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Peak to Average Power Ratio Analysis for LTE Systems

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Abstract—The 3rd generation partnership project (3GPP) long term evolution (LTE) standard uses single carrier frequency division multiple access (SCFDMA) scheme for the uplink transmissions and orthogonal frequency division multiplexing access (OFDMA) in downlink. SCFDMA uses DFT spreading prior to OFDMA modulation to map the signal from each user to a subset of the available subcarriers i.e., single carrier modulation. The efficiency of a power amplifier is determined by the peak to average power ratio (PAPR) of the modulated signal. In this paper, we analyze the PAPR in 3GPP LTE systems using root raised cosine based filter. Simulation results show that the SCFDMA subcarrier mapping has a significantly lower PAPR compared to OFDMA. Also comparing the three forms of SCFDMA subcarrier mapping, results show that interleave FDMA (IFDMA) subcarrier mapping with proposed root raised cosine filter reduced PAPR significantly than localized FDMA (LFDMA) and distributed (DFDMA) mapping. This improves its radio frequency (RF) power amplifier efficiency and also the mean power output from a battery driven mobile terminal.

Index Terms—3GPP LTE, SCFDMA, OFDMA, IFDMA, LFDMA, PAPR.

I. INTRODUCTION

The further increasing demand on high data rates in wireless communications systems has arisen in order to support broadband services. Long term evolution (LTE) is standardized by the third generation partnership project (3GPP) and is an evolution to existing 3G technology in order to meet projected customer needs over the next decades. 3GPP LTE uses orthogonal frequency division multiplexing access (OFDMA) for downlink transmission and single carrier frequency division multiple access (SCFDMA) for uplink. SCFDMA is a promising technique for high data rate transmission that utilizes single carrier modulation and frequency domain equalization. Single carrier transmitter structure leads to keep the peak to average power ratio (PAPR) as low as possible that will reduced the energy consumption. SCFDMA has similar throughput performance and essentially the same overall complexity as OFDMA [2], [7], [8]. A highly efficient way to cope with the frequency selectivity of wideband channel is OFDMA. OFDMA is an effective technique for combating multipath fading and for high bit rate transmission over mobile wireless channels. In OFDMA system, the entire channel is divided into many narrow subchannels, which are transmitted in parallel, thereby increasing the symbol duration and reducing the intersymbol-interference (ISI) [3], [5]. Despite many benefits of OFDMA for high speed data rate services, they suffer from high envelope fluctuation in the time domain, leading to large PAPR. Because high PAPR is detrimental to user equipment (UE) terminals, SCFDMA has drawn great attention as an attractive alternative to OFDMA for uplink data transmission. It can be regarded as DFT-spread OFDMA (DFTS-OFDM), where time domain data signals are transformed to frequency domain by a DFT before going through OFDMA modulation. The main benefit of DFTS-OFDM compared to OFDM scheme, is reduced variations in the instantaneous transmit power, implying the possibility for increased power-amplifier efficiency, low-complexity high-quality equalization in the frequency domain, and flexible bandwidth assignment [8].

In order to solve the high PAPR problem seen in the uplink of OFDMA, research is now addressing techniques such as a SCFDMA. The most of the previous work related to 3GPP LTE uplink has been mainly focused on implementation problems in the physical layer [1], [4], [6], [9]. In [7], [8] proposed raised cosine pulse shaping method that compare PAPR characteristics using the complementary cumulative distribution function (CCDF) for different subcarrier mapping. But raised cosine pulse shaping method provide lower PAPR reduction compared to root raised cosine method.

PAPR analysis is of major importance in case of high amplitude signals subject to non linear power amplification. This situation more and more occur due to the ever-growing demand in high spectral efficiency telecommunications systems implying multi dimensional waveforms considerations for which the PAPR is high. Pulse shaping is required for a single carrier system to bandlimit the transmit signal. This paper addresses a theoretical analysis of the PAPR of SCFDMA when root raised cosine (RRC) filter is considered. RRC is frequently used as the transmit and receive filter in a digital communication system to perform matched filtering. The combined response of two such filters is that of the raised cosine filter. We analytically derive the time and frequency domain 3GPP LTE uplink. Simulation results show that the SCFDMA has a significantly lower PAPR compared to OFDM. Also

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comparing the three forms of SCFDMA subcarrier mapping, the interleave FDMA (IFDMA) subcarrier mapping with root raised cosine based pulse shaping reduced PAPR significantly than localized FDMA (LFDMA) and DFDMA mapping. This improves its RF power amplifier efficiency and also the mean power output from a battery driven mobile terminal.

The remainder of the paper is organized as follows: section II gives an overview of LTE system model. Section III describes SCFDMA subcarrier mapping. Section IV addresses pulse shaping method. Section V presents the results obtained through computer simulation and, finally, section VI gives the conclusions.

II. LTE SYSTEM MODEL

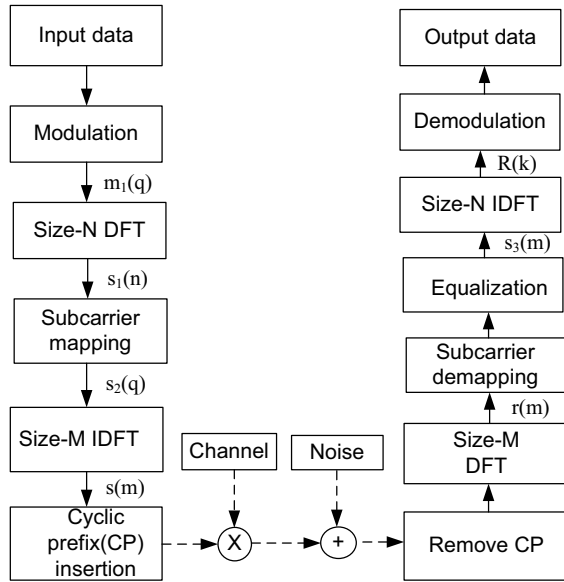A simplified block diagram of the 3GPP LTE SCFDMA transceiver is depicted in Figure 1.

Fig. 1.   LTE uplink transceiver system model.

At the transmitter side, a baseband modulator transmits the binary input to a multilevel sequences of complex number $m_1(q)$ in one of several possible modulation formats including, quandary phase shift keying (QPSK), and 16 level-QAM. These modulated symbols, are perform an N-point discrete Fourier transform (DFT) to produce a frequency domain representation [2]:

$$s_1(n) = \frac{1}{\sqrt{N}} \sum_{q=0}^{N-1} m_1(q)e^{\left(\frac{-j2\pi qn}{N}\right)}, \qquad (1)$$

where m_1 is the discrete symbols, q is the sample index, j is the imaginary unit, and $m_1(q)$ is the data symbol. The DFT followed by IDFT in a subcarrier mapping setup operates as efficient implementation to an interpolation filters. This may justify the reduced peak to average power ratio (PAPR) experienced in the IDFT output. The details description of the subcarrier mapping mode are in section III. PAPR is a comparison of the peak power detected over a period of sample occurs over the same time period. The PAPR of the transmit signal is defined as [10]:

$$PAPR = \frac{\max_{0<m<T} |s(m)|^2}{\frac{1}{TN} \int_0^{TN} |s(m)|^2 dm}, \qquad (2)$$

where T is the symbol period of the transmitted signal $s(m)$. PAPR is best described by its statistical parameter, complementary cumulative distribution function (CCDF). CCDF measures the probability of signal PAPR exceeding certain threshold [8], [10]. To further reduce the power variations of the DFTS-OFDM signal, explicit spectrum shaping can be applied. Spectrum shaping is applied by multiplying the frequency samples with some spectrum shaping function, e.g., a root raised cosine function (raised cosine shaped power spectrum). The IDFT module output is followed by a cyclic prefix insertion that completes the digital stage of the signal flow. A cyclic extension is used to eliminate ISI and preserve the orthogonality of the tones [5].

The transmitted symbols propagating through the radio channel can be modeled as a circular convolution between the channel impulse response (CIR) and transmitted data blocks. At the receiver, the opposite set of the operation is performed. The cyclic prefix samples are discarded and the remaining N samples are processed by the DFT to retrieve the complex constellation symbols transmitted over the orthogonal sub-channels. The received signals are de-mapped and equalizer is used to compensate for the radio channel frequency selectivity. After IDFT operation, the corresponding output is demodulated and soft or hard values of the corresponding bits are passed to the decoder.

III. SUBCARRIER MAPPING

There are two principal subcarrier mapping modes: localized, and distribution mode. In distributed subcarrier mode, the outputs are allocated equally spaced subcarrier, with zeros occupying the unused subcarrier in between. While in localized subcarrier mode, the outputs are confined to a continuous spectrum of subcarrier [7], [8]. Except the above two modes, interleaved subcarrier mapping mode of SCFDMA (IFDMA) is another special subcarrier mapping mode. The difference between DFDMA and IFDMA is that the outputs of IFDMA are allocated over the entire bandwidth, whereas the DFDMA's outputs are allocated every several subcarriers. If there are more than one user in the system, different subcarrier mapping modes give different subcarrier allocation [7], [8]. An example of SCFDMA transmit symbols in the frequency domain for 2 user, 3 subcarrier per user and 6 subcarrier in total is illustrated in Figure 2.

In order to accommodate multiple access to the system and to preserve the constant envelope property of the signal, the elements of transmitted signal $s(m)$ are mapped, by using the LFDMA or IFDMA subcarrier mapping rule. Here is output symbol calculation in IFDMA in time domain. The frequency

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$s_1(0)$ $s_1(1)$ $s_1(2)$

(a)

(b)

(c)

→ User 1
→ User 2
→ User 3

Complex
→ weight
→ Zeros
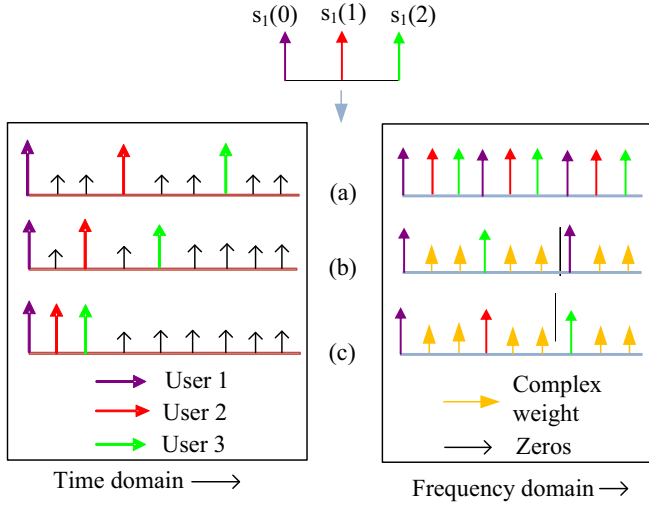
Time domain ⟶

Frequency domain →

Fig. 2. Subcarrier frequency allocation methods for multiples users (a) IFDMA mode (b) DFDMA mode and (c) LFDMA.

samples after IFDMA subcarrier mapping is [8], [12]:

$$s_2(q) = \begin{cases} s_1(q/C) = 1 & 0 \leq n \leq N-1 \\ 0 & else \end{cases}$$

where $q = Cn$, and $C = M/N$ and it is the bandwidth expansion factor of the symbol sequence. If $N = M/C$ and all terminals transmit N symbols per block, the system can handle C simultaneous transmissions without co-channel interference. After M-point IDFT operation $(M > N)$, time domain signal can be described as follows. Let $m = Nc + q$, where $0 \leq c \leq C-1$ and $0 \leq q \leq N-1$. The time domain IFDMA transmitted signal can be express as [8], [12]:

$$s(m) = \frac{1}{C} m_1(q), \tag{3}$$

where $m_1(q) = \frac{1}{N} \sum_{n=0}^{N-1} s_1(n) e^{\left(\frac{j2\pi qn}{N}\right)}$ is the N-point IDFT operation. Therefore in case of IFDMA, every output symbol is simple a repeat of input symbol with a scaling factor of $1/C$ in time domain. When the subcarrier frequency allocation starts from fth subcarrier i.e. $q = Cn + f$ then the frequency samples after IFDMA subcarrier mapping is

$$s_2(q) = \begin{cases} s_1(q/C - f) = 1 & 0 \leq n \leq N-1 \\ 0 & else \end{cases}$$

and the time domain transmitted signal can be express as

$$s(m) = \frac{1}{C} [\frac{1}{N} \sum_{n=0}^{N-1} s_1(n) e^{\left(\frac{j2\pi qn}{N}\right)}] e^{\left(\frac{j2\pi mf}{M}\right)}$$

$$= \frac{1}{C} e^{\left(\frac{j2\pi mf}{M}\right)} m_1(q). \tag{4}$$

Thus, when the subcarrier frequency allocation starts from fth instead of zero then there is an additional phase rotation of $e^{j2\pi mf/M}$.

Here is output symbol calculation in LFDMA subcarrier mapping in time domain. After DFT operation the frequency

domain subcarrier mapping signal can be written as

$$s_2(q) = \begin{cases} s_1(l) = 1 & 0 \leq l \leq N-1 \\ 0 & N \leq l \leq M-1 \end{cases}$$

After IDFT operation, time domain signal can be described as follows. Let $m = Cq + c$, where $0 \leq c \leq N-1$ and $0 \leq c \leq C-1$. Then time domain transmitted signal can be represent as [8], [12]:

$$s(m) = \frac{1}{C} (1 - e^{j2\pi c/C}) \frac{1}{N} \sum_{n=0}^{N-1} \frac{m_1(p)}{1 - e^{(j2\pi(q-p)/N + c/CN)}} \tag{5}$$

So, the time domain LFDMA subcarrier mapping signal has exact copies of input time signals with a scaling factor of $1/C$ in the N-multiple sample positions and in between values are sum of all the time input symbols in the input block with different complex-weighting (CW) [8].

The frequency samples after DFDMA subcarrier mapping is [8], [12]:

$$s_2(q) = \begin{cases} s_1(q/\tilde{C}) = 1 & 0 \leq n \leq N-1 \\ 0 & else \end{cases}$$

where $0 \leq c \leq C-1$, $q = Cn$, and $0 \leq \tilde{C} \leq C$. Let $m = Nq + c$ where $0 \leq c \leq C-1$ and $0 \leq q \leq N-1$ and $0 \leq q \leq N-1$. The time domain DFDMA transmitted signal can be express as [8], [12]:

$$s(m) = \frac{1}{M} \sum_{l=0}^{M-1} s_2(q) e^{\left(\frac{j2\pi ml}{M}\right)}$$

$$= \frac{1}{C} \frac{1}{N} \sum_{l=0}^{N-1} s_1(l) e^{\left(\frac{j2\pi(Cq+c)l}{CN} \tilde{C}_l\right)} \tag{6}$$

if $c = 0$ then

$$s(m) = \frac{1}{C} m_1(\tilde{C}q) \tag{7}$$

Since $m_1(q) = \sum_{p=0}^{N-1} m_1(p) e^{\left(\frac{-j2\pi lp}{N}\right)}$ and if $c \neq 0$ then

$$s(m) = \frac{1}{C} (1 - e^{j2\pi \tilde{C}c/C}) \frac{1}{N} \sum_{n=0}^{N-1} \frac{m_1(p)}{1 - e^{(j2\pi(\tilde{C}q-p)/N + \tilde{C}c/CN)}} \tag{8}$$

So, the time domain symbols of DFDMA subcarrier mapping have the same structure as those of LFDMA subcarrier mapping.

IV. PULSE SHAPING METHOD

In a single carrier system, pulse shaping is required to bandlimit the signal and ensures it meets the spectrum mask. In this paper, a root raised cosine (RRC) filter is used to pulse shape the SCFDMA signals. RRC is frequently used as the transmit and receive filter in a digital communication system to perform matched filtering. The combined response of two such filters is that of the raised cosine filter. The raised cosine filter is frequently used for pulse shaping in digital modulation due to its ability to minimize intersymbol interference (ISI). Its name stems from the fact that the non zero portion of the frequency spectrum of its simplest form $\beta = 1$ (called

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the roll-off factor) is a cosine function, raised up to sit above the horizontal axis. The RRC filter is characterized by two parameters such as β, and T_s (the reciprocal of the symbol rate) and the impulse response can be given as:

$$h(t) = \begin{cases} 1 - \beta + 4\beta/\pi, t = 0 \\ \beta/\sqrt{2}[(1+2/\pi)\sin(\pi/\beta4) + (1-2/\pi)\cos(\pi/\beta4)], \\ t = \pm T_s/\beta4 \\ \frac{\sin[\pi t/T_s(1-\beta)] + 4\beta t/T_s\cos[\pi t/T_s(1+\beta)]}{\pi t/T_s[1-(4\beta t/T_s)^2])}, else \end{cases}$$

V. COMPUTER SIMULATIONS AND DISCUSSIONS

Complementary cumulative distribution function (CCDF) of PAPR, which is the probability that PAPR is higher than a certain PAPR value PAPR0, is calculated by Monte Carlo simulation. The parameters used for the calculation of PAPR are illustrated in Table I.

TABLE I
THE SYSTEM PARAMETERS USED FOR SIMULATIONS

System parameters	Specifications
System bandwidth	$5MHz$
Number of subcarriers	512
Data block size	16
Roll of factor	0.0999999999
Oversampling factor	4
Number of iteration	10^4
Subcarrier mapping schemes	DFDMA, IFDMA, LFDMA
Modulation data type	Q-PSK and 16-QAM
Spreading factor for IFDMA	32
Spreading factor for DFDMA	31

We compare the PAPR value that is exceeded with probability less than 0.1 percentile PAPR. The PAPR calculation using various subcarrier mapping schemes for SCFDMA and OFDMA system is shown in Figure 3. The modulation scheme used for this calculation is QPSK. It can be seen that SCFDMA subcarrier mapping schemes gives lower PAPR values as compared to OFDMA scheme. Also the proposed root raised cosine pulse shaping method has lower PAPR than the case of existing pulse shaping method by more than $3dB$. Due to the phase rotation it is unlikely that the LFDMA samples will all add up constructively to produce a high output peak after pulse shaping. But it is shown that LFDMA has a lower PAPR than DFDMA when pulse shaping is applied. Another PAPR calculation using various subcarrier mapping schemes for SCFDMA system is shown in Figure 4. The modulation scheme used for this calculation is 16-QAM. It show that IFDMA has lowest value of PAPR at $7.8dB$ which is $6.7dB$ in case of QPSK as modulation technique. Finally we conclude that the higher values of PAPR by using 16-QAM which is undesirable because they cause non linear distortions at the transmitter.

VI. CONCLUSIONS

In this paper, we analysis PAPR for different subcarrier mapping scheme under the umbrella of the 3GPP LTE systems. We analytically derive the time and frequency domain signals of different subcarrier mapping, and numerically compare
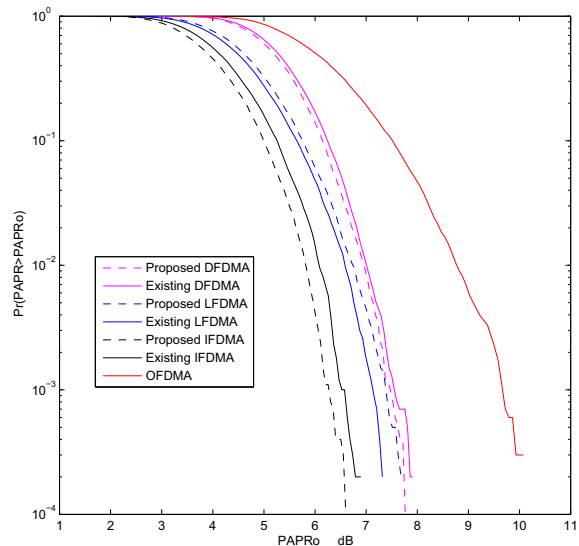

Fig. 3. PAPR comparison for SCFDMA subcarrier mapping with OFDMA using QPSK.
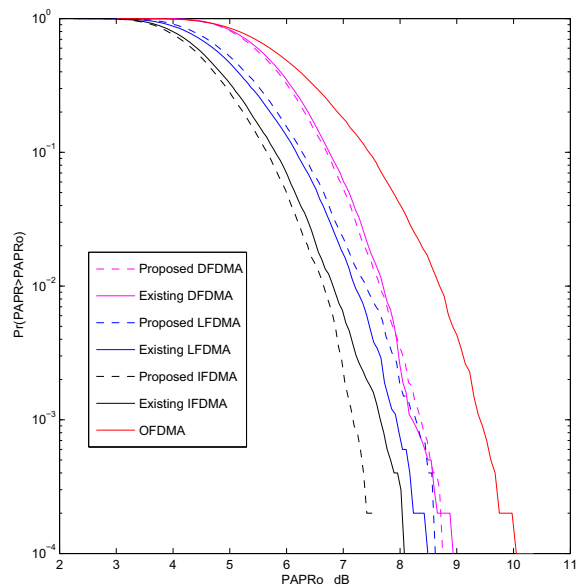

Fig. 4. PAPR comparison for SCFDMA subcarrier mapping with OFDMA using 16-QAM.

PAPR characteristics using CCDF of PAPR. Computer simulations demonstrate the correctness of theoretical analysis and we can come to the conclusion that the IFDMA subcarrier mapping with root raised cosine pulse shaping method has lowest PAPR values compare to the other subcarrier mapping methods. So, SCFDMA is attractive for uplink transmissions since it reduces the high PAPR seen with OFDMA.

REFERENCES

[1] E. Dahlman, S. Parkvall, J. Skold, and P. Beming, "3G evolution HSPA and LTE for mobile broadband," *Academic Press is an Imprint of Elsevier*, 2007.

[2] B. Karakaya, H. Arslan, and H. A. Cirpan, "Channel estimation for LTE uplink in high doppler spread," *Proc. WCNC*, pp. 1126-1130, April 2008.

[3] J. Berkmann, C. Carbonelli, F.Dietrich, C. Drewes, and W. Xu, "On 3G LTE terminal implementation standard, algorithms, complexities and challenges," *Proc. Int. Con. on Wireless Communications and Mobile Computing*, pp. 970-975, August 2008.

[4] A. Ancora, C. Bona, and D.T.M. Slock, "Down-sampled impulse response least-squares channel estimation for LTE OFDMA," *Proc. Int. Con. on Acoustics, Speech and Signal Processing*, Vol. 3, pp. 293-296, April 2007.

[5] L. A. M. R. D. Temino, C. N. I Manchon, C. Rom, T. B. Sorensen, and P. Mogensen, "Iterative channel estimation with robust wiener filtering in LTE downlink," *Proc. Int. Con. on Vehicular Technology Conference*, pp. 1-5, September 2008.

[6] J. Zyren, "Overview of the 3GPP long term evolution physical layer," *Dr. Wes McCoy, Technical Editor*, 2007.

[7] H. G. Myung, J. Lim, and D. J. Goodman, "Single carrier FDMA for uplink wireless transmission," *IEEE Vehicular Technology Magazine*, vol. 1, no. 3, pp. 30-38, September 2006.

[8] H.G. Myung, J. Lim, and D. J. Goodman, "Peak to average power ratio for single carrier FDMA signals," *Proc. PIMRC*, 2006.

[9] S. Maruyama, S. Ogawa, and K.Chiba, "Mobile terminals toward LTE and requirements on device technologies," *Proc. Int. Con. on VLSI Circuits*, pp. 2-5, June 2007.

[10] S. H. Han, and J. H. Lee, "An overview of peak to average power ratio reduction techniques for multicarrier transmission," *IEEE Wireless Communications*, April 2005.

[11] H. G. Myung, "Introduction to single carrier FDMA," *Proc. Int. Con. on European Signal Processing (EUSIPCO)*, Poznan, Poland, Sep. 2007.

[12] A. Sohl, and A. Klein, "Comparison of localized, interleaved and block-interleaved FDMA in terms of pilot multiplexing and channel estimation," *Proc. Int. Con. on PIMRC*, 2007.