

NOVEL MULTIPLE LEVEL SUBCARRIER ALLOCATION SCHEME IN SC-FDMA FOR LTE-A UPLINK

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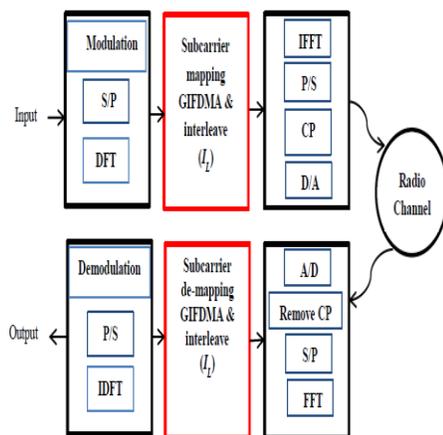
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Graphical abstract



Abstract

Long Term Evolution-Advanced (LTE-A) uses Single-Carrier Frequency Division Multiple Accesses (SC-FDMA) for uplink, because it has robust performance against the Peak Average Power Ratio (PAPR), compared to Orthogonal Frequency Division Multiple Access (OFDMA). SC-FDMA schemes include Interleaved FDMA (IFDMA) and Localized FDMA (LFDMA), both of which are commonly practiced in LTE-A uplink. IFDMA allocates distributed frequency carriers for users, whereas LFDMA allocates localized frequency carriers for users. The frequency allocation in an IFDMA scheme exhibits better PAPR performance, whereas the advantage of LFDMA is its lower complexity requirements. In this paper, a new scheme is introduced that integrates IFDMA and LFDMA by using a variable interleave allocation of subcarriers in the bandwidth. Here, Generalized Interleaved Frequency Division Multiple Accesses (GIFDMA), is used as a master key that controls the allocation for interleaved and localized FDMA, also known as L/I FDMA. This integration of IFDMA and LFDMA has been derived theoretically and empirically. Simulations are conducted to investigate the effect of different parameters on the GIFDMA PAPR performance, which is compared to that of conventional IFDMA and LFDMA. The simulation results revealed that the proposed GIFDMA provides PAPR performance comparable to that of both LFDMA and IFDMA.

Keywords: LTE-A, OFDMA, SC-FDMA, IFDMA, GIFDMA

Abstrak

Evolution Jangka Panjang-Lanjutan (LTE-A) menggunakan Akses Pelbagai Pembawa-Tunggal Bahagian Frekuensi (SC-FDMA) untuk pautan-pautan naik, kerana ia mempunyai prestasi yang teguh terhadap Nisbah Puncak Kuasa Purata (PAPR), berbanding Akses Pelbagai Bahagian Frekuensi Ortogon (OFDMA). Skim SC-FDMA termasuk FDMA Menyisip (IFDMA) dan FDMA Disetamatkan (LFDMA), yang kedua-duanya biasa diamalkan di pautan-pautan naik LTE-A. IFDMA memperuntukkan pembawa frekuensi diedar untuk pengguna, manakala LFDMA memperuntukkan pembawa frekuensi setempat untuk pengguna. Peruntukan frekuensi di dalam sesuatu skim IFDMA mempamerkan prestasi PAPR yang lebih baik, manakala kelebihan LFDMA adalah keperluan kerumitan yang lebih rendah. Dalam kertas ini, suatu skim baru diperkenalkan yang mengintegrasikan IFDMA dan LFDMA dengan menggunakan peruntukan menyisip subpembawa berubah di dalam lebar jalur tersebut. Di sini, Akses Pelbagai Bahagian Frekuensi Menyisip Teritlak (GIFDMA), digunakan sebagai kunci utama yang mengawal peruntukan untuk FDMA menyisip dan setempat, juga dikenali sebagai L/I FDMA. Integrasi IFDMA dan LFDMA ini telah diperolehi secara teori dan empirik. Simulasi dijalankan untuk mengkaji kesan parameter yang berbeza kepada prestasi PAPR GIFDMA, yang dibandingkan dengan IFDMA dan LFDMA konvensional. Keputusan simulasi

menunjukkan bahwa GIFDMA yang dicadangkan memberi prestasi PAPR standing dengan kedua-dua LFDMA dan IFDMA.

Kata kunci: LTE-A, OFDMA, SC-FDMA, IFDMA, GIFDMA

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1.0 INTRODUCTION

Digital broadcast technologies have advanced to fulfill the growing demands of higher data rates and high spectral efficiency in telecommunications between users for both wired and wireless connections [1, 2]. These demands can be met by using a modulation scheme that is gradually adopted in the communications range [3, 4]. Prospective LTE-A provides a high data rate and a wide bandwidth; furthermore it is often combined with advanced modulation techniques. The LTE-A standards have been established by the 3GPP as the next mobile communications technologies for the demanding applications, such as streaming High Definition (HD) audio & video and expected to meet the various requirements of mobile data. Initially, LTE is designed to improve network performance by providing high data rates, system capacity, and flexible bandwidth operation in a seamless integration with other wireless communication systems [5].

However, the focus on the LTE standard is coming to an end [6]. The next compatible standard, which is LTE-A, has been confirmed by the International Telecommunication Union (ITU) as the future IMT-Advanced 4G technology, to supersede the initial LTE [7]. Orthogonal Frequency Division Multiple Access (OFDMA) is the core of the LTE/LTE-A downlink transmissions because of its large number of integrated parallel-data and narrow-band subcarriers. For these reasons, OFDMA is considered to be the optimum modulation technique for the downlink transmission process of LTE, whereas single-carrier frequency division multiple Access (SC-FDMA) is used as the uplink transmission process [8].

In OFDM, the use of cyclic prefixes allows for robust symbol transitions that are protected against the effects of temporal dispersion on the radio channel, thus minimizing the need for advanced and potentially complex receiver-side channel equalization for downlink communications, this feature can help to simplify the receiver baseband processing and result in decreased maximum cost and power consumption. These advantages are particularly noteworthy for accommodating the wide transmission bandwidths of LTE and integration with sophisticated multi-antenna schemes such as spatial multiplexing. However, for uplink transmission, there is a need to resolve the high PAPR problem associated with OFDMA scheme [9].

Although many methods such as companding transform schemes [10, 11], selective mapping (SLM) [12], and partial transmit sequence (PTS) have been

proposed for reducing the PAPR, they are inefficient due to information redundancy or computational complexity and thus are impractical [13]. Consequently, SC-FDMA was adopted in LTE-A as the uplink multiple access schemes [14] because of its low PAPR compared to OFDM.

There are two main subcarrier mapping schemes used in SC-FDMA, namely interleaved and localized [15] and are described as follows:

- IFDMA: the subcarriers are spread over the entire bandwidth, and an equalizer at the receiver is needed to avoid inter-symbol interference (ISI).
- LFDMA: data are transmitted in a group of adjacent subcarriers; a portion of the system consisting of several adjacent subcarriers is allocated for each user's DFT outputs. The advantage of this scheme is that it supports user diversity, but its disadvantage is the lack of frequency diversity [16].

In this work, a new generalized allocation scheme is proposed, which inhibits the advantages of both IFDMA and LFDMA in providing variable frequency diversity. This scheme is achieved through the introduction of interleave level (I_L) that defines the level of interleaving used in allocating subcarriers per user in the bandwidth. Figure 1 demonstrates the SC-FDMA transmitter and receiver with I_L as depicted in the subcarrier mapping block in the Figure.

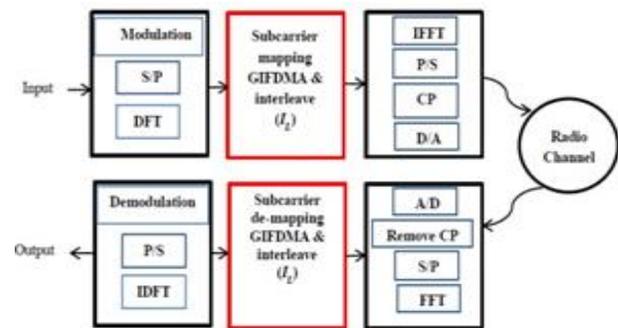


Figure 1 SC-FDMA Transmitter and Receiver

The rest of this paper is arranged as follows. Section 2 focuses on related work. Section 3 explains the mathematical modeling. Section 4 describes the simulation. Section 5 provides results and discussion. Finally, Section 6 highlights the conclusion of this paper.

2.0 RELATED WORKS

Research in LTE/LTE-A related to uplink evolution has accelerated over the last decade. Most of the studies have focused on how to improve the PAPR in the uplink transmission to enhance the performance of SC-FDMA, which fundamentally has a better PAPR performance as compared to OFDMA because of its inherent single carrier transmission structure and it, therefore, has been adopted by 3GPP LTE-A as the uplink transmission scheme. Block interleaved frequency division multiple access is proposed in [17] for power efficiency, robustness, flexibility, and scalability whereas authors in [18] studied the impact of frequency diversity and multi-user diversity in IFDMA. They theoretically derived the average BER performance of IFDMA in the multi-user environment by taking into account frequency diversity, multi-user diversity and inter-chip interference (ICI). SC-FDMA signals PAPR is analyzed theoretically in [19] and compared with that of OFDMA. Specifically, they derived the time domain signals of IFDMA and LFDMA, and compared the PAPR characteristics using the CCDF of PAPR. in [20] The time-reverse space time code (TR-STC) was proposed as a STC method for single carrier systems over frequency selective channels (FSCs) and it is proved that spatial multiplexing can be employed with time-reversal space-time coding (TR-STC). Finally, authors in [3] conducted a performance analysis of DFT-spread OFDM systems, where they analyzed the performance of DFT-spread OFDM and proposed a method for reducing the PAPR in OFDM.

In this paper, a new subcarrier allocation scheme is introduced. The proposed subcarrier allocation scheme involves an integration of IFDMA and LFDMA. This integration is achieved by proposing an interleave level that can be used to move from the IFDMA scheme towards the LFDMA scheme. Therefore, the proposed subcarrier allocation scheme is generalized forms of IFDMA with a variable interleave level. The proposed scheme will be referred as Generalized IFDMA (GIFDMA) throughout this paper.

3.0 MATHEMATICAL MODELING

The concept of GIFDMA and the variable allocation level, IL and its effect on changing the allocation per user is explained through the mathematical derivation of the output signals. The introduction of IL in the subcarrier allocation would alter the sequence of user symbols in the receiver side. Thus, to study the impact of the interleave level on the retrieved signal mathematically, IL is defined as:

$$I_l = 2^x, \text{ where } x = 0, 1, \dots, \log_2(M) \quad (1)$$

Where I_L is the interleave level, x is the interleave index, and M is the number of subcarrier allocation per user. From the definition of the IL, in eq. (1), it is clear that this scheme allows a variable interleaving of user symbols in the bandwidth. For example, for $M=4$ the interleave index x will have the values in the range of $\{0, 1, 2\}$ and, consequently, the interleave level I_L , according to eq. (1), takes the values in the range $\{1, 2, 4\}$. This range of interleave corresponds to the IFDMA, GIFDMA and LFDMA cases respectively as explained in Figure 2. With this interleave level

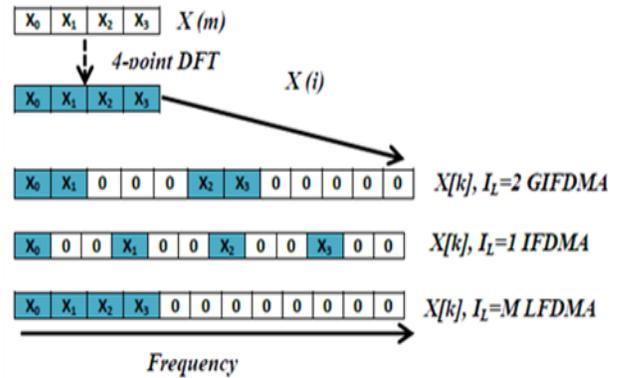


Figure 2 Partitions and assignment of multiple mobile Terminal users

The recovered signal can be expressed as follows:

$$[k] = \begin{cases} X[\bar{k}] & k = m_l I_L + l, m_l = 0, 1, \dots, \frac{M}{I_L} - 1 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

$$s = 0, 1, \dots, S-1 \quad m = 0, 1, \dots, M-1 \quad l = 0, 1, \dots, I_L-1 \quad (3)$$

Where S is the number of users, and s, l and m are defined as in eq. (3)

The overall system bandwidth is expressed as:

$$N = SM \quad (4)$$

And the transmitted signal index can be written as:

$$\bar{k} = k - (S-1)I_L m_l = I_L m_l + l \quad (5)$$

For example, the bandwidth considered is $N=12$ and the spreading factor is $S=N/M$. the number of users is 3 where the number of subcarriers (M) is 4. By applying eq. (5), the retrieved signal can be calculated for different subcarrier mapping schemes. The representation of the m, m_l, s, S , and n for GIFDMA when $I_L=2$, IFDMA when $I_L=1$, and LFDMA when $I_L=4$

are shown in Figures 3, 4 and 5 respectively. Furthermore, the mathematical interpretation of the follows:

3.1 GIFDMA Case

The GIFDMA case is characterized by the defining l_L for the example depicted in Figure 2. Thus, with $S=3$, the m_l , m , l and s indices defined in eq. (2) to (3) are as follows:

$$m_l = 0,1 \quad m = 0,1,2,3 \quad l = 0,1 \quad s = 0, \dots, 2 \quad I_L = 2 \quad (6)$$

In this structure, the whole domain is sectioned into blocks of l_L subcarrier length. The indexing of the subcarriers is controlled by m_l to account for the number of blocks and by l to account for the subcarrier index within each block, as shown Figure 2. The index of the retrieved signal can be written as:

$$n = [(S - 1)m_l + s]I_L + m \quad (7)$$

Partitions and assignment of proposed scheme GIFDMA as depicted in Figure 2. In the proposed method, the mapping scheme is controlled by setting l_L to be 1 for IFDMA and for LFDMA setting l_L to be the total number of subcarriers allocated per user M . Figure 2 shows the DFT spreading for a single user in a bandwidth of 12 subcarriers where s is an index of the user, and it takes values in the range defined by eq. (3). The index of the retrieved signal, n , in Figure 3 is calculated by eq. (7)

	X_0	X_1	0	0	0	0	X_2	X_3	0	0	0	0
m	0	1	0	0	0	0	2	3	0	0	0	0
m_l	0	0	0	0	0	0	1	1	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	0	0
S	3	3	0	0	0	0	3	3	0	0	0	0
n	0	1	0	0	0	0	6	7	0	0	0	0

Figure 3 Partitions and assignment of GIFDMA, $l_L=2$

The index of the retrieved signal, n , in Figure 4 is calculated by eq. (15)

	X_0	0	0	X_1	0	0	X_2	0	0	X_3	0	0
m	0	0	0	1	0	0	2	0	0	3	0	0
m_l	0	0	0	1	0	0	2	0	0	3	0	0
s	0	0	0	0	0	0	0	0	0	0	0	0
S	3	0	0	3	0	0	3	0	0	3	0	0
n	0	0	0	3	0	0	6	0	0	9	0	0

Figure 4 Partitions and assignment of IFDMA $l_L=1$

$$\tilde{x}[n] = \frac{1}{N} \sum_{k=0}^{N-1} x[k] e^{j2\pi \frac{n}{N} k} \quad (8)$$

Substituting the index k in eq. (2) into eq (8) gives

$$\tilde{x}[n] = \frac{1}{SM} \sum_{k=0}^{M-1} x[k] e^{j2\pi \frac{n}{SM} [mSI_L + l]} \quad (9)$$

$$\tilde{x}[n] = \frac{1}{SM} \sum_{k=0}^{M-1} x[k] e^{j2\pi \frac{nmSI_L}{SM} e^{j2\pi \frac{n}{SM} l}} \quad (10)$$

Note that from eq. (5):

$$I_L m_l = \bar{k} - l \quad (11)$$

Substituting eq. (11) in eq. (10) yields

$$\tilde{x}[n] = \frac{1}{SM} \sum_{k=0}^{M-1} x[k] e^{j2\pi \frac{n(k-l)}{SM}} e^{j2\pi \frac{\pi}{SM} l} \quad (12)$$

	X_0	X_1	X_2	X_3	0	0	0	0	0	0	0	0
m	0	1	2	3	0	0	0	0	0	0	0	0
m_l	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	0	0
S	3	3	3	3	0	0	0	0	0	0	0	0
n	0	1	2	3	0	0	0	0	0	0	0	0

Figure 5 Partitions and assignment of LFDMA $l_L=M$

By rearranging the terms in eq. (12), the integration between IFDMA and LFDMA can be shown as follows:

$$\tilde{x}[n] = \frac{1}{SM} \sum_{k=0}^{M-1} x[k] e^{j2\pi \frac{n}{M} k} e^{j2\pi \frac{n}{M} l (\frac{1}{S} - 1)} \quad (13)$$

The index of the retrieved signal, n , in Figure 5 is calculated by eq. (19)

It can be clear from eq. (13) that the system can distinguish between and IFDMA and LFDMA. Therefore, overcome the drawbacks related to user and frequency diversity. Moreover, the GIFDMA recovered signal represented in eq. (12) consists of a multiplication between IFDMA and LFDMA terms. Thus, both IFDMA and LFDMA can be derived directly from eq. (13).

3.2 IFDMA Case

For Case IFDMA, it can be derived by assuming:

$$I_L = 1 \quad l = 0 \quad m_1 = 0,1,2,3 \quad (14)$$

$$n = Sm_1 + s \quad (15)$$

By substituting l_L, l , and m_1 defined in eq. (14) into eq. (13), provides

$$\tilde{x}[Sm_1 + s] = \frac{1}{SM} \sum_{k=0}^{M-1} \tilde{x}[\bar{k}] e^{j2\pi \frac{n}{M} \bar{k}} = \frac{1}{s} x(m) \quad (16)$$

This scheme is shown as an example in Figure 4 with the assignment of the indices that demonstrate the IFDMA

3.3 LFDMA Case

Conversely, For LFDMA is given by assuming:

$$I_L = M \quad m_1 = 0 \quad l = m = 0,1,2,3 \quad (17)$$

In this case the signal indices would be given as:

$$\bar{k} = l = m \quad (18)$$

$$n = sM + m \quad (19)$$

By substituting eq. (17) to (18) in eq. (13) and rearranging the terms, yields:

$$\tilde{x}[Sm_1 + s] = \frac{1}{SM} \sum_{l=0}^{M-1} \tilde{x}[l] e^{j2\pi \frac{sM+m}{M} l} e^{j2\pi \frac{sM+m}{M} l (\frac{1}{s}-1)} \quad (20)$$

$$\tilde{x}[Sm_1 + s] = \frac{1}{SM} \sum_{l=0}^{M-1} \tilde{x}[l] e^{j2\pi \frac{sM+m}{M} l} e^{j2\pi \frac{(sM+m)l}{SM}} e^{-j2\pi \frac{sM+m}{M} l} \quad (21)$$

$$\tilde{x}[sM + m] = \frac{1}{SM} \sum_{l=0}^{M-1} \tilde{x}[l] e^{j2\pi \frac{(sM+m)l}{SM}} \quad (22)$$

For $s=0$

$$\tilde{x}[sM + m] = \frac{1}{SM} \sum_{l=0}^{M-1} \tilde{x}[l] e^{j2\pi \frac{(M+m)l}{M}} = x(m) \quad (23)$$

Figure 5 demonstrate the LFDMA case with the assignment of the l_L, m, m_1 indices and n . Therefore, the proposed GIFDMA can be thought of as a

generalized IFDMA, where the interleave level is variable. The variability of the interleave level made the transition from IFDMA to LFDMA to be seamless and controlled through the l_L . Consequently, both IFDMA and LFDMA are shown to be special cases from the proposed GIFDMA.

4.0 SIMULATION SETTINGS

The proposed GIFDMA is simulated under PAPR situation, assuming a subcarrier allocation per user M , and an interleaved level, l_L . The IFDMA and LFDMA cases occur when $l_L=1$ and, respectively. GIFDMA is assumed when $l_L \in \{2, 4, \dots, 2^{x-1}\}$ where x is defined in eq. (1). Random data, containing 5000 frames were generated and transmitted for each value of l_L . The roll-off factor ranged from zero to one, the oversampling is considered as eight bit, and several FFT sizes were assumed in the simulation.

To obtain a diversity of results, 16-QAM and 64-QAM are used to verify the performance of the proposed GIFDMA at different modulation schemes as compared to the conventional IFDMA and LFDMA. The simulation parameters are summarized in Table 1. The PAPR was calculated for every frame according to the following equation:

$$PAPR = \frac{\max(x_n * conj(x_n))}{\text{mean}(x_n * conj(x_n))} \quad (24)$$

Where x_n is the received signal

PAPR values were recorded to compare the behaviors of PAPR for each interleave level l_L and for different interleaving schemes by using different filter roll-off factors. GIFDMA is designed as master keys that partitions and assigns multiple mobile terminal users and controls the allocations for frequency division multiple accesses (L/I FDMA). The location of each subcarrier is determined through the l_L . Subcarriers that do not belong to the first user are assumed zeros in the simulation for a single user case.

5.0 RESULTS AND DISCUSSIONS

As shown in Figures 6 to 9, the cumulative distribution function (CDF) represents simulation parameters of 16-QAM, a 256 bandwidth with 64 subcarriers are allocated per user. Furthermore, Figures 6 and 7 show the difference in PAPR between IFDMA and LFDMA respectively.

Table 1 Simulation parameters

Parameter	Value
Roll off factor	0 and 1
Spectrum allocation	5MHz
oversampling	8bit
Shaping filter type	Raised cosine impulse
FTT Size	256-1048
No of bits per QAM	4-6

The PAPR of the proposed scheme is in the range of that of IFDMA and LFDMA. By comparing the PAPR in Figures 6 and 7, it can be deduced that the PAPR level has improved by approximately 0.5 dB less than its level when the value of alpha, α , was changed from zero to one respectively; moreover, the change in interleave level l_L corresponds with decreasing alpha, α , which indicates that the roll-off factor selection is significant in the proposed GIFDMA scheme. For the 64-QAM with 1024 bandwidth and 64 subcarrier allocations per user the signal PAPR for different roll-off factor and interleave levels is shown in Figures 8 and 9. The performance of the PAPR for different values of interleave level l_L is improving with higher α . As mentioned before, the behavior of PAPR can be captured for different modulation schemes. There is no significant impact on the PAPR when either the bandwidth or the value of the QAM is changed. This finding is verified in Figures 13 and 14. The PAPR for different values of interleaving level l_L exhibits a weak relation to the bandwidth and QAM schemes used.

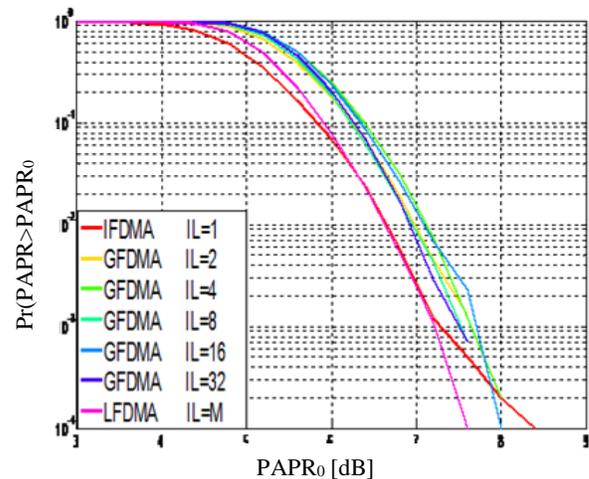
Moreover, the behavior of the PAPR in relation to the modulation scheme can be noticed by comparing Figures 6 and 7 with Figures 8 and 9. It can be seen that there is no major effect on PAPR in the IFDMA, GIFDMA, and LFDMA. This emphasizes that changing the QAM value and the bandwidth does not significantly impact the signal PAPR in all the schemes. The effect of α on the average PAPR for different interleave levels and different bandwidths and comparisons between IFDMA, LFDMA and GIFDMA are shown in Figure 10 to 12. Changing the roll-off factor α is from 0 to 1 account for an average reduction in PAPR by almost 0.5dB. The figures show a smooth, seamless transition from IFDMA to LFDMA; this transition benefits from the advantages of both schemes. In spite of the fact that, the quantity of users in figure 11 has been expanded to 8 users in contrast with the number of users in figure 10 the PAPR essentially improved slightly. Moreover, a comparison of the average PAPR values for different bandwidths at roll-off factor $\alpha=1$, with all the other parameters are fixed, is shown in Figure 13.

The differences in PAPR behavior for different l_L are minor, but the effect of the modulation scheme in Figure 14 and the subcarrier allocation per user in Figure 15 on PAPR is more noticeable. In general, the

proposed scheme's PAPR is in the range between the PAPRs levels of both IFDMA and LFDMA, with better PAPR levels for higher α . This finding shows that the transition from IFDMA to LFDMA is seamless with PAPR comparable to that of conventional IFDMA and LFDMA. Furthermore, it is obvious from Figure 15 that PAPR is enhanced with smaller subcarrier allocation $M=64$ as compared to larger $M=128$; this means that the PAPR is better when the number of users is higher within the same bandwidth. These parameters are also investigated in Figures 10 through 12.

6.0 CONCLUSION

In this paper, a new subcarrier allocation scheme, known as the Generalized Frequency Division Multiple Accesses (GIFDMA) is derived, analyzed and investigated. The proposed GIFDMA is an integration of the IFDMA and LFDMA schemes. This integration is achieved by introducing an interleave level metric that controls the subcarrier allocation per user in the system. The relationship between the new metric and the subcarrier allocation per user is identified. Moreover, its relationship with the received signal is derived. The PAPR behavior of the proposed scheme is studied with respect to different system parameters, such as the roll-off factor, system bandwidth, number of subcarrier allocation per user, modulation scheme, and more importantly the interleave level, l_L . In all cases, the proposed scheme showed a PAPR behavior that matches that of both IFDMA and LFDMA. These results suggest that there is a smooth seamless transition from IFDMA to LFDMA. Thus, it can be concluded that the proposed GIFDMA inherits similar advantages of both IFDMA and LFDMA.

**Figure 6** CCDF of PAPR for QAM=16, N= 256, M=64, $\alpha=0$

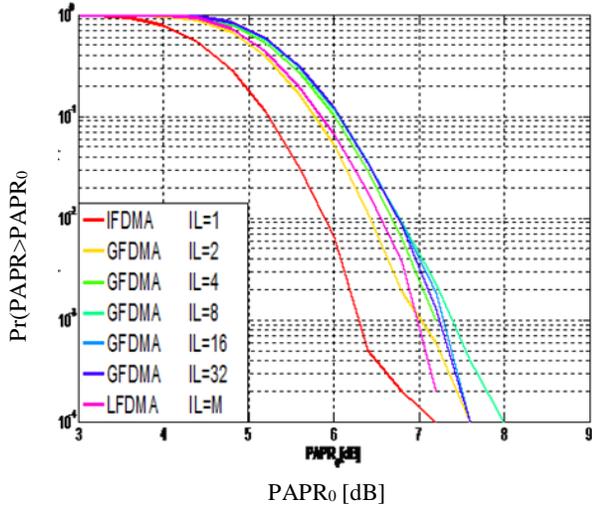


Figure 7 CCDF of PAPR for QAM=16, N= 256, M=64, $\alpha=1$

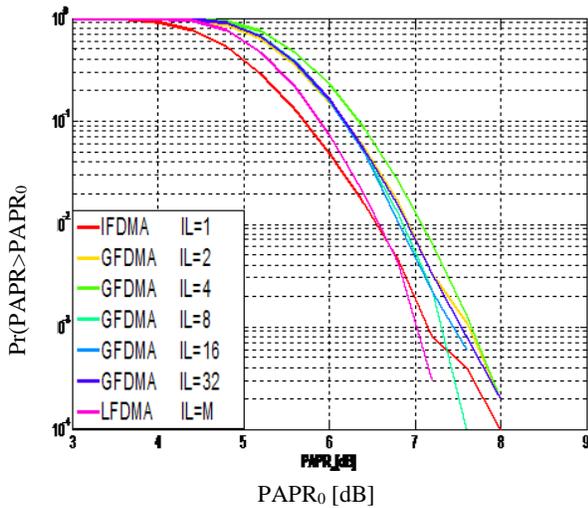


Figure 8 CDF of PAPR for QAM=64, N=1024, M=64, $\alpha=0$

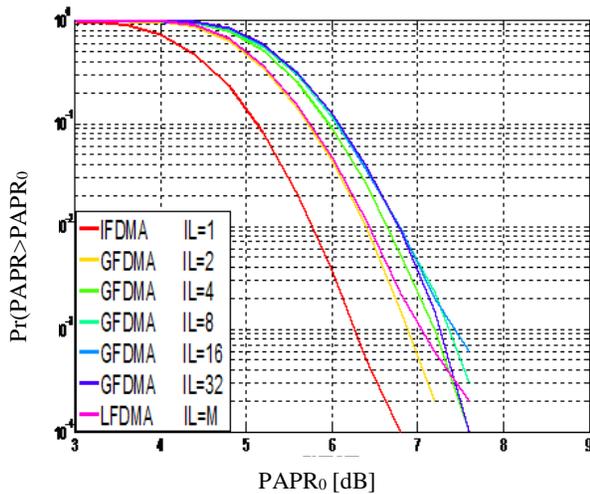


Figure 9 CFDF of PAPR for QAM=64, N=1024, M=64, $\alpha=1$

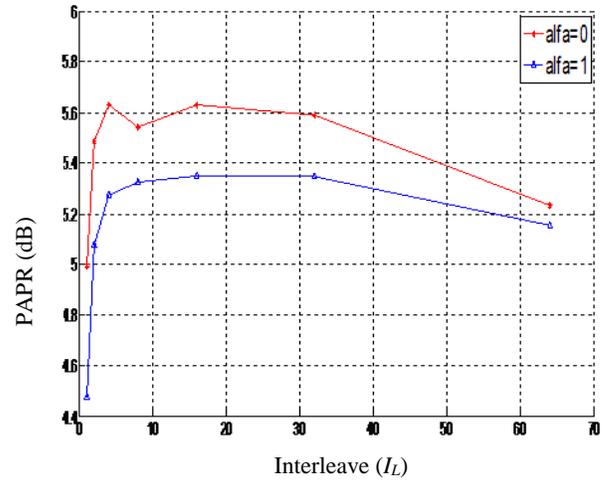


Figure 10 PAPR Average versus Interleave Level (I_L) for N= 256, M= 64, users=4

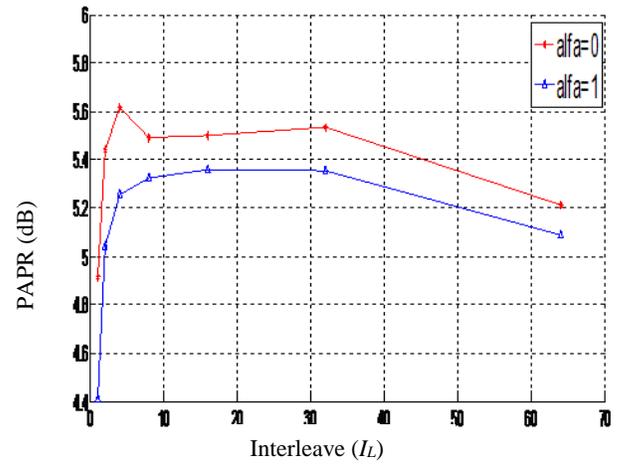


Figure 11 PAPR Average versus Interleave Level (I_L) for N= 512, M= 64, users =8

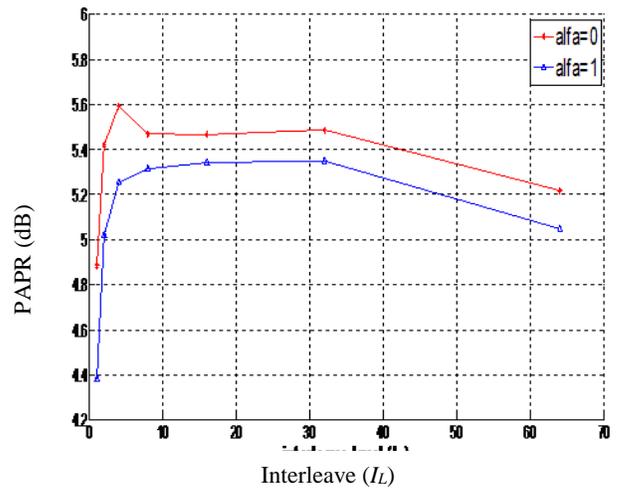


Figure 12 PAPR Average versus Interleave Level (I_L) for N= 1024 M= 64 users =16

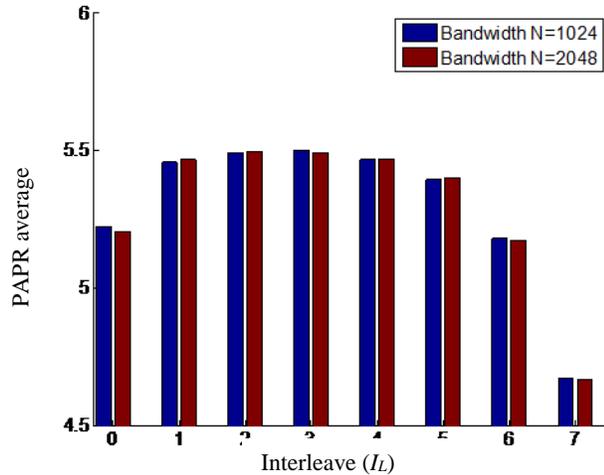


Figure 13 PAPR versus Bandwidth for different L , $M=128$

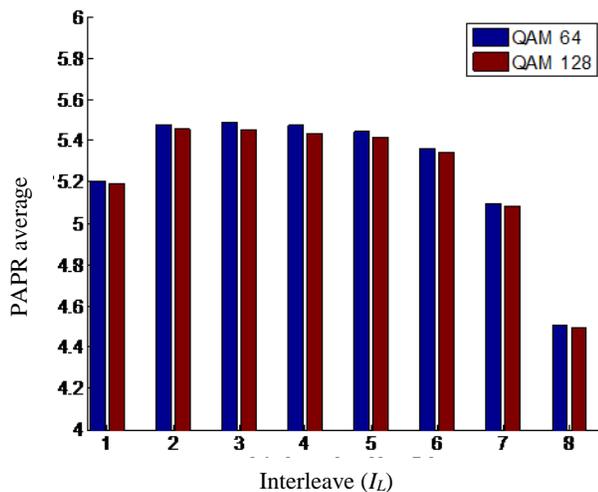


Figure 14 PAPR versus Modulation Scheme, $M=256$

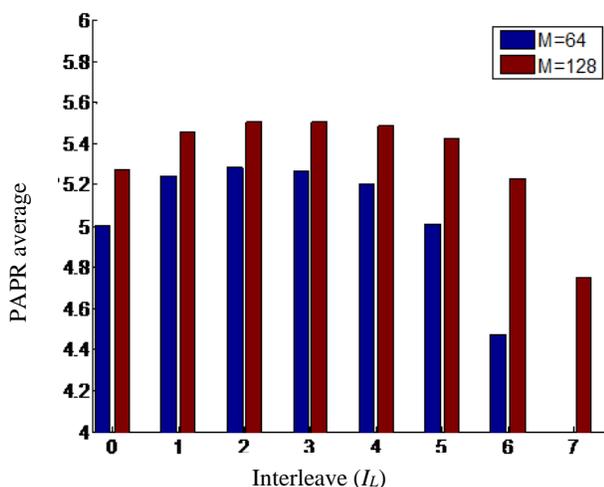


Figure 15 PAPR versus subcarrier allocation per user, $N=256$

Acknowledgment

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