Performance Evaluation of 4G-LTE-SCFDMA Scheme under SUI and ITU Channel Models

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Performance Evaluation of 4G-LTE-SCFDMA Scheme under SUI and ITU Channel Models

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***Abstract*— There is considerable interest in the use of Single Carrier Frequency Division Multiple Access (SC-FDMA) as the uplink transmission scheme in the Third-generation Partnership Project-Long Term Evolution 3GPP-LTE standard. This interest is justified by the inherent single carrier structure of SC-FDMA, which results in reduced sensitivity to phase noise and a lower Peak-to-Average Power Ratio (PAPR) compared to Orthogonal Frequency Division Multiple Access OFDMA. This consequently makes it more attractive for low cost devices with limited transmit power. In this paper the LTE and SCFDMA specifications will be explained in details and the performance of the system will be examined under two types of equalization method which are zero forcing ZF and minimum mean square error MMSE method. Also the system was tested under two types of subcarrier mapping which are localized and distributed mapping in two types of channel models which are International Telecommunications Union (ITU) and Stanford University Interim (SUI). The results show that the system gives better performance with localized distributed mode and also give good performance with the minimum mean square error MMSE method and the system will give different response through the different channel cases.**

***Index Term*— LTE, SCFDMA, PAPR, ZF, MMSE, ITU channel, SUI channel**

I. INTRODUCTION

Just a decade ago mobile communications was mainly focusing on speech transmission, while nowadays mobile internet and multimedia applications demand for high data rates and a high quality of service of communications links [1].

Wireless communications is moving rapidly towards small, low cost devices. However, the mobility and value of these devices is often limited by battery life since device miniaturization is progressing at a faster rate than battery technology optimization. Thus, the issue of battery life represents a key concern in the next generation of wireless communication systems [2].

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To go beyond 3G, 4G (4th Generation) mobile networks are evolving to provide a comprehensive IP-based integrated solution at an affordable price where voice, data and streamed multimedia can be given to users on an anytime, anywhere basis, and at higher data rates than previous generations. This will be achieved after the convergence of all types of wired and wireless technologies and will be capable of providing data rates between 100 Mbps and 1 Gbps (both indoors and outdoors), with premium quality and high security. High data rate calls upon an improved spectral efficiency [3].
The Third Generation Partnership Project Long Term Evolution 3GPP-LTE radio access standard is based on shared channel access providing peak data rates of 50 Mbps in the uplink and 100 Mbps in the downlink [4]. SCFDMA has been proposed for use on the uplink of the LTE standard [5]

II. LTE FUNDAMENTAL OVERVIEW

Long Term Evolution started in December 2004. The objective was to develop a framework for the evolution of the 3GPP radio access technology towards a high-data-rate, low-latency, and packet-optimized radio access technology [6]. 3GPP standard is focused on next generation cellular systems called Long Term Evolution (LTE) [7],[8]. The scalable bandwidth of LTE is 1.25MHz-20MHz. The LTE features are high peak data rate, flexibility of spectrum usage, low latency times, and higher capacity per cell. LTE is based on OFDMA in the downlink and SC-FDMA in the uplink [9].

The linear convolution of the multipath channel is transformed into circular convolution, which enables the receiver to equalize each subcarrier present in the channel by scaling with a complex gain factor. The main advantage of SCFDMA over OFDMA is low PAPR. As it has got lower PAPR, the power efficiency is high [10].

Talking more explicitly, main objectives and targets of LTE development can be stated as follows [11]:

1. Increase in system capacity and reduced cost per bit, as well as utilization of existing 2G and 3G spectrum along with the new spectrum.
2. Achieving of notably higher data rates weighed against the existing 3G systems, with goal of 100Mbps in uplink and over 50Mbps in downlink.
3. Greater coverage by providing higher data rates over wider areas and flexibility of use of existing and new frequency bands
4. Attaining higher system capacity up to three times the

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capacity of current systems and increased service provisioning more services at lower cost with better user experience.

Some key requirements and capability targets for the LTE are [12],[13]:

1. Low latency : for both user plane and control plane, with a 5MHz spectrum allocation the latency target is below 5 ms
2. Bandwidth Scalability : different bandwidths can be used depending upon the requirements (1.25 to 20 MHz)
3. Peak Data Rates : 100 Mbps for DL , 50 Mbps for UL
4. 2 to 4 times capacity over existing Release 6 scenarios with HSDPA
5. Only Packet Switched Domain support
6. Improved Cell edge performance
7. Inter-working with the existing 2G and 3G systems and non-3GPP systems
8. Optimized for low mobile speed but also support high mobile speeds
9. Reduction of complexity in both system and terminals Ease of migration from existing networks

The LTE SC-FDMA subcarrier spacing equals 15 kHz. The selection of the subcarrier spacing in an SCFDMA based system needs to carefully balance overhead from the cyclic prefix against sensitivity to Doppler shift and other types of frequency errors and inaccuracies. The choice of 15 kHz for the LTE subcarrier spacing was found to offer a good balance between these two constraints. Assuming an FFT-based transmitter/receiver implementation, 15 kHz subcarrier spacing corresponds to a sampling rate $f_s = 15k \times N_{FFT}$ where N_{FFT} is the FFT size. It is important to understand though that the LTE specifications do not in any way mandate the use of FFT-based transmitter/ receiver implementations and even less so a particular FFT size or sampling rate. Nevertheless, FFT-based implementations of OFDM are common practice and an FFT size of 2048, with a corresponding sampling rate of 30.72 MHz, is suitable for the wider LTE carrier bandwidths, such as bandwidths of the order of 15 MHz and above. However, for smaller carrier bandwidths, a smaller FFT size and a correspondingly lower sampling rate can very well be used [14].

In frequency domain 12 subcarriers are grouped together and make up the Resource Block RB in one slot as shown in Fig. 1. So a Resource Block occupies 180 KHz in the frequency domain and 0.5 ms in the time domain [11].

A resource element, consisting of one subcarrier during one OFDM symbol, is the smallest physical resource in LTE. Furthermore, as illustrated in Fig. 1, resource elements are grouped into resource blocks. Each resource block thus consists of 7*12=84 resource elements in the case of a normal cyclic prefix and 6*12=72 resource elements in the case of an extended cyclic prefix. Although resource blocks are defined over one slot, the basic time-domain unit for dynamic scheduling in LTE is one sub-frame, consisting of two consecutive slots. The minimum scheduling unit consisting of two time-consecutive resource blocks within one sub frames (one resource block per slot), can be referred to as a resource-block pair [14].

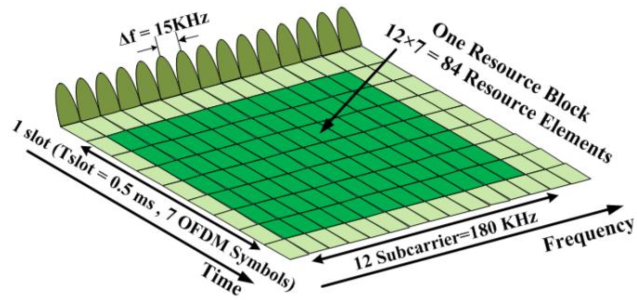

Fig. 1. The Resource Block in LTE

Transmission parameters in LTE consist of frequency, space, and time to create transmission resources for carrying data. All of the time units in LTE are specified as a factor of $T_s = 1/(15k \times 2048)$ in which 2048 is the FFT length. The LTE radio frame for downlink and uplink transmission is $307200 \times T_s = 10\, msec$ long. LTE supports two radio frame structures [15]:

1. FDD (Frequency division duplex), which uses type 1 frame structure.
2. TDD (Time division duplex), which is applicable to type2 frame structure.

A radio frame consists of 10 sub frames $307200 \times T_s = 1\, msec\ long$ in FDD and two half- frames $153600 \times T_s = 5\, msec\ long$ in TDD as shown in Fig. 2. A half-frame is divided into four sub frames and a special sub frame, or five sub frames, based on downlink to uplink switch point periodicity. The TDD frame structure can be configured in seven different sub frame formats; however sub frames 0 and 5 and DwTS are reserved for downlink transmission. The sub frame that appears after special sub frame as well as UpPTS, is always assigned to uplink transmission. Each sub frame in both FDD and TDD has two slots of $15360 \times T_s = 0.5\, msec\ long$. The important parameters of LTE can be found in Table I

TABLE I
THE DOMINANT PARAMETERS OF 3GPP-LTE

Parameters	Quantity					
BW (MHz)	1.25	2.5	5	10	15	20
Resource Block	6	12	25	50	75	100
FFT Size	128	256	512	1024	1536	2048
Fs.(MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Sample per slot	960	1920	3840	7680	11520	15360
No. sub carrier	76	151	301	601	901	1201
Carrier spacing	15 KHz					
(PRB) BW	180 KHz					
Full mobility	Up to 500 Km/h					
Capacity	> 200 User per cell					
Cell size	5-100 Km					

III. SCFDMA

Nowadays, mobile radio system is immersed by more and more services with data rate from few Kbit/s up to several Mbit/s. Presently, research beyond 3rd generation mobile radio systems is in progress worldwide to enable the future mobile radio system supporting different types of services with different data rates and providing high flexibility and high performance. An important decision for the future mobile radio system is the choice of the multiple access schemes [16].

SC-FDMA has drawn great attention as an attractive alternative to OFDMA, especially in the uplink communications where lower PAPR greatly benefits the mobile terminal in terms of transmit power efficiency. SC-FDMA has been adopted for the uplink multiple access scheme for the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) [17].

SC-FDMA is a single carrier block transmission technique with cyclic prefix (CP). Each block is called an SC-FDMA symbol [18]. With the aid of CP, SC-FDMA converts the multipath frequency selective fading channel into several flat fading sub-channels and enables efficient frequency domain equalization (FDE) at the receiver. SC-FDMA signals have low PAPR, which greatly increases the power efficiency of user equipment (UEs) [19].

When the channel is in good condition, the transmission is performed with higher data rates (such as 64QAM), and when the channel is in poor condition, the transmission rate is lowered (such as QPSK) with small constellation and low-rate codes. The channel side information is feedback to transmitter in order to control transmit power; transmit constellation and the coding rate. The resource allocation and modulation would give a distribution as in Fig. 2. In this figure it can show that how each user get its modulation type and get its time allocation and fixed amount of subcarrier according to channel type that the signal will transfer through it. The power level of the modulation is adjusted to overcome the fading of the channel. The channel may be assumed to be reciprocal. BS is able to estimate the channel of all BS-to-mobile links based on the received uplink transmission as long as the channel variation is slow [20].

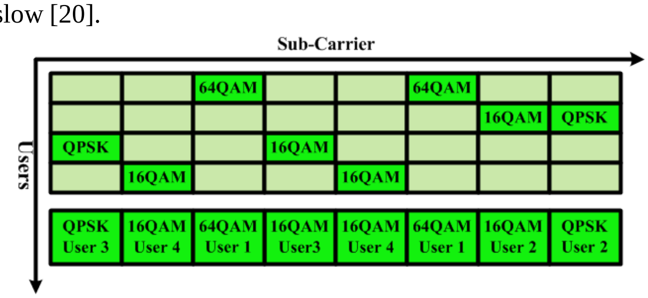

Fig. 2. The resource allocation and modulation for each user in SC-FDMA

As shown in Fig. 3, the transmitter of an SC-FDMA system converts a binary input signal to a sequence of modulated subcarriers. At the input to the transmitter, a baseband modulator transforms the binary input to a multilevel sequence of complex numbers x_n in one of several possible modulation formats. The transmitter next groups the modulation symbols $\{x_n\}$ into blocks each containing N symbols. The first step in modulating the SC-FDMA subcarriers is to perform an N-point DFT to produce a frequency domain representation X_k of the input symbols. The DFT equation is represented as [21]:

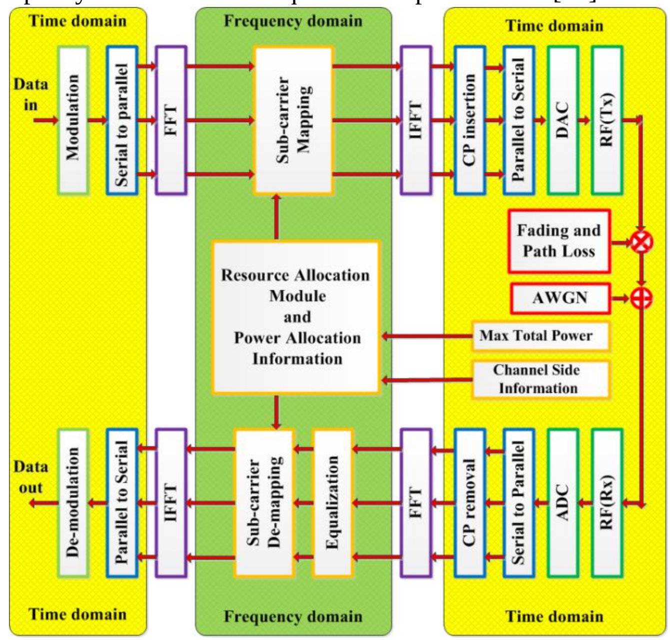

Fig. 3. The block diagram of the SCFDMA system

$$X_k = \sum_{k=0}^{N-1} x_n \, e^{\frac{-2\pi jkn}{N}} \quad k = 0,1 \dots N-1 \tag{1}$$

It then maps each of the N DFT outputs to one of the M (> N) orthogonal subcarriers that can be transmitted. If $N = M/Q$ and all terminals transmit N symbols per block, the system can handle Q simultaneous transmissions without co-channel interference. Q is the bandwidth expansion factor of the symbol sequence. The result of the subcarrier mapping is the set $\tilde{X}_l$ (l = 0, 1, 2…, M-1) of complex subcarrier amplitudes, where N of the amplitudes are non-zero. As in OFDMA, an M-point IDFT transforms the subcarrier amplitudes to a complex time domain signal $\tilde{x}_m$. The Inverse discrete Fourier transform IDFT equation is represented as [21]:

$$\tilde{x}_m = \frac{1}{M} \sum_{l=0}^{M-1} X_l \, e^{\frac{2\pi jkm}{M}} \quad m = 0,1 \dots M-1 \tag{2}$$

There are M subcarriers, among which N (< M) subcarriers are occupied by the input data. In the time domain, the input data symbol has symbol duration of T seconds and the symbol duration is compressed to $\tilde{T} = T\frac{N}{M}$ seconds after going through SC-FDMA modulation.

As shown in Fig. 4 there are three methods of assigning subcarriers to DFT outputs: localized subcarrier mapping (LFDMA), distributed subcarrier mapping (DFDMA) and Interleaved sub carrier mapping (IFDMA) [22]. In the case of LFDMA, the DFT outputs are assigned to adjacent subcarriers. With DFDMA, DFT outputs are distributed over the entire bandwidth with zero amplitude assigned to the unused subcarriers. When M/N is an integer, the occupied subcarriers are equally spaced and the DFDMA assignment is referred to as Interleaved FDMA (IFDMA) [23].

The data block consists of N complex modulation symbols generated at a rate R_{source} (symbols/sec). The N-point FFT produces N frequency-domain symbols that modulate N out of M orthogonal sub-carriers spread over a bandwidth W. The sub-carriers mapping process can be shown in Fig. 5. Where W can be defined as [24]:

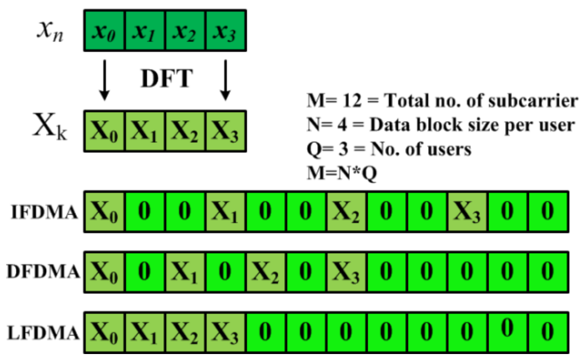

Fig. 4. The types of subcarrier mapping.

$$W = M.F_0 \quad Hz \tag{3}$$

Where F_0 (Hz) is the sub-carriers frequency spacing. The channel transmission rate is:

$$R_{channel} = [M/N].R_{source} \quad \text{(Symbol/sec)} \tag{4}$$

The bandwidth spreading factor Q is given by:

$$Q = R_{channel}/R_{source} = M/N \tag{5}$$

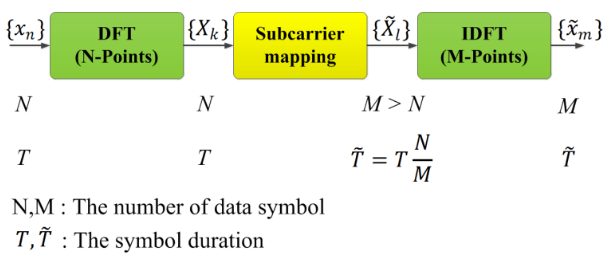

Fig. 5. The process of sub-carriers mapping.

For LFDMA, the frequency samples after subcarrier mapping $\{\tilde{X}_l\}$ can be described as follows [25]:

$$\tilde{X}_l = \begin{cases} X_l\,, & 0 \le l \le N-1 \\ 0\,, & 0 \le l \le M-1 \end{cases} \tag{6}$$

Let $m = Q.n + q, where\ 0 \le n \le N-1$
$and\ 0 \le q \le Q-1\ Then$

$$\tilde{x}_m = \tilde{x}_{Qn+q} = \frac{1}{M}\sum_{l=0}^{M-1} x_l\, e^{j2\pi i\frac{m}{M}} \tag{7}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{l=0}^{n} x_l e^{j2\pi i\frac{Qn+q}{QN}}\, x_l \tag{8}$$

If q=0 then

$$\tilde{x}_m = \tilde{x}_{Qn} = \frac{1}{Q}\frac{1}{N}\sum_{l=0}^{N-1} X_l e^{j2\pi l\frac{Qn}{QN}} \tag{9}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{l=0}^{N-1} X_l e^{j2\pi l\frac{n}{N}} \tag{10}$$

$$= \frac{1}{Q}x_n = \frac{1}{Q}x_{(m)_{mod\,N}} \tag{11}$$

If $q \neq 0, since\ X_l = \sum_{p=0}^{N-1} x_p\, e^{-j2\pi l\frac{p}{N}}$ then eqn. 6 can be expressed as follows:

$$\tilde{x}_m = x_{Qn+q} = \frac{1}{Q}\frac{1}{N}\sum_{l=0}^{N-1} X_l\, e^{j2\pi l\frac{Qn+q}{QN}} \tag{12}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{l=0}^{N-1}\left(\sum_{p=0}^{N-1} x_p\, e^{-j2\pi l\frac{p}{N}}\right) e^{j2\pi l\frac{Qn+q}{QN}} \tag{13}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{l=0}^{N-1}\sum_{p=0}^{N-1} x_p e^{j2\pi l\left\{\frac{(n-p)}{N}+\frac{q}{QN}\right\}} \tag{14}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{p=0}^{N-1} x_p\left(\sum_{i=0}^{n} e^{j2\pi l\left\{\frac{(n-p)}{N}+\frac{q}{QN}\right\}}\right) \tag{15}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{p=0}^{N-1} x_p\, \frac{1-e^{j2\pi(n-p)}e^{j2\pi\frac{q}{Q}}}{1-e^{j2\pi\left\{\frac{(N-P)}{N}+\frac{q}{QN}\right\}}} \tag{16}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{p=0}^{N-1} x_p\, \frac{1-e^{j2\pi\frac{q}{Q}}}{1-e^{j2\pi\left\{\frac{(n-p}{N}+\frac{q}{QN}\right\}}} \tag{17}$$

$$= \frac{1}{Q}\left(1-e^{j2\pi\frac{q}{Q}}\right)\frac{1}{N}\sum_{p=0}^{N-1}\frac{x_p}{1-e^{j2\pi\left\{\frac{(n-p)}{N}+\frac{q}{QN}\right\}}} \tag{18}$$

As can be seen from eqn. 9 and 16, LFDMA signal in the time domain has exact copies of input time symbols with a scaling factor of 1/Q in the N-multiple sample positions and in between values are sum of all the time input symbols in the input block with different complex-weighting.

Now, For DFDMA, the frequency samples after subcarrier mapping $\tilde{X}_l$ can be described as follows.

$$\tilde{X}_l = \begin{cases} X_{l/\tilde{Q}}, & l = \tilde{Q}.k \quad (0 \le k \le N-1) \\ 0 & ,otherwise \end{cases} \tag{19}$$

Where $0 \le l \le M-1\,,\ M = Q.N,\ and\ \ 1 \le \tilde{Q} \le Q$
Let $m = Q.n + q\ (0 \le n \le N-1\,,\ 0 \le q \le Q-1)$
Then

$$\tilde{x}_m\left(= \tilde{x}_{Q.n+q}\right) = \frac{1}{M}\sum_{l=0}^{N-1}\tilde{X}_l\, e^{j2\pi l\frac{m}{M}} \tag{20}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\tilde{Q}k\frac{Qn+q}{QN}} \tag{21}$$

If q=0 then

$$\tilde{x}_m = \tilde{x}_{Q.n} = \frac{1}{Q}\frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\tilde{Q}k\frac{Qn}{QN}} \tag{22}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{i=0}^{n} X_k e^{j2\pi\tilde{Q}k\frac{n}{N}} \tag{23}$$

$$= \frac{1}{Q}\frac{1}{N}\sum_{i=0}^{n} X_k\, e^{j2\pi k\frac{\tilde{Q}n}{N}} \tag{24}$$

$$= \frac{1}{Q}\left(\frac{1}{N}\sum_{i=0}^{n} X_k\, e^{j2\pi k\frac{(\tilde{Q}.n)_{mod\,N}}{N}}\right) \tag{25}$$

$$\frac{1}{Q}x_{(\tilde{Q}.n)_{mod\,N}} = \frac{1}{Q}x_{(Q(m)_{mod\,N})_{mod\,n}} \tag{26}$$

If $q \neq 0$, since $X_k = \sum_{p=0}^{N-1} x_p e^{-j2\pi k\frac{p}{N}}$ Eqn. 21 can be expressed as follows after derivation

$$\tilde{x}_m = \tilde{x}_{Q.n+q} = \frac{1}{Q}\left(1-e^{j2\pi q\frac{\tilde{Q}}{Q}}\right)\frac{1}{N}\sum_{p=0}^{N-1}\frac{x_p}{1-e^{j2\pi\left\{\frac{(\tilde{Q}n-p)}{N}+\frac{\tilde{Q}q}{QN}\right\}}} \tag{27}$$

From a resource allocation point of view, subcarrier mapping methods are further divided into static and channel-dependent scheduling (CDS) methods. CDS assigns subcarriers to users according to the channel frequency response of each user [26]. CDS is of great benefit with localized subcarrier mapping because it provides significant multi-user diversity which leads to improved system capacity and performance [27].. For these reasons only LFDMA concept is proposed to use in the 3GPP-LTE specifications.

The result of the subcarrier mapping is the set of complex subcarrier amplitudes, where N of the amplitudes are non-zero.

An M-point inverse DFT (IDFT) transforms the subcarrier amplitudes to a complex time domain signal. Each then modulates a single frequency carrier and all the modulated symbols are transmitted sequentially. 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. The receiver transforms the received signal into the frequency domain via DFT, performs frequency domain equalization and then de-maps the subcarriers. Because SC-FDMA uses single carrier modulation, it suffers from inter-symbol interference (ISI) and thus equalization is necessary to combat the ISI. The equalized symbols are transformed back to the time domain via IDFT, and detection and decoding take place in the time domain. Disadvantages of OFDMA compared to SC-FDMA are its strong sensitivity to carrier frequency offset and strong sensitivity to nonlinear distortion in the power amplifier due to the high PAPR, both properties of the multicarrier nature of OFDMA. PAPR was a major factor in selecting SC-FDMA over OFDMA as the uplink air interface for 3GPP LTE [28].

The transmitted SCFDMA signals suffer from multipath fading and Doppler Effect while propagating through the wireless channel, which performs like a filter. In order to get correct demodulation and decoding at the receiver, the channel transfer function must be estimated by the receiver. Channel estimation is followed by channel equalization, which simply divides all the received data symbols by the estimated channel transfer function. Channel estimation can be done both in time domain and frequency domain. For an SCFDMA system FFT need to be performed for all carriers so frequency domain processing is straightforward [29].

The equalization can be done in two domains which are:

- Equalization in time domain
- Equalization in frequency domain

We can position the equalizer on time domain data symbols and try to make these received symbols as close as possible to the transmitted symbols. This is called Time Domain Equalization (TEQ) which computationally complex method. The second method to design equalizer is the Frequency Domain Equalizer (FEQ). The frequency domain equalizer is simple and computationally less complex as compared to time domain equalizer. In the case of frequency domain equalization the received signal is first transformed into frequency domain by means of N-point DFT and then equalization is performed as frequency domain filtering.

In our work we have performed frequency domain linear equalization for the received data symbols as shown in Fig. 6.

The received signal is equalized in the frequency domain. After the equalization block the equalized signal is then transformed back to the time domain using the IFFT by the following steps [30]:

Let E(n) where (n=0, 1, 2…N_{FFT} -1) denote the equalizer coefficient for the n^{th} sub carrier, the time domain equalized signal K(n) can be expressed as:

$$k(n) = \frac{1}{N_{FFT}} \sum_{n=0}^{N_{FFT}-1} E(n) G(n)\, e^{\frac{i2\pi n}{N_{FFT}}} \tag{28}$$

Where $n = 0,1,2,\ldots,N_{FFT} - 1$, The equalizer coefficients E(n) are determined to minimize the mean square error between the equalized signal and the original signal. The equalizer coefficients are computed according to the types of the frequency domain equalization (FDE) in two methods as follows [31]:

A. The zero forcing (ZF) Equalizer is

$$E(n) = 1/H(n) \qquad n = 0,1,2,\ldots,N_{FFT} - 1 \tag{29}$$

B. The Minimum Mean Square Error (MMSE) is

$$E(n) = H^*(n)/[|H(n)|^2 + (E_b/N_0)^{-1}] \tag{30}$$

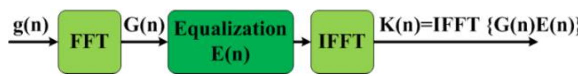

Fig. 6. The process of channel equalization

Where * denotes the complex conjugate, H(n) is the transfer function of the channel and E_b/N_0 is average energy-per-bit to noise power spectral density. Equalization will be used to eliminate the effect of ISI. The MMSE method is better than the ZF method and gives lower BER compared with other method. This improvement can be shown in Fig. 14. Therefore, in all tests and simulations for channel models, the MMSE method will be use.

In the receiver side, OFDMA utilizes a simple equalizer per subcarrier after FFT. But, SC-FDMA utilizes a complex equalizer before sending the resultant to IFFT. IFFT removes the effect of the FFT in the transmitter. Notice that result of the IFFT is again a time domain signal; the time domain signal is sent to a single detector to create the bits. These differences in receiver side are illustrated in Fig. 7. In which we can see the equalizer simplicity of OFDMA against SC-FDMA. As you can see, SC-FDMA receiver is more complex than OFDMA, but in the transmitter simpler power amplifiers can be utilized to reduce the power consumption. These fortify the SC-FDMA as an uplink transmission scheme, since power efficiency and complexity is important for mobile stations but not in the base station [32].

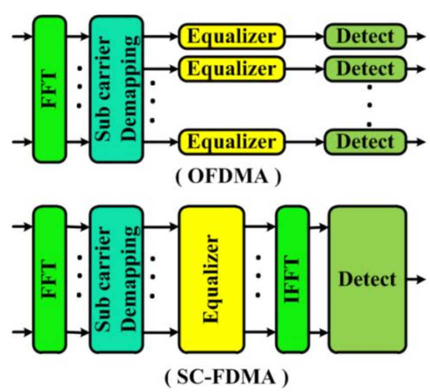

Fig. 7. The equalization in OFDMA and SCFDMA

IV. The Characteristics of the Wireless Communication Channels

In a wireless mobile communication system, a transmitted signal propagating through the wireless channel often encounters multiple reflective paths until it reaches the receiver [33]. We refer to this phenomenon as multipath propagation and it causes fluctuation of the amplitude and phase of the received signal [34]. We call this fluctuation multipath fading and it can occur either in large scale or in small scale as shown in Fig. 8.

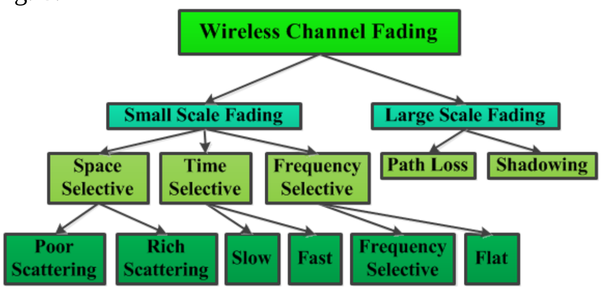

Fig. 8. The characterization of fading channel

Large-scale fading represents the average signal power attenuation or path loss due to motion over large areas. Small-scale fading occurs due to small changes in position and we also call it as Rayleigh fading since the fading is often statistically characterized with Rayleigh probability density function (pdf). Rayleigh fading in the propagation channel, which generates inter-symbol interference (ISI) in the time domain, is a major impairment in wireless communications and it significantly degrades the link performance. With a wider transmission bandwidth, frequency selectivity of the channel becomes more severe and thus the problem of ISI becomes more serious. In a conventional single carrier communication system, time domain equalization in the form of tap delay line filtering is performed to eliminate ISI. However, in case of a wide band channel, the length of the time domain filter to perform equalization becomes prohibitively large since it linearly increases with the channel response length.

The wireless communication system suffer from more than one types of impairments that effect on the activity of the system and this impairment can be category into three groups which are [12]:

A. Transmission impairment due to Physical of radio propagation which include:

1) Attenuation

The energy radiated from an omnidirectional antenna fills a sphere, and therefore the fraction of the original energy incident on a receiving antenna varies inversely with the distance between the transmitting and receiving antennas. In free space the received energy would be inversely proportional to the square of the distance (*d* meters).

2) Shadowing

If attenuation were the only effect of distance on signal strength, a signal would be received with equal power at all points equally distant from a transmitter. However, due to differences in the path taken by the transmitted signal, there is noticeable variation in the power in received signals at different points on a circle surrounding a transmitter. The effect of shadow can be shown in Fig. 9.

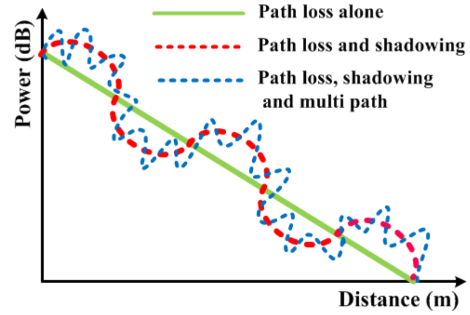

Fig. 9. The effect of path loss, shadowing and Multipath on signal power

3) Doppler

When the transmitted signal is a sine wave and the transmitter and/or receiver is moving, the frequency of a single ray within the received signal is different from the frequency of the transmitted signal. The difference is the *Doppler shift* and it is proportional to $fd = v/\lambda$ Hz, where v (in m/s) is the relative velocity of the transmitter and receiver and λ (in meter) is the wavelength of the transmitted sine wave [33]. For example, the Doppler frequency of a 2 GHz sine wave at a cellular phone in a vehicle moving at 120 km/h is $fd = 222.2$ Hz. The typical other value of Doppler frequency can be shown in table II. The effect of Doppler frequency on the channel can be shown in Fig. 10 and 11. In this figure it can notice that when the speed is high then the effect will be increase and disturb the channel.

TABLE II
PERCEIVED MAXIMUM DOPPLER FREQUENCIES AT DIFFERENT SPEEDS AND CARRIER FREQUENCIES

F_c	*V*=3 Km/h	*V*=60 Km/h	*V*=120 Km/h
1.5 GHz	4.16 Hz	83.33 Hz	166.67 Hz
2.0 GHz	5.6 Hz	111.11 Hz	222.22 Hz
2.4 GHz	6.67 Hz	133.33 Hz	266.67 Hz

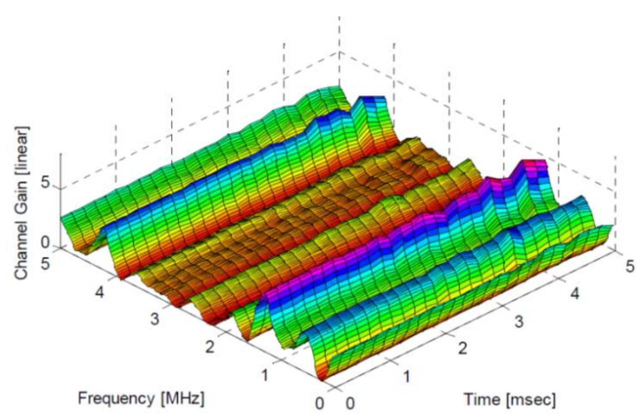

Fig. 10. The Rayleigh fading channel behavior under mobile speed of 3km/h.

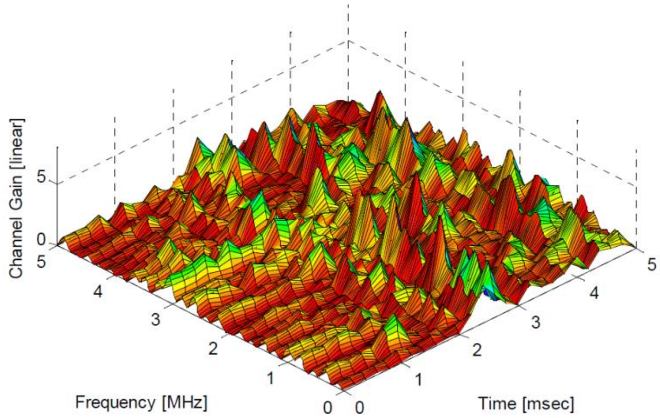

Fig. 11. The Rayleigh fading channel behavior under mobile speed of 60km/h.

4) Inter-Symbol Interference

Multipath propagation is a pervasive phenomenon in cellular signal transmission. Due to the features of the operating environment, components of the transmitted signal arrive at the receiver after reflections from the ground and various natural features and manmade structures as shown in Fig. 12. Therefore, the impulse response of the channel can be modeled as a set of impulses arriving with relative delays proportional to the path lengths of the different signal components.

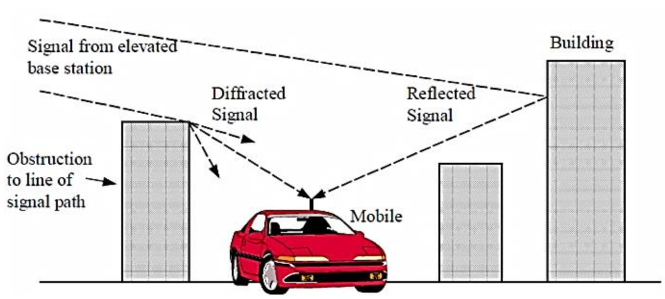

Fig. 12. The radio propagation effects.

5) Flat Fading and Frequency-Selective Fading

When the signal bandwidth *BS* Hz is small compared to the width of the frequency response, the fast fading is referred to as "flat" because all the frequency components of the transmitted signal are attenuated approximately equally. Otherwise the fast fading is "frequency selective". By other word in the flat fading channel the $BW_{channel}$> BW_{signal} while in case of selective fading channel the $BW_{channel}$< BW_{signal} .the effect of flat fading and selective fading channel on the signal transfer through these channels can be shown in Fig.13.

B. Transmission impairment due to extraneous signals which include:

1) Co-Channel Interference

Co-channel interference is a well-known consequence of cellular reuse. In order to use the cellular radio spectrum efficiently, several base stations in a service area use the same physical channels simultaneously.

2) Adjacent Channel Interference

Adjacent channel interference also occurs in all cellular systems. Even though a signal occupies a nominal bandwidth

3) Noise

Co-channel interference and adjacent channel interference are effects of signals generated by a cellular system and therefore under the control of the cellular network operator.

C. Transmission impairment due to transmitting and receiving equipment which include:

1) Thermal Noise

Thermal noise in device electronics enhances the atmospheric noise power in a radio receiver. The added noise is usually expressed as a receiver noise figure, which is the ratio of the total noise power in the receiver to the atmospheric noise

2) Nonlinear Distortion

Nonlinearity in the transmitter power amplifier is the imperfection that most influences performance of frequency-division techniques.

3) Frequency Offset

There are inevitable differences in the frequencies and phases of local oscillators at the transmitter and receiver of a communication system.

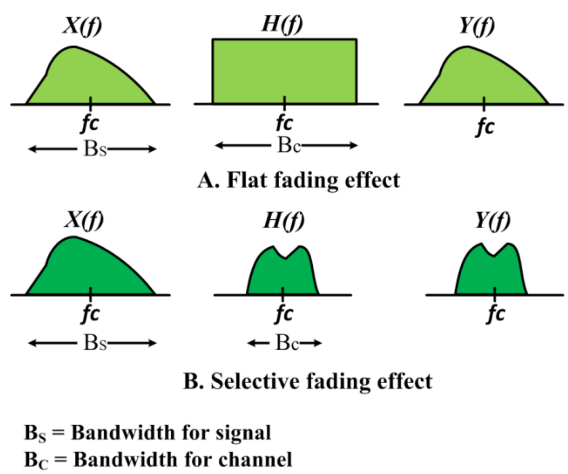

Fig. 13. The effects of flat and selective fading on signals.

V. THE WIRELESS CHANNEL MODELS

A wireless channel can be modeled by trying to calculate the physical processes which modify the transmitted signal. Statistically, communication channels are modeled as a triple consisting of an input alphabet, an output alphabet, and for each pair of input and output elements a transition probability [35]. A realistic model will be a combination of both physical and statistical modeling. A typical example is a wireless channel modeled by a random attenuation (fading) followed by AWGN. The statistics of the random attenuation are decided by previous measurements or physical simulations [36].

There are more channel models that can be studies but in this paper two types of channel models will be discussed which are International Telecommunications Union (ITU) and Stanford University Interim (SUI)

A. ITU Channel Model

For the selection of the air interface of third-generation cellular systems, the International Telecommunications Union (ITU) developed set of models that is available only as a tapped-delay-line implementation [37]. ITU recommendation is also commonly used as an empirical channel model. ITU recommends six channels for three cases and two different delay spreads: indoor, pedestrian, vehicular with low delay spread (Channel A) and medium delay spread (Channel B) [38]. Pedestrian environment is characterized by small cells and low transmit power. Base stations with low antenna height are located outdoors while pedestrian users are located on the streets and inside buildings and residences. The mobile speed is assumed to be 3 km/h [39]. The number of paths in Pedestrian A model is 4 while in Pedestrian B model is 6. The average powers and relative delays for the taps of multipath channels based on ITU recommendations are given in Table III, IV and V. Vehicular environment is characterized by large cells and higher transmit power. Received signal is composed of multipath components with NLOS case only. The number of paths in Vehicular A and B model is 6 [40]. The performance of the system under this channel can be shown in Fig. 15, 16 and 17.

TABLE III
THE AVERAGE POWER AND RELATIVE DELAYS OF ITU INDOOR MODELS

delay (ns)	Chan. A (dB)	Chan. B (dB)
0	0	0
50	-3	
100		-3.6
110	-10	
170	-18	
200		-7.2
290	-26	
300		-10.8
310	-32	
500		-18
700		-25.2

TABLE IV
THE AVERAGE POWER AND RELATIVE DELAYS OF ITU PED. MODELS

delay (ns)	Chan. A (dB)	Chan. B (dB)
0	0	0
110	-9.7	
190	-19.2	
200		-0.9
410	-22.8	
800		-4.9
1200		-8
2300		-7.8
3700		-23.9

TABLE V
THE AVERAGE POWER AND RELATIVE DELAYS OF ITU VEH. MODELS

delay (ns)	Chan. A (dB)	Chan. B (dB)
0	0	-2.5
300		0
310	-1	
710	-9	
1090	-10	
1730	-15	
2510	-20	
8900		-12.8
12900		-10
17100		-25.2
20000		-16

B. SUI

Stanford University Interim (SUI) model is developed by Stanford University. It is used for frequencies above 1900 MHz the modified Stanford University Interim (SUI) channel models consist of a set of 6 typical channels used to simulate the channel models [32]. In this propagation model, three different types of terrains or areas are considered. These are called as terrain A, B and C. Terrain A represents an area with highest path loss, it can be a very dense populated region while terrain B represents an area with moderate path loss, a suburban environment. Terrain C has the least path loss which describes a rural or flat area.

A set of six typical channels was selected for the three terrain types. These models can be used for simulations, design, development, and testing of technologies suitable for fixed broadband wireless applications. The multipath fading is modeled as a tapped delay line with 3 taps with non-uniform delays. Each modified SUI channel model has three taps. Two sets of relative powers are specified for each channel model: one for an omnidirectional antenna, and one for a 30 degrees directional antenna [41]. The distribution of the channel types can be shown in tables VI to XI. The performance of the system under this channel can be shown in Fig. 18, 19, 20 and 21

TABLE VI
SPECIFICATION OF THE SUI1 CHANNEL MODEL

SUI-1 Channel Model	Tap 1	Tap 2	Tap 3
Delay (µs)	0	0.4	0.9
Power (dB) (Omni Antenna)	0	-15	-20
Power (dB) (30º Antenna)	0	-21	-32
Terrain Type	C		
Doppler Spread	Low		
Spread	Low		
LOS	High		

TABLE VII
SPECIFICATION OF THE SUI2 CHANNEL MODEL

SUI-2 Channel Model	Tap 1	Tap 2	Tap 3
Delay (µs)	0	0.4	1.1
Power (dB) (Omni Antenna)	0	-12	-15
Power (dB) (30º Antenna)	0	-18	-27
Terrain Type	C		
Doppler Spread	Low		
Spread	Low		
LOS	High		

TABLE VIII
SPECIFICATION OF THE SUI3 CHANNEL MODEL

SUI-3 Channel Model	Tap 1	Tap 2	Tap 3
Delay (µs)	0	0.4	0.9
Power (dB) (Omni Antenna)	0	-5	-10
Power (dB) (30 ° Antenna)	0	-11	-22
Terrain Type	B		
Doppler Spread	Low		
Spread	Low		
LOS	Low		

TABLE IX
SPECIFICATION OF THE SUI4 CHANNEL MODEL

SUI-4 Channel Model	Tap 1	Tap 2	Tap 3
Delay (µs)	0	1.5	4
Power (dB) (Omni Antenna)	0	-4	-8
Power (dB) (30 ° Antenna)	0	-10	-20
Terrain Type	B		
Doppler Spread	High		
Spread	Med		
LOS	Low		

TABLE X
SPECIFICATION OF THE SUI5 CHANNEL MODEL

SUI-5 Channel Model	Tap 1	Tap 2	Tap 3
Delay (µs)	0	4	10
Power (dB) (Omni Antenna)	0	-5	-10
Power (dB) (30 ° Antenna)	0	-11	-22
Terrain Type	A		
Doppler Spread	High		
Spread	Low		
LOS	High		

XI
SPECIFICATION OF THE SUI6 CHANNEL MODEL

SUI-6 Channel Model	Tap 1	Tap 2	Tap 3
Delay (µs)	0	14	20
Power (dB) (Omni Antenna)	0	-10	-14
Power (dB) (30 ° Antenna)	0	-16	-26
Terrain Type	A		
Doppler Spread	High		
Spread	High		
LOS	Low		

VI. RESULTS AND DISCUSSION

The system (3GPP-LTE-SCFDMA) based on FFT was simulated and run using MATLAB package version 7.12 (R2011a). The behavior of the system was monitored while change the parameters that effect on the performance of the system. The parameters are listed in table I.

TABLE XII
THE PARAMETERS FOR SIMULATION OF (3GPP-LTE-SC-FDMA)

Parameters	Value
System bandwidth	5 MHz
Modulation types	QPSK
Carrier Frequency (fc)	2GHz
Sub-carriers spacing	15 KHz
Sub-carriers mapping	Localized, Distributed
No. of sub-carrier	256
Channel equalization	MMSE
Target BER	10-3
Channel estimation	Perfect
Channel Types	SUI, ITU

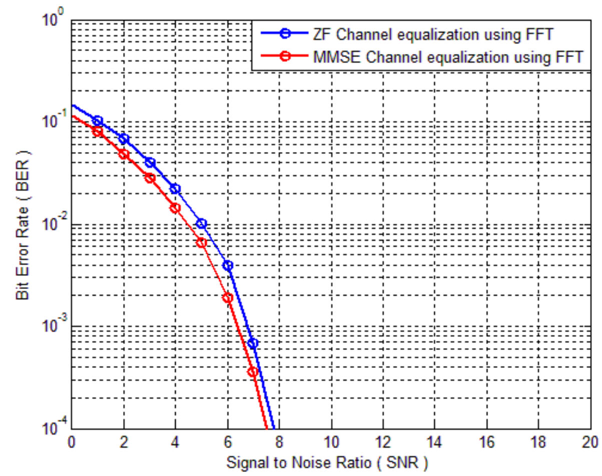

Fig. 14. The performance under two types of channel equalization.

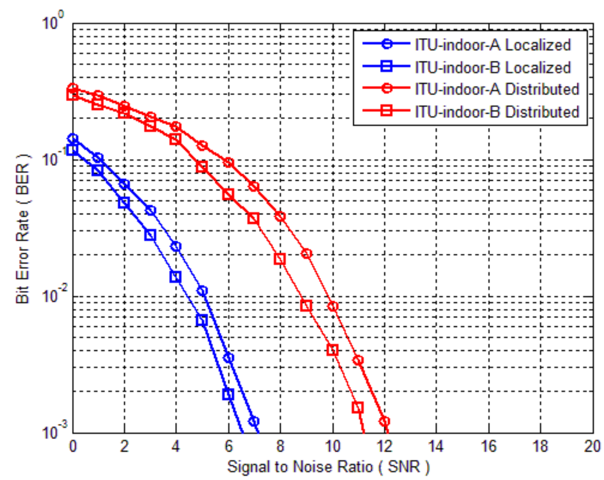

Fig. 15. The performance of SCFDMA under the ITU indoor channel.

 I J E N S

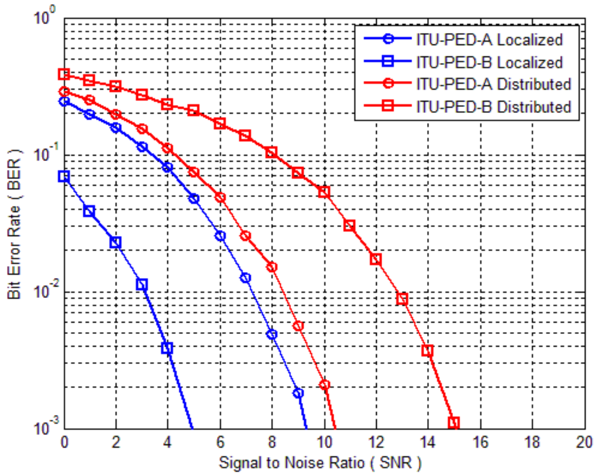

Fig. 16. The performance of SCFDMA under the ITU pedestrian channel

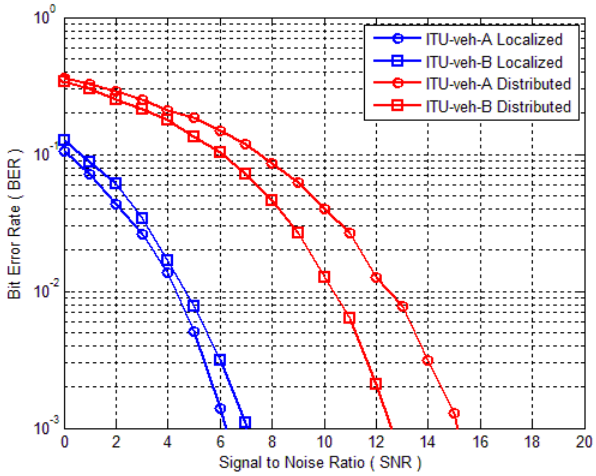

Fig. 17. The performance of SCFDMA under the ITU vehicular channel

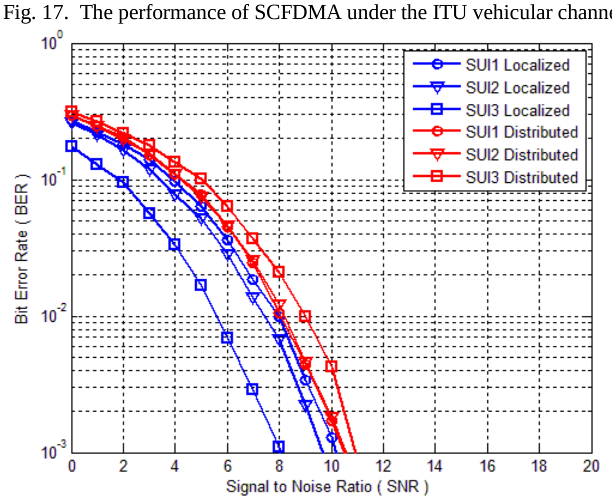

Fig. 18. The performance of SCFDMA system under the SUI1, SUI2, and SUI3 channels (Omni Antenna).

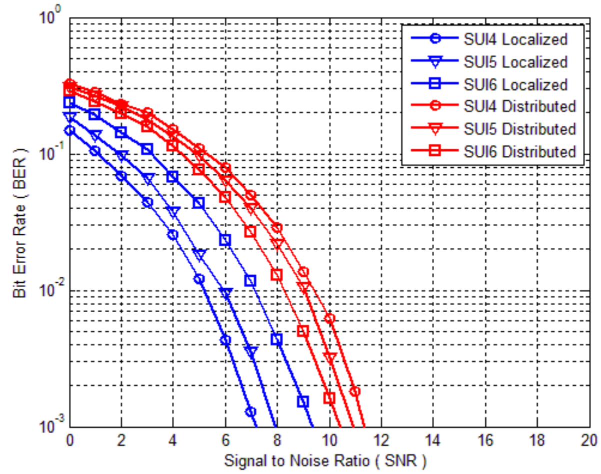

Fig. 19. the performance of SCFDMA system under the SUI4, SUI5, and SUI6 channels (Omni Antenna).

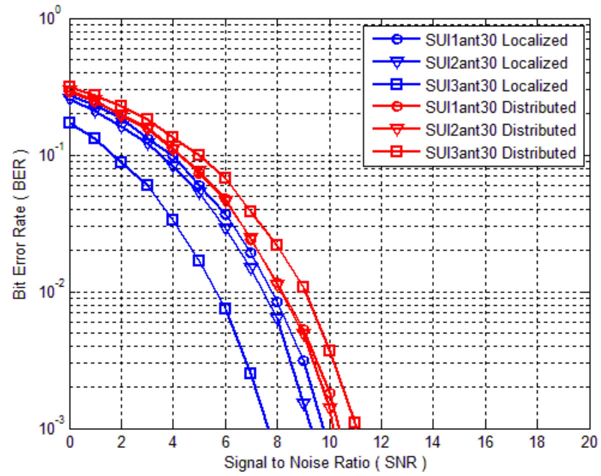

Fig. 20. The performance of SCFDMA system under the SUI1, SUI2, and SUI3 channels (30˚ Antenna).

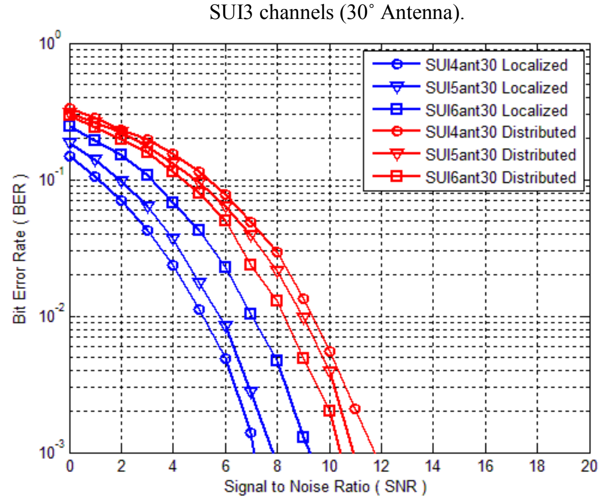

Fig. 21. The performance of SCFDMA system under the SUI4, SUI5, and SUI6 channels (30˚ Antenna).

VII. Conclusion

In this paper work, an effective study, analysis and evaluation of the LTE specification in general and in special a SCFDMA downlink performance with two channel models has been carried out. The performance is evaluated with respect to two definitive metrics namely signal to noise ratio (SNR) and bit error rate (BER). The comparison between two types of channel equalization was done and it is found that the performance of the minimum mean square error MMSE method was better than the zero forcing ZF method. In case of changing the channel types first the ITU channel was selected, the system was run under three cases of channels which are indoor, pedestrian, and vehicular. In case of indoor it is found that there is no high difference between terrain A and B in case of BER but found that there is more benefit when using localized subcarrier mapping and give lower BER as compare with distributed mode and the difference more than 4dB. In case of ITU pedestrian channel model it is found that the difference between localized terrain A and B is about 4dB while the difference between localized and distributed in terrain A equal to 1dB and 10dB in case of terrain B. finally in case of vehicular channel model it is found that there is the difference in case of localized is less than 1dB while in case if terrain A it is found that the difference between localized and distributed mode is 9dB and 6dB in case of terrain B.

The system was tested now under the SUI channel case. The SUI channel models are consisting of six channel models which are SUI1, SUI2… SUI6 and it is found that the system under the localized subcarrier mapping give lower bit error rate than the distributed subcarrier mapping. Also it is found that the channel SUI3 and SUI4 give BER lower than SUI2, SUI1, SUI5 and SUI6 respectively in case of Omni and 30˚ antenna.

Totally for all, it can be concluded that the MMSE equalization is better than ZF method and the localized subcarrier mapping is better than the distributed subcarrier mapping. And also concluded that the SCFDMA system give different response due to different channel model cases.

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