COMPARISON OF PAPR ANALYSIS FOR OFDMA AND SC-FDMA IN LTE SYSTEMS

Brindha G.

Lord Jegannath College of Engineering and Technology, Anna University, Chennai, TamilNadu, India

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 tosupport high data rate and avoid the high Peak-to-AveragePower Ratio (PAPR),SingleCarrier Frequency Division Multiple Access(SC-FDMA) is usedin 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 resultsfrom a PAPR analysis, comparing OFDMA and SC-FDMA usingdifferent 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 incellular and local area wireless communicationssystems 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 bitrates in commercially deployed wireless systems areachieved by means of Orthogonal Frequency DivisionMultiplexing (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 thattransmit simultaneously.

In cellular applications, a big advantage of OFDMA is itsrobustness in the presence of multipath signal propagation[2]. The immunity to multipath derives from the factthat an OFDMA system transmits information on *M*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]. LTEis continuously being developed to make sure that future requirements and scenarios are being metand 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 bothfrequency division duplex (FDD) and time divisionduplex (TDD). So far, a large number of bands havebeen identified by 3GPP for LTE, and there are morebands to come.

Networks for mobile communication are typically dividedinto a Radio Access Network (RAN) and a Core Network.The RAN handles functionality related to the physical andlink layers such as coding, interleaving, modulation, headercompression etc. The core network handles for example subscriberInformation, data policy control and interconnectionto external networks[4]. The design targets of LTE is to provide a peak data rateof at least 100 Mbps in the downlink and 50 Mbps in theuplink when operating in a bandwidth of 20 MHz. This couldalso be specified as 5 bit/s/Hz and 2.5 bit/s/Hz respectively. Additionally, LTE should support both Frequency andTime-Division-Duplex (FDD, TDD), meaning that in FDDdifferent frequency bands are used for the downlink and uplinkwhile in TDD downlink and uplink transmissions use the samefrequency band but are done in separate time slots. [2]. To fulfill all the requirements LTE uses a transmissionscheme called Orthogonal Frequency Division Multiplexing(OFDM) for the downlink and SC-FDMA for the uplink.SC-FMDA will be described in more detail in the followingsections.

II. SYSTEM MODEL

While PAPR is a major concern in portableterminals,information throughput is an even more important indicatorof system performance. As in OFDMA, throughput inSC-FDMA depends on the way in which information symbols are applied to subcarriers[7]. There are two approaches to apportioning subcarriers among terminals. Inlocalized SC-FDMA (LFDMA), each terminal uses a set ofadjacent subcarriers to transmit its symbols. Thus thebandwidth of an LFDMA transmission is confined to afraction of the system bandwidth. The alternative to LFDMA is distributed SC-FDMA in which the subcarriersused by a terminal are spread over the entire signal band.One realization of distributed SC-FDMA is interleavedFDMA (IFDMA) where occupied subcarriers are equidistantfrom each other [6].

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

The SC-FDM modulation is quite similar to the OFDMexcept that before the Inverse DFT (IDFT) in transmissionside of OFDM, an extra DFT processing is added in theDFTS-OFDM and vice versa after the DFT in OFDM receiverside. The extended transformations make the information of eachinformation bit spread over all the subcarriers, which resultsin significantly smaller variations in the instantaneous powerof the transmitted signal, which is usually enjoyed by 'singlecarrier'transmission schemes. The similarities with thesetechniques are the reason for the name of SC-FDMA[10]. Fig. 1displays a comparison between OFDM and SC-FDMA andshows how each symbol is spread to multiple subcarriers instead of being transmitted over one subcarrier.

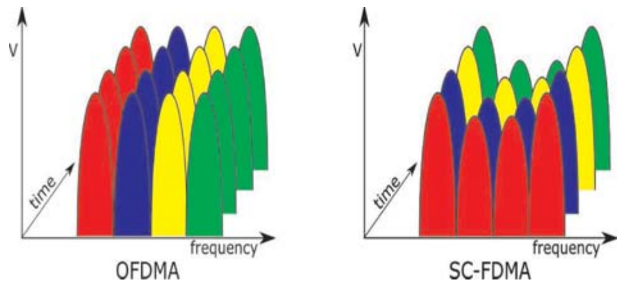

Fig. 1. Comparison between OFDMA and SC-FDMA

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 its much easier because DFT size doesnt 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 quaternaryPSK (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 Xk 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.

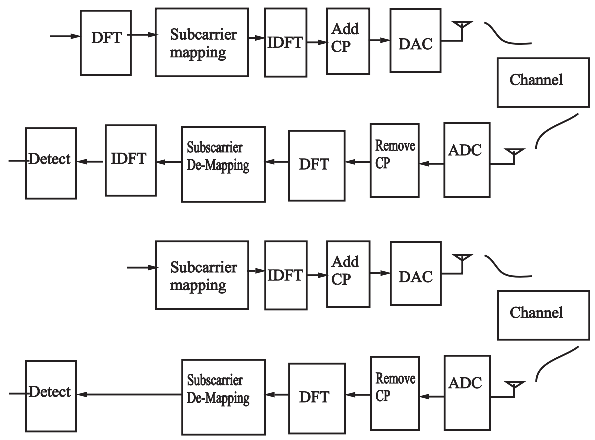

Fig. 2.Transmitter and receiver structure of SC-FDMA and OFDMA systems
CP-Cyclic Prefix,**ADC**-Analog to Digital Converter,**DAC**-Digital to Analog Converter

IV. MATHEMATICAL CALCULATION FOR PAPR

Let the data block of length be represented by a vector $X=[X_0,X_1,\ldots,X_{N-1}]T$. 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 $fn = n \Delta f$, where $n \Delta f = 1/NT$ 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

$$X(t) = \frac{1}{\sqrt{N}} \sum_{0}^{N} x_n e^{2 \pi n\, DELTa\, ft}, \; 0 \le t \le NT \qquad \ldots(1)$$

The PAPR of the transmitted signal is defined as,

$$PAPR = \frac{\max |X(t)|^2}{\frac{1}{NT} \int_0^{NT} |X(t)|^2 \, dt} \qquad \ldots(2)$$

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

$$F(z) = 1 - \exp(z) \qquad \ldots(3)$$

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:

$$P(PAPR > z) = 1 - P(PAPR \le Z) \qquad \ldots(4)$$

$$= 1 - F(z)\, N$$

$$= 1 - (1 - \exp(-z))\, N \qquad \ldots(5)$$

In this section, we analyze the PAPR of the SC-FDMA signal.We use the notation in Figure 3 and assume that thetotal number of subcarriers is $M = Q$ EN, where N is thenumber of subcarriers per block[15]. The integer Q is themaximum 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 PAPR*(*Pr{PAPR>PAPR0}*)*.Our simulations apply to 256 subcarriersin a transmission bandwidth of 5 MHz.

V. SIMULATION RESULTS

There are someimportant 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 Figure4 we present the comparison for the same without pulse shaping using QPSK.

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 2.5 dB for QPSK.

Table.1 Simulation Parameters

Parameters	Values
Data blocksize(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

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.

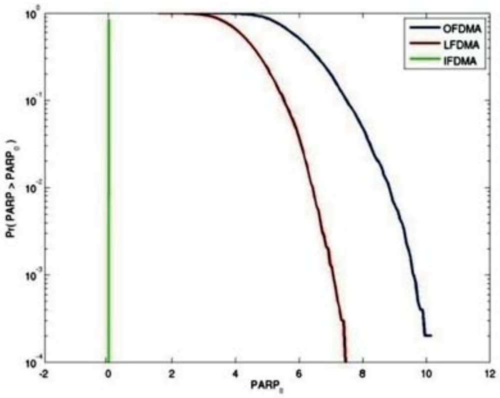

Fig. 3. PAPR analysis comparison OFDMA, LFDMA and IFDMAwith cosine pulse shaping using Q-PSK

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 Fig5.shows the simulation plot for spectral efficiency with SNR for OFDMA system and SC-FDMA system with 2×2 and 2×4 users. In this the SC-FDMA system gives better performance than OFDMA systems.

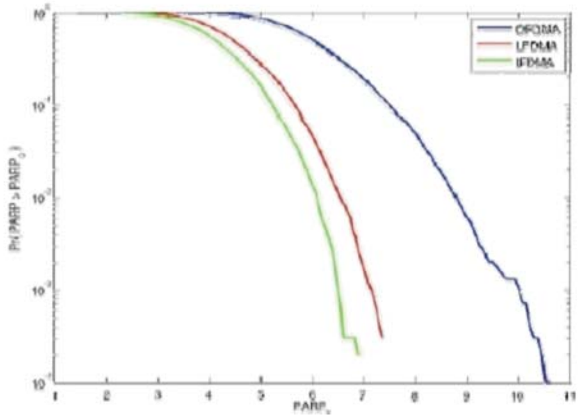

Fig. 4. PAPR analysis comparison OFDMA, LFDMA and IFDMA without pulse shaping using Q-PSK

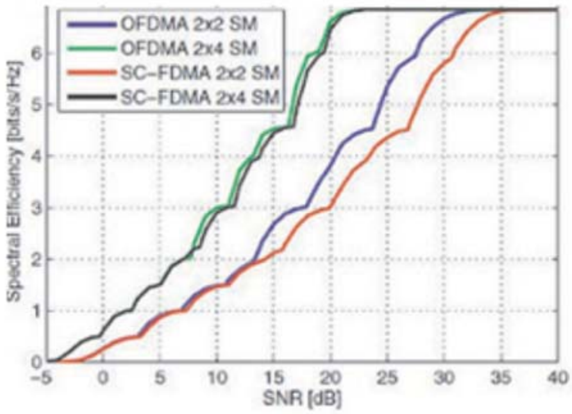

Fig. 5.Spectral Efficiency Vs SNR plot

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 hasthe 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.

REFERENCES

[1] Hikmei Sari Cristina Ciochina. 2010 A review of ofdma and single-carrier fdma and some recent results. Advances in Electronics and Telecommu-nications, 1(1),.

[2] Skold J. Beming P. Dahlman E., Parkvall.S. 2008 3G Evolution: HSPA and LTE for Mobile Broadband. Academic Press, UK, 2nd edition,.

[3] Ken Gentile. 2002 The care and feeding of digital, pulse-shaping filters. RF Design,.

[4] Andrew Goldsmith. Wireless Communication. Cambridge University Press, 2005.

[5] Hall G. Malm P. Noren T. Olsson M. Beming P., Frid L. and Rune.G. 2007, LTE-SAE architecture and performance. Ericsson Review, (3):98–104,.

[6] Stefan Parkvall. 3G Evolution HSPA and LTE for Mobile Broadbands. Presentation at Chalmers University of Technology.

[7] Rohde and Schwarz. UMTS Long Term Evolution (LTE) Technology Introduction.

[8] AtitR.PatelSaumilS.Shah. Lte single carrier frequency division multiple access.

[9] Agilent Technologies. 2007 Agilent Technologies Solutions for 3GPP LTE. Agilent Technologies Inc., USA,.

[10] Agilent Technologies. Uplink resource block. Agilent Technologies Inc, USA, 2007.

[11] Schnell M. Sorger U., De Broeck.I. 1998. Interleaved FDMA - A new Spread Spectrum Multiple Access Scheme. In Proc. IEEE ICC '98, pages 1013– 1017, Atlanta,IEEE.

[12] Wulich D. and Goldfeld.L. 2005. Bound of the distribution of instantaneous power in single carrier modulation. IEEE Trans. Wireless Commun, 4(4):1773–1778.

[13] Goodman D.J.,1997 *Wireless Personal Communications Systems*, Addison-Wesley,.

[14] van R. Nee and Prasad R., 2000 *OFDM for Wireless Multimedia Communications*,Artech House,.

[15] Ekström H., Furuskär A., Karlsson J., Meyer M., Parkvall S., Torsner J., and Wahlqvist M., 2006. "Technical Solutions for the 3G Long-Term Evolution," *IEEE Commun.Mag.*, vol. 44, no. 3, pp. 38–45,

[16] 3rd Generation Partnership Project (3GPP); Requirements for Evolved UTRA (EUTRA)and Evolved UTRAN (E-UTRAN), http://www.3gpp.org/ftp/ Specs/htmlinfo/ 25913.htm.

[17] 3GPP TS 36.211, 2010, "Physical channels and modulation," Tech. Rep., Release 9. Available: http://ftp.3gpp.org/Specs/html-info/36211.htm

[18] Damnjanovic A., Montojo J., Wei Y., Ji T., Luo T., Vajapeyam M. Yoo T., Song O., and Malladi D., 2011. "A survey on 3GPP heterogeneousnetworks," *IEEE Personal Commun. Mag.*