ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2015

Performance Analysis of PAPR Reduction Using DFT-Spreading OFDMA Technique

Alcardo Alex Barakabitze, Tan Xiaoheng

School of Communication Engineering, Chongqing University, China

ABSTRACT: The 3GPP long term evolution (3GPP-LTE) has adopted the Discrete Fourier Transform Spreading Orthogonal Frequency Division Multiple Access (DFTS-OFDMA) technique to be used in the uplink air interface for the next generation cellular systems. The DFTS-OFDMA is also a candidate of radio interface technologies for the IMT-Advanced standards in ITU-R. This technique has been adopted for uplink transmission due to its attractive feature of lower PAPR archived by precoding data symbols using a DFT operation at the transmitter.

In this paper, we analyse the performance of DFT-Spreading OFDMA technique in PAPR reduction by using the IFDMA and LFDMA subcarriers mapping modes. We also analyse the performance of the DFTS OFDMA technique for PAPR reduction as the number of subcarriers allocated to each user varies, specifically with the LFDMA subcarriers mapping mode. Simulation results show that, the IFDMA improves PAPR performance significantly than LFDMA with pulse shaping and wihout pulse shaping but at a cost of increased bandwidth.Moreover, the performance of DFT-Spreading with LFDMA improves when the number of subcarriers allocated to users becomes small. Although, in-terms of PAPR power efficiency, the IFDMA performs better than LFDMA allocation scheme, but LFDMA is very superior in terms of throughput when channel dependent scheduling is utilized and has been widely implemented in LTE.

KEYWORDS: OFDMA, Peak to Average Power Ratio (PAPR), Subcarriers, FDMA, Orthogonal

1. INTRODUCTION

The Discrete Fourier Transform Spread Orthogonal Frequency Division Multiple Access (DFT-S-OFDMA) has been an attracting technology to be used in the uplink air interface and OFDMA to be used for downlink in the next generation cellular systems [1].The DFTS-OFDMA technique has been adopted for uplink transmission in the 3GPP LTE as the air interface in order to reduce PAPR. This technique has been also evolved into one of the candidate radio interface technologies for the IMT-Advanced standards in the International Telecommunication Union Radio (ITU-R)[7]. The DFTS-OFDMA is commonly referred to as a frequency-domain generalization of Single Carrier-Frequency Division Multiple Access (SC-FDMA).In LTE[13], the uplink transmissions is multiplexed by the DFT in a specific frequency allocation blocks within the overall system bandwidth according to the scheduler instructions provided by the *eNodeB*(the *eNodeB* is the hardware that is connected to the mobile phone network that communicates directly with mobile handset, like a base transceiver station(BTS) in GSM networks)[6]. In fact, the DFT-S-OFDMA is a modified technique of OFDMA where a number of users are scheduled to transmit their data simultaneously on orthogonal sets of subcarriers. In the DFTS-OFDMA scheme, each data symbol is spread over many tones by the DFT operation at the transmitter before being sent to the OFDM modulator. By using the Space-Division Multiple-Access (SDMA), users can transmit over the same frequency and time resource block. The receiver technique for such DFTS-OFDMA systems involves tone-by-tone single-tap equalization followed by an inverse DFT operation. The key advantage of DFTS-OFDMA is its considerable lower envelope fluctuations in the signal waveform transmitted by each user which results into minimum PAPR compared to the classical OFDMA technique [1][2].However, the difference between DFTS-OFDMA and the classical OFDMA is that, each user in DFTS-OFDMA spreads its coded and modulated information bits using a DFT matrix and the precoded symbols are then mapped to its allocated subcarriers[1].The sub-carriers in OFDMA systems are partitioned and then allocated to a number of mobile users/terminals. In the uplink OFDMA systems, each terminal utilizes a subset of the subcarriers for transmitting its own data and the remaining subcarriers will be filled with zeros(0).

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

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Vol. 3, Issue 3, March 2015

Suppose that, *M* is the number of subcarriers allocated to each user, then the DFTS-OFDMA will use *M*-point DFT for spreading and the output of DFT is assigned to the subcarriers of IFFT. Myung *et.al* [3] has shown that, PAPR reduction effect is highly dependent on the way of assigning the subcarriers to each terminal as explained in the next section.

In this paper, we will examine the PAPR performance of transmit symbols for each block in the IFDMA and LDFMA with pulse shaping numerically. We analyse the PAPR reduction performance of DFTS-OFDMA technique with IFDMA and LFDMA with different values of the roll-off factor $(0 \le \alpha \le 1)$ of the RC filter with pulse shaping after IFFT. The rest of this paper is organized as follows: section II provides the literature review of related works concerning DFTS-OFDMA system. Section III describes the DFTS-OFDMA system model and subcarriers mapping schemes. Section IV highlights the PAPR of DFT-Spreading OFDMA Signals. We provide the numerical simulation results in section V before concluding our remarks in section VI.

II. RELATED WORKS

The DFTS-OFDMA is regarded to be a good solution of single carrier based uplink multi-access scheme for PAPR reduction. Wu and Haustein [16] has reported the PAPR reduction by DFT precoding technique and studied the energy and spectral efficiency in the uplink for 3GPP-LTE.They showed that, the DFT precoding with filtering similar to that of single carrier transmission with appropriate pulse shaping is a reasonable option to increase the cell edge throughput. Li *et.al* [17] investigated the PAPR reduction in MC/DS CDMA systems by using the DFT Spreading codes where about 6dB PAPR was achieved at CCDF of 10^{-3} in the MC/DS CDMA system with 12 data carriers. Wu et.al [19*]* studied on the visible light communication (VLC) using LED Array with DFT-Spread OFDM. Based on their detailed comparisons of DFT-Spread OFDM in terms of PAPR reduction for VLC and RF systems, the simulation results show that DFT-Spread OFDM leads to a reduced PAPR and achieves a performance gain in BER without any loss of system transmission rate. Basak *et.al* [19] explored the improvement of PAPR in the uplink by using the DFT spreading technique so as to preserve the limited battery power in a mobile terminal. They found that, SC-FDMA systems with IFDMA and LFDMA have better PAPR performances, as compared to OFDMA systems.The PAPR performance comparison between Localized and Distributed-Based SC-FDMA techniques was done in [20]. Myung[21] studied the *SC-FDMA* focusing on physical layer aspects, PAPR characteristics and channel-dependent resource scheduling of SCFDMA. He found that, the two different categories of subcarrier mapping methods, localized and distributed, give the system designer the flexibility of adapting to different radio environments.Soltani[21] compared the SC-FDMA and OFDMA as 3GPP Long-Term Evolution Uplink. It was concluded that, the SC-FDMA is the better option for a cellular uplink in LTE, because of its higher efficiency due to low PAPR, its lower sensitivity to frequency offset because it has at most only two adjacent users, and its capacity is about the same as OFDMA. Azurdia-Meza *et.al* [22] derived the pulse shaping filter which satisfy the Nyquist-I criterion and implemented the PAPR reduction over SC-FDMA scheme. The simulation results showed that PAPR was greatly reduced compared to that of the raised cosine filter, which is widely used in wireless communications. In [23], the PAPR reduction of SC-FDMA by hybrid (clipping & pulse shaping) technique is reported to enhance the power efficiency of the handset as well as improving the uplink throughput and operating range.

III. DFT-SPREADING OFDMA SYSTEM MODEL

Fig.1 shows the block diagram of a DFT-Spreading OFDMA technique which is also referred to as a SC-FDMA. The data input symbols are first encoded and converted from serial to parallel before transforming the symbols to frequency domain by DFT operation. The OFDMA modulation is then performed followed by pulse shaping filter that shape the signal to get the desired spectrum and then transmit the analogue signals through a channel after DAC conversion. Since different subcarriers in the frequency domain are occupied by every user like in OFDMA technique, then, the orthogonality of users is highly maintained. In the receiver, the analogue signal is first converted to digital before applying OFDMA demodulation. The parallel to serial conversion is then performed and decoding the signal to obtain the desired output data.

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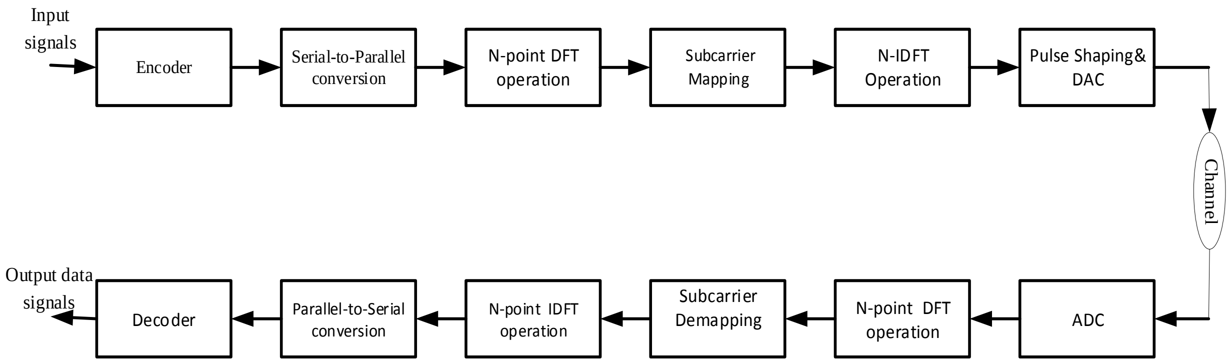

Fig.1:A block diagram of DFT-Spreading OFDMA system

A. Subcarriers mapping schemes

The performance of DFTS-OFDMA system is mainly affected by the type of subcarrier mapping scheme being used. Three different schemes are used in the DFT-Spreading technique to assign subcarriers among users. These schemes are: The Distributed Frequency Division Multiplexing Access (FDMA), the Localized FDMA (LFDMA) and the Interleaved FDMA (IFDMA) approach.

- ***Localized FDMA***

In the localized scheme, each user is allowed to use a set of adjacent subcarriers to transmit data. This means for localized DFTS-OFDMA, only a fraction of the total bandwidth is used by one user as shown in Fig.2. The advantage of LFDMA is that, it achieves multi user diversity in frequency selective channel if each user is assigned subcarriers that have high channel gain [11]. The drawback of this subcarrier mapping scheme is that, it eliminates the chance of getting frequency diversity in the channel. It also requires channel state information (CSI) to map the data into the best adjacent symbols [12].In the localized subcarrier mapping mode, the modulation symbols are assigned to M adjacent subcarriers [8].

- ***Distributed FDMA***

The subcarriers in a distributed mode used by a user are spread over the entire bandwidth. The information to spread is used to provide inherent frequency diversity. In the DFDMA, M DFT point outputs are distributed over the total N subcarriers with zeros filled in (N-M) unused subcarriers (see Fig.2 and Fig.4). However, when the DFT outputs in DFDMA are distributed with an equal distance such that N/M= S, then this kind of technique is termed as the Interleaved FDMA (IFDMA) and becomes a special case of DFDMA scheme where S represents the bandwidth spreading factor[7].The drawback of this scheme is that, it loses user diversity[11]. Figure 2 shows the two approaches of allocating subcarriers in the DFDMA and IFDMA with M=4, S=4, and N=16.

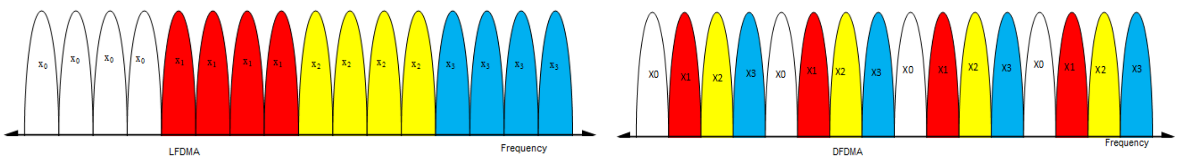

Figure 2: Assignment of subcarriers to 4 users with N=12; M=4 and S=4

Fig.3 also shows the mapping of subcarriers for uplink transmission in OFDMA systems

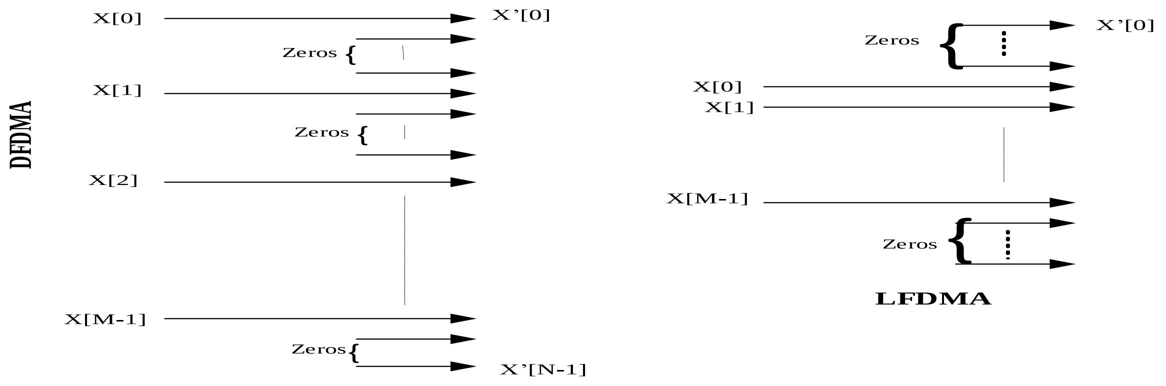

Fig.3: Mapping of subcarriers for uplink in OFDMA systems using LFDMA and DFDMA

The subcarriers mapping relationship between 4-point DFT and 12-point IDFT and the examples of DFT spreading in DFDMA, LFDMA, and IFDMA with number of subcarriers N=12, number of subcarriers allocated to users(M)=4, and the spreading factor(S)=3 is shown in Fig.4 below.

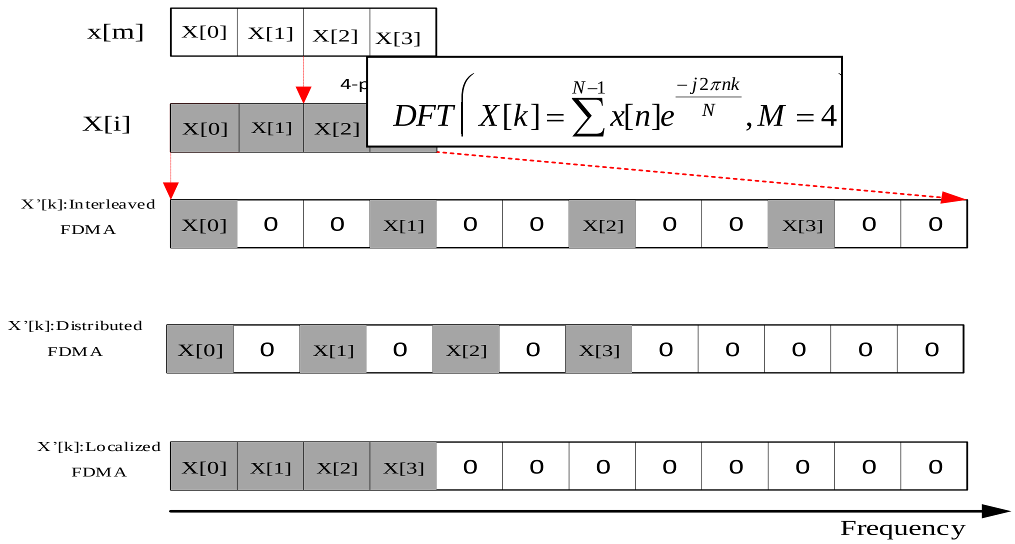

Fig.4: DFT Spreading in DFDMA, LFDMA, and IFDMA

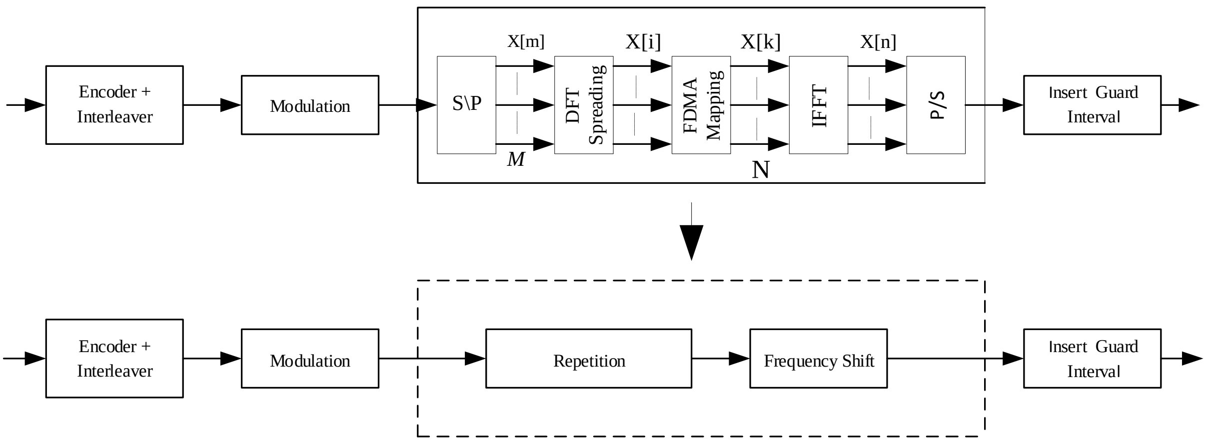

Fig.5: A Block diagram of IFDMA uplink transmitter with DFT-spreading technique.

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

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Fig.5 shows the block diagram of IFDMA uplink transmitter with DFT-Spreading technique where the input data $x[m]$ is DFT-spread in order to generate $X[i]$.FDMA mapping is then performed to generate data symbols $X[k]$ before IFFT operation to obtain $x[n]$ and convert the signal from parallel to serial. The guard interval that is larger than the maximum channel delay is then inserted as a cyclic prefix (CP) like in standard OFDMA in order to avoid interference from preceding transmission symbols. In fact, IFDMA is equivalent to OFDMA-Code Division Multiplexing (CDM) with block interleaved frequency allocation and can be completely generated in the time domain without using the Fourier transform [9]. The time domain generation of IFDMA uses compression and repetition as described in more detail in [10].

IV. PAPR OF DFT-SPREADING OFDMA SIGNALS

We consider the PAPR reduction of the DFTS-OFDMA for distributed subcarrier mapping mode, the IFDMA. Through our derivations, we let *N*/*M*= S. Suppose the data to be modulated is $\{x_n : n = 0,1,...,M-1\}$ and $\{x_k : k = 0,1,...,M-1\}$ are the frequency domain samples after operation of the DFT on $\{x_n : n = 0,1,...,M-1\}$.Consider also the frequency domain samples after subcarrier mapping to be $\{\tilde{X}_l : l = 0,1,...,N-1\}$.The time symbols after IDFT of $\{\tilde{X}_l : l = 0,1,...,N-1\}$ will be $\{\tilde{x}_n : n = 0,1,...,N-1\}$.Therefore, the complex pass-band transmit signal of DFT-Spreading OFDMA $x(t)$ for a block of data can be expressed as:

$x(t) = e^{j\omega_c t}\sum_{n=0}^{N-1}\tilde{x}_n r(t - n\tilde{T})$ **(1)** where ω_c is the carrier frequency of the DFT-Spreading system and $r(t)$ is the baseband pulse. In this paper, we investigate the effect of pulse shaping on the PAPR performance of DFT-spreading technique. In order to achieve our objectives, we employ the Raised-Cosine (RC) which is the widely used pulse shape in wireless communications [4], and defined in time domain as follows:

$$r(t) = \sin\left(\pi \frac{t}{\tilde{T}}\right)\frac{\cos(\pi\alpha t)}{1 - \frac{4\alpha^2 t^2}{\tilde{T}^2}}$$ **(2)** Where α represent the roll-off-factor of the RC which ranges from 0 to 1.Then, the PAPR of the DFT-Spreading OFDMA transmit signal $x(t)$ with pulse shaping is defined as follows:

$$PAPR = \frac{\max_{0 \le t \le N\tilde{T}} |x(t)|^2}{\frac{1}{N\tilde{T}}\int_0^{N\tilde{T}} |x(t)|^2} = \frac{\text{peak power of } x(t)}{\text{average power of } x(t)} \quad \textbf{(3)}$$

Without pulse shaping we mainly refer to the use of the rectangular pulse shaping where the symbol rate sampling gives the same PAPR as the continuous case due to the fact that the DFT-Spreading OFDMA signal is modulated over a single carrier[5].Therefore, by using symbol rate sampling, the PAPR reduction without pulse shaping is expressed as follows:

$$PAPR = \frac{\max_{n=0,1,...,N-1} |\tilde{x}_n|^2}{\frac{1}{N}\sum_{n=0}^{N-1}|\tilde{x}_n|^2} \quad \textbf{(4)}$$

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It has been shown in [17] and [44] that, the analytical time domain symbols of IFDMA is $\tilde{x}_m = \frac{1}{S}.x_m$ **(5),** whereas the analytical time domain symbols of LFDMA is $\tilde{x}_m = \frac{1}{S}\left(1-e^{j2\pi\frac{q}{S}}\right).\frac{1}{M}\sum_{p=0}^{M-1}\frac{x_p}{1-e^{j2\pi\left\{\frac{(n-p)}{M}+\frac{q}{SM}\right\}}}$ **(6)** for

$m = S.n+q,\ 0 \le n \le N-1\ and\ 0 \le q \le S-1$

It has been also shown that from **(6)**, the LFDMA signal in the time domain, has exact copies of input time symbols in N-multiple sample positions. In-between values are sum of all the time input symbols in the input block with different complex-weighting, which would increase the PAPR. In fact, the time-domain LFDMA signal becomes the 1/S-scaled copies of the input sequence at the multiples of S in the time domain. On the other hand, the resulting time symbols of $\{\tilde{x}_m\}$ in IFDMA subcarrier mapping mode, becomes just a repetition of the original input symbols $\{x_n\}$ in the time domain as shown in Fig.5.

The next section examines the PAPR performance of transmit symbols for each block in the IFDMA and LDFMA with pulse shaping and without pulse shaping numerically. Through simulations, we analyse the PAPR reduction performance of DFT-spreading OFDMA technique with IFDMA and LFDMA with different values of the roll-off factor $(0 \le \alpha \le 1)$ of the RC filter. We also analyse the performance of the DFT-S OFDMA technique for PAPR reduction as the number of subcarriers allocated to each user varies(i.e No. of subcarriers allocated to each user=*M*).

V. SIMULATION RESULTS

This section presents the simulation results of the DFTS-OFDMA technique for PAPR reduction. The CCDFs of PAPR for LFDMA and IFDMA are evaluated and compared through simulations. We analyse the PAPR reduction performance of DFT-spreading OFDMA technique with IFDMA and LFDMA with different values of the roll-off factor $(0 \le \alpha \le 1)$ of the RC filter with pulse shaping and without pulse shaping after the IFFT operation. Simulation parameters used are as follows: 100000 OFDM blocks for iteration were used in order to generate the CCDF of the PAPR.128 subcarriers were considered where the input data block size *M* was 32 and the spreading factor *S* was 4.The 8 times oversampling factor for pulse shaping with the RC $(0 \le \alpha \le 1)$ was used whereas the symbol constellation considered were QPSK and 16-QAM.

Fig.6 shows the CCDF and PAPR performance of IFDMA and LFDMA spreading techniques with *N*=256 and QPSK symbol constellations.Simulation results shows that with no pulse shaping,both IFDMA and LFDMA performs poor because of considerable high PAPR.However,with pulse shaping,the IFDMA performs better with significant PAPR reduction as the value of the RC increases.It is clear from Fig.6 that,the 10^{-4} PAPR of IFDMA is 2.27 dB,while PAPR of LFDMA is 8.71dB indicating high PAPR.

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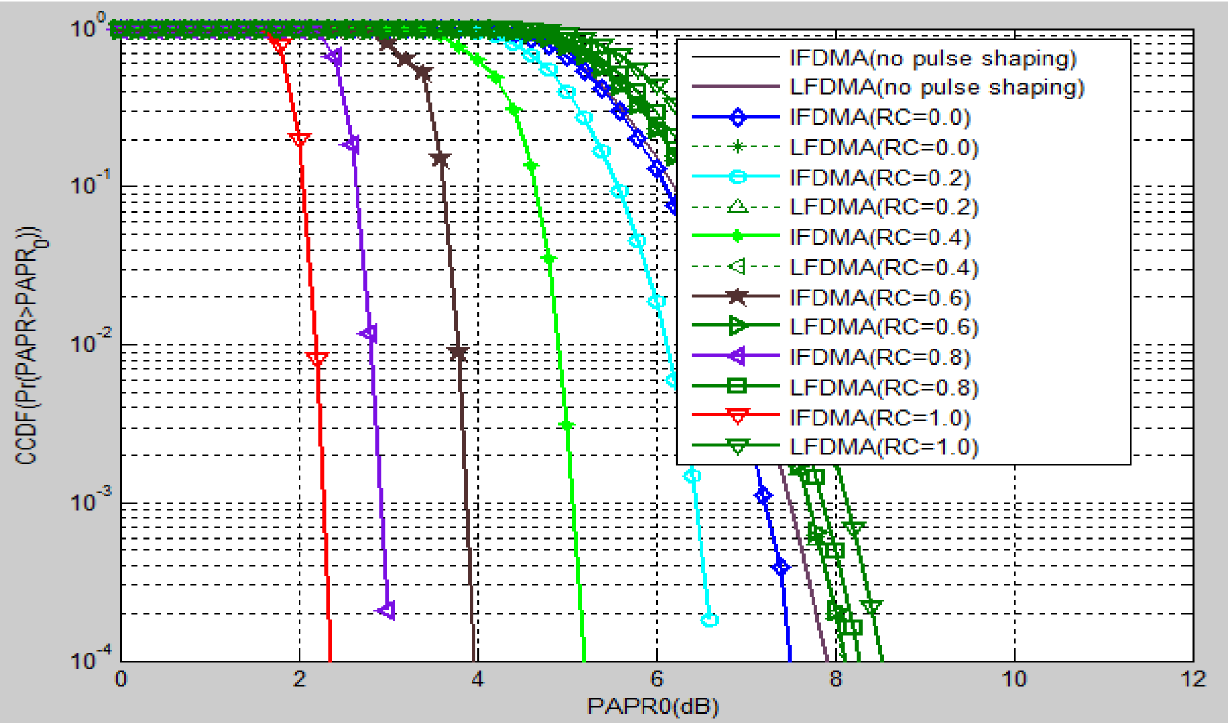

Fig.6: The Performance of IFDMA and LFDMA by using pulse shaping and without pulse shaping with QPSK,N=128 and $\textit{Raised}\ \text{Cosine(RC)}, \alpha = 0.0, 0.2, 0.4, 0.6, 0.8 \text{ and } 1.0$

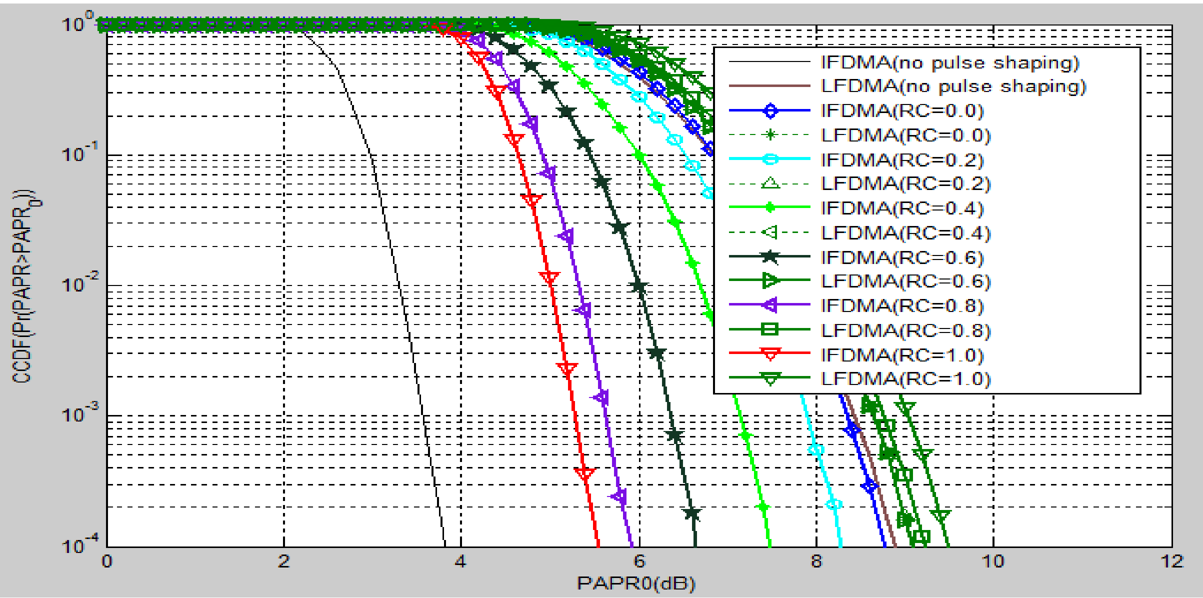

Fig.7:The Performance of IFDMA and LFDMA by using pulse shaping and without pulse shaping with 16-QAM,N=128, and $\textit{Raised}\ \text{Cosine(RC)}, \alpha = 0.0, 0.2, 0.4, 0.6, 0.8 \text{ and } 1.0$

Fig .7 shows the CCDF and PAPR performance of IFDMA and LFDMA spreading techniques with *N*=256 and 16-QAM symbol constellations. Simulation results shows that with no pulse shaping,the IFDMA performs better with 10^{-4} PAPR of 3.87dB indicating a low PAPR.This also indicates that,the IFDMA is not affected by pulse shaping

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International Journal of Innovative Research in Computer and Communication Engineering

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using the RC factor.However, with pulse shaping,the performance of IFDMA is better compared to LFDMA with 10^{-4} PAPR of 5.51dB while that of LFDMA is 9.51dB.It can be concluded that, IFDMA improves PAPR performance significantly than LFDMA with shaping and wihout shaping but at a cost of increased bandwidth.Another observation is that,the pulse shaping increases also the PAPR(Fig.7).

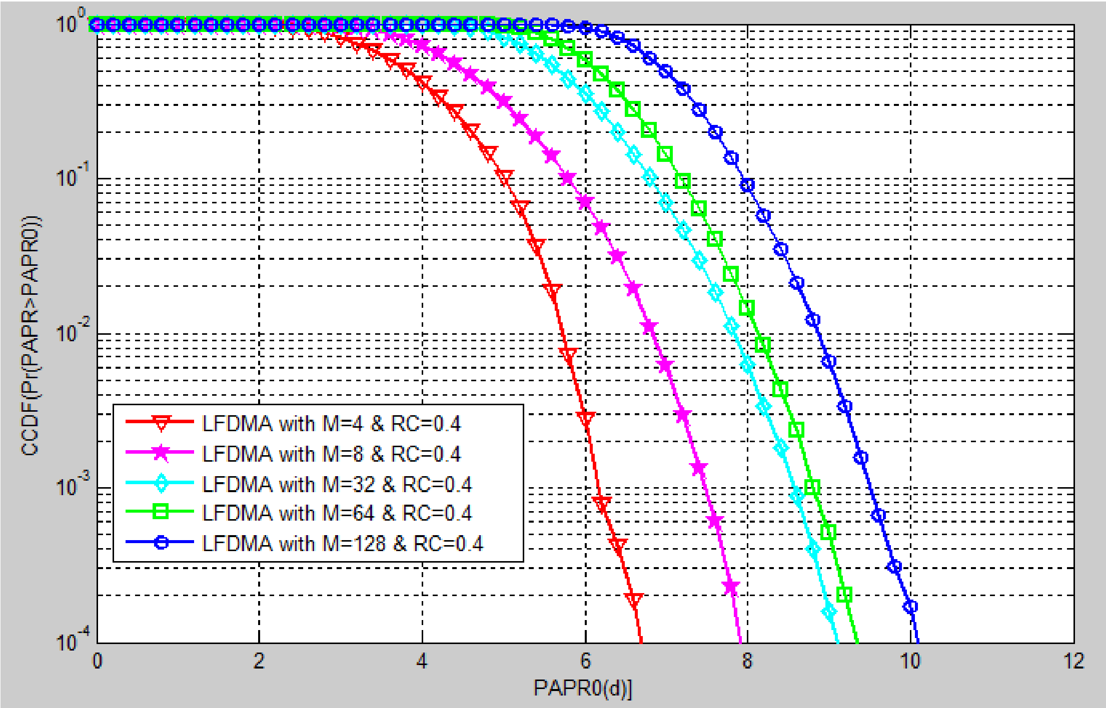

Fig.8: Performance of the DFT-S OFDMA technique for PAPR reduction as the number of subcarriers allocated to users varies (N=128, 64-QAM and $Raised\ \text{Cosine(RC)} = 0.4$).

Fig.8 shows the performance of the DFT-Spreading OFDM technique when the number of subcarriers allocated to users varies. The simulation results show that, the performance of DFT-Spreading with LFDMA improves when the number of subcarriers allocated to users becomes small. It is evident that, the 10^{-4} PAPR of LFDMA is 6.82dB when *M*=4 and 10.1Db when *M*=128.It is shown that, though, in-terms of PAPR power efficiency the IFDMA performs better than LFDMA allocation scheme, but LFDMA is very superior in terms of throughput when channel dependent scheduling is utilized and has been widely implemented in LTE. IFDMA is not preferred in practical implementation because it needs the use of additional resources such as pilots and guard band in allocating subcarriers to users [8].

VI. Conclusion and Future Work

The DFTS-OFDMA has been adopted by the 3GPP-LTE to be used in the uplink air interface for the next generation cellular systems due to its attractive feature of lower PAPR. The DFTS-OFDMA is regarded to be a good solution of single carrier based uplink multi-access scheme. In fact, it is the modified form of OFDMA where users are allowed to transmit their data through multiple subcarriers (frequencies) such that any two users are allocated non-overlapping sets of subcarriers.

In this paper, we have analysed the performance of DFTS-OFDMA technique in PAPR reduction by using the IFDMA and LFDMA subcarriers mapping modes. We also showed the performance of the DFTS-OFDMA technique for PAPR reduction as the number of subcarriers allocated to each user varies specifically, using the LFDMA subcarriers mapping mode. Simulations results shows that, the IFDMA improves PAPR performance significantly than LFDMA with pulse shaping and wihout pulse shaping but at a cost of increased bandwidth.Moreover, the performance of DFT-

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International Journal of Innovative Research in Computer and Communication Engineering

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Spreading with LFDMA improves when the number of subcarriers allocated to users becomes small. Although, in-terms of PAPR power efficiency the IFDMA performs better than LFDMA allocation scheme, but LFDMA is very superior in terms of throughput when channel dependent scheduling is utilized and has been widely implemented in LTE[13]. In general, the IFDMA subcarrier mapping mode has a considerable performance than LFDMA in terms of PAPR reduction. In the future, we will extend this work by comparing the performance of DFTS-OFDMA and that of the classical OFDMA through extensive simulations. We will also work on our recent papers [14][15] and extend our work regarding to PAPR reduction techniques used in OFDM systems for wireless communications.

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