Software Implementation and Comprehensive Performance of Uplink Channel on Mobile 4th Generation Technology

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Abstract

According to the further increase of demand on high data rates in wireless communications systems, the 4th generation (4G) of mobile telecommunication networks have been introduced by 3GPP (3rd Generation Partnership Project). These systems have adopted orthogonal frequency division multiplexing access (OFDMA) for downlink physical layer and single carrier frequency division multiple access (SCFDMA) for uplink physical layer. In this paper, SC-FDMA is simulated and analyzed for all the parameters and for various modulation index of phase shift keying. This research also focused on the calculation of Peak-to-Average Power Ratio (PAPR) for SC-FDMA. Finally, a performance evaluation for SC-FDMA implemented with different conditions are perform to show the effect of the data symbol duration and FFT (Fast Fourier Transform) size on the uplink physical layer of the 4G.

Keywords: *4G, SC-FDMA, PAPR, Uplink*

1. Introduction

The wireless mobile communication technology is moving fast from the Third Generation to the latest Fourth Generation (4G) communication. Recently, much attention has been focused on techniques such as MC-CDMA, WiMAX and LTE. In addition to the subcarrier spacing, the major difference between the two standards is that 4G adopts the Single-Carrier Frequency-Division-Multiple-Access (SC-FDMA) system for uplink transmission, rather than the commonly used Orthogonal Frequency Division Multiple Access (OFDMA) system. Since the SC-FDMA signal has a much lower PAPR than the OFDMA signal, therefore it greatly benefits the mobile terminal in terms of transmit power efficiency and terminal costs [1].

Comparing to OFDMA, SC-FDMA performs a Discrete Fourier Transform (DFT) prior to the conventional Inverse Fast Fourier Transform (IFFT) operations, which spreads the data symbols over all the subcarriers and produces a virtual single-carrier structure. This modification not only reduces consumed power significantly, but also keeps the advantages of OFDMA (such as high spectral efficiency and robustness to multipath fading) [2].

This paper presents all the principles of SC-FDMA including its transmission structure, subcarrier mapping methods in Section 2, while Section 3 explains the Mathematical formulas of PAPR considering that it is the most important property of SC-FDMA. Simulations, results with all the main conclusions from this research are presented in Sections 4 and 5.

2. 2 SC-FDMA Principles

Single-carrier FDMA scheme provides orthogonal access to multiple users simultaneously accessing the system to minimize intra cell interference and maximize capacity. SCFDMA scheme referred to as IFDMA, means that the user’s data sequence is first repeated in a predetermined number of times. Then the repeated data sequence is multiplied with a user specific phase vector. Another way of looking at this approach is FFT pre coding of the data sequence and then mapping of the FFT-pre coded data sequence to uniformly spaced subcarriers at the input of IFFT [3, 4]. The uniform spacing is determined by the repetition factor Q. The multiplication of the repeated data sequence with a user-specific phase vector can be seen as frequency shift applied in order to map transmissions from multiple users on non-overlapping orthogonal subcarriers. It should be noted that each data modulation symbol is spread out on all the subcarriers used by the UE. This can provide a frequency-diversity benefit in a frequency-selective channel. However, there may be some impact on performance as well as due to loss of orthogonally or noise enhancement when data subcarriers experience frequency selective fading. Therefore IFDMA scheme can be referred to as distributed FDMA (DFDMA). The mapping of FFT-pre coded data sequence to contiguous subcarriers results in a localized transmission in the frequency domain. Similar to distributed mapping or DFDMA, localized mapping is more practical to be implemented in real application because it can avoid inter carrier interference owing to Doppler frequency shift [5]. The distributed and localized mapping of FFT pre-coded data sequence to OFDM subcarriers is sometimes collectively referred to as DFT-spread OFDM [4].

In case of distributed FDMA, the input samples to IFFT are given as:

$$\tilde{X}_l = \begin{cases} X_{\frac{l}{Q}} & l = Q \cdot k, 0 \le k \le M-1 \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

Define n = M ×q+m, where $0 \le q \le Q-1$ and $0 \le m \le M-1$. The time domain samples at the output of IDFT are then given as:

$$\tilde{x}_n = \frac{1}{N} \sum_{l=0}^{N-1} \tilde{X}_l e^{j2\pi \frac{n}{N} l} \tag{2}$$

Using the relationship of Equation (1), the above equation can be simplified as:

$$\tilde{x}_n = \frac{1}{Q \cdot M} \sum_{k=0}^{M-1} X_k e^{j2\pi \frac{n}{M} k} \tag{3}$$

Now if n is introduced as n = M × q + m

$$\begin{aligned}\tilde{x}_n &= \frac{1}{Q\cdot M}\sum_{k=0}^{M-1} X_k e^{j2\pi\frac{M\times q+m}{M}k} \\ &= \frac{1}{Q}\left(\frac{1}{M}\sum_{k=0}^{M-1} X_k e^{j2\pi\frac{m}{M}k}\right) \\ &= \frac{1}{Q}x_m.\end{aligned} \tag{4}$$

It can be seen that the time-domain symbols at the output of size N IDFT are repetitions of time-domain symbols at the input of size M DFT. In the case of localized FDMA, the input samples to IFFT are given as:

$$\tilde{X}_l = \begin{cases} X_l & 0 \le l \le M-1 \\ 0 & M \le l \le N-1. \end{cases} \tag{5}$$

Define n = Q×m+q, where 0 ≤ q ≤ Q−1 and 0 ≤ m ≤ M −1. The time-domain samples at the output of IDFT are then given as:

$$\tilde{x}_n = \frac{1}{N}\sum_{l=0}^{N-1} \tilde{X}_l e^{j2\pi\frac{n}{N}l} \tag{6}$$

Using the relationship of Equation (14) and n = Q × m + q, the above equation can be simplified as:

$$\tilde{x}_n = \frac{1}{Q\cdot M}\sum_{l=0}^{M-1} X_l e^{j2\pi\frac{Q\times m+q}{QM}k} \tag{7}$$

Now if q is introduced as q = 0

$$\begin{aligned}\tilde{x}_n &= \frac{1}{Q}\cdot\frac{1}{M}\sum_{l=0}^{M-1} X_l e^{j2\pi\frac{m}{M}k} \\ &= \frac{1}{Q}x_m.\end{aligned} \tag{8}$$

It can be seen that every Qth time-domain sample at the output of size N IDFT is the same as the time-domain sample at the input of size M DFT. For q≠ 0, the time-domain sample at the output of size N IDFT is the sum of time-domain samples at the input of size M DFT with different complex weighting. An example of DFDMA and LFDMA mapping for M = 4,N = 8 and Q = NM = 2 is displayed in Figure 1.

The transmitted and received chains for LFDMA are given in Figures 2 and 3 respectively. All UEs use the same IDFT size of N. However, different UEs can use different DFT-precoding sizes. The size of the DFT precoder for a UE is proportional to the orthogonal subcarriers allocated to the UE for uplink transmission. Let Mi represent DFT-precoding size for the ith UE, then the following applies:

$$\sum_{i=1}^{K} M_i \le (N - G)\,, \qquad (9)$$

where K represents the number of UEs transmitting simultaneously and G the number of guard subcarriers. In the case of uplink multi-user MIMO (multiple input multiple output), different UEs can be allocated for overlapping subcarriers and therefore the condition in Equation (9) does not apply.

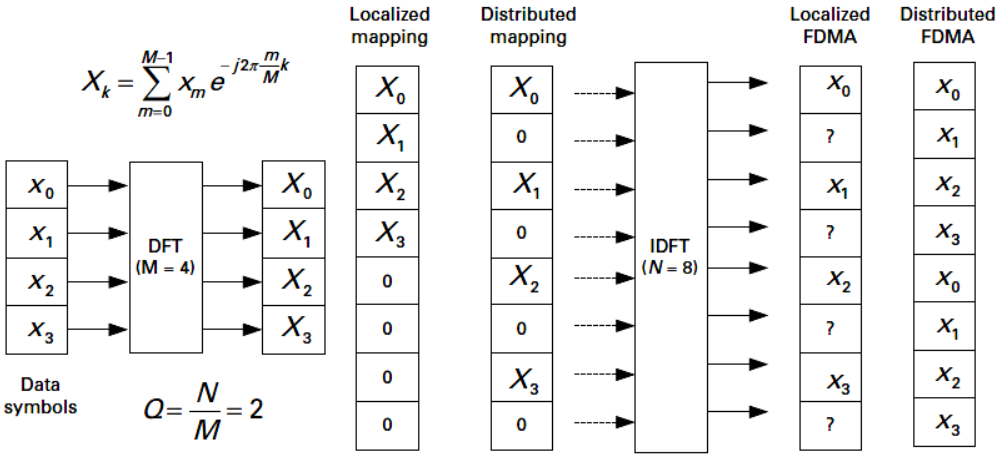

Figure 1. Subcarrier mapping for Localized and Distributed FDMA

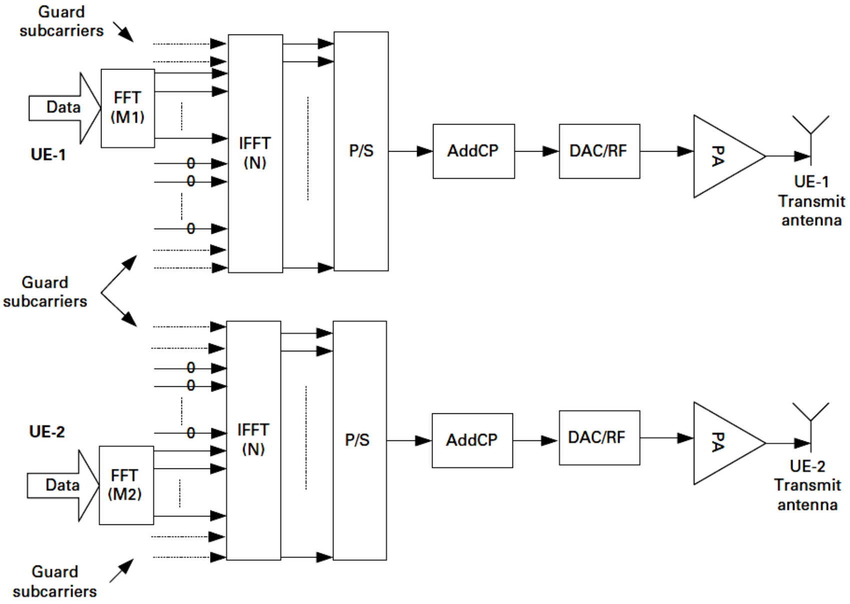

Figure 2. Localized SC-FDMA transmitter

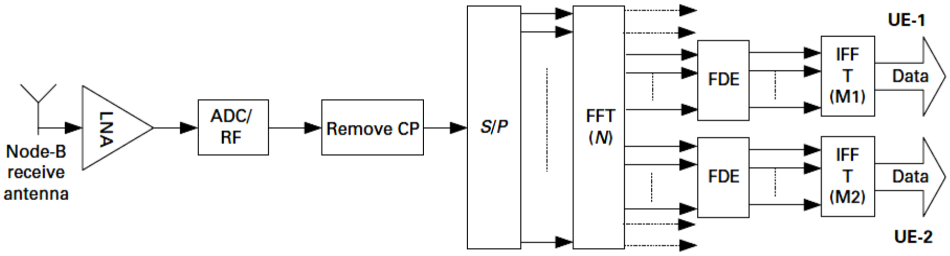

Figure 3. Localized SC-FDMA Receiver

A cyclic prefix is added after IDFT operation and the resulting sequence is an up-converted to RF, amplified and transmitted. All UEs transmitting simultaneously with their data mapped to orthogonal subcarriers perform this operation independently. Each UE power amplifier then sees a single FFT-pre coded transmission, which leads to a low signal peakiness single carrier transmission. In Figure 2, for example, UE1 and UE2 use DFT sizes of M1 and M2 for transmission from their respective power amplifiers. If, for example, FFT pre coded data sequences of UE1 and UE2 are both mapped to the same IDFT and transmitted from a single power amplifier that will no longer be a low signal peakiness single-carrier transmission. This is one of the reasons why SC-FDMA is generally not considered for downlink transmissions. In the downlink, Node-B generally transmits simultaneous signals to multiple UEs on orthogonal subcarriers using a single common power amplifier.

In the receiver side, the received signal is filtered, amplified and down-converted from RF. The cyclic prefix samples are discarded and a size N DFT operation is performed on the received samples sequence. The symbols for each UE are separated by collecting data from the subcarriers allocated to a UE. A frequency-domain equalization (FDE) operation is performed using channel estimates obtained from pilots or reference signals received for each UE. An IDFT operation is then performed separately for each UE to recover the transmitted data sequence. It should be noted that data demodulation in SC-FDMA happens in the time domain after the IDFT operation.

From a resource allocation point of view, subcarrier mapping methods are further divided into static scheduling and channel-dependent scheduling (CDS) methods. CDS assigns subcarriers to users according to the channel frequency response of each user. For both scheduling methods, distributed subcarrier mapping provides frequency diversity because the transmitted signal is spread over the entire bandwidth. With distributed mapping, CDS incrementally improves performance. By contrast, CDS is of great benefit with localized subcarrier mapping because it provides significant multi-user diversity [6].

3. Peak-to-Average Power Ratio of SC-FDMA system

PAPR is the ratio between the maximum power and the average power of the complex passband signal s(t), that is [7],

$$PAPR\{\tilde{s}(t)\} = \frac{\max\left|\mathrm{Re}\left(\tilde{s}(t)e^{j2\pi f_c t}\right)\right|^2}{E\left\{\left|\mathrm{Re}\left(\tilde{s}(t)e^{j2\pi f_c t}\right)\right|^2\right\}} = \frac{\max|s(t)|^2}{E\left\{|s(t)|^2\right\}} \tag{10}$$

SC-FDMA is a variation of OFDM that incorporates the advantages of OFDM with the low PAPR trait of single carrier systems. In SC-FDMA, to have the low PAPR trait needed, resources assigned to the same user equipment (UE) must be contiguous in the frequency domain, making packet scheduling for the uplink an unprecedented problem [8].

The peak-to-average power ratio for a single carrier modulation signal depends on its constellation and the pulse shaping filter roll-off factor. For a Gaussian distributed OFDM signal, the cumulative distribution function (CDF)i of the PAPR for 99.0%, 99.9%, and 99.99% are approximately 8.3, 10.3, and 11.8 dB, respectively. Since the OFDM signal has a high PAPR, it could be clipped in the transmitter power amplifier, because of its limited dynamic range or non-linearity. Higher output backoff is required to prevent performance degradation and inter-modulation products spilling into adjacent channels. Therefore, RF power amplifiers should be operated in a very large linear region. Otherwise, the signal peaks leak into the non-linear region of the power amplifier, causing signal distortion. This signal distortion introduces inter-modulation among the sub-carriers and out-of-band emission. Thus, the power amplifiers should be operated with large power back-offs. On the other hand, this leads to very inefficient amplification and expensive transmitters. Thus, it is highly desirable to reduce the PAPR. In addition to inefficient operation of the power amplifier, a high PAPR requires a larger dynamic range for the receiver analog-to-digital (A/D) converter [9]. In order to reduce the PAPR, several techniques have been proposed and used such as clipping, channel coding, temporal windowing, Tone Reservation, and Tone Injection. However, most of these methods are unable to simultaneously achieve a large reduction in PAPR with low complexity, with low coding overhead, without performance degradation, and without transmitter receiver symbol handshake. The PAPR x of the OFDM signal is defined as follows:

$$\xi = \left. \frac{\max|s(t)|^2}{E\{|s(t)|^2\}} \right|_{mT_u \leq t \leq (m+1)T_u} \tag{11}$$

In the above equation, E{.} denotes the expectation operator and m is an integer. From the central-limit theorem, for large values of N_{FFT}, the real and imaginary values of s(t) would have a Gaussian distribution. Consequently, the amplitude of the OFDM signal has a Rayleigh distribution with zero mean and a variance of N_{FFT} times the variance of one complex sinusoid. Assuming the samples are mutually uncorrelated, the cumulative distribution function for the peak power per OFDM symbol is given by:

$$P(\xi > \gamma) = [1 - (1 - e^{-\gamma})^{N_{FFT}}] \tag{12}$$

From the above equation, it can be seen that a large PAPR occurs only infrequently due to the relatively large values of N_{FFT} used in practice.

4. Simulation and Results

Single carrier FDMA scheme guarantees a low PAPR. This is essential for the power efficiency of the mobile terminal transmitter. A certain amount of flexibility in resource allocation and scheduling is achieved with DFT-spread OFDM in the uplink [10]. It is known that the maximum frequency in the uplink of the 4G is 20 MHz, therefore this value is considered as a sampling frequency. The bock diagram of the uplink (transmitter and receiver) system is shown in the Figure 4.

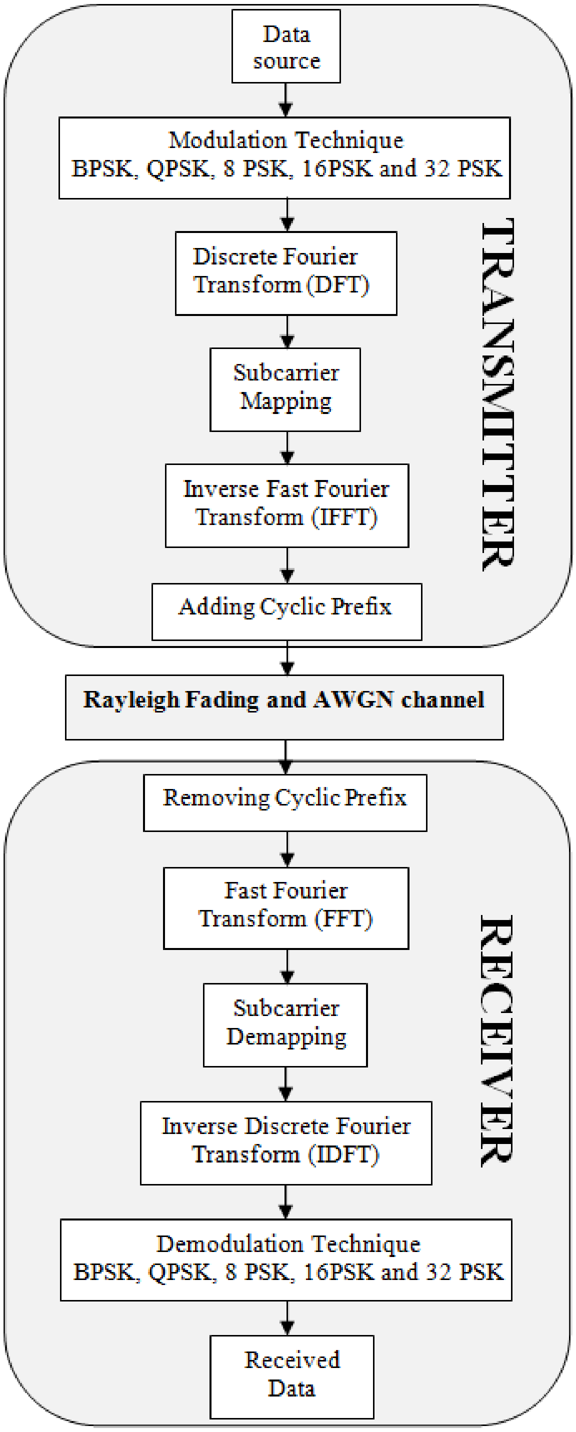

Figure 4. SC-FDMA System Model

The implementation of the system is done using various indexes of phase shift keying modulation technique.

The system is implemented under two cases:

- The first case is when the size of the fast fourier transform is 64,then the data symbol duration (*Td)* is equal :

$$Td = FFT\ Size/FFT\ Sampling\ frequency \qquad (13)$$

Td=64/20x10^6 ; thus in this case *Td* is 3.2μs.

Figure 5 shows the bit error rate with different values of signal to noise ratio. It is clear that the bit error rate has the minimum values when using BPSK and start to increase with the increase of different modulation technique.

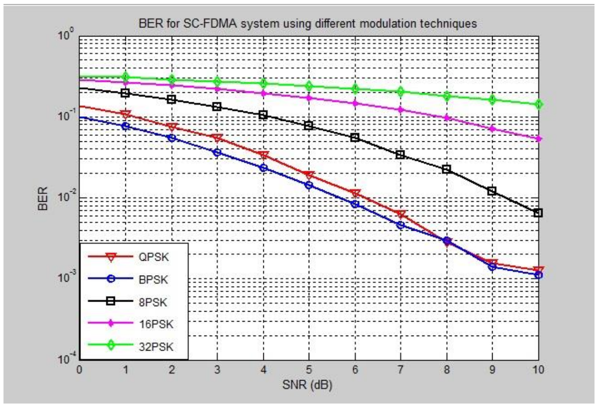

Figure 5. SC-FDMA BER using different modulation techniques at FFT size =64

- The second case of the system is when the size of FFT is increased to 128. Therefore the data symbol duration will be increased because it is directly proportional to FFT size referring to equation 4, where Td will be 6.4 μs. The number of cyclic prefix in this system is 16 which is used in adding and removing CP.
  Figure 6 shows the bit error rate with different values of signal to noise ratio. BPSK and QPSK have the best results with least errors compared to others.

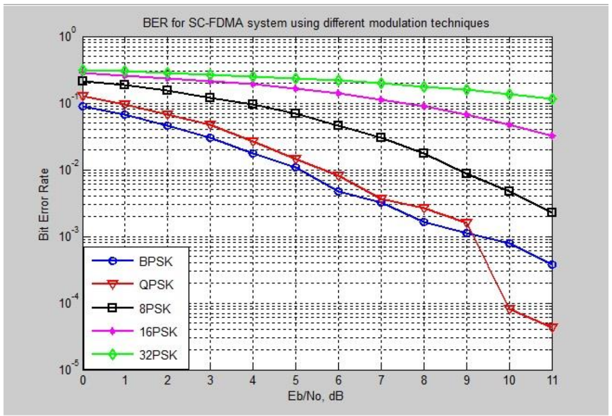

Figure 6. SC-FDMA BER using different modulation techniques at FFT size =128

It is noticeable from Figure 7(a) and (b) that the bit error rate of the system with FFT size= 128 is less than the bit error rate in the system with FFT size=64. This shows that the bit error rate is directly proportional to the modulation index despite the size of the FFT (in both cases). The bit error rate starts to increase with the increase of modulation index from the value of 2 to 32.

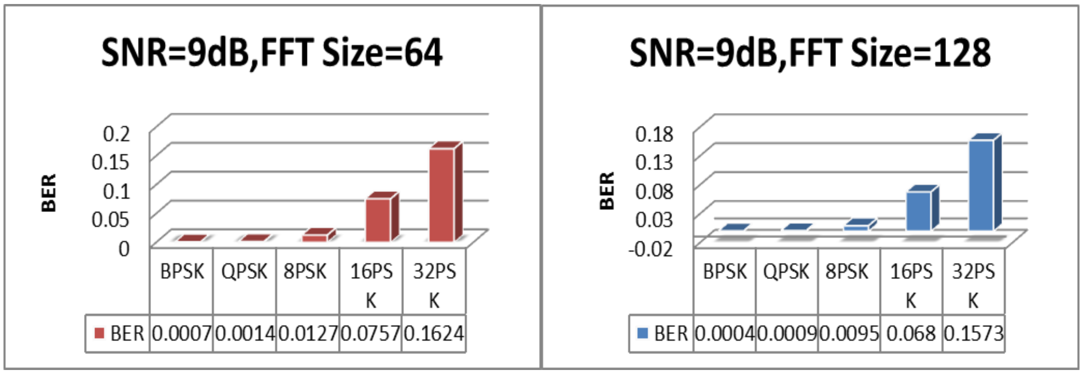

Figure 7. The Values of BER at SNR=9dB for the system with (a) 64 FFT size, (b) 128 FFT size

The most important advantage of the SC-FDMA is the low PAPR. PAPR is a performance measurement that is indicative of the power efficiency of the transmitter. In case of an ideal linear power amplifier where achieving linear amplification up to the saturation point, reaching the maximum power efficiency when the amplifier is operating at the saturation point. A positive PAPR in dB means that a power backoff is required to operate in the linear region of the power amplifier and high PAPR degrades the transmitted power efficiency performance [11].

Figure 8 shows the low PAPR for SC-FDMA, this low PAPR indicates that the SC-FDMA can be used in the uplink of the 4Generation to optimize the range and power consumption in the uplink [12].

Sufficiently low PAPR of the transmitted waveform is to avoid excessive cost, size and power consumption of the UE Power Amplifier (PA) [13].

Single-Carrier Frequency-Division Multiple Access schemes are employed as alternative access schemes, which offer reduced PAPR as compared to OFDMA's high PAPR. A signal with lower PAPR is desired, as it improves the power efficiency of the employed non-linear amplifier. SC-FDMA utilizes single-carrier modulation at the transmitter and frequency domain equalization at the receiver and typically achieves lower PAPR [14].

A certain amount of flexibility in resource allocation and scheduling is achieved with SC-FDMA in the uplink. PAPR of SC-FDMA is much lower because of single carrier transmission [15].

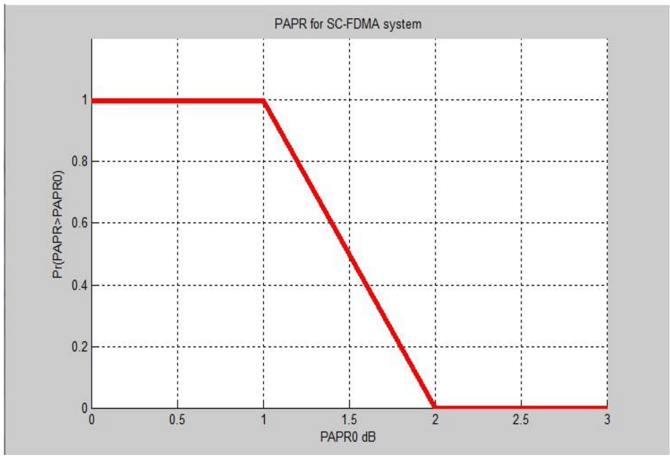

Figure 8. PAPR for SC-FDMA system

SC-FDMA has drawn great attention as an attractive alternative to OFDMA, especially in the uplink communications where lower PAPR greatly is better for the mobile terminal in terms of transmit power efficiency. SC-FDMA is currently a working assumption for the uplink multiple access scheme in 3GPP Long Term Evolution-Advanced [16].

5. Conclusions

The simulation of the uplink physical layer of 4G is performed in this research to show that the performance of the system is different for various conditions. The transmitter and receiver system are implemented to evaluate the simulated system, so that bit error rate for all cases can be plotted. It is clear that the bit error rate has the minimum values for the system with FFT size=64 when using the BPSK and starts to increase with the increase of index modulation for different modulation technique. On the other hand when FFT size=128, BPSK and QPSK give the best results with least errors. It is noticed that the BER of the system with FFT size= 128 is less than in the system with FFT size=64. This indicates that the bit error rate is inversely proportional to the modulation index, despite the size of the FFT (in both cases). Finally, due to the low PAPR for SC-FDMA, SC-FDMA is used in the present and future as uplink of the forth and next generations.

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