International Congress on Telecommunication and Application'14
University of A.MIRA Bejaia, Algeria, 23-24 APRIL 2014

PAPR Comparison of OFDMA, LFDMA and IFDMA for LTE Wireless Transmission

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Abstract— **LTE 3GPP has adopted Orthogonal Frequency Division Multiplexing (OFDM) for the downlink transmission. OFDM meets the LTE requirement for spectrum flexibility and anables cost efficient solutions for very wide carriers with peak to average power ratio (PAPR) of the transmitting signals has limited its application. This high PAPR causes interference when the OFDM signals are passed through an amplifier which does not have enough linear range. In this paper we investigate a DFT spreading PAPR reduction for Interleaved SC-FDMA (IFDMA) and Localized SC-FDMA (LFDMA) compared with OFDMA without DFT-spreading. Simulation results show that OFDMA exhibits a higher PAPR compared to SC-FDMA (LFDMA and IFDMA). This low PAPR makes the SC-FDMA the preferred technology for the LTE uplink transmission.**

Index Terms: OFDMA, SC FDMA, LFDMA, IFDMA, PAPR, LTE

I. Introduction

Orthogonal frequency division multiple access (OFDMA) has undeniably become one of the main references in modern communications systems. Almost all recent communication standards rely on an OFDMA downlink air interface and implement multiple- input multiple-output (MIMO) techniques [1]. Such is the case in IEEE 802.11n for wireless local area networks, IEEE 802.16e-2005 for mobile WiMAX, Long-Term Evolution (LTE) of Universal Mobile Telecommunications System, and also in the future LTE-advanced standard.

The general acceptance of OFDMA as a good option for the downlink of recent communications systems is motivated by its well-known advantages: good spectral efficiency, good coverage, flexible dynamic frequency allocation and simple equalization at tone level [2]. Even though OFDMA is widely employed in the downlink, its use in the uplink is hampered by the high peak-to average power ratio (PAPR). The PAPR problem, common for all MC transmission schemes, induces numerous performance issues such as reduced power efficiency, spectral regrowth and in-band distortion when using nonlinear high power amplifiers (HP

Many efforts were directed to efficiently alleviating the PAPR problem [3-6], but because of either some standard-compatibility issues or some practical system limitations the problem is not yet considered as completely solved [7].

While the PAPR problem, inevitable in the downlink, can be coped with by using highly linear (and thus expensive) HPAs for example, this is a much more sensitive issue in the uplink. Mobile users strive for good coverage and good autonomy handsets, but do not neglect the associated costs. On one hand, backing-off the uplink signal level to the linear region of the HPA would reduce the coverage. On the other hand, using highly linear HPAs would increase the handset cost.

SC-FDMA is a combination of single carrier modulation, orthogonal frequency multiplexing and frequency domain equalization (FDE) [8]. SC-FDMA also provides the multipath resistance and flexible sub-carrier frequency allocation offered by OFDMA. SC-FDMA commonly exploits one of three subcarrier mapping schemes: Distributed FDMA (DFDMA), Localized FDMA (LFDMA) or Interleaved FDMA (IFDMA).

This paper presents a PAPR analysis of the DFT Spreading of Interleaved SC FDMA (IFDMA) and Localized SC FDMA (LFDMA) compared with OFDMA without DFT-spreading. This paper is organized as follows: Section II describes the SC-FDMA system; in section III we present the subcarrier mapping LFDMA and DFDMA. Section IV presents the computer simulation results and section V concludes the paper.

II. SC-FDMA

SC-FDMA is a new multiple access technique that utilizes single carrier modulation, DFT spread orthogonal frequency multiplexing, and frequency domain equalization. It has a similar structure and performance as OFDM. Transmitter and receiver structure for SC-FDMA is given in Fig 1. It is evident from the figure that SC-FDMA transceiver has similar structure as a typical OFDM system except the addition of a new DFT block before subcarrier mapping. Hence, SC-FDMA can be considered as an OFDM system with a DFT mapper. After mapping data bits into modulation symbols, the transmitter groups the modulation symbols into a block of N symbols. An N-point DFT transforms these symbols in time domain into frequency domain. The frequency domain samples are then mapped to a subset of M subcarriers. Similar to OFDM, an M-point IFFT is used to generate the time-domain samples of these subcarriers, which is followed by cyclic prefix, parallel to serial converter, DAC and RF subsystems.

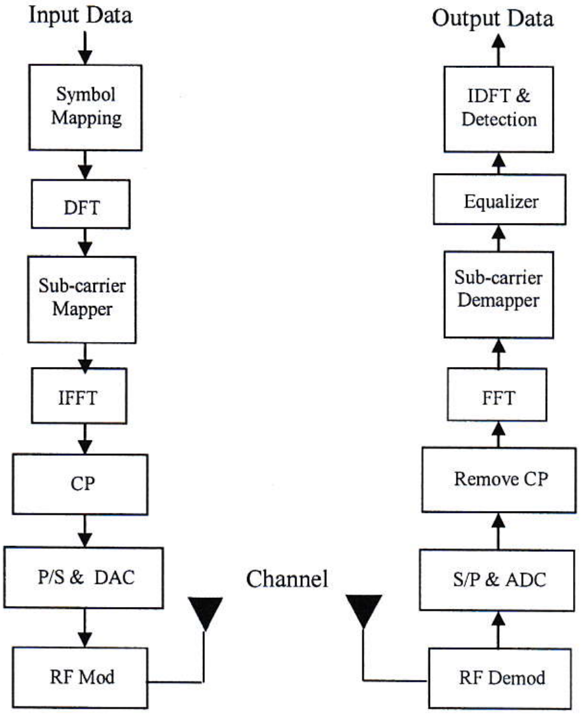

Fig. 1. Transmitter and receiver structure of SC-FDMA.

III. SUBCARRIER ALLOCATION

In OFDMA systems, subcarriers are partitioned and assigned to multiple mobile terminals (users). Unlike the downlink transmission, each terminal in uplink uses a subset of subcarriers to transmit own data. The rest of subcarriers, not used for its own data transmission, will be filled with zeros. Here it will be assumed that the number of subcarriers allocated to each user is M. In the DFT spreading technique, M-point DFT is used for spreading, and the output of DFT is assigned to the subcarriers of IFFT.

There are two different approaches of assigning subcarriers among users DFDMA (Distributed FDMA) and LFDMA (Localized FDMA)

A. Distributed SC FDMA (DFDMA)

DFDMA distributes M DFT outputs over the entire band (of total N subcarriers) with zeros filled in (N-M) unused subcarriers. When DFDMA distributes DFT outputs with equi-distance N/M=S, it is referred to as IFDMA (Interleaved FDMA) where S is called the bandwidth spreading factor.

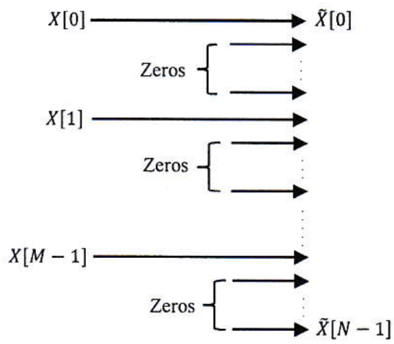

Fig. 2. IFDMA.

The input data $x[m]$ is DFT spread to generate $X[i]$ and then allocated as

$$\tilde{X}[k] = \begin{cases} X[k/S], & k = S.m_1,\ m_1 = 0,1,2,\dots,M-1 \\ 0, & otherwise \end{cases} \quad (1)$$

The IFFT output sequence $\tilde{x}[n]$ with $n = M.s + m$ for $s = 0,1,2,\dots,S-1$ and $m = 0,1,2,\dots,M-1$ can be expressed as

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

$$= \frac{1}{S}\cdot\frac{1}{M}\sum_{m_1=0}^{M-1} X[m_1] e^{j2\pi \frac{n}{M} m_1}$$

$$= \frac{1}{S}\cdot x[m] \quad (2)$$

Which turns out to be a repetition of the original input signal $x[m]$ scaled by $1/S$ in the time domain [9].

In the IFDMA where the subcarrier mapping starts with the r[th] subcarrier $(r = 0,1,2,\dots,S-1)$, the DFT spread can be expressed as

$$\tilde{X}[k] = \begin{cases} X[(k-r)/S], k = S.m_1 + r, m_1 = 0,1,2,\dots,M-1 \\ 0, \qquad otherwise \end{cases} \tag{3}$$

Then, the corresponding IFFT output sequence $\tilde{x}[n]$ is given by

$$\begin{aligned}\tilde{x}[n] = \tilde{x}[Ms+m] &= \frac{1}{N}\sum_{k=0}^{N-1}\tilde{X}[k]e^{j2\pi\frac{n}{N}k} \\ &= \frac{1}{S}.\left(\frac{1}{M}\sum_{m_1=0}^{M-1}X[m_1]\,e^{j2\pi\frac{m}{M}m_1}\right).e^{j2\pi\frac{n}{N}r} \\ &= \frac{1}{S}e^{j2\pi\frac{n}{N}r}.x[m]\end{aligned} \tag{4}$$

We can see that the frequency shift of subcarrier allocation starting point by r subcarriers results in the phase rotation of $e^{j2\pi\frac{n}{N}r}$ in IFDMA.

B. Localized SC FDMA (LFDMA)

LFDMA allocates DFT outputs to M consecutive subcarriers in N subcarriers.

In the DFT-spreading scheme for LFDMA, the IFFT input signal $\tilde{X}[k]$ at the transmitter can be expressed as

$$\tilde{X}[k] = \begin{cases} X[k], & k = 0,1,2,\dots,M-1 \\ 0, & k = M, M+1,\dots,N-1 \end{cases} \tag{5}$$

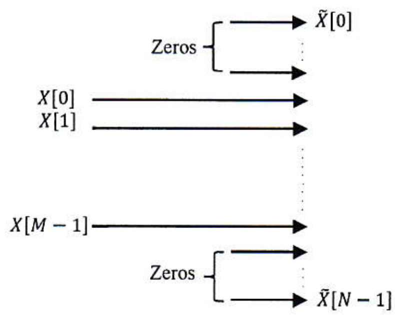

Fig. 3. LFDMA.

The IFFT output sequence $\tilde{x}[n]$ with $n = S.m + s$ for $s = 0,1,2,\dots,S-1$ can be expressed as follows [9]:

$$\begin{aligned}\tilde{x}[n] = \tilde{x}[Sm+s] &= \frac{1}{N}\sum_{k=0}^{N-1}\tilde{X}[k]e^{j2\pi\frac{n}{N}k} \\ &= \frac{1}{S}.\frac{1}{M}\sum_{k=0}^{M-1}X[k]\,e^{j2\pi\frac{Sm+s}{SM}k}\end{aligned} \tag{6}$$

For $s = 0$

$$\tilde{x}[n] = \tilde{x}[Sm] = \frac{1}{S}.\frac{1}{M}\sum_{k=0}^{M-1}X[k]\,e^{j2\pi\frac{m}{M}k} = \frac{1}{S}.x[m] \tag{7}$$

It can be seen that the time domain LFDMA signal becomes the $1/S$ scaled copies of the input sequence.

IV. SIMULATION AND RESULTS

The PAPR of LFDMA and IFDMA signals using DFT-spreading compared with OFDMA without DFT-spreading are presented in this section. The number of subcarriers N=256 and the number of subcarriers allocated to each user is M=64. In order to mesure the PAPR of transmission block, the complementary cumulative distribution function (CCDF) is used:

$$CCDF = \Pr(PAPR > PAPR_0) \tag{8}$$

$PAPR_0$ represents a PAPR threshold.

The PAPR is compared against the above threshold to determine how often it is exceeded. We then plot the Complementary Cumulative Density Function (CCDF) against the $PAPR_0$ threshold.

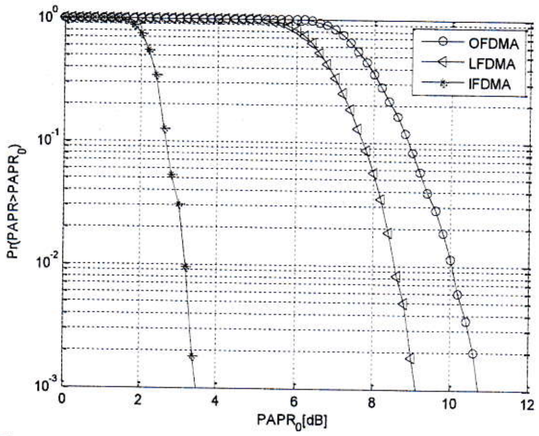

Fig. 4. PAPR comparison of LFDMA, IFDMA and OFDMA with 8PSK.

Fig 4 show the CCDF of the PAPR for OFDMA and SC FDMA with different subcarrier mapping schemes using 8PSK modulation. LFDMA and IFDMA exhibit a lower PAPR compared to OFDMA, they provide approximately 1.6 dB and 7.8 dB improvement over OFDMA.

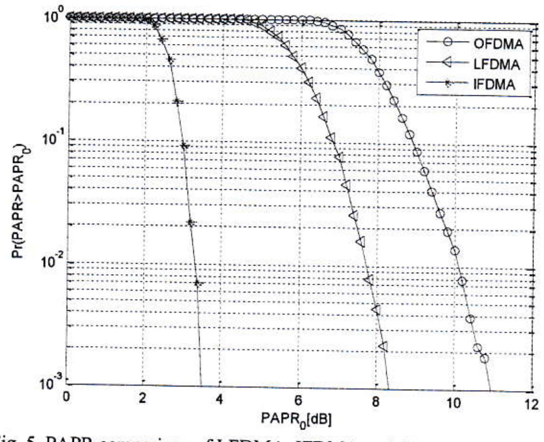

Fig. 5. PAPR comparison of LFDMA, IFDMA and OFDMA with 16QAM.

The CCDF of the PAPR for OFDMA and SC FDMA with different subcarrier mapping schemes using 16QAM modulation is shown in Fig 5. It can be seen that OFDM exhibits a higher PAPR compared to LFDMA and IFDMA.

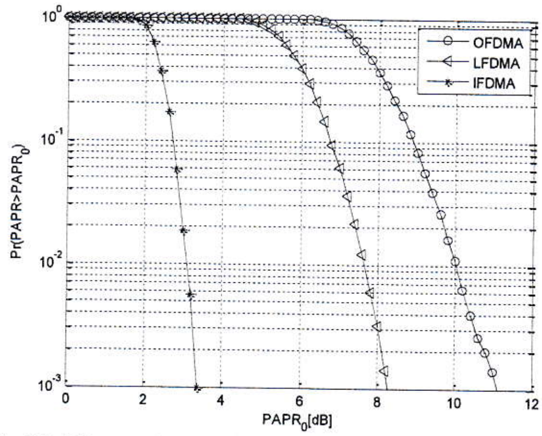

Fig. 6. PAPR comparison of LFDMA, IFDMA and OFDMA with 32QAM.

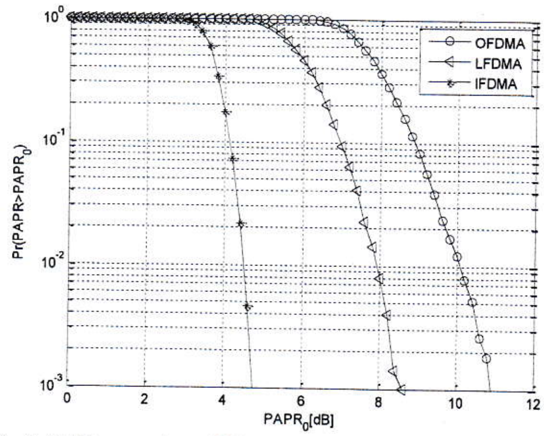

Fig. 7. PAPR comparison of LFDMA, IFDMA and OFDMA with 64QAM.

The CCDF of the PAPR for OFDMA and SC-FDMA with different subcarrier mapping schemes using 32 QAM and 64 QAM modulations is shown in Fig 6 and Fig 7. It can be seen that the PAPR performance of the DFT-spreading technique varies depending on the subcarrier allocation method. In the case of 64 QAM, the values of PAPRs with IFDMA, LFDMA and OFDMA of 10^{-3} are 4.8dB, 8,6dB and 10.8dB respectively. It implies that the PAPRs of IFDMA and LFDMA are lower by 6dB and 3.2dB respectively than that of OFDMA with no DFT spreading.

V. CONCLUSION

The SC FDMA system with Interleaved-FDMA or Localized-FDMA performs better than Orthogonal-FDMA in the uplink transmission where transmitter power efficiency is of great importance in the uplink. LFDMA and IFDMA result in lower average power values due to the fact that OFDM and OFDMA map their input bits straight to frequency symbols where LFDMA and IFDMA map their input bits to time symbols. Although the IFDMA has a lower PAPR than LFDMA, the LFDMA is usually preferred for implementation. It is attributed to the fact that subcarriers allocation with equi-distance over the entire band (IFDMA) is not easy to implement, since IFDMA requires additional resources such as guard band and pilots.

ACKNOWLEDGMENTS

In the Name of ALLAH, the Most Beneficent, the Most Merciful. All gratitude is due to ALLAH, who made this success possible and affordable. No words can ever express our thanks to every person who contributed to the fulfillment of this work.

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