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Research Article

Performance Analysis of a Modified SC-FDMA-DSCDMA Technique for 4G Wireless Communication

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Single-carrier FDMA (SC-FDMA) is becoming more and more popular in multiuser communication because of its lower PAPR value. Apart from this, many other hybrid access techniques have also been explored in the literature for application to 4G wireless mobile communication. Still there is a need to explore newer techniques which could further reduce the PAPR value without any degradation in system BER. Keeping this in view, a modified hybrid technique SC-FDMA-DSCDMA has been proposed in this paper and it is found to provide significantly lower PAPR than SC-FDMA system with no degradation in BER performance. This paper extensively compares the BER and PAPR performance of various other multicarrier techniques for 4G wireless communications such as OFDMA, MC-DS-CDMA, and SC-FDMA with proposed SC-FDMA-DSCDMA scheme. Simulation results show that SC-FDMA-DSCDMA technique performs better than any other OFDM-CDMA based system for wireless communication.

1. Introduction

The demand for high data rate services has been increasing very rapidly and there is no slowdown in sight. Demands for media-rich wireless data services have brought much attention to high speed broadband mobile wireless techniques in recent years. Orthogonal frequency division multiplexing (OFDM), which is a discrete multitone modulation (DMT), consists of a large number of closely spaced orthogonal subcarriers carrying user data. The user data is divided into several parallel data streams or channels, one for each subcarrier. Each subcarrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [1].

OFDMA is a multiple access scheme which is an extension of OFDM to accommodate multiple simultaneous users. The advantage of OFDMA is its robustness in the presence of multipath signal propagation. OFDMA presents the benefits of flexible resource allocation and scheduling. Dynamic allocation of subcarriers in OFDMA can further improve performance compared to fixed allocation. Because of these advantages, OFDMA has been adopted in wireless standards including WiMax and LTE. Despite many advantages, OFDMA suffers from various drawbacks; that is, it exhibits very pronounced envelope fluctuations resulting in a high PAPR, a need for an adaptive or coded scheme to overcome spectral nulls in the channel and high sensitivity to frequency offset. Frequency offset destroys the orthogonality of the transmissions, thus resulting in MAI. Therefore, LTE uses OFDMA only on the downlink and not on the uplink.

To overcome these drawbacks, 3GPP introduced a modified form of OFDMA for uplink transmissions in the long term evolution (LTE). The modified version of OFDMA, referred to as single-carrier FDMA (SC-FDMA), provides similar throughput performance and complexity. As in OFDMA, the transmitters in an SC-FDMA system use different orthogonal frequencies (subcarriers) to transmit information symbols. However, these transmitters transmit the subcarriers sequentially, rather than in parallel. Unlike in OFDMA, this arrangement reduces considerably the envelope fluctuations in the transmitted waveform. Therefore, SC-FDMA signals have lower PAPR than OFDMA signals. However, in cellular

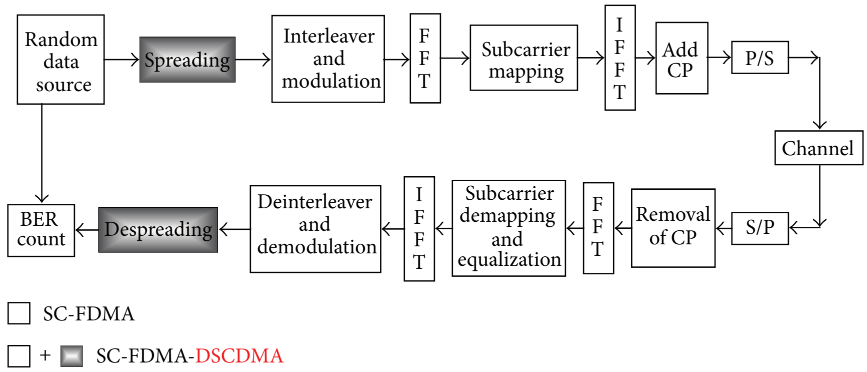

Figure 1: Modified SC-FDMA-DSCDMA system model. CDMA spreading operation has been performed before interleaving and modulation.

systems with severe multipath propagation, the SC-FDMA signals arrive at a base station with intersymbol interference. Therefore to cancel this ISI, base station employs adaptive frequency domain equalization (FDE). This arrangement provides useful model in cellular system because it reduces the burden of linear amplification in portable terminals at the cost of complex signal processing (frequency domain equalization) at the base station [2, 3].

Next, direct sequence code division multiple access (DS-CDMA) is a multiple access technique based on spread spectrum modulation. A spread spectrum system is one in which the transmitted signal is spread over a wider bandwidth required to transmit the information being sent [4, 5]. Spreading is accomplished with the help of a code which is independent of the data. At receiver, the same code is used to despread and recover the transmitted data. DS-CDMA system offers several advantages in cellular environments including easy frequency planning, high immunity against MAI if high processing gain is used, and flexible data rate adaptation [5].

The combination of DS-CDMA and OFDM leads to the development of MC-DS-CDMA. The multicarrier DS-CDMA transmitter spreads the S/P converted data streams using a given spreading code in the time domain [6] and after that multicarrier modulation (OFDM) is performed by IFFT operation [4]. This combination is very effective in combating severe multipath interference and provides multiple access simultaneously. However, MC-DS-CDMA suffers from high PAPR value because of multicarrier.

Now, we have considered, in this paper, a modified hybrid technique SC-FDMA-DSCDMA obtained by combination of SC-FDMA and DS-CDMA. A similar technique has also been considered earlier by Luo and Xiong [5]. However, in this paper, a modified technique is proposed where CDMA spreading operation is performed before interleaving and modulation operation (Figure 1). We call this technique "SC-FDMA-DSCDMA," which inherits merits of SC-FDMA as well as DS-CDMA. In addition to this, the available literature lacks the exhaustive analysis and comparison of this hybrid technique. This technique could prove to be a good alternative to the SC-FDMA technique and thus simultaneously providing better PAPR performance.

This paper is organized as follows. Section 2 provides the background that led to the formulation of problem considered in this paper. Section 3 covers a brief overview of the modified SC-FDMA-DSCDMA technique. Furthermore in the subsequent sections, we discuss the comparative BER performance of SC-FDMA-DSCDMA with respect to different multicarrier techniques over different fading channel conditions. Next, PAPR performance of SC-FDMA-DSCDMA with respect to different FFT size is analyzed and then comparative PAPR performance analysis of the proposed technique with different multicarrier techniques is also done. Finally, the relevant results of the paper are concluded.

2. Background and Problem Formulation

As already mentioned, a CDMA system coupled with multicarrier modulation offers many potential benefits, but it also suffers from a major drawback due to multicarrier transmission, that is, high PAPR. Depending on the user data, the summation of subcarriers may result in a signal with large amplitude or small amplitude. And as a result, the peak power of signal is much greater than the average power. The high PAPR causes out-of-band radiations due to nonlinear power amplifier. Therefore, the transmit power amplifier must be operated in linear region but it results in poor power conversion efficiency. The multicarrier modulation (OFDMA) has now been replaced with SC-FDMA, which provides further reduction in PAPR value of the transmit signal.

A number of approaches have been proposed in the literature [7] for reducing high value of PAPR in OFDM systems. Broadly speaking, these PAPR reduction techniques can be divided into two categories, namely, distortion-based and distortionless techniques. The distortion-based techniques achieve significant PAPR reduction but at the cost of increased BER, high computational complexity, data rate loss, and so forth. On the other hand, distortionless techniques achieve PAPR reduction without any degradation in BER and spectral efficiency. The distortionless techniques mainly rely on hybrid structures without introducing any deliberate distortion in the transmit signal. Keeping in view this advantage of distortionless techniques, we have proposed a modified hybrid technique, that is, SC-FDMA-DSCDMA, which is a combination of SC-FDMA and DS-CDMA. A similar technique has also been considered earlier by Luo and Xiong [5]. But in this paper, we have explored an idea that PAPR can be reduced further by proper placement of spreading/despreading block in hybrid OFDM-CDMA systems. In the technique proposed by us, CDMA spreading operation is performed before interleaving and modulation operation (Figure 1). However, Luo and Xiong [5] have used the spreading process after modulation.

Thus, the main focus of this paper is on the reduction in PAPR value without any BER degradation through the use of modified hybrid SC-FDMA-DSCDMA technique. Further, it is aimed at establishing the proposed technique as a suitable alternative to the technique proposed by Luo and Xiong [5] and other existing techniques like SC-FDMA, MC-DS-CDMA, and OFDMA by comparing the PAPR and BER performance under different channel conditions. Firstly, it will be ensured that no degradation in BER performance takes place due to the modified system. Then, the extent of improvement in PAPR performance offered by the proposed modified SC-FDMA-DSCDMA technique will be analyzed.

3. Overview of Proposed SC-FDMA-DSCDMA

Figure 1 shows the modified SC-FDMA-DSCDMA system structure. Unlike OFDMA or OFDM-CDMA, SC-FDMA-DSCDMA is a single-carrier spread spectrum technique. In this technique, the signal is generated by serial concatenation of DS-CDMA and SC-FDMA. The key model of this system is SC-FDMA model. The principle of SC-FDMA-DSCDMA is firstly to map the chips of a spread data symbol in frequency domain.

The transmitter of this system groups the modulation symbols into blocks each containing N symbols. The SC-FDMA system involves an N-point FFT operation, and then it maps each of the N-FFT outputs to one of the M ($> N$) orthogonal subcarriers that can be transmitted. Then, an M-point IFFT transforms the subcarrier amplitudes to a complex time domain signal. After that it inserts cyclic prefix to provide guard time [8, 9].

Therefore, transmitted data propagating through the channel can be modelled as a circular convolution between the channel impulse response and the transmitted data block through the use of cyclic prefix. At receiver side, the received signal is converted into frequency domain via DFT and then frequency domain equalization is performed after demapping the subcarriers. The equalized symbols are transformed back to the time domain via IDFT, and decoding takes place in the time domain. At last, despreading is done by multiplying each symbol with the same pseudorandom code and then detection takes place [8].

4. PAPR of SC-FDMA-DSCDMA Signals

In this section, we analyze the PAPR of the SC-FDMA-DSCDMA signal for localized FDMA. The information symbols are represented by $b_k = \{b_k(n),\ n = 1, 2, \ldots, N\}$ for user k, where $k = 1, 2, \ldots, K$. The random data b_k is first multiplied with the spreading code, yielding y_k. It is Kronecker product of b_k and $C_k/\sqrt{L}$, as shown in

$$y_k = b_k \odot \frac{C_k}{\sqrt{L}}. \quad (1)$$

Each data symbol is mapped into complex-valued data symbol, that is, d_k. In the process of spreading, the spreading code will be normalized. We call the elements in y_k "chips." Then, y_k is passed to SC-FDMA modulation after DFT precoded operation, yielding Y_k [5]. Let $Y_k : k = 0, 1, \ldots, N-1$ denote the frequency domain samples after DFT of $\{y_k\}$. Define $\{\widetilde{Y}_k : k = 0, 1, \ldots, M-1\}$ as the frequency domain samples after subcarrier mapping, which can be described as follows:

$$\widetilde{Y}_k = \begin{cases} Y_k, & 0 \le k \le N-1 \\ 0, & N \le k \le M-1. \end{cases} \quad (2)$$

Define $\{\widetilde{y}_m : m = 0, 1, \ldots, M-1\}$ as the time domain symbols after IDFT of $\{\widetilde{Y}_k\}$. Then let $m = Qn + q$, where $0 \le q \le Q-1$ and $0 \le n \le N-1$. Then, $\{\widetilde{y}_m\}$ can be expressed as follows [10]:

$$\widetilde{y}_m = \widetilde{y}_{Qn+q} = \begin{cases} \dfrac{y_n}{Q}, & q = 0, \\ \dfrac{1 - e^{j2\pi(q/Q)}}{QN} \cdot \displaystyle\sum_{p=0}^{N-1} \frac{y_p}{1 - e^{j2\pi((n-p)/N + q/QN)}}, & q \neq 0. \end{cases} \quad (3)$$

As expressed in (3), $\{\widetilde{y}_m\}$ has $1/Q$ weighed copies from the initial sequence $\{\widetilde{y}_m\}$ in positions where $q = 0$. However, in those positions where $q \neq 0$, $\{\widetilde{y}_m\}$ is the linear combination of $\{\widetilde{y}_m\}$, which can be regarded as the interpolation process that leads to PAPR. Hence, the PAPR of LFDMA can be defined as [10]

$$\text{PAPR} = \frac{\max_{0 \le t \le MT} |y(t)|^2}{(1/MT)\int_0^{MT} |y(t)|^2\, dt}, \quad (4)$$

where $y(t)$ represents the analog time domain signal of SC-FDMA-DSCDMA data block after considering the effect of baseband pulse shaping filter and T is the period.

5. Simulation Results

To evaluate the BER and PAPR performance of the proposed SC-FDMA-DSCDMA system, the MATLAB Simulink model has been developed for uplink over different fading channels (AWGN, Rayleigh fading, and Rician fading) and with respect to different size of FFT. Table 1 shows the various parameters considered in the Simulink model for performance evaluation.

Figure 2 shows the BER performance of modified SC-FDMA-DSCDMA obtained for fixed number of users with QPSK modulation over AWGN channel.

Table 1: Simulation parameters.

Parameter	Value
Modulation scheme	QPSK
Normalization factor	$1/\sqrt{2}$
FFT size	64
Spreading code	Pseudorandom codes
Coding mode (rate)	Convolutional (1/2)
Cyclic prefix	1/4
Channel	AWGN, Rayleigh, and Rician
Channel estimation	Ideal
Channel equalization	Zero-forcing equalizer

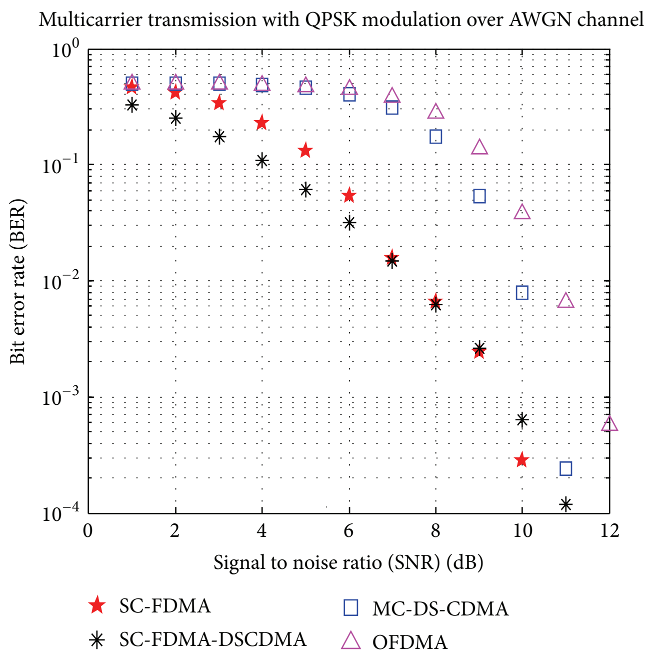

Figure 2: BER performance of the proposed SC-FDMA-DSCDMA technique compared with other multicarrier techniques (over AWGN channel). BER performance of the proposed technique is best and very close to that of SC-FDMA and Luo and Xiong [5]. No degradation in BER.

Simultaneously it is compared with BER performance of other multicarrier techniques such as SC-FDMA, MC-DS-CDMA, and OFDMA. The figure shows that the BER performance is improved with increase in SNR value. It can be very clearly observed from Figure 2 that, at BER of 10^{-3} over AWGN channel, the SNR requirement of SC-FDMA system and SC-FDMA-DSCDMA system is 9.2 dB and 9.6 dB, respectively. Further, MC-DS-CDMA system requires SNR value around 10.5 dB whereas the OFDMA system's requirement is 11.7 dB. Thus, it can be concluded from this figure that BER v/s SNR performance of the proposed SC-FDMA-DSCDMA system is best when compared to MC-CDMA as well as OFDMA and very close to that of SC-FDMA system. It has also been observed that the BER performance of the proposed technique does not show any degradation in BER with

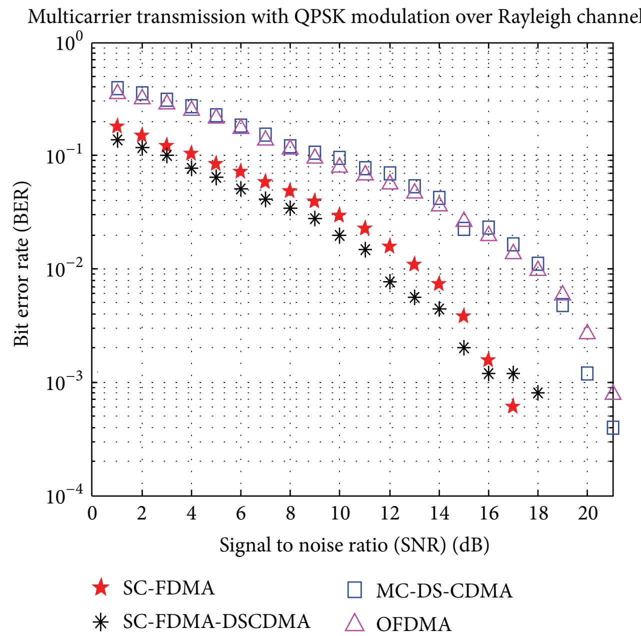

Figure 3: BER performance of the proposed SC-FDMA-DSCDMA technique compared with other multicarrier techniques (over Rayleigh channel). BER performance of the proposed technique is again best and very close to that of SC-FDMA. No degradation due to modified technique.

respect to technique described in [5]. Figure 3 shows the comparative BER curves for the different systems, that is, SC-FDMA-DSCDMA, SC-FDMA, MC-CDMA, and OFDMA, over Rayleigh fading channel.

The comparative BER curves in Figure 3 depict similar behaviour to that of Figure 2 under AWGN. It can be observed from Figure 3 that, to achieve a BER of 10^{-3} over Rayleigh channel, the SC-FDMA, SC-FDMA-DSCDMA, MC-DS-CDMA, and OFDMA systems require SNR value of 16.8 dB, 17.5 dB, 20 dB, and 21 dB, respectively. The BER performance of SC-FDMA-DSCDMA is again found to be very close to that of SC-FDMA and no degradation in BER has taken place due to the use of proposed technique. Figure 4 also shows a similar BER performance of different multicarrier systems over Rician channel.

The different relevant parameters are clearly marked in Figure 4. We have used localized subcarrier mapping for SC-FDMA-DSCDMA. Thus, it can be concluded that BER v/s SNR performance of the proposed SC-FDMA-DSCDMA system shows no degradation in the BER due to change in the placement of CDMA spreading block. The proposed technique is best when compared to MC-CDMA as well as OFDMA and very close to that of SC-FDMA system. Further, these results are clearly in line with earlier reported research work by Luo and Xiong [5].

After ensuring that no degradation in BER performance takes place due to the use of proposed SC-FDMA-DSCDMA technique, now it is imperative to determine the extent of improvement in PAPR performance offered by the proposed technique. PAPR is a performance measurement that is

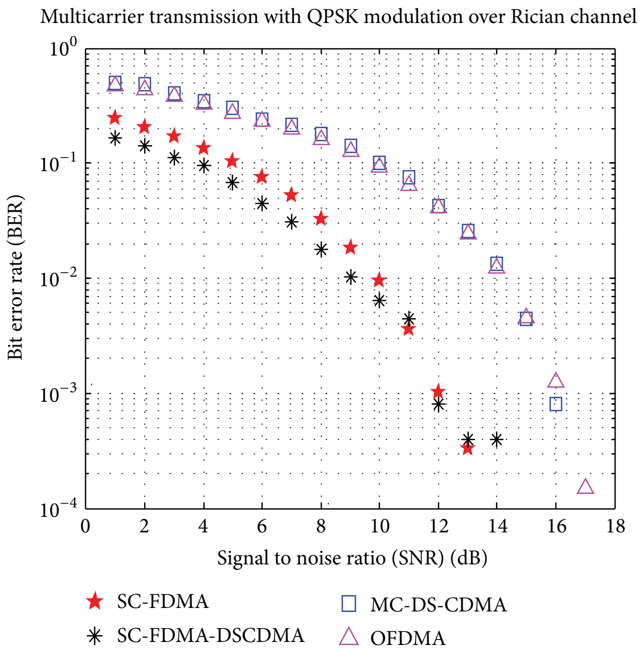

FIGURE 4: BER performance of the proposed SC-FDMA-DSCDMA technique compared with other multicarrier techniques (over Rician channel). BER performance of the proposed technique is again best and very close to that of SC-FDMA. No degradation due to modified technique.

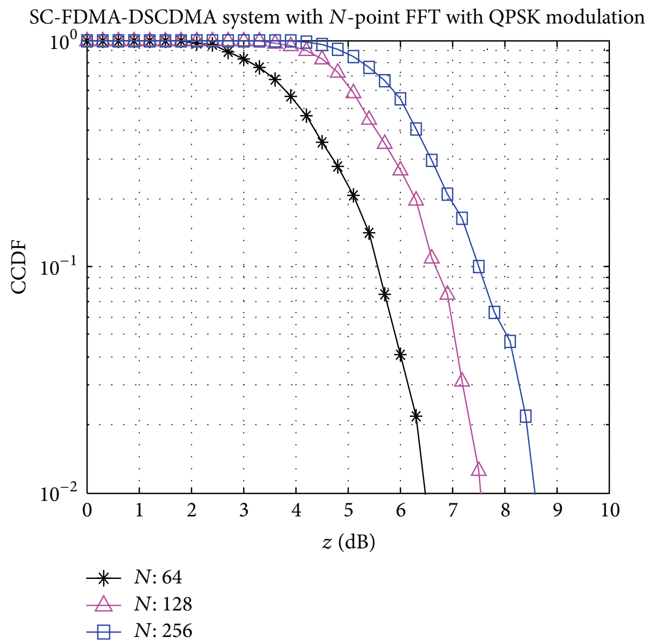

FIGURE 5: PAPR performance of the proposed SC-FDMA-DSCDMA technique for different FFT size with QPSK modulation. FFT size: N indicates the number of subcarriers. PAPR increases with increase in FFT size.

indicative of the power efficiency of the transmitter. A positive PAPR in dB means that we need a power backoff to operate in the linear region of the power amplifier and high PAPR degrades the transmit power efficiency performance. We calculate the CCDF (complementary cumulative distribution function) of PAPR, which is the probability that PAPR is higher than a certain PAPR value PAPR_0 ($\Pr\{\text{PAPR} > \text{PAPR}_0\}$). Figure 5 shows the PAPR performance of SC-FDMA-DSCDMA with respect to different N-point FFT with QPSK modulation.

It has been observed that as the FFT size increases, the PAPR value is also increased. For example, in Figure 5, 64-point FFT has PAPR of 6.4 dB; 128-point FFT has PAPR of 7.55 dB, whereas 256-point FFT has PAPR of 8.6 dB. Next, the PAPR performance of the proposed SC-FDMA-DSCDMA technique is being illustrated in Figure 6.

Figure 6 shows the CCDF curves of PAPR for different multicarrier systems while modulation technique is QPSK and FFT size is 256. This plot clearly shows that the proposed modified technique, that is, SC-FDMA-DSCDMA, provides best PAPR performance among all multicarrier systems considered in this paper. From the figure it is observed that OFDMA has the highest PAPR of 11.2 dB followed by MC-DS-CDMA (9.8 dB), SC-FDMA (9.5 dB), and the proposed SC-FDMA-DSCDMA (8.6 dB), respectively. SC-FDMA-DSCDMA thus provides the best PAPR performance around 1 dB better than SC-FDMA. Further, an improvement of around 2 dB has also been obtained by the proposed modified technique as compared to the technique by Luo and Xiong [5]. Therefore, we can say that the modified SC-FDMA-DSCDMA technique is best suited for uplink in next generation wireless communication.

6. Conclusion

The main objective of this paper was to propose such a technique which could provide improved PAPR performance without any degradation in the system BER. In view of this, we proposed a modified hybrid technique, that is, SC-FDMA-DSCDMA, which is a combination of SC-FDMA and DS-CDMA. In this paper, we have explored an idea that PAPR can be reduced further by proper placement of spreading/despreading block in hybrid OFDM-CDMA systems. The proposed technique has been obtained by modifying the technique considered by Luo and Xiong [5].

In order to justify the relevance of the proposed technique, firstly it was ensured that no degradation in BER performance takes place due to the modified technique when simulated under different fading channel conditions (AWGN, Rayleigh, and Rician). Then, the extent of improvement in PAPR performance offered by the proposed modified SC-FDMA-DSCDMA technique has been analyzed.

Simulation results prove that BER v/s SNR performance of the proposed SC-FDMA-DSCDMA system shows no degradation in the BER due to change in the placement of CDMA spreading block. The proposed technique is best when compared to MC-CDMA as well as OFDMA and very close to that of SC-FDMA system. Further, these results are

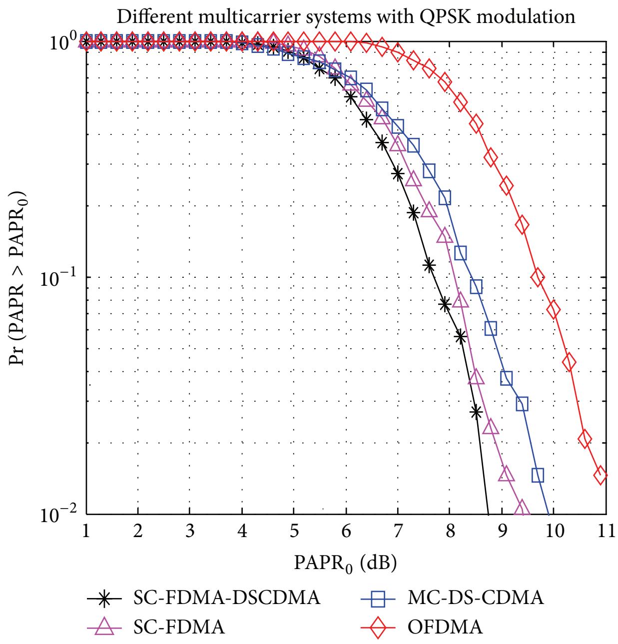

Figure 6: PAPR performance of the proposed SC-FDMA-DSCDMA technique compared with other multicarrier techniques. QPSK modulation with FFT size being 256. PAPR performance of the proposed technique is best: 1 dB better than SC-FDMA and 2 dB better than Luo and Xiong [5].

clearly in line with earlier reported research work by Luo and Xiong [5] without any degradation.

After ensuring that no degradation in BER performance takes place due to the use of proposed SC-FDMA-DSCDMA technique, the main objective of determining the extent of improvement in PAPR performance offered by the proposed technique has been realized. Simulation results showed that the proposed modified technique, that is, SC-FDMA-DSCDMA, provides an improvement of around 1 dB over SC-FDMA technique and 2 dB over the technique reported by Luo and Xiong [5].

Thus, it can be concluded that the proposed modified SC-FDMA-DSCDMA technique provides improved PAPR performance with no degradation in the system BER. It performs better than any other existing OFDM-CDMA based system for next generation wireless communication and, thus, could prove to be a good alternative technique. However, the BER and PAPR performance could further be improved through various equalization techniques and by implementing other coding/spreading/PAPR reduction techniques.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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