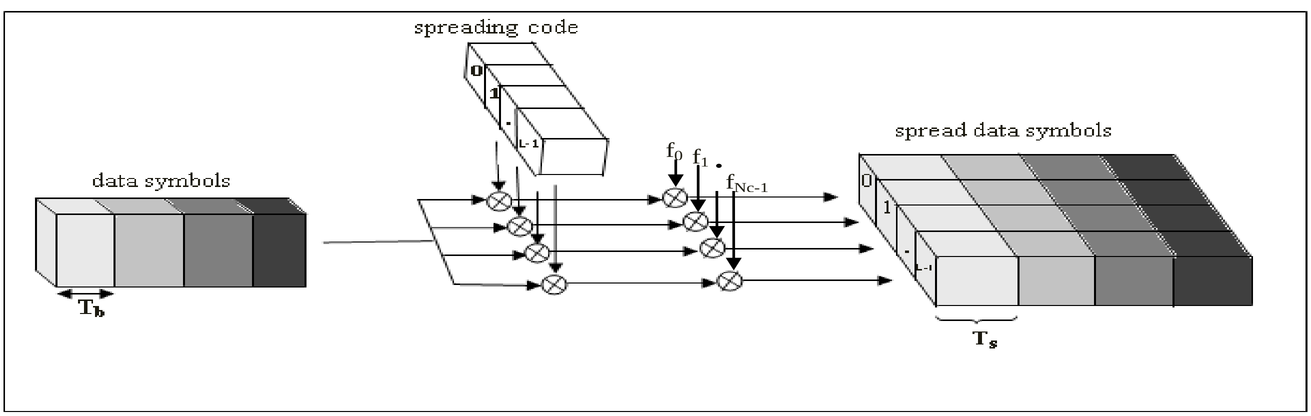

Figure 2 MC-CDMA signal generation for one user

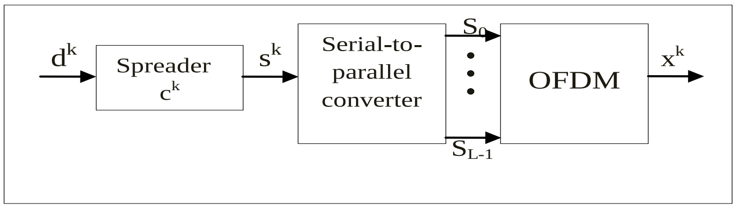

Figure 3 MC-CDMA Transmitter.

several narrowband sub-channels. These sub-channels are multiplied by the chips of the user-specific spreading code as described in [7] figure 2. Multi-carrier modulation is realized by using the low-complex OFDM operation. Since the fading on the narrowband sub-channels can be considered flat, simple equalization with one complex-valued multiplication per subchannels can be realized. MC-CDMA offers a flexible system design, since the spreading code length does not have to be chosen equal to the number of sub-carriers.

The MC-CDMA [12] scheme is categorized primarily into two sets. One spread the original data stream using a given spreading code, and afterwards modulates a different subcarrier with each chip (spreading operation in frequency domain), and other spreads the serial-to-parallel (S/P) converted data stream using a given spreading code, and then modulates a different subcarrier with each of the data stream (spreading operation in time domain) as given in figure 3 [7], which describes the multi-carrier spectrum spreading of one complex-valued data symbol d^k assigned to user k. The rate of the serial data symbols is $1/T_d$. For briefness, but without loss of generality, the MC-CDMA signal generation is described for a single data symbol per user as far as possible, such that the data symbol index can be neglected. In the transmitter, the complex-valued data symbol d^k is multiplied with the user specific spreading code c^k of length L. The complex-valued sequence [6] obtained after spreading is given by,

$$s^k = d^k c^k = (S_0, S_1, \ldots\ldots S_{L-1})$$

A multi-carrier spread spectrum signal is obtained after modulating the components S_l, $l = 0, 1, \ldots, L-1$, in parallel onto L subcarriers.

The main advantages [7] of MC-CDMA are summarized as follows:

- The high spectral efficiency and the low receiver complexity of MC-CDMA make it a good candidate for the downlink of a cellular system.
- Simple implementation with FFT.
- Low complex receivers.
- High frequency diversity gain due to spreading in frequency direction.

III. OFDMA with different Subcarrier Allocation

Several approaches to mapping transmission symbols to OFDMA subcarriers are under consideration. In this section, we specify the models of the system with two major subcarrier allocations, namely interleaved and localized, and effect of these subcarrier allocations on throughput and PAPR is also analyzed.

A. Interleaved Subcarrier Allocation

Interleaved subcarrier allocation scheme is an important case of distributed subcarrier allocation scheme [13]. To reduce the complexity of the mapping, subcarriers are clustered into slices (chunks) and all of the subcarriers in a slice are assigned together [5]. For e.g. 256 subcarriers grouped in 32 slices of 8 subcarriers per slice or 16 slices with 16 subcarriers per slice. Figure 4(a) and (b) exemplify the time domain and frequency domain transforms of interleaved signal generation [14] with three users, respectively. X_i is the corresponding frequency-domain vector for the time domain vector x_i with the same length by IDFT. For each user, the input symbols are clustered into blocks, and then each block is repeated multiple times, which result in the spectrum of the transmitted signal. Then the repeated symbol block is multiplied with a user-dependent phase rotation. For I-OFDMA, time symbols are simply a repetition of the original signals with a

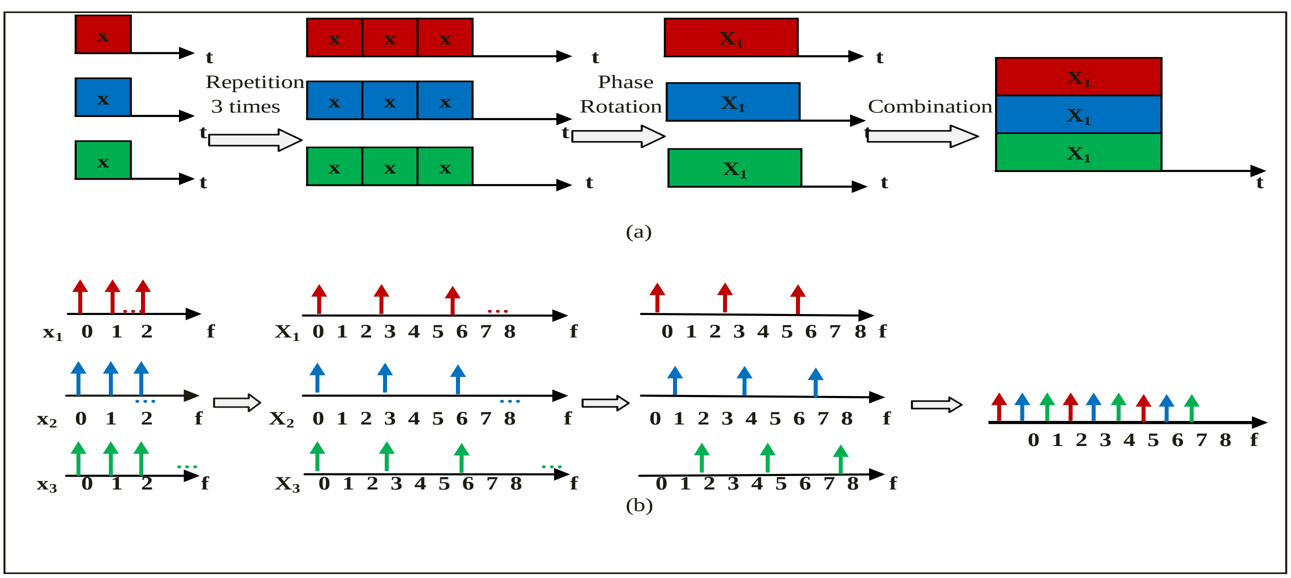

Figure 4. Signal generation for the interleaved allocation scheme.
(a) Time-domain transformation. (b) Corresponding frequency-domain transformation.

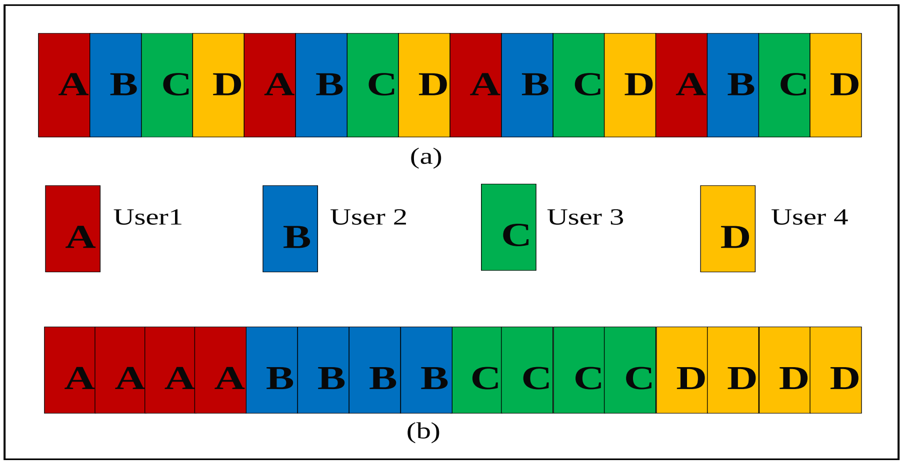

Figure 5 (a) Interleaved OFDMA, (b) Localized OFDMA.

systematic phase rotation applied to each symbol in the time domain [4]. The phase rotation [14] can be written as:

$$f_s(n) = exp\left\{-j\,\frac{2\pi l n}{QR}\right\}, l = 0,1,2 \ldots\ldots (QR-1)$$

n = 0,1,2……., N-1

where N is number of users, Q is the length of original symbol block and R is the repetition factor.

The element wise multiplication in the time domain will result in a shift of the user's non-zero subcarriers in frequency domain so that each user is allocated to a set of subcarriers orthogonal to the subcarrier sets of all other users [15]. Next, the blocks for the four users being combined, the signal of each user occupies only one in every M subcarrier, as shown in figure 4(b). Further, figure 5 (a) indicates the subcarrier mapping in interleaved mode, where the subcarriers are mapped equidistant to each other. In this type of allocation, a user is assigned subcarriers that are uniformly distributed over a given band. For Interleaved signals, time symbols are simply a repetition of the original input symbols with a systematic phase rotation applied to each symbol in the time domain. In addition to the advantages of interleaved OFDMA, it provides low envelope fluctuations of the transmitted signal [16].

B. Localized Subcarrier Allocation

Figure 5 (b) [15] indicates the concept of localized subcarrier mapping, where the subcarriers are mapped in adjacent to each other. In localized-OFDMA uplink system, the baseband modulated symbols are passed through serial-to-parallel (S/P) converter which generates complex vector of size M. After that user is assigned an adjacent slice of subcarriers or subcarriers are mapped blockwise [11]. No subcarriers are allocated to other users lying within this slice [15]. One distinct advantage of localized mapping over interleaved mapping is that localized mapping provides the feasibility of multiuser diversity, which leads to improved system capacity and/or performance.

IV. Simulation and Analysis

In different OFDMA schemes, PAPR and BER are the two most important performance parameters. In this section, we are going to evaluate the PAPR and BER performances for different MA schemes based on OFDMA. For the purpose of comparing the performance of OFDM, MC-CDMA and OFDMA (interleaved and localized), we have developed the simulation model by using LabVIEW software. In our simulation we set the number of users Q = 4, where all the users use the same transmit power. The number of subcarriers per user are N = 32, therefore the FFT size for OFDM and MC-CDMA is M = N = 32, and for interleaved OFDMA and localized OFDMA the FFT size is M = NQ = 128 [10]. Here we estimate the BER and PAPR performances of OFDM, MC-CDMA, localized OFDMA and interleaved OFDMA via computer simulations and verify our results with the results given in [10], [11], [17], [18] and [19]. In our simulations, we have engaged QPSK, and 16-QAM modulation schemes as shown in figure 6 and 7 respectively. In all the figures presenting BER

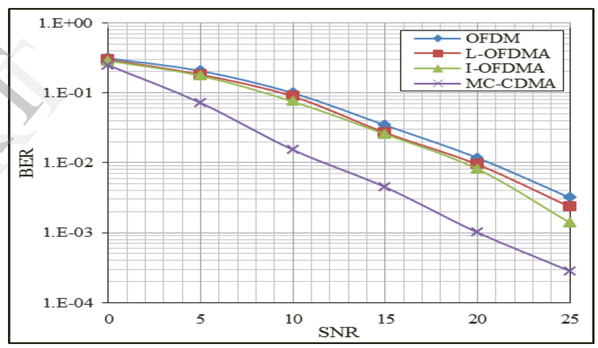

Figure 6 BER performances of different MA techniques using QPSK.

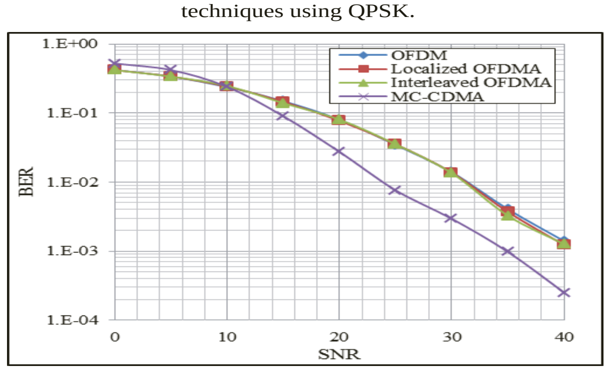

Figure 7 BER performances of different MA schemes using 16-QAM.

performance horizontal axes indicate the signal-to-noise ratio (SNR) in dB and vertical axes is the bit error rate (BER) in dB over 3000 iterations.

It has been observed from the figures above that as SNR increases, BER decreases. Further, the BER performance of OFDM, localized OFDMA and interleaved OFDMA overlaps. The MC-CDMA provides best BER performance because of inclusion of CDMA technique.

Further, we investigate second most important parameter namely PAPR. High PAPR has been

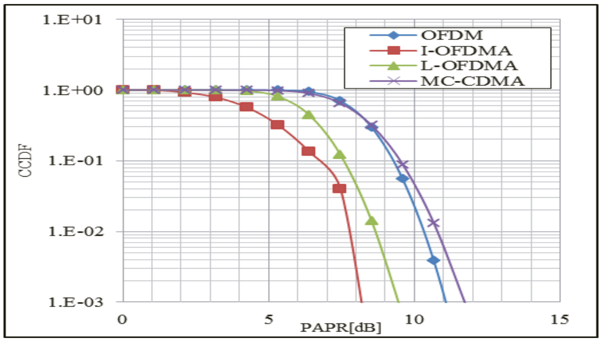

Figure 8 PAPR performances of different MA schemes.

recognized as one of the major practical problem involving OFDM modulation. High PAPR results from the nature of the modulation itself where multiple subcarriers are added together to form the signal to be transmitted. The variation of the envelope of a multi-carrier signal can be defined by the peak-to-average power ratio (PAPR). The complementary cumulative distribution function (CCDF) is used to denote the statistical probability that the PAPR of a data block exceeds a given threshold $PAPR_0$. Figure 8 describe the CCDF comparison of OFDM, MC-CDMA, localized OFDMA and interleaved OFDMA with QPSK modulation. It is clearly observed that I-OFDMA provides best PAPR performance followed L-OFDMA. Thus, I-OFDMA proves to be the best techniques providing minimum PAPR and tolerable BER performance.

V. Concluding Remarks

We elaborated in detail the concept and signal structure of OFDM, MC-CDMA, localized OFDMA and interleaved OFDMA techniques. The techniques were then compared in terms of bit-error-rate (BER) and peak-to-average power ratio (PAPR) through computer simulation results. It was established that interleaved subcarrier allocation scheme provide better performance than localized subcarrier allocation. The results also demonstrated that MC-CDMA provides the lowest BER for a given E_b/N_o as compared to other MA techniques. Results also shows that selection of a suitable subcarrier allocation scheme led to a reduction in the PAPR. We can significantly improve the BER and PAPR performances of the MA techniques by just employing a suitable subcarrier mapping.

References

[1] Dongwoon Bai et al. "LTE-Advanced Modem Design: Challenges and Perspectives," IEEE Communication Magazine, Vol. 50, Issue 2 February 2012, pp. 178-186.

[2] Woo Cheol Chung et al. "Signaling and Multiple Access Techniques for Ultra Wideband 4G Wireless Communication System," IEEE Wireless Communications, No. 5, April 2005, pp. 46- 55.

[3] Samuel C. Yang "OFDMA System Analysis and Design," Samuel C. Yang, Mobile Communication series, 2010.

[4] Hyung G. Myung et al. "Single Carrier FDMA for Uplink Wireless Transmission," IEEE Vehicular Technology Magazine, Vol. 1, No. 3, September 2006, pp. 30-38.

[5] Vassilis Dalakas et al. "A Comparative Study Between SC-FDMA and OFDMA Schemes for Satellite Uplinks," IEEE Transaction on Broadcasting, Vol. 58, No.3, September 2012, pp. 370-378.

[6] Afzal lodhi et al. "Performance Comparison of Space-Time Block Coded and Cyclic delay diversity MC-CDMA systems," IEEE Wireless Communications, Vol. 12, Issue 2, April 2005, pp. 38-45.

[7] S. Kaiser et al. "Multi-Carrier and Spread Spectrum Systems," John Wiley & Sons Ltd, England, 2003.

[8] Branislav M. popovic, "Spreading Sequences for Multicarrier CDMA Systems," IEEE Transaction on Communications, Vol. 47, No. 6, June 1999, pp. 918-926.

[9] Zhongqiang Luo et al. "Performance Comparison of SC-FDMA-CDMA and OFDM-CDMA Systems for Uplink," IEEE Consumer Electronics, Communications and Networks (CECNet), 2011 International Conference, pp. 1475-1479.

[10] Fumiyuki Adachi et al. "Broadband CDMA Techniques," IEEE Wireless Communications, Vol. 12, Issue 2, April 2005, pp. 8-18.

[11] Yuki Yoshida "Analysis and Compensation of Transmitter IQ Imbalances in OFDMA and SC-FDMA Systems," IEEE Transaction on Signal Processing, Vol. 57, No.8, August 2009, pp. 3119-3129.

[12] Shinsuke Hara et al. "Overview of Multicarrier CDMA," IEEE Communication Magazine, Vol. 35, Issue 12, December 1997, pp. 126-133.

[13] Tobias Frank et al. "Interleaved Orthogonal Frequency Division Multiple Access with Variable data rates," Proc. of OFDM-Workshop, September 2005, pp. 179-183.

[14] Hui Yang et al. "Cost-Effective Upstream Scheme for the Next-Generation PON Based on Interleaved Frequency-Division Multiple Access," IEEE Photonics Technology Letters, Vol. 24 No. 9, May 2012, pp. 784-786.

[15] Imran Baig et al. "On the peak-to-average power ratio reduction in mobile WiMAX: A discrete cosine transform matrix precoding based random-interleaved orthogonal frequency division multiple access uplink system,"Journal of Network and Computer Applications, Vol. 36, Issue 1, January 2013, pp. 466-475.

[16] Bilal Ranjha et al. "Interference Analysis of Interleaved and Localized Mapping Schemes in OFDMA system with Carrier Frequency Offset," Center for Information and Communications Technology Research (CICTR), 2013.

[17] M. F. Ghanim et al. "A Novel PAPR Reduction in MC-CDMA System Using Single Carrier FDMA Techniques," IEEE Conference at Sustainable Utilization and Development in Engineering and Technology (STUDENT), 2012, pp. 129-134.

[18] Syed M. zafi et al. "Performance Comparison of OFDM, MC-CDMA and OFCDM for 4G Wireless Broadband Access and Beyond," PIERS Proceedings, Morocco, March 2011, pp. 1396-1399.

[19] Imran Baig et al. "Novel Precoding based PAPR reduction schemes for Localized OFDMA Uplink of LTE-A," University Technology PETRONAS, Malaysia, Vol.2 No. 1, June 2010, pp. 49-57.