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COMPARISON OF PERFORMANCES BETWEEN SC-FDMA AND OFDMA SYSTEMS UNDER DIFFERENT SUBCARRIER MAPPING SCHEMES

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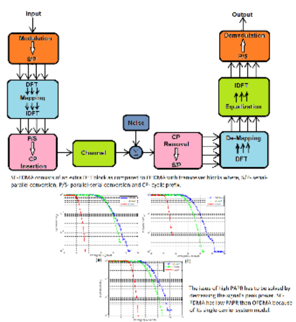
Graphical abstract



Abstract

To improve the uplink performance of wireless network for long term evolution (LTE) single carrier frequency division multiple access (SC-FDMA) and orthogonal frequency division multiple access (OFDMA) are used. Two major concerns of these SC-FDMA and OFDMA are high peak-to-average power ratio (PAPR) and efficient subcarrier mapping scheme. This paper presents a performance comparison of SC-FDMA and OFDMA under different subcarrier mapping schemes which includes localized FDMA (LFDMA), distributed FDMA (DFDMA) and interleaved FDMA (IFDMA). Quadrature amplitude modulation (QAM) with different constellation sizes is used. The symbol error rate (SER) in SC-FDMA is minimized using appropriate mapping scheme. The PAPR is less in SC-FDMA compared to OFDMA. SC-FDMA with IFDMA shows better performance for the PAPR reduction compared to the OFDMA. Compared to OFDMA, using SC-FDMA with 8-QAM and IFDMA, PAPR is reduced by 78%, using SC-FDMA with 16-QAM and IFDMA, PAPR is reduced by 80%, using SC-FDMA with 64-QAM and IFDMA, PAPR is reduced by 68%.

Keywords: OFDMA, PAPR, SC-FDMA, LTE, Subcarrier mapping.

1.0 INTRODUCTION

The obstruction for the wireless transmission of wide bandwidth data is frequency selectivity feature of the channel. The frequency selective attribute of channel gives rise to critical inter-symbol-interference (ISI) ensuing substandard performance with large data rate signal. Orthogonal frequency division multiplexing (OFDM) is selected as the technique for transmission of multiple carriers, which reduces ISI [1]. OFDM is already used by various wireless networks such as IEEE802.11a and IEEE802.16 and is to be used in the future generation communication [2]. In multiple input multiple output (MIMO) system where OFDM is the modulation scheme used, by not increasing the power, the improvement in physical layer makes it suitable for broadband communication [3]. The performance of traditional multi-carrier technique, OFDM is bounded because it has high PAPR which makes it irrelevant in LTE uplink. In uplink, major problems are the usage of power and at the transmitting end, mobile units are the transmitters. A fruitful solution for uplink is single SC-FDMA where before proceeding to OFDM modulation, each transmitted symbol is spreaded over multiple subcarriers using discrete Fourier transform (DFT) [4]. As it degrades the PAPR of the input signal to the single-carrier transmission level, 3rd generation partnership project (3GPP) introduces SC-FDMA to be used for LTE uplink [5]. Here a comparison between different mapping schemes is also manifested. However, SC-FDMA is restricted to LTE uplink because the increased processing time will put certain pressure on the base station, which should tackle multiple user transmission [6]. Both the techniques use almost the same transmitter and receiver sections, except the DFT pre-coding stage at transmitter end and inverse pre-coding stage at receiver end, which are additional in SC-FDMA. Because of those additional blocks, SC-FDMA has low envelope fluctuations of input signal hence, PAPR is less than OFDM resulting greater power efficiency [7,8]. Also, SC-FDMA system complexity mainly concentrates on the receiver end and hence suitable technique for uplink for low complexity at the base station. In SC-FDMA the DFT process before the inverse fast Fourier transform (IFFT) operation distributes the power of one over all assigned subcarriers, so that in the channel spectral nulls are decreased with averaging [9]. The outcome of the DFT of input data if distributed over the total bandwidth, then it is distributed FDMA and if the result is placed in consecutive subcarriers, it is Localized FDMA [10]. In these cases, vacant subcarriers are kept zero. In IFDMA, subcarriers are uniformly spaced over total bandwidth [11].

Subcarrier mapping is one of the major concerns for the LTE uplink where a sub-set of subcarriers are used to transmit its own data. There are different types of subcarrier mapping schemes. In [12], error rate performances of OFDMA system and SC-FDMA systems are reported using localized mapping and interleaved mapping. In [13], a blind carrier frequency offset estimation algorithm is proposed for SC-FDMA uplink system and its performance is verified by using localized subcarrier mapping and the proposed method also works well for interleaved mapping. A comparison between the performances of SC-FDMA and OFDMA is reported [14] where localized mapping and distributed mapping are used. To overcome the shortcomings of OFDM RADAR, the design and analysis of SC-FDMA RADAR is described in [15] where interleaved subcarrier mapping is exploited. SC-FDMA with localized and interleaved subcarrier mapping schemes is used [16] for a proposed combined minimum mean square error and parallel interference cancellation methods to improve the error performance of an SC-FDMA system. Localized and interleaved subcarrier mapping schemes are used [17] to investigate the PAPR performance of single carrier spread spectrum techniques which shows that a proposed hybrid multiple access scheme performs well than SC-FDMA. To obtain multi-user diversity and lower PAPR, the localized subcarrier mapping is used [18] for MIMO system where improved spectrum efficiency and power efficiency are achieved.

In this paper the performances of SC-FDMA and OFDMA are compared. In SC-FDMA three types of subcarrier mapping schemes, like, localized FDMA (LFDMA), distributed FDMA (DFDMA) and interleaved FDMA (IFDMA) are used. Constellation sizes of 8, 16 and 64 of QAM are used to estimate the PAPR performances of OFDMA system and SC-FDMA system under the above three mapping techniques. The performances of SER and PAPR for SC-FDMA are better than OFDMA. In this paper in section 2, the SC-FDMA system is described. In section 3, the PAPR is defined with the help of required equations for SC-FDMA and OFDM. The simulated results for PAPR for SC-FDMA and OFDM systems are compared in section 4. Conclusion and future scope of research work are described in section 5.

2.0 SYSTEM DESCRIPTION

Cyclic prefix (CP) as guard interval is used to maintain the orthogonality of subcarriers. In OFDM, source symbols are independently assigned to each subcarrier and in SC-FDMA, the signal for each subcarrier, at same time is a linear combination of all modulated transmitted data symbols. Before mapping, SC-FDMA consists of an extra DFT block as displayed in Figure 1 with transceiver blocks where, S/P- serial-parallel conversion and P/S-parallel-serial conversion. The parameters used are described in Table 1.

As per the modulation the source information is first assembled and then mapped. For u^{th} user, the source data is collected into a data set $s^{(u)}$ of size M after transforming to constellation symbols. An M-point DFT converts $s^{(u)}$ to frequency domain signal $S^{(u)}$ [8].

$$S^{(u)}(k) = \sum_{m=0}^{M-1} s^{(u)}(m) e^{-j2\pi mk/M} \quad (1)$$

for k is any integer having values 0 to M-1, all the subcarriers are inserted with pilots uniformly among the data sequence, as per various allocation techniques, $S^{(u)}$ is mapped to P as,

$$X^{(u)} = D^{(u)} \cdot S^{(u)} \quad (2)$$

For u=1,2,…….,U. Then $x^{(u)}$, a time domain signal is found by using inverse discrete Fourier transform (IDFT).

$$x^{(u)}(m) = \frac{1}{P} \sum_{k=0}^{P-1} X^{(u)}(k) e^{j2\pi mk/P} \quad (3)$$

After IDFT, guard interval is inserted which is greater than the required delay spread to mitigate the ISI. With usage of CP, the SC-FDMA signal is formed and converted to serial. Via the fading channel transmitted signal $x^{(u)}(m)$ will pass. $y^{(u)}(m)$ is the received signal [19],

$$y^{(u)}(m) = x^{(u)}(m) \otimes h^{(u)} + w(m) \quad (4)$$

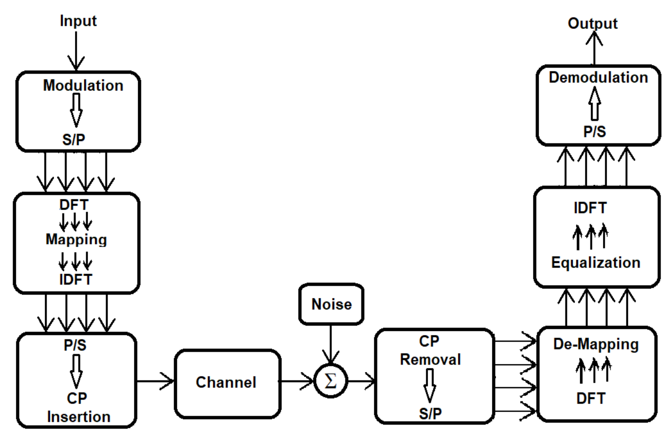


Figure 1 SC-FDMA Block Diagram

Table 1 Parameter Description

No.	Parameters	Description
1	U	Total users in system
2	P	Number of subcarriers used
3	M	Subcarriers for each user
4	$D^{(u)}$	Matrix of resource allocation
5	m	Sample time
6	$w(m)$	AWGN
7	$h^{(u)}$	Impulse response of channel
8	L_u	Delay spread (max)
9	$h^{(u)}(m, l)$	Channel response with sample spacing
10	L	Total Paths of fading channel
11	σ_w^2	Variance
12	$H(k)$	Frequency domain channel response
13	$W(k)$	Fourier transform of $w(m)$
14	K^H	De-mapping matrix

After removal of CP, the transmitted signal is circularly convoluted to impulse response of channel to give away the received signal.

$$y^{(u)}(m) = \sum_{u=0}^{U-1}\sum_{l=0}^{L-1} h^{(u)}(m,l)x^{(u)}(m-l) + w(m) \quad (5)$$

Then the received signal is,

$$y^{(u)}(m) = \frac{1}{P}\sum_{k=0}^{P-1} x^{(u)}(k)\sum_{u=0}^{U-1} H^{(u)}(k,m)e^{(j2\pi mk/P)} + w(m) \quad (6)$$

Here, $H(k,m) = \sum_{l=0}^{L-1} e^{-j\pi lk/P}$. After DFT, frequency domain signal is given as [13],

$$Y^{(u)}(k) = \sum_{p=0}^{P-1} y^{(u)}(m)e^{-j2\pi pk/P}$$
$$= x^{(u)}(k)H^{(u)}(k) + W(k) \quad (7)$$

$H(k) = \frac{1}{P}\sum_{k=0}^{P-1} H(k,m)$ and $W(k) = \sum_{p=0}^{P-1} w(m)e^{-j2\pi pk/P}$

In the channel estimation block, after removing pilots $\hat{H}^{(u)}(k)$ the estimated channel is found. The signal transmitted is estimated to be,

$$\hat{X}^{(u)}(k) = \frac{Y^{(u)}(k)}{\hat{H}^{(u)}(k)} \quad (8)$$

In frequency domain equalization, with the de-mapping matrix K^H,

$$R^{(u)} = K^H Y^{(u)} + W \quad (9)$$

Next, de-mapped symbol is applied an M-point IDFT, the output signal is,

$$r^{(u)}(m) = \frac{1}{M}\sum_{k=0}^{M-1} R^{(u)}(k)e^{j2\pi mk/M} \quad (10)$$

Then IDFT output is fed to demodulation block and the final bit stream generated by receiver. Result is sent to IDFT but before that a complex equalizer is used [14].

3.0 PAPR: PEAK TO AVERAGE POWER RATIO

In OFDMA and SC-FDMA, an IFFT process is used by adding all the carriers, which may result in a signal having large peaks and dynamic range in time domain. For a SC-FDMA signal *x(t)*, the PAPR is calculated as:

$$PAPR\{x(t)\} = \frac{\max_{0\le t\le T}\{|x(t)|^2\}}{E\{|x(t)|^2\}} \quad (11)$$

$max\{|x(t)|^2\}$ is the peak signal power and $E\{|x(t)|^2\}$ is the average signal power [22]. *Xn* denotes the transmitted discrete time domain signal. If the number of subcarriers *N* is increased, the PAPR power also increases. Large *Xn* are zero mean Gaussian random variables [23]. And for *Xn* complex Gaussian the OFDM signal is Rayleigh distributed with variance σ_n^2, and the phase of the signal is uniform [24].

$$\check{F}_{PAPR_{max}}(PAPR_0) = 1 - F_{PAPR_{max}}(PAPR_0)^N \quad (12)$$

The fixation of threshold value ranges from zero to maximum value. The threshold value can be calculated by using the equation below [25]. Threshold value is frequently updated and a complementary cumulative density function (CCDF) plot is drawn.

$$Threshold = \left(\frac{PAPR_{max} - PAPR_{min}}{PAPR_{max}PAPR_{min}}\right) \quad (13)$$

As at the transmitting end, the power amplifiers (PA) would be driven to saturation by a high PAPR, which in turn produces interference between the subcarriers as well as reduces the performance of BER and the spectrum of the signal is corrupted. If the signal's average power can be reduced then this situation where the PA is driven into saturation can be avoided. But this solution degrades the SNR and the performance of BER [26]. So, the issue of high PAPR has to be solved by decreasing the signal's peak power. SC-FDMA has low PAPR than OFDMA because of its single-carrier system model. Particularly for battery driven units and transmission for shorter range, it is necessary that the signal waveforms should be transmitted with low dynamic range [27]. Hence, it permits the PA to function in its linear range without surplus back-off which guarantees lower PAPR.

4.0 SIMULATION RESULTS

In this paper the simulation tools are generated using MATLAB analyzing the SC-FDMA and OFDM System. Figure 2 shows SER vs. SNR comparison for the two schemes where for lower values of SNR, performance of both systems is similar but increasing SNR provides better performance for SC-FDMA than OFDM. In Figure 3 it is shown that localized mapping schemes performs better than that of distributed schemes.

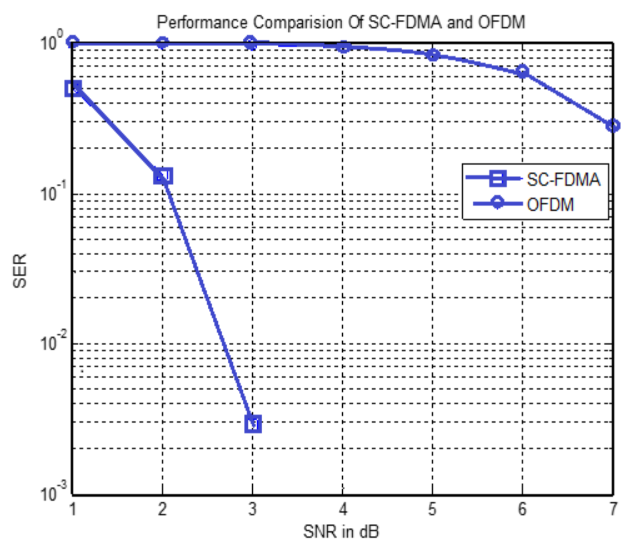


Figure 2 Performance of SC-FDMA and OFDM

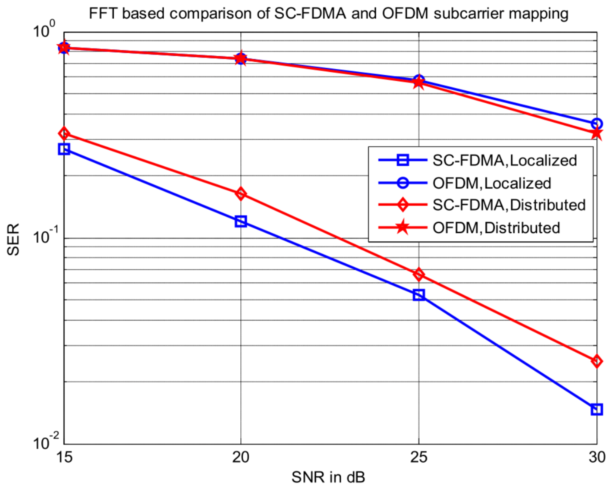
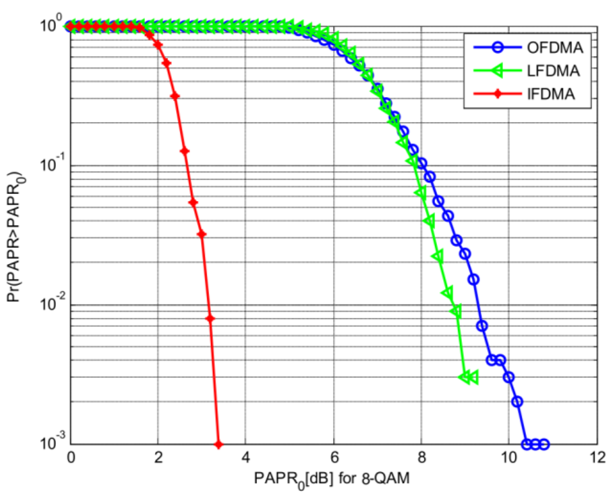


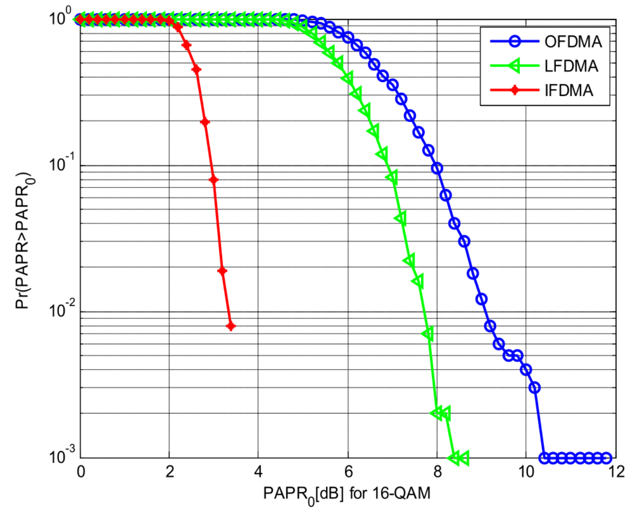
Figure 3 Comparison of Localized and Distributed mapping techniques

Figure 4 below presents the CCDF of the PAPR for Orthogonal FDMA, Localized FDMA and Interleaved FDMA subcarrier mapping technique of SC-FDMA with 8-QAM, 16-QAM and 64-QAM. For both the techniques, *N*- total subcarriers used is 256, and each user accessible subcarriers are 64, spreading factor *Q* is 4. The length of cyclic prefix *P* is 8. For each Orthogonal FDMA and Single Carrier-FDMA transmitted symbol, PAPR is calculated. Therefore, from the plots it is clear that SC-FDMA provides a PAPR which is lower than OFDMA.

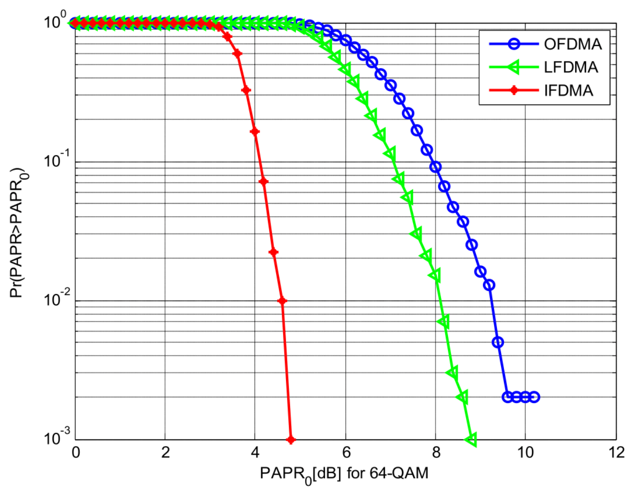
The system model of SC-FDMA is basically a single carrier design; due to this the PAPR is very sensitive to the number of input constellation of the SC-FDMA waveform, contrary to OFDMA. Consequently, after the IDFT, the output is an up sampled form of original modulated symbol.



(a)



(b)



(c)

Figure 4 The CCDF of PAPR for OFDMA, LFDMA and IFDMA subcarrier mapping technique for (a) 8-QAM, (b) 16-QAM, (c) 64-QAM

From Figure 4(a), for CCDF of 10^{-3}, PAPR of IFDMA is 3.5 dB, that of LFDMA is 9 dB and that of OFDMA is 10.2 dB. From Figure 4(b), PAPR of IFDMA is 3.5 dB, that of LFDMA is 8.2 dB and that of OFDMA is 10.5 dB. In Figure 4(c), PAPR of IFDMA is 4.8 dB, that of LFDMA is 9 dB and that of OFDMA is 9.8 dB. Therefore, for 8-QAM, PAPR of IFDMA is 2.24, that of LFDMA is 7.94 and that of OFDMA is 10.47. Therefore using SC-FDMA with LFDMA, PAPR is reduced by 24% compared to OFDMA and using IFDMA that is reduced by 78% than OFDMA. For 16-QAM, PAPR of IFDMA is 2.24, that of LFDMA is 6.61 and that of OFDMA is 11.22. Therefore using SC-FDMA with LFDMA, PAPR is reduced by 41% compared to OFDMA and using IFDMA that is reduced by 80% than OFDMA. For 64-QAM, PAPR of IFDMA is 3.02, that of LFDMA is 7.94 and that of OFDMA is 9.55. Therefore using SC-FDMA with LFDMA, PAPR is reduced by 16% compared to OFDMA and using IFDMA that is reduced by 68% than OFDMA.

5.0 CONCLUSION

In this paper, using different constellation sizes of QAM technique, the PAPR performance of SC-FDMA and OFDMA system under different types of subcarrier mapping schemes are compared. After simulation using different subcarrier mapping schemes, it is found that PAPR is less in SC-FDMA compared to OFDM in all types of subcarrier mappings. The interleaved mode of SC-FDMA has greater performance over the other two methods and approximately 4-6 dB advantage over the localized mapping in all the cases simulated. In future this work will be extended for a hybrid SC-FDMA and direct sequence code division multiple accesses (DS-CDMA) scheme for improved performance.

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