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PAPR Reduction of OFDM with DFT Spreading Method

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Abstract

Future communication systems will demand the transmission of huge amounts of data, therefore will require a highly linear power amplifier. The Orthogonal Frequency Division Multiplexing (OFDM) technique is widely used in multimedia services for providing high data rates and providing high Quality of Service. The transmitter power amplifier's range of operation in a communication system is linear. Signal distortion happens when the input signal's amplitude exceeds the linear range of the transmitter power amplifier. Therefore, the transmitter's input signal has to have a low peak to average power ratio (PAPR). The OFDM system has been recognized as the high rate wireless radio channel transmission. Therefore, it will also be highly beneficial for the high-speed communication system. However, due to the extremely high PAPR issue, using the OFDM system in a communication system is not simple. It results in extremely low power efficiency. Therefore, it is crucial to lower the PAPR in the OFDM system in order to employ it in the communication system. By using a discrete Fourier matrix, the Discrete Fourier Transform spreading strategy may significantly lower the PAPR of an OFDM signal. This paper describes the PAPR reduction approach in OFDM signals and examines the effectiveness of OFDM.

Keyword: DFT Spread, OFDM, PAPR, PSD, BER, SNR, cyclic prefix (CP)

1. Introduction

Nowadays wireless communication (WC) demands a high throughput and speed. Since high-speed wired communications gained popularity decades ago, WCs have become more and more common [1]. For downlink communication, the majority of wireless networks employ OFDM. They are perfect for usage with challenging channels since they are adaptable. It's a wise decision to employ OFDM for 4G communications. However, the

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fundamental drawback of OFDM is its PAPR [2]. The PAPR can be decreased using a variety of techniques. Rapid advancements in mobile communication technology can be linked to rising mobile usage and the scale of connected industries. As a result, WC systems need to handle faster transmission rates, have larger capacities, and utilize bandwidth resources more effectively. Due to a lack of spectrum resources, the system must increase its spectrum use [3]. WC networks are now saturated as a result of the exponential rise in users and the corresponding rise in demand for wireless applications [4]. Researchers and network designers seek to provide extremely high data speeds, broad radio coverage, and a huge number of highly effective and low-latency linked devices in order to address these basic issues. The growth of 5G wireless networks will depend heavily on intelligent and effective wireless network solutions [4-5]. For a 5G network to be dependable, secure, and effective, it must be able to overcome significant obstacles.

A multicarrier (MC) orthogonal communication system is OFDM. OFDM systems are the preferred option for modern communication systems and are being used in many of them, including WLAN, LTE, DAB, and DVB [6]. They also have high data rates and are immune to fading. Although OFDM offers a number of benefits, it has some problems. Tight frequency synchronization, temporal offset, PAPR, and channel estimation are a few of these problems. High data rates are always in demand for cellular and local area WCs systems in the future [7]. The OFDM technology, which is based on the IEEE 802.11a and 802.11g standards, claims to give the greatest bit rates in widely deployed wireless networks. The 3GPP employs OFDMA to attain greater data rates while developing cellular systems in the future [8,18]. OFDM modulation is the foundation of OFDMA. It is based on the idea of using an IDFT operation to divide the data stream into several narrowband subcarriers that are orthogonal to one another [9]. Because it converts the frequency-selective fading channel into a flat fading channel using a simple receiver, the OFDM system is superior to conventional communication methods in several ways. It is also spectrally efficient, making it perfect for multimedia communications, and it has been mostly adopted for use in future communications for various services. However, it also has drawbacks, including a high PAPR, sensitivity to time and frequency synchronization issues, ICI, and CCI. Each OFDM symbol has a CP, which is a repetition of the final portion of an OFDM symbol, appended at the beginning. ISI and ICI related distortions are prevented if the duration of the CP is longer than the channel's maximum delay [10]. The receiver's equalization process is greatly simplified by the narrowband subcarriers' avoidance of frequency selective multipath fading and guarantee of just flat fading response. Because subcarriers are orthogonal to one another, there is a chance that they may overlap, creating a system with a high spectral efficiency.

Independent phases of subcarriers in a MC communication system may have a positive or negative impact. A high PAPR and peak amplitude are produced by the constructive effect when all subcarriers utilize the same phase [18]. The transmitter amplifier may operate in the saturation area if the amplitude of the OFDM signal exceeds its linear operating range, which causes nonlinear distortion. Numerous techniques have been explored to reduce this high PAPR [11]. The multiple access approach known as DFT- spread, often referred to as SC-FDMA, is based on the SC-FDM modulation method. Its operation is predicated on the OFDM concept [12]. As a result, low-complexity equalization and multipath mitigation are both fully realized. However, DFT-spread differs from OFDM in that it spreads the data symbols over complete subcarriers before the IDFT operation, creating a structure that is essentially single carrier. DFT-main spreading's benefit is that it has a lower PAPR than an OFDM system. Since PAPR has a lower value, uplink transmissions are good matches because of the advantage of transmitted power efficiency. As all symbols are present in all subcarriers, it also enables the channel's frequency selectivity. If a specific subcarrier is badly faded, information can still be retrieved from other subcarriers with good channel conditions. When DFT despreading is performed at the receiver, noise is distributed over all subcarriers, which has the negative effect of enhancing noise [13].

This paper provided a brief history of OFDM and the PAPR reduction approach. The remaining of the article is structured as follows. Section 2 gives information on the OFDM system model. The DFT spreading technique is explained in Section 3. Section 4 discusses the results, and Section 5 provides a conclusion.

2. OFDM

The information symbols are transmitted using OFDM, a modern MC broadcast technique, via a number of orthogonal components [14]. In contrast to frequency-based fading networks, MC communication is a robust method with exceptional spectral efficiency and excellent bit rate performance. In the OFDM system, the IDFT is utilized to regulate the OFDM movements in order to create the orthogonal subcarriers. The time domain amplitude of the OFDM system has relatively large oscillations that might generate considerable disturbance in terms of fluctuations due to the grouping of several subcarrier components in the transmission [15]. The PAPR is used to describe these large variations. When OFDM signals with frequent PAPR are subjected to high pass amplification, the signals are trimmed, which leads to performance deterioration, out-of-band signaling, and noise [16-18].

An OFDM system block diagram is shown in Figure 1. First, binary data are combined and mapped into signals with multiple amplitudes and phases. The modulated data *X(k)* are delivered to an IFFT after pilot insertion. Multiplexing the converted data into *x(n)* as

$$s(n) = \sum_{m=0}^{N-1} S(m) e^{\frac{j 2 \Pi m n}{N}} \; ; n = 0 \; to \; N-1$$

Here, no. of subcarriers are N. To avoid ISI, the guard interval g_n is introduced.

The produced $s_g(n)$ samples are

$$s_g(n) = \begin{Bmatrix} s(N+n); & n = g_n, g_n - 1, \ldots, -1 \\ s(n); & n = 0, 1, 2, \ldots, N-1 \end{Bmatrix}$$

Here, the no. of samples that make up the guard interval are g_n. After that, a frequency-selective multipath fading channel receives the broadcast signal. The signal that was received can be given as

$$y_g(n) = s_g(n) \otimes h(n) + w_G(n)$$

Where $\otimes$ is the circular convolution, $w_G(n)$ is the AWGN, and h(n) is the impulse response.

The time domain signal *s(n)* is associated to PAPR. Baseband signals are delivered with transmitted pulses in communication systems. Therefore, the multi-amplitude multi-phase sequence of *s(n)* is represented by

$$x(t) = \sum_{m}^{N} s(n) P_t(t - m T_s)$$

Here T_s symbol duration and $P_t(t)$ represent the transmit pulse. The PAPR is complex signal's maximum power to average power ratio.

$$PAPR_{x(t)} = \frac{\max \left| [x(t)] \right|^2}{E\left[|x(t)|^2 \right]}$$

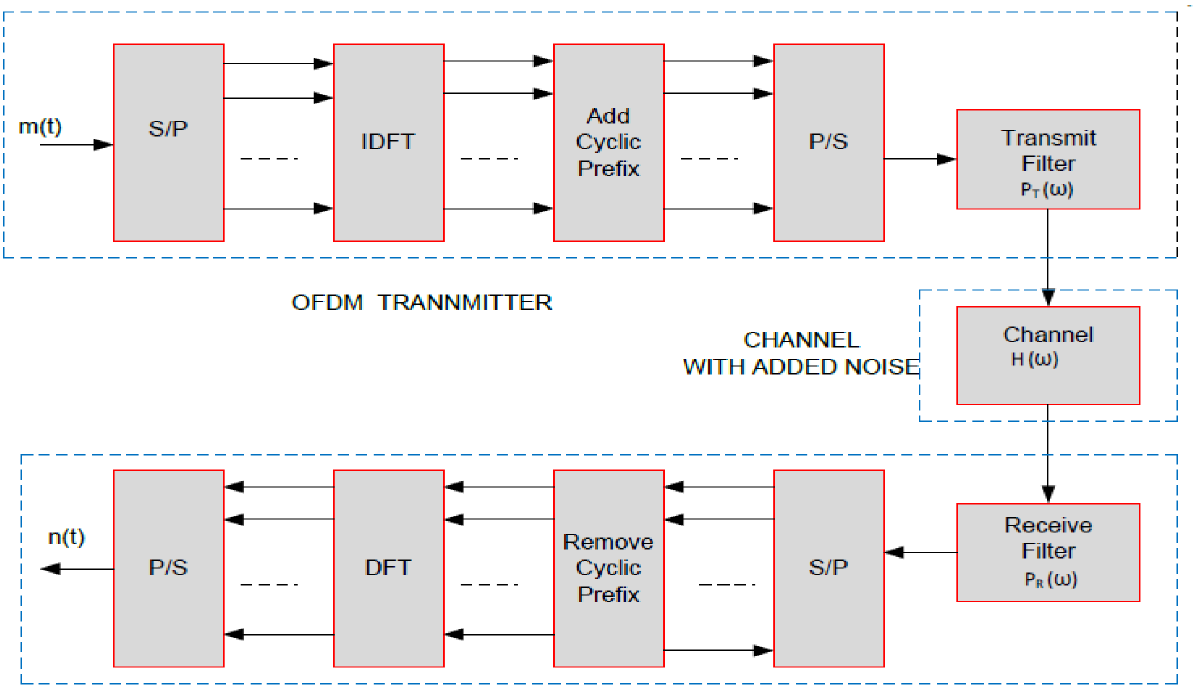

Figure 1. OFDM system [8]

3. DFT Spreading

Similar to OFDM, a DFT spreading system's transmitter is made up of a S/P converter, DFT spreading, IDFT operation, P/S converter, adding CP, DAC, and finally RF modulation in order to convert baseband signal into pass band signal before forwarding through the channel. Figure 2 depicts the DFT spread block diagram.

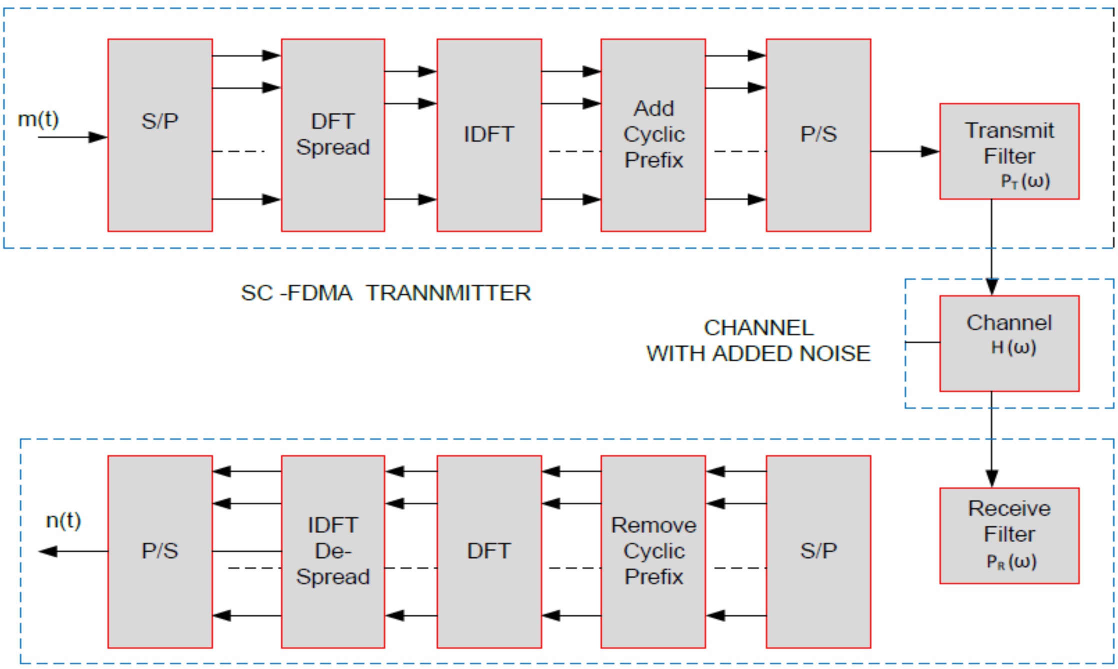

Figure 2. DFT spread block diagram [8]

Consider the OFDMA system before going to the DFT-spreading approach. As shown in Figure 3, let's assume that the DFT is utilized as a (spreading) code and has the same size as the IFFT. Because the DFT and IDFT procedures essentially cancel each other out, the OFDMA system therefore equals the SC-FDMA system. The transmit signal in this scenario will have the same PAPR as a SC system.

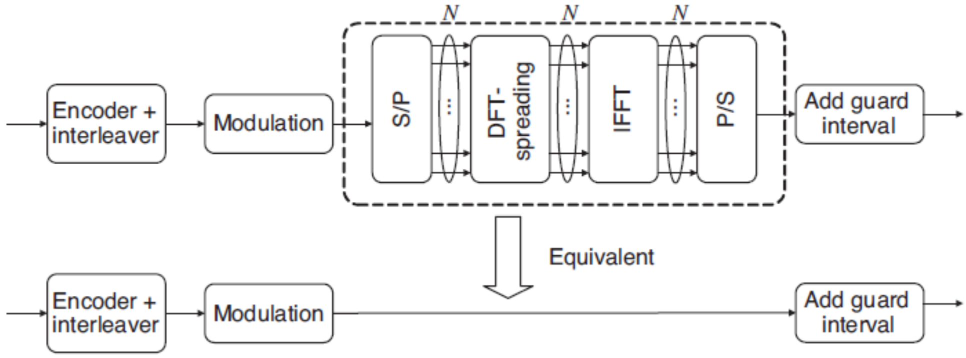

Figure 3. OFDMA with DFT-spreading [17]

Subcarriers are divided up and allotted to various mobile terminals in OFDMA systems. Every terminal in the uplink transmission employs a specific subset of subcarriers to send its own information, however unlike downlink transmission. Subcarriers will be filled with zeros for the remaining ones, if they are not used for its own information transfer. Here, it will be assumed that each user has access to M subcarriers. The output of the DFT is allocated to the subcarriers of the IFFT in the M-point DFT spreading approach.

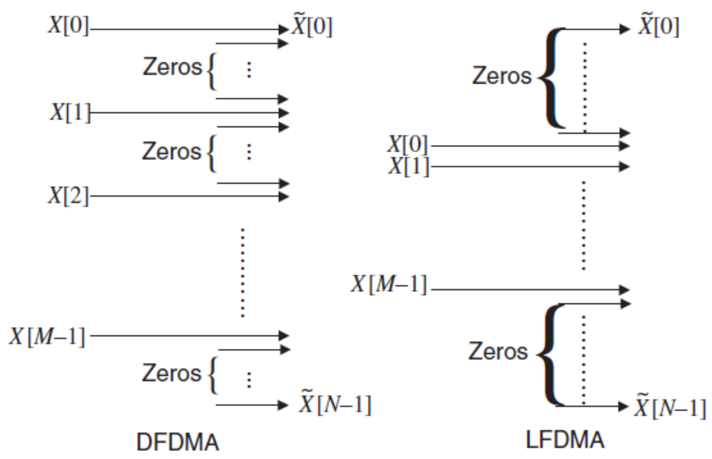

Figure 4. Sub carrier mapping in DFDMA and LFDMA uplink [17]

The method used to assign subcarriers to each terminal determines the effect of the PAPR reduction. DFDMA and LFDMA are two distinct methods of allocating subcarriers among users, as seen in Figure 4. While LFDMA distributes DFT outputs to M successive subcarriers in N subcarriers, DFDMA distributes M DFT outputs throughout the full band with N-M unused subcarriers filled with zeros. IFDMA is referring to DFDMA, when it distributes DFT outputs with equi-distance bandwidth spreading factor (S) = N/M.

The subcarriers transmitted in the DFDMA and IFDMA are shown in Figure 5. DFT spreading in DFDMA, LFDMA, and IFDMA are shown in Figure 6. It demonstrates the link between a 4-point DFT and a 12-point IDFT subcarrier mapping.

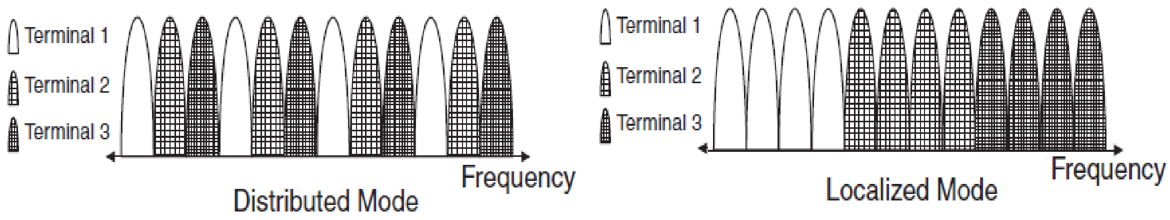

Figure 5. Subcarrier allotment to multiple users [17]

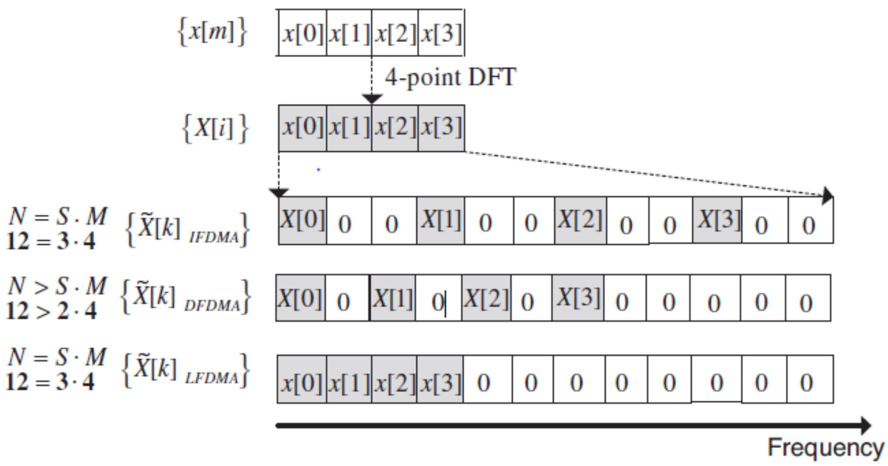

Figure 6. DFT spreading : IFDMA, DFDMA, LFDMA [17]

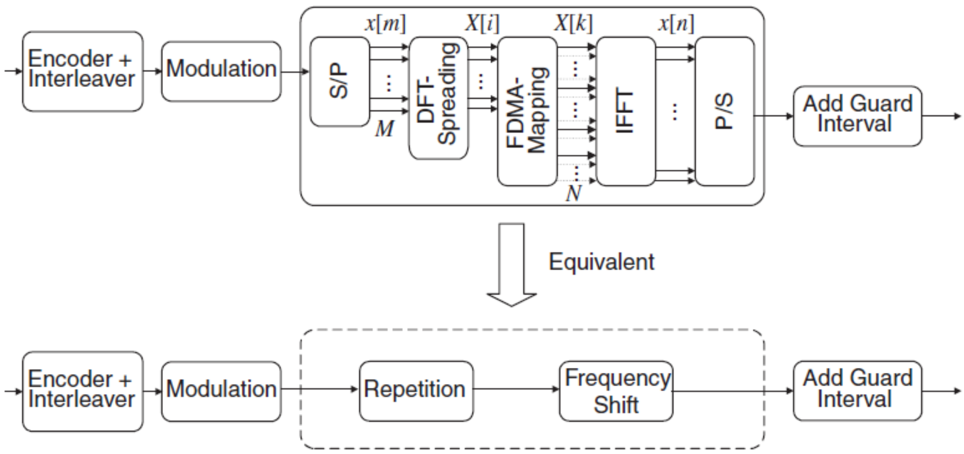

Figure 7. Uplink transmitter using the IFDMA DFT-spreading approach [17]

A block schematic of the IFDMA-based DFT-spreading uplink transmitter is depicted in Figure 7. The input data x(m) in this instance is DFT-spread to produce X[i], which is then allocated as

$$\tilde{X}[k] = \begin{cases} X\left(\frac{k}{S}\right); & k = S.m_1; m_1 = 0 \ to \ M-1 \\ 0; & otherwise \end{cases}$$

The output of the IFFT $\tilde{x}[n]$ with n=Ms+m for s=0 to S-1; m= 0 to M-1 can be represented as

$$\tilde{x}[n] = \frac{1}{N}\sum_{k=0}^{N-1} \tilde{X}[k] e^{\frac{j2\Pi nk}{N}} = \frac{x[m]}{S}$$

This is shown to be a time domain repeat of the first input signal x(m) scaled by 1/S. The DFT-spread symbol in the IFDMA when the subcarrier mapping begins with the r^{th} (r=0 to S-1) subcarrier may be written as

$$\tilde{X}[k] = \begin{cases} X\left(\frac{k-r}{S}\right); & k = S.m_1 + r \\ 0; & otherwise \end{cases}$$

The output sequence of the IFFT is written by

$$\tilde{x}[n] = \tilde{x}[Ms+m] = \frac{x[m].e^{\frac{j2\Pi nr}{N}}}{S}$$

4. Simulation Results

Using MATLAB, we examine the OFDM system's performance. The SNR vs BER of OFDM is shown in Figure 8. Figure 9 depicts the frequency spectrum of the original OFDM signal, with the no. of subcarriers to be 8, the no. of transmitted symbols equal to 128, and the overall frequency being 100 MHz. Figure 10 compares the PAPR performances for the IFDMA, LFDMA, and OFDMA when the DFT-spreading approach is used. Here, a SC-FDMA system with N=256, M=64, and S=4 uses QPSK, 16 and 64-QAM. Figure 10 illustrates how the subcarrier allocation method affects the PAPR effectiveness of the DFT-spreading method. The values of PAPRs for IFDMA, LFDMA, and OFDMA for CCDF of

10-4 in the case of 16-QAM are 5.3 dB, 9.6 dB, and 12.4 dB, respectively. The PAPR of IFDMA is lower as compared to OFDMA and LFDMA.

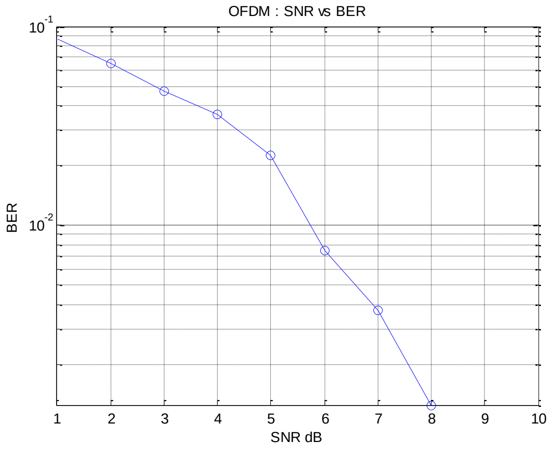

Figure 8. SNR vs BER

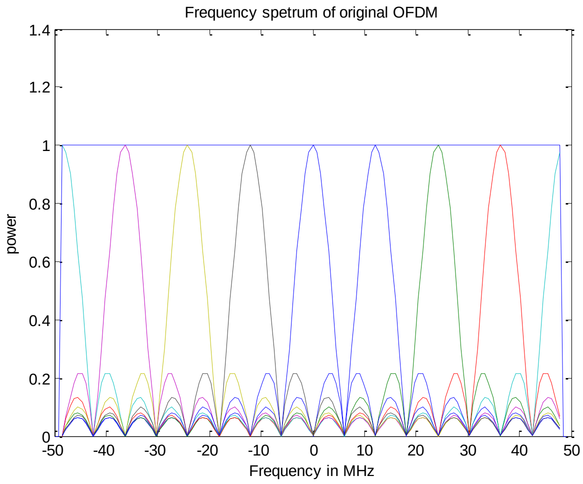

Figure 9. Frequency spectrum

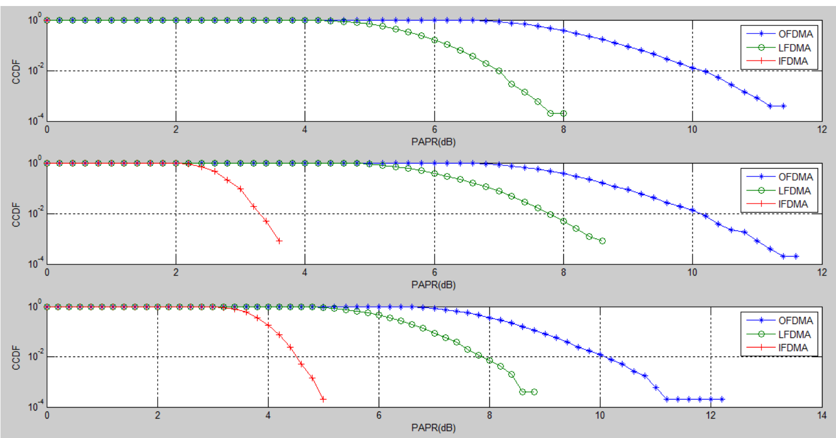

Figure 10a. DFT-spreading approach PAPR results for IFDMA, LFDMA, and OFDMA (QPSK, 4QAM, 16QAM for N=256)

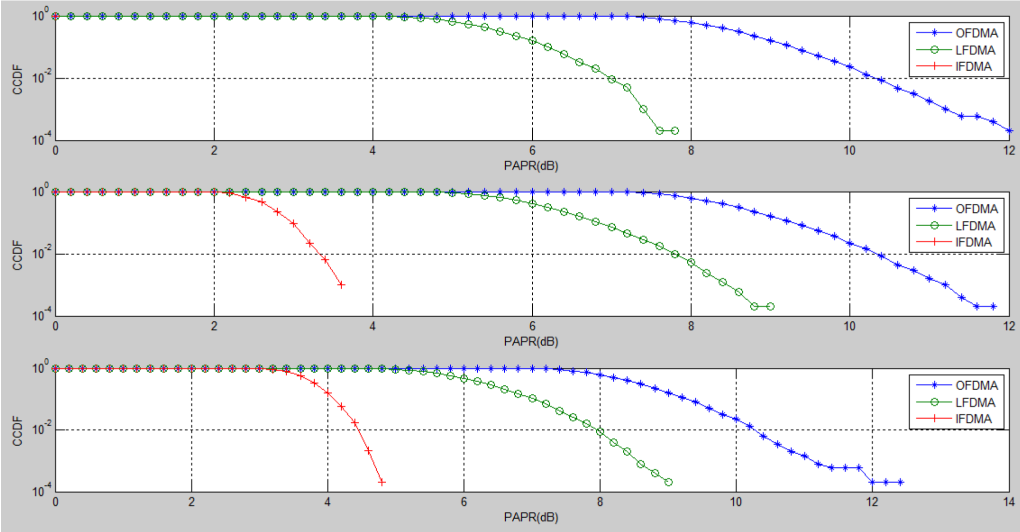

Figure 10b. DFT-spreading approach PAPR results [N=512]

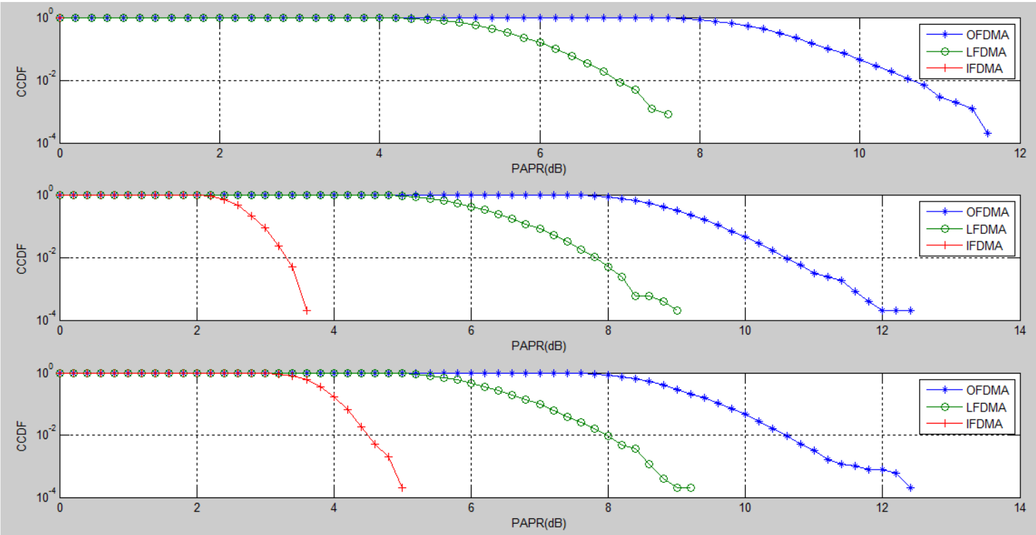

Figure 10c. DFT-spreading approach PAPR results [N=1024]

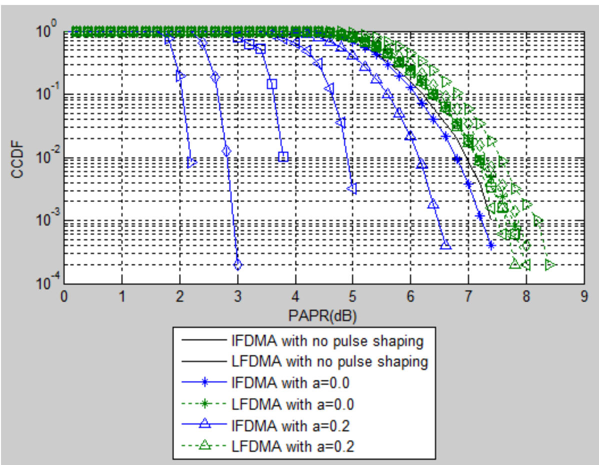

Figure 11a. PAPR of DFT-spreading method with RC filter for QPSK

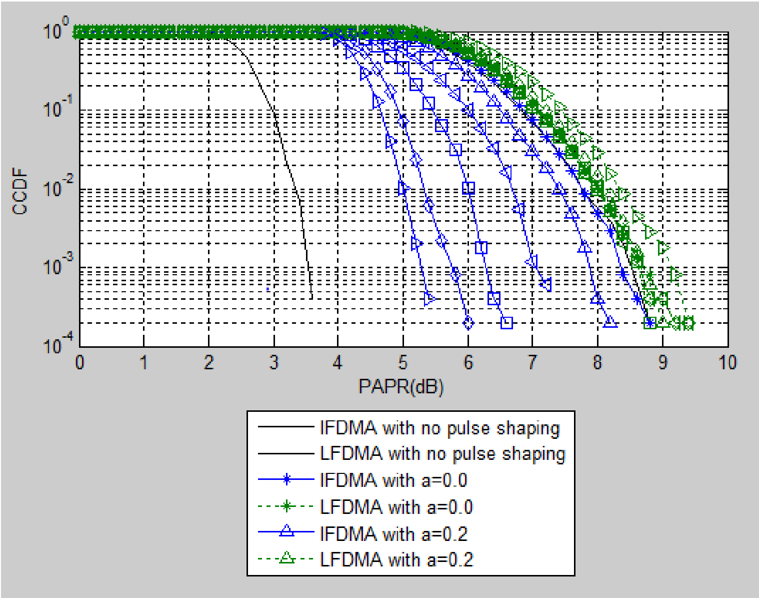

Figure 11b. PAPR of DFT-spreading method with RC filter for 16-QAM

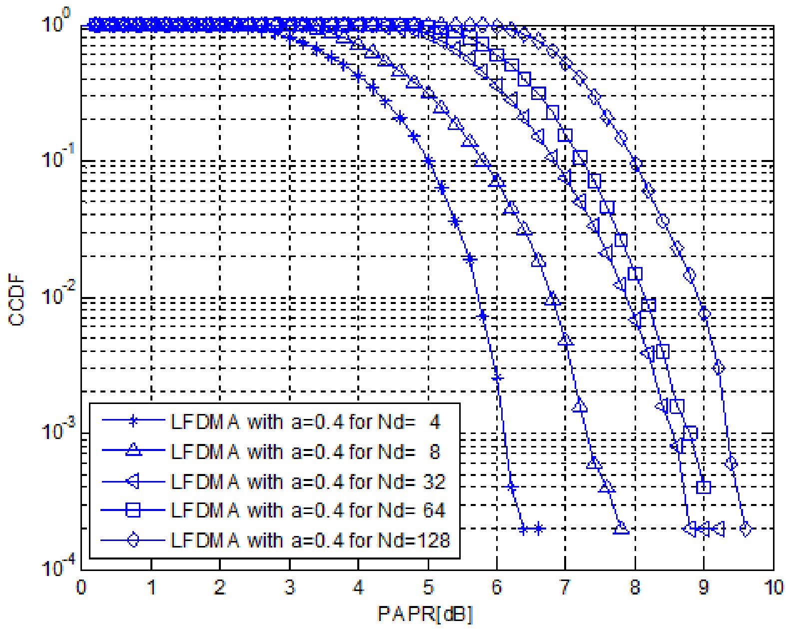

Figure 12. PAPR of DFT-spreading method when sub-blocks vary

Figure 11 depicts how the roll-off factor of the RC filter for pulse shaping after IFFT affects the PAPR analysis of the DFT-spreading approach with IFDMA and LFDMA. This figure illustrates how raising the roll-off factor from a = 0 to 1 may considerably enhance the PAPR performance of IFDMA. LFDMA is not as significantly impacted by pulse shaping. Since additional bandwidth rises as the roll-off factor gets larger, it suggests that IFDMA has to choose between PAPR performance and excess bandwidth. The simulation parameters used in this analysis for both QPSK and 16-QAM were N=256, M=64, spreading factor S=4, and oversampling factor=8.

Figure 12 illustrates that, using LFDMA with a roll-off factor of 0.4, the PAPR performance of the DFT-spreading approach degrades as no. of blocks rises. The SC-FDMA system with 256-point FFT in this case uses 64-QAM.

5. Conclusion

Even though one of the best spectrally efficient modulation methods for upcoming high-speed communication systems is OFDM, it has a very high PAPR value, which reduces the linearity of power amplifiers. Power amplifiers function in the nonlinear region when PAPR is high. There are several methods used to reduce PAPR. In this article, the principle of OFDM and reduction PAPR using DFT spreading is presented. The simulation results indicate that this approach efficiently lowers the PAPR and can be utilized in an OFDM transmitter. High data rates for uplink communications with a reduced PAPR are offered by the DFT spread approach. The PAPR is obtained almost similar to that of the single carrier communication systems. It offers advantages for low-complexity equalization and multipath mitigation. When used with a pulse-shaping network and a higher roll-off factor, IFDMA system exhibits a large decrease in PAPR. The effectiveness of the CCDF is evaluated. The performance of the DFT spreading method is determined to be higher than other algorithms. SC-FDMA systems with IFDMA and LFDMA perform better than OFDMA systems in terms of PAPR.

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