



## Performance simulation of Single Carrier Frequency Division Multiple Access modulation of uplink LTE system

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**Abstract** Since past few decades different types of cellular networks were launched and went successful on the radio links such as WiMAX, that became very popular because of its high data rate (70Mbps) and support for providing wireless internet services over 50km distance. The UMTS Long Term Evolution (LTE) is an emerging technology in the evolution of 3G cellular services. LTE runs on an evolution of the existing UMTS infrastructure already used by over 80 percent of mobile subscribers globally. We have very limited resources in cellular technologies and it is important to utilize them with high efficiency. Single Carrier Frequency Division Multiple Access (SC-FDMA) is introduced recently and it became handy candidate for uplink multiple access scheme in LTE system that is a project of Third Generation Partnership Project (3GPP). In this paper, we investigate the performance of SC-FDMA of LTE system by considering different modulation schemes (BPSK, QPSK, 16QAM and 64QAM) on the basis of peak to average power ratio (PAPR), bit error rate (BER), power spectral density (PSD) by simulating the model of SC-FDMA. We use Additive White Gaussian Noise (AWGN) channel and introduce frequency selective (multipath) fading in the channel by using Rayleigh Fading model to evaluate the performance in presence of noise and fading.

**Keywords:** SC-FDMA, LTE, BER, PAPR.

محاكاة أداء نظام تضمين الناقل الواحد للتقسيم الترددي متعدد النفاذ المستخدم في الوصلة الصاعدة

لمنظومة التطور بعيد المدى

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**المخلص** منذ العقود القليلة الماضية تم إطلاق أنواع مختلفة من الشبكات الخلوية وكانت ناجحة على وصلات الراديو مثل (WiMAX) التي أصبحت شعبية جدا بسبب ارتفاع معدل البيانات (70Mbps) ودعم وتوفير الإنترنت اللاسلكية على مسافة 50 كيلومتر. تكنولوجيا UMTS في منظومة التطور بعيد المدى هي التكنولوجيا الناشئة في الخدمات الخلوية للجبل الثالث. منظومة التطور بعيد المدى تعمل على تطوير البنية التحتية لتكنولوجيا UMTS التي يستخدمها 80% من مستخدمي الهاتف المحمول على مستوى العالم. نحن نمتلك موارد محدودة جدا في التكنولوجيات الخلوية ومن المهم استخدامها بكفاءة عالية. تم مؤخراً تقديم نظام الناقل الواحد للتقسيم الترددي متعدد النفاذ وأصبح مرشحاً مهماً لنظام النفاذ المتعدد للوصلة الصاعدة في نظام التطور بعيد المدى وهو مشروع (3GPP). في هذه الورقة نتحقق من أداء نظام الناقل الواحد للتقسيم الترددي متعدد النفاذ لمنظومة التطور بعيد المدى على مخططات تضمين مختلفة وهي (BPSK, QPSK, 16QAM and 64QAM). حيث نقوم بحساب النسبة بين الذروة ومتوسط القدرة (PAPR) لإشارة الناقل الواحد للتقسيم الترددي متعدد النفاذ وحساب معدل الخطأ في البت (BER) وحساب الكثافة الطيفية للقدرة (PSD) بواسطة محاكاة نظام الناقل الواحد للتقسيم الترددي متعدد النفاذ بالماتلاب. وقد استخدمنا قناة تضيق ضجيج جاوس الأبيض (AWGN) وإدخال تردد انتقائي (متعدد المسرات) يتلاشى في القناة باستخدام نموذج ريلي (Rayleigh Fading) لحساب الأداء في وجود الضجيج والتلاشي.

**الكلمات المفتاحية:** الناقل الواحد للتقسيم الترددي متعدد النفاذ، التطور بعيد المدى، معدل الخطأ في البت، النسبة بين الذروة ومتوسط القدرة.

### Introduction

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a new technology utilizes for uplink physical layer in LTE. SC-FDMA is the multiple access adaptation of Single Carrier Frequency Domain Equalization (SC-FDE), which is similar to Orthogonal Frequency Division Multiplexing (OFDM), in that they both accomplish channel estimation and equalization in the frequency domain. Multiple accesses are acquired in frequency domain in SC-FDMA. Thus to

changeover from SC-FDE to SC-FDMA requires division frequency amongst frequencies. The use of SC-FDMA in LTE is confined to the uplink because the raised time-domain processing would be an abundant burden on the base station, which has to carryover the movements of multi-user transmission. SC-FDMA can content all of the benefits mentioned for OFDM in addition to low Peak Average Power Ratio (PAPR). Similar to OFDM, the bandwidth is divided into multiple parallel sub-

carriers with cyclic prefix within order to stay orthogonal to each other and annihilate Inter Symbol Interference (ISI). In SC-FDMA, the undisturbed combination of all data symbols that are transmitted at the identical time is modulated to a given subcarrier [1]. In a given symbol period, all transmitted subcarriers of a SC-FDMA signal are sustaining a component of each modulated data symbol.

### 1. SC-FDMA SIGNAL IMPLEMENTATION

The block diagram of SC-FDMA is shown in Figure(1). The input data groups are first modulated to single carrier symbols by using QPSK, 16-QAM or 64-QAM. The accumulated modulated symbols become the inputs of the functional blocks of SC-FDMA. The description of every functional block is described below



Fig.1: SC-FDMA Transmission Model

#### 1.1 Series To Parallel Converter

The input data is a serial sequence fed to a serial-to-parallel converter that partitions the input data into  $N$  subcarrier, each subcarrier takes the same number of data bits, and the number of bits in each subcarrier is determined by the constellation of the signal mapping.

#### 1.2 Modulator:

These subcarriers of bits are then converted to  $N$  symbols by using a mapper (modulator). Each symbol carries a number of bits determined by the type of the mapper. For example, when using binary phase shift keying (BPSK) mapper each symbol carries one bit of information and this is very low data rate. With quadrature phase shift keying (QPSK) each symbol carries two bits of information and with 16-QAM (quadrature amplitude modulation) each symbol carries four bits of information and this is high data rate

#### 1.3 Fast Fourier Transform (FFT):

the  $N$  Point FFT (Fast Fourier Transform) Converts time domain single carrier blocks into  $N$  discrete frequency tones

#### 1.4 Subcarrier mapping:

DFT output of the data symbols is mapped to a subset of subcarriers, a process called subcarrier mapping. The subcarrier mapping assigns FFT output complex values as the amplitudes of some of the selected subcarriers. Subcarrier mapping can be classified into two types: Localized mapping and Distributed mapping. In localized mapping, the FFT outputs are mapped to a subset of consecutive sub-carriers thereby confining them to only a fraction of the system bandwidth. In distributed mapping, the

DFT outputs of the input data are assigned to subcarriers over the entire bandwidth non-continuously, resulting in zero amplitude for the

remaining subcarriers. A special case of distributed SC-FDMA is called interleaved SC-FDMA, where the occupied subcarriers are equally spaced over the entire bandwidth. Figure(2) is a general picture of localized and distributed mapping [2].

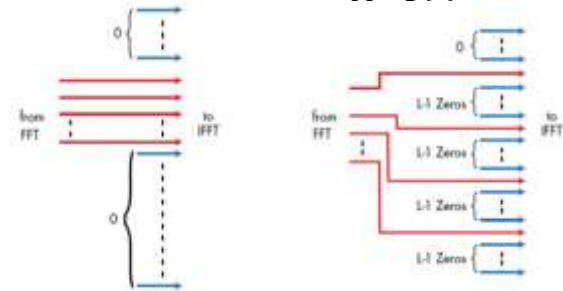


Fig.2: Localized mapping Vs. Distributed mapping

It maps each of the  $N$ -FFT outputs to one of the ( $M > N$ ) orthogonal subcarriers that can be transmitted, and  $N = M/Q$  is an integer sub multiple of  $M$ .  $Q$  is the bandwidth expansion factor of the symbol sequence. If all terminals transmit  $N$  symbols per block, the system can handle  $Q$  simultaneous transmissions without co-channel interference. The result of the subcarrier mapping is the set  $(0, 1, 2, \dots, M-1)$  of complex subcarrier amplitudes, where  $N$  of the amplitudes are non-zero. An example of subcarrier mapping is shown in Figure(3).

The example assumes three users sharing 12 subcarriers. Each user has a block of four data symbols to transmit at a time. The DFT output of the data block has four complex frequency domain samples, which are mapped over 12 subcarriers using different mapping

schemes. The distributed SC-FDMA is more robust with respect to frequency selective fading and offers additional frequency diversity gain, since the information is spread across the entire system bandwidth. Localized SC-FDMA in combination with channel-dependant scheduling can potentially offer multi-user diversity in frequency selective channel conditions.

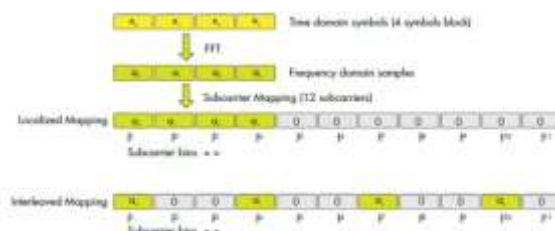


Fig.3: Subcarrier Mapping Example

#### 1.5 Inverse Fast Fourier Transform (IFFT):

An  $M$ -point inverse FFT (IFFT) transforms the subcarrier amplitudes to a complex time domain signal. Each signal then modulates a single frequency carrier and all the modulated symbols are transmitted sequentially. The data samples are processed with FFT and IFFT are shown in the Figure (4).



Fig.4: Time domain samples

### 1.6 Cyclic Prefix

The transmitter performs two other signal processing operations prior to transmission. It inserts a set of symbols referred to as a cyclic prefix (CP) in order to provide a guard time to prevent inter-block interference (IBI) due to multipath propagation. The transmitter also performs a linear filtering operation referred to as pulse shaping in order to reduce out-of-band signal energy. In general, CP is a copy of the last part of the block, which is added at the start of each block for a couple of reasons. First, CP acts as a guard time between successive blocks. If the length of the CP is longer than the maximum delay spread of the channel, or roughly, the length of the channel impulse response, then, there is no IBI. Second, since CP is a copy of the last part of the block, it converts a discrete time linear convolution into a discrete time circular convolution. Thus transmitted data propagating through the channel can be modeled as a circular convolution between the channel impulse response and the transmitted data block, which in the frequency domain is a point wise multiplication of the FFT frequency samples. Then, to remove the channel distortion, the FFT of the received signal can simply be divided by the FFT of the channel impulse response point-wise or a more sophisticated frequency domain equalization technique can be implemented.

### 2. Simulation of SC-FDMA model

We simulate the model of SC-FDMA in Matlab. The block diagrams of SC-FDMA are given in figure(1). Practically there are some losses in the system as compared to theoretical values, therefore we use the Additive White Gaussian Noise (AWGN) channel, which is commonly used to simulate the background noise of the channel. We use a built-in Matlab function *awgn* in which the noise level is described by SNR per sample, which is the actual input parameter to the *awgn* function.

We also introduce the frequency selective (multipath) fading in the channel and use the Rayleigh fading model which is a reasonable statistical fading model for multipath situation in the absence of LOS component. We use a built-in Matlab function *rayleighchan* for Rayleigh fading and the parameters used for that are given below.

Number of Sub-carriers is 512, CP length is 64, Range of SNR in dB is 0 to 30, Data Block Size 16 (Number of Symbols), System Bandwidth 5 MHz. We use adaptive modulation schemes (BPSK, QPSK, 16-QAM and 64-QAM) to analyze the Peak to Average Power Ratio (PAPR), Bit Error Rate (BER) and Power Spectral Density (PSD) for SC-FDMA.

### 2.1 the Peak to Average Power Ratio (PAPR) of SC-FDMA:

Power saving in transmission is an extensive issue for the multiple access techniques used in LTE, therefore we consider here an important transmission factor PAPR for SC-FDMA

The PAPR is calculated by representing a CCDF (Complementary Cumulative Distribution Function) of PAPR. The CCDF of PAPR is the probability that the PAPR is higher than a certain PAPR value  $PAPR_0$  ( $\Pr \{PAPR > PAPR_0\}$ ) [3]. It is an important measure that is widely used for the complete description of the power characteristics of signals.

The PAPR of SC-FDMA for BPSK, QPSK, 16-QAM and 64-QAM modulations are shown in figure (5)

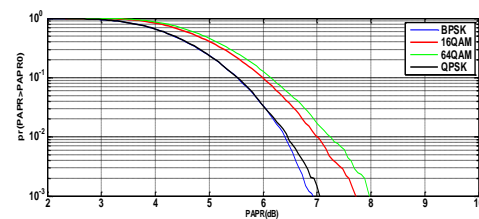


fig.5: PAPR performance of SC-FDMA

From figure (5) we can observe that the PAPR value of SC-FDMA is almost similar for both modulation schemes (BPSK, QPSK) i.e. 7 dB. Whereas the PAPR of SC-FDMA increases to 7.6 dB (in case of 16-QAM) and becomes 8 dB (in case of 64-QAM). Hence for SC-FDMA the PAPR increases for higher order modulation.

### 2.2 Power Spectral Density (PSD) of SC-FDMA:

The power spectral density (PSD) is an important function that describes the power distribution of a signal with respect to frequency. In mobile communication, to perform the correct decision of radio resource management (RRM) at base station, the PSD plays a vital role, especially for the transmission format allocation including modulation and bandwidth [4]. In our simulation, we use a Matlab function *spectrum* that is used to estimate the spectrum characteristics of a signal, along with *psd* (describes power characteristics of a signal). The average power of a signal in a given frequency band is determined by the integral of PSD over that frequency band. In our case, we analyze the average power distribution in SC-FDMA symbols over a 5 MHz bandwidth. This 5 MHz bandwidth may exist in any LTE carrier frequency band (900 MHz, 1800 MHz, and 2600 MHz). For baseband modulation, we estimate the power characteristics of SC-FDMA symbols over a sampling frequency that is equal to twice of bandwidth (10 MHz). The total power in the frequency band for the periodic signal with N period would be [5]

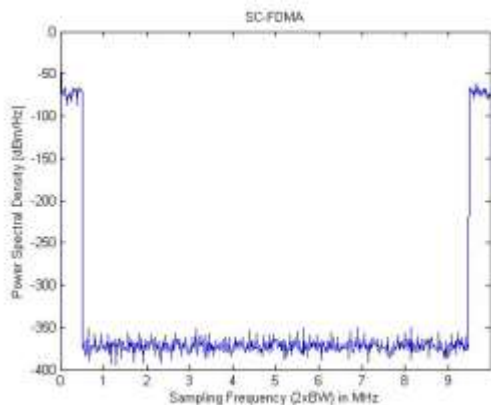
$$P_{xx}(m) = \frac{1}{f_s N} |DFT_N\{x(n)\}|^2$$

Where,

$f_s$  = Sampling Frequency (10 MHz)

$N$  = Number of FFT

We calculate the PSD at the output of IFFT block in the transmitter of SC-FDMA as shown in figure(6)

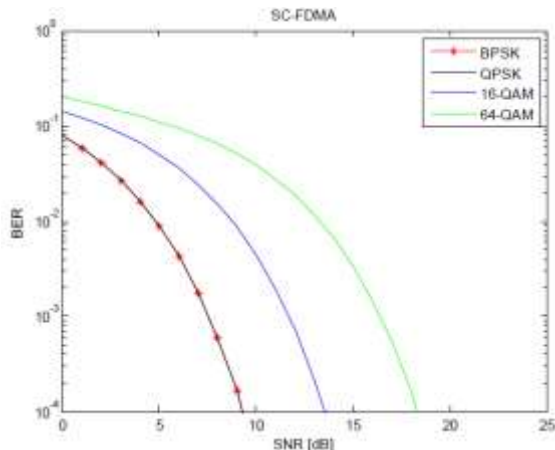


**Fig.6:** Power Spectral Density of SC-FDMA

Figure (6) shows the power spectral density of the SC-FDMA. We can observe that the average power of all SC-FDMA symbols (512) is nearly -375dB. This result also shows the transmit power requirements of SC-FDMA symbols.

### 2.3 Bit error rate (BER) performance of SC-FDMA:

For any modulation scheme, the BER is expressed in terms of SNR. BER is measured by comparing the transmitted signal with received signal, and compute the error counts over total number of bits transmitted. The BER vs SNR of SC-FDMA is shown in figure (7).



**Fig.7:** BER vs SNR of SC-FDMA with Adaptive Modulation

At a specific value of BER ( $10^{-3}$ ), the BPSK and QPSK have same SNR values of 6.5, but in 16-QAM and 64-QAM have SNR values of 11.7 and 16.4 respectively. The 64-QAM has highest value of SNR (16.4) which shows that 64-QAM is more efficient in terms BER.

### Conclusion

We conclude from our results that, the BER increases as order of modulation scheme increases. Therefore the selection of modulation schemes in adaptive modulation is quite crucial based on these results.

The power consumption at the user end such as portable devices is again a vital issue for uplink transmission in LTE system. From our simulation results we also conclude that the higher order modulation schemes have an impact on the PAPR of SC-FDMA. The PAPR increases in SC-FDMA for higher order modulation schemes. Based on our result we conclude to adopt low order modulation scheme i.e. BPSK, QPSK and 16-QAM for uplink in order to have less PAPR at user end.

### Arabic section:

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### Abbreviations and Acronyms

SCFDMA	Single Carrier Frequency Division Multiple access
LTE	Long Term Evolution
3GPP	Third Generation Partnership Project
AWGN	Additive White Gaussian Noise
PSD	power spectral density
BER	bit error rate
PAPR	peak to average power ratio
SC-FDE	of Single Carrier Frequency Domain Equalization
OFDM	Orthogonal Frequency Division Multiplexing
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
CP	cyclic prefix
IBI	inter-block interference
CCDF	Complementary Cumulative Distribution Function
RRM	radio resource management

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