

# Comparison of PAPR Analysis for OFDMA and SC-FDMA in LTE Systems

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**Abstract** – Single carrier frequency division multiple access (SCFDMA), a modified form of Orthogonal FDMA (OFDMA), is a promising technique for high data rate uplink communications in future cellular systems. In order to support high data rate and avoid the high Peak-to-Average Power Ratio (PAPR), Single Carrier Frequency Division Multiple Access (SC-FDMA) is used in the LTE cellular systems. SCFDMA is currently a strong candidate for the uplink multiple access scheme in the Long Term Evolution of cellular systems under consideration by the Third Generation Partnership Project (3GPP). Among the possible subcarrier mapping approaches, we find that localized FDMA (LFDMA) with channel-dependent scheduling (CDS) results in higher throughput than interleaved FDMA (IFDMA). However, the PAPR performance of IFDMA is better than that of LFDMA. Additionally results from a PAPR analysis, comparing OFDMA and SC-FDMA using different subcarrier mapping schemes, are presented. Finally the paper proposed a technique for good transmission performance with low PAPR.

**Keywords** – SC-FDMA, PAPR, LFDMA, CDS, IFDMA, OFDMA, LTE.

## I. INTRODUCTION

Over the past fifteen years, the bit rates achieved in cellular and local area wireless communication systems have increased steadily. The demands on mobile communication networks have ever been higher[1]. The introduction of smart phones, almost constant access to wireless networks for laptops and an increase of mobile broadband for laptops have had a major impact on our habit of having constant access to the Internet. The highest bit rates in commercially deployed wireless systems are achieved by means of Orthogonal Frequency Division Multiplexing (OFDM) in wireless LANs. The next advance in cellular systems, under investigation by the Third Generation Partnership Project (3GPP), also anticipates the adoption of OFDMA to achieve higher bit rates. The problem with OFDMA in cellular uplink transmissions derives from the inevitable offset in frequency references among the different terminals that transmit simultaneously.

In cellular applications, a big advantage of OFDMA is its robustness in the presence of multipath signal propagation[2]. The immunity to multipath derives from the fact that an OFDMA system transmits information on orthogonal frequency carriers, each operating at  $1/M$  times the bit rate of the information signal. Signals with a high PAPR require highly linear power amplifiers to avoid excessive intermodulation distortion. To achieve

this linearity, the amplifiers have to operate with a large backoff from their peak power[3]. The result is low power efficiency.

The 3rd Generation Partnership Program (3GPP) leads the specification of the next radio access technology, known as Long-Term Evolution (LTE). LTE is not required to be compatible with old technologies[5]. LTE is continuously being developed to make sure that future requirements and scenarios are being met and prepared for in the best way. One of the requirements of LTE is that it should provide downlink peak rates of at least 100Mbps. LTE supports flexible carrier bandwidths, from 1.4MHz up to 20MHz. LTE also supports both frequency division duplex (FDD) and time division duplex (TDD). So far, a large number of bands have been identified by 3GPP for LTE, and there are more bands to come.

Networks for mobile communication are typically divided into a Radio Access Network (RAN) and a Core Network. The RAN handles functionality related to the physical and link layers such as coding, interleaving, modulation, header compression etc. The core network handles for example subscriber information, data policy control and interconnection to external networks[4]. The design targets of LTE is to provide a peak data rate of at least 100 Mbps in the downlink and 50 Mbps in the uplink when operating in a bandwidth of 20 MHz. This could also be specified as 5 bit/s/Hz and 2.5 bit/s/Hz respectively. Additionally, LTE should support both Frequency and Time-Division-Duplex (FDD, TDD), meaning that in FDD different frequency bands are used for the downlink and uplink while in TDD downlink and uplink transmissions use the same frequency band but are done in separate time slots. [2]. To fulfill all the requirements LTE uses a transmission scheme called Orthogonal Frequency Division Multiplexing (OFDM) for the downlink and SC-FDMA for the uplink. SC-FDMA will be described in more detail in the following sections.

## II. SYSTEM MODEL

While PAPR is a major concern in portable terminals, information throughput is an even more important indicator of system performance. As in OFDMA, throughput in SC-FDMA depends on the way in which information symbols are applied to subcarriers[7]. There are two approaches to apportioning subcarriers among terminals. In localized SC-FDMA (LFDMA), each terminal uses a set of adjacent subcarriers to transmit its symbols. Thus the bandwidth of an LFDMA transmission

is confined to a fraction of the system bandwidth. The alternative to LFDMA is distributed SC-FDMA in which the subcarriers used by a terminal are spread over the entire signal band. One realization of distributed SC-FDMA is interleaved FDMA (IFDMA) where occupied subcarriers are equidistant from each other [6].

The high data rates of the LTE standard does not only need wider bandwidth but also a more advanced modulation technique. While Orthogonal Frequency Division Multiplexing (OFDM) is considered to be the optimum modulation technique to fulfill the downlink transmission requirement, the high Peak-to-Average Power Ratio (PAPR) property of OFDM makes it less favorable for the uplink transmission [8]. Instead, the Single-Carrier FDMA technique is used. This technique is also known as DFT-Spread OFDM (DFTS-OFDM) where DFT is an acronym for Discrete Fourier Transform.

The SC-FDM modulation is quite similar to the OFDM except that before the Inverse DFT (IDFT) in transmission side of OFDM, an extra DFT processing is added in the DFTS-OFDM and vice versa after the DFT in OFDM receiver side. The extended transformations make the information of each information bit spread over all the subcarriers, which results in significantly smaller variations in the instantaneous power of the transmitted signal, which is usually enjoyed by 'single carrier' transmission schemes. The similarities with these techniques are the reason for the name of SC-FDMA [10]. Fig. 1 displays a comparison between OFDM and SC-FDMA and shows how each symbol is spread to multiple subcarriers instead of being transmitted over one subcarrier.

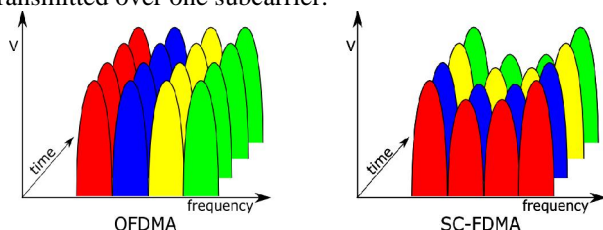


Fig.1. Comparison between OFDMA and SC-FDMA

### III. SYSTEM CONFIGURATION OF SINGLE CARRIER FDMA

An alternative approach was sought known as Single Carrier Frequency Division Multiple Access (SCFDMA). As in OFDMA, the transmitters in an SCFDMA system use different orthogonal frequencies (subcarriers) to transmit information symbols [16]. However, they transmit the subcarriers sequentially, rather than in parallel. This reduces envelope fluctuation relative to OFDMA. So SCFDMA has inherently low PAPR than OFDMA. But now it has the problem of ISI. It can be removed by adaptive channel equalization algorithms in the frequency domain [17]. Time domain equalization is very complex because of long channel impulse response in time domain and large tap size of filters. But using Discrete Fourier Transform (DFT) in frequency domain is much easier because DFT size doesn't increase linearly with channel response.

At the input to the transmitter, a baseband modulator transforms the binary input to a multilevel sequence of complex numbers  $x_n$  in one of several possible modulation formats including quaternary PSK (QPSK), 16-level quadrature amplitude modulation (16-QAM) and 64-QAM etc. Then serial bit stream is converted to parallel bit stream of  $N$  data points [9]. The first step is to produce a frequency representation  $X_k$  of the input symbols. It then maps each of the  $N$  DFT outputs to one of the  $M$  ( $>N$ ) orthogonal subcarriers that can be transmitted, where  $M=N*Q$ ,  $Q$  is the bandwidth expansion factor of symbol sequence [11].

In **Localized FDMA** each terminal uses a set of adjacent subcarriers to transmit its symbols. Thus the bandwidth of an LFDMA transmission is confined to a fraction of the system bandwidth.

In **Interleaved FDMA** the subcarriers used by a terminal are spread over the entire signal band.

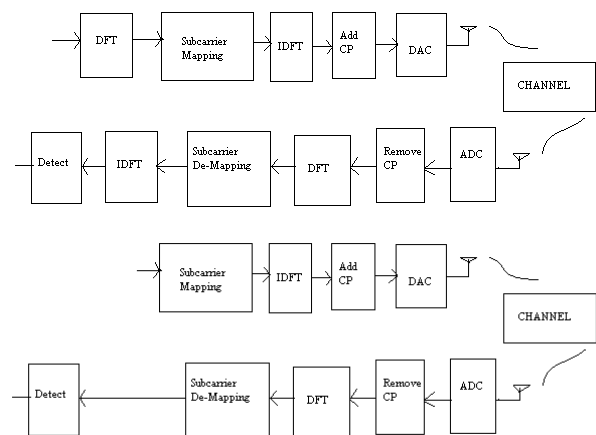


Fig.2. Transmitter and receiver structure of SC-FDMA and OFDMA systems

CP-Cyclic Prefix, ADC-Analog to Digital Converter, DAC-Digital to Analog Converter

### IV. MATHEMATICAL CALCULATION FOR PAPR

Let the data block of length be represented by a vector  $X=[X_0, X_1, \dots, X_{N-1}]^T$ . Duration of any symbol  $X_k$  in the set  $X$  is  $T$  and represents one of the sub-carriers set [12]. As the  $N$  sub-carriers chosen to transmit the signal are orthogonal, so we can have  $f_n = n f$ , where  $n f = 1/NT$  and  $NT$  is the duration of the OFDM data block  $X$ . The complex data block for the OFDM signal to be transmitted is given by

$$X(t) = \frac{1}{N} \sum_{n=0}^{N-1} x_n e^{j2\pi n f t}, 0 \leq t < NT \dots \dots (1)$$

The PAPR of the transmitted signal is defined as,

$$PAPR = \frac{\max_t |X(t)|^2}{\frac{1}{NT} \int_0^{NT} |X(t)|^2 dt} \dots \dots \dots (2)$$

The cumulative distribution function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency of any PAPR technique. Normally, the complementary CDF (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold [18].

The CDF of the PAPR of the amplitude of a signal sample is given by

$$F(z) = 1 - \exp(-z) \dots\dots\dots(3)$$

The CCDF of the PAPR of the data block is desired in our case is to compare outputs of various reduction techniques. This is given by:

$$P \dots\dots\dots(4)$$

$$\dots\dots\dots(5)$$

In this section, we analyze the PAPR of the SC-FDMA signal. We use the notation in Figure 3 and assume that the total number of subcarriers is  $M = Q \cdot N$ , where  $N$  is the number of subcarriers per block [15]. The integer  $Q$  is the maximum number of terminals that can transmit simultaneously. The PAPR is defined as the ratio of peak power to average power of the transmitted signal in a given transmission block [13]. Without pulse shaping, that is, using rectangular pulse shaping, symbol rate sampling will give the same PAPR as the continuous time domain case since an SC-FDMA signal is modulated over a single carrier [14]. To evaluate PAPR of individual system configurations, we have simulated the transmission of 105 blocks of symbols. After calculating PAPR for each block, we present the data as an empirical CCDF. The CCDF is the probability that PAPR is higher than a certain PAPR value  $P_{APR}$  ( $\Pr\{PAPR > P_{APR0}\}$ ). Our simulations apply to 256 subcarriers in a transmission bandwidth of 5 MHz.

## V. SIMULATION RESULTS

There are some important simulation parameters used for the analysis of PAPR in SC-OFDMA as shown in Table.1. In Figure 3 we present the comparison between PAPR of SC-FDMA (IFDMA and LFDMA) and OFDMA systems with cosine pulse shaping using QPSK. In Figure 4 we present the comparison for the same without pulse shaping using QPSK.

Table.1. Simulation Parameters

Parameters	Values
Data block size(N)	16
M/N	32
Transmission Bandwidth	5MHz
Oversampling Factor	4
Number of runs	10
Guard band interval	64
Sub channels	256
Number of iteration	500

After comparing the figures it could be easily seen that indeed OFDMA signals have much higher PAPR than SC-FDMA signals. When considering systems without pulse shaping the LFDMA has lower PAPR than OFDMA by about 2.5dB for QPSK.

The biggest differences were revealed between OFDMA and IFDMA and they are more than 10dB when using QPSK. But it has to be said that these values were achieved in systems without pulse shaping, which makes them more theoretical than practically usable.

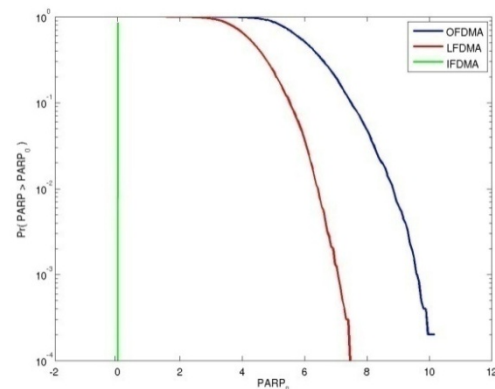


Fig.3. PAPR analysis comparison OFDMA, LFDMA and IFDMA with cosine pulse shaping using Q-PSK

After observing the results several conclusions could be drawn. First of all, after applying raised-cosine pulse shaping PAPR values for both IFDMA and LFDMA decreased. Moreover pulse shaping seems to be more harmful for IFDMA PAPR values than for LFDMA. Comparing PAPR values for IFDMA using Q-PSK between Fig.3 (with pulse shaping) and Fig. 4 (without pulse shaping) it could be seen that the difference between these values is about 7dB. In contrast difference for LFDMA with and without pulse shaping is much less significant and varies from 0.2dB for Q-PSK to about 0.5dB. Then Fig.5 shows the simulation plot for spectral efficiency with SNR for OFDMA system and SC-FDMA system with 2x2 and 2x4 users. In this the SC-FDMA system gives better performance than OFDMA systems.

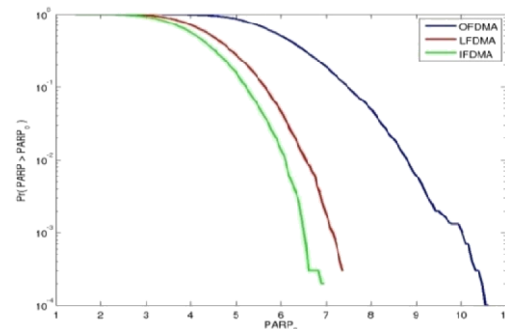


Fig.4. PAPR analysis comparison OFDMA, LFDMA and IFDMA without pulse shaping using Q-PSK

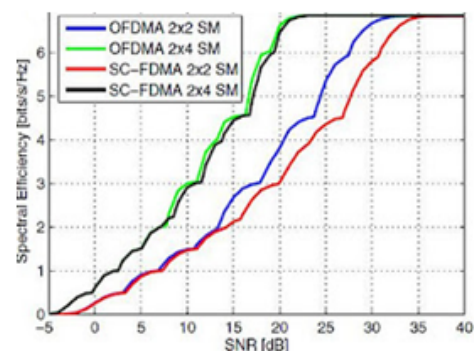


Fig.5. Spectral Efficiency Vs SNR plot

In comparison, SC-FDMA have indeed lower PAPR than OFDMA in general. Also, using raised-cosine pulse shaping is decreasing PAPR the most significant when using IFDMA frequency mapping scheme and Q-PSK modulation, which has the lowest PAPR (over 10dB difference compared to OFDMA) when no pulse shaping is used.

## VI. CONCLUSION

SC-FDMA is the new multiple access technique adopted in the LTE uplink transmission scheme. Compared with the popular OFDMA, which is used in the LTE downlink transmission and WiMAX, SC-FDMA has a better performance interms of PAPR and Frame Error Rate (FER) due to its coherent 'single-carrier' property and built-in frequency diversity. PAPR comparison between OFDM and SC-FDMA variations such as interleaved SC-FDMA and localized SC-FDMA has been done in [2]. With no pulse shaping filters, interleaved-SC-FDMA shows the best PAPR.

In this paper, we have given an overview of LTE. The advanced technology behind the uplink transmission: SC-FDMA is analyzed specifically. A comparison between the OFDMA and SC-FDMA is also done, which shows that SC-FDMA has a much lower PAPR than OFDMA. And different subcarrier mapping schemes will also result in different PAPRs. IFDMA has a slightly better performance in terms of PAPR than LFDMA.

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