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BER Evaluation in LTE SC-FDMA under Multipath Channels

Sahar Ebadinezhad, Saddam Hasan

Abstract*: Channel equalization is very essential step in Single Carrier Frequency Division Multiple Access (SC-FDMA) transmission for overcoming the inter-symbol interference (ISI). Also, to evaluate the data-link and network scheduling of LTE technique, a particular channel modelling is crucial. Due to the techniques' complexity and requirement of high bandwidth for data transmission in literature, we motivated to perform a comparative analysis for BER reduction in SCFDMA scheme with and without equalizer. Therefor, in order to enhance efficiency of performance and functionality of network application, due to huge demand for lower delay, latency and higher speed by the modern users, BER reduction is a significant factor for enhancing signal quality. The substantial focus of this research is to improve the uplink signal of LTE technology by using two type of linear equalization methods such as zero forcing (ZF) and minimum mean square error (MMSE) at receiver part. Moreover, analysis of BER and SNR for SC-FDMA systems are obtained under several channel models and two different sub-mapping. This evaluation is performed for SC-FDMA in uplink by aid of adaptive modulation techniques like QPSK. Finally, for evaluating the channel equalization efficiency with SC-FDMA and for investigating the response of an uplink transmitter, MATLAB framework, is applied in this study. The results reveal that PAPR reduction does not have significant impact on BER performance.

Keywords*: Channel Equalization, Channel models, Long Term Evolution, Sub-mapping.

I. INTRODUCTION

LTE is a Long-Term Evolution and is the fourth generation of cellular communication with larger bandwidth and more applications, and uses a traditional QAM modulator within the uplink direction. This technique was developed in order to obtain high data transmission, increased quality for video and voice and decreased latency. In LTE, the data transmission rate is up to 50 Mbps and 100Mbps for uplink and downlink, respectively. LTE technology utilizes two multiple access mode: one is OFDMA for the downlink direction, which can increase the data rate but requires high power, whereas the second one is SC-FDMA for the uplink direction, in which the power is confined

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* Correspondence Author
Sahar Ebadinezhad*, Department of Computer Information System, Near East University, Nicosia TRNC, Mersin 10, Turkey; sahar.ebadinezhad@neu.edu.tr
Saddam Hasan, Department of Electronic and Electrical Engineering, Cyprus International University, Lefkoşa, via Mersin 10, Turkey; saddamalhejazee92@gmail.com

(i.e. in upload, a lower power consumption technique must be used to save the battery life of mobile phones [1] [2]. An attractive alternative for OFDMA, is SC-FDMA which has lower PAPR on uplink transmission that increases the power transmission [3]. Nevertheless, different performance can be obtained from distinguished differences of SC-FDMA and OFDMA. These differences are listed in

[3]. Our study focuses on SC-FDMA, which is designed for the uplink transmission of LTE technology. Furthermore, this scheme (SC-FDMA) is adopted from OFDMA due to its advantage of having a PAPR. The purpose of this work is to provide efficiency in the uplink direction of the LTE system. This system uses a different scheme of modulation techniques such as QPSK, 16QAM and 64QAM.The environment of radio propagation is an important aspect of the performance evaluation of wireless communication. The reason is the significant impact of the physical channels and signals that can have on the quality of the wireless environment. Practical channel modelling is important to evaluate the data-link and system of LTE, as well as for the network scheduling of LTE technique. The transmitted signal is exposed to a number of factors while being transmitted from the mobile station to the base station; these factors have negative effects on the characteristics of the signal, which makes the signal attenuated and weakened at the receiver. These factors include ISI and distortion that occurs due to multipath, which will consequently cause a loss in data rate transmission and this phenomenon is unwanted in wireless communication.The motivation for this comprehensive study was to evaluate the performance of channel equalization of SC-FDMA in the uplink with adaptive modulation techniques like QPSK. Channel equalization is a very significant step in SC-FDMA transmission that is used to decrease the ISI that results from the delay propagation of the channel by setting the pulse shape (symbol) so that it does not interfere with the adjacent pulses. This study presents one of the common significant equalization methods, which is classified as linear equalization. Linear equalization is typically a linear altering process used to overturn the channel transfer function to be able to reduce impacts of the channel from the obtained signal. In this paper, we apply two schemes of linear equalization as ZF equalizers and MMSE equalizers [4]. Moreover, we provided list of terminologies that used in this study and can be found in Table I.The rest of this paper includes the following sections. The next section provides an overview of previous studies as well as summary of the different types of channel equalization.

The measurement of system performance on wireless communication and Modulation in LTE uplink will be explained in Sections III and IV, respectively. Also, we will continue to propose our framework and simulation result in Sections V and VI, respectively. Finally, the study will be concluded in Section VII.

Table- I: Abbreviations list

Notaion	Meaning
QAM	Quadrature Amplitude Modulation
LTE	Long Term Evolution
OFDMA	Orthogonal frequency-division Multiple Access
SC-FDMA	Single Carrier Frequency Division Multiple Access
QPSK	Quadrature Phase Shift Keying
ISI	Inter-Symbol Interference
ZF	AWGN, Rayleigh fading, Pedestrian A , Vehicular A
MMSE	Minimum Mean Square Error
ZFE	Zero Forcing Equalizer
SNR	Signal to Noise Ratio
BER	Bit Error Rate
ZF-FDE	Zero-Forcing FDE
STBC	Space-Time Block Codes
AWGN	Additive White Gaussian Noise
LMS	Least Mean Square
CE	Concurrent Equalizer
ICI	Inter carrier Interference
GP	Guard period
PAPR	Peak to Average Power Ratio
SLM	Selected Mapping
PTS	Partial Transmit Sequence
CQI	channel quality information
FFT	Fast Fourier Transform
FDE	Frequency Domain Equalizer
IFDMA	Interleaved Frequency Division Multiple Access
LFDMA	Localized Frequency Division Multiple Access

II. LITERATURE REVIEW

The author in [5] actualized zero forcing equalization and minimum mean squared error equalizer that is utilized as a part of OFDM framework. The goal of this undertaking was to examine a correspondence OFDM framework utilizing orthogonal subcarriers. The concentration of the investigation is the execution of Zero Forcing and MMSE equalization systems with a specific end goal to decrease interference. A discrete-time 4-QAM OFDM framework utilizing Cyclic Prefix, Equalization and AWGN. In [6], channel equalization and estimation were reported as the most important difficulties in the design of transmitters and receivers. In this research, researchers display a provision based on the LMS. Also, CE system is studied for LTE SC-FDMA framework. Those CE strategy utilization versatile estimator which has the ability on redesign parameters of the estimator continuously, are not needed more error details and channel learning. Simulating outcomes indicate that those LMS CE plan with 500 Hz Doppler need 3 dB finer exhibitions compared for 1.5 kHz Doppler frequency.

In [7], the author recommended an insertion algorithm in view of versatile request polynomial fitting for estimation of LTE uplink channel on relieve ICI on secondary Doppler spread. The proposed scheme has shown excellent performance compared to traditional scheme. Because the recommended system will be progressed the BER execution of LTE frameworks.

In [8], turbo coding is defined as a propelled iterative adjustment and decoding strategy that permits improvement to the execution of the information transition over a frequency particular channel fading. Turbo equalization's operation is an iterative process. The reaction majority of the data received, starting with the decoder is consolidated under those adjustment methodologies. In this life cycle, the execution is moved forward through an iterative trade by adding extraneous data to the middle of the equalizer and the decoder. These iterative processes, provide diminishment of the ISI, multi stream interference, as well as noise. The results of this paper show that a turbo equalizer can improve the bit error rate BER by approximately one dB compared to an MMSE equalizer. The maximum production gain is acquired with two iterations of the turbo equalizer.

In [9], an elective method of calculating the bit error rate in SC-FDMA framework with ZF-FDE over channels of fading was introduced based on analysis of the improved noise without channel response. In [10], the author mentioned the reliability and efficiency of communication on wireless systems by focusing on parameters such as BER, data rate, bandwidth, among others. Several systems have been introduced like SC-FDMA and OFDM with channel coding of STBC by applying various modulation methods like QAM, QPSK and PSK. The conclusions in this study were the performance of SC-FDMA with STBC is more efficient compared to OFDM with STBC.

Equalizers consist of channel equalization, which includes two different types of equalization. Linear Equalization is a community type of channel equalization that is used in practice to reduce ISI, whereas Nonlinear Equalization reduces the strong distortion effect caused by linear equalization. To combat the existing ISI in SC-FDMA, usage of a cyclic prefix can be improving the equalization. Equalizing the channel on receiver side will be happened due to converting the linear convolution to a circular convolution by cyclic prefix under different channel [11]. SC-FDMA is affected by inter-symbol interference in cases where the transmission is across a fading channel. Hence, for cellular mobile applications, SC-FDMA needs Equalization at the receiver. In this aim, Guard Period (GP) can be utilized for recovering difficulties of the mobile wireless technology due to the decrease of spectral efficiency. The important component of the LTE receiver is channel equalization.

Improving performance of BER & PAPR by companding technique is introduced for SC-FDMA system in [12]. This method used logarithmic function to achieve its aim. There are many studied based on BER reduction on SCFDMA but most of them are complicated and their bandwidth requirements for data transmitting is high. We can name these methods such as SLM [13], pulse shaping [14], pre-coding technique [15] and Partial Transmit Sequence (PTS) [16].

As the literature mentioned the techniques complexity in most methods, motivated us to propose a simple technique for BER reduction in SCFDMA scheme.

III. SYSTEM PERFORMANCE MEASURES FOR WIRELESS COMMUNICATION

The communication systems are featured based on the service quality which is lowest SNR of acceptable signal that receives by the receiver. The bit error ratio or error probability quantifies the receiver's quality signal by digital communication systems.

A typical bit error performance curve shows function E_b/N_0 which (E_b) is the energy per bit and (N_0) is the noise density ratio. Moreover, the characteristic curve depends on the order of modulation M, where the characteristic curve can be varied by the modulation order specified in M-PSK and M-QAM.

A. *Bit Error Rate (BER)*

BER is the measurement for quantifying the errors' rate of the total bits' number that is presented in (1). The role of BER is to foresee the quality of the communication system by evaluating the robustness of data communication between any transmitter and receiver. When information is sent across a data connection, there is a probability of errors remaining added into the system [17].

$$\mathrm{BER} = \frac{\text{Number of errors}}{\text{Total number of bits}} \tag{1}$$

B. *Signal to Noise Ratio (SNR)*

SNR is the ratio between the total noise power and the total signal power. SNR is expressed as logarithmic scale, called decibel (dB) which is 10 times the logarithms of any value. Clearly, the more the SNR value the better, since higher value of SNR depict less noise power. In fact, higher SNR express the existence of more preferable information rather than undesirable data [18].

C. *Energy bit per noise ratio (E_b/N_0)*

The value of E_b/N_0 specifies the ratio of energy per bit and noise power spectral density ratio. In fact, E_b/N_0 is the normalized SNR which is known as "SNR per bit", and is a vital factor in digital communication [19].

IV. MODULATION IN LTE UPLINK

LTE uses a traditional QAM modulator within the uplink direction. There are available modulation methods which save the user data, namely QPSK, 16QAM, and 64QAM. 16QAM and 64-QAM methods are found in all devices, while QPSK is available in the uplink side. The QPSK modulation on SC-FDMA provides highest efficiency of transmitter power compare to 16QAM or 64QAM modulation at transmit power. The mentioned modulations techniques are the same in the downlink and uplink directions. Feasibility usage of various modulations for every sub-carrier for an OFDM system is explicit. In order to have channel quality information (CQI), this granularity is not an optimal task due to the excessive overheads. There would be numerous bits in the downlink direction if the modulation was specific to any sub-carrier. Consequently, detailed CQI feedback would be required in the uplink direction to be able to get a sub-carrier level in the adaptation. Moreover, PSK has been designated for channels control, which utilize both QPSK and PSK for controlling data transmission. For controlling channel, the modulation cannot easily be modified and an error single signaling must not interrupt discovering following control channel information. Like HSDPA/ HSUPA, in this manner, channels control have their parameters fixed to reject propagation of error which results in frame loss events. Data controlling on uplink while multiplexing by the user data, is an exception in this process, even when 16QAM or 64QAM are used. Note that data modulation and control modulation are equal. In fact, it relaxes the multiplexing rules [20]. In this regard, this paper will investigate SC-FDMA channel equalization as LTE uplink.

A. *Single Carrier-FDMA as LTE uplink*

In the uplink transmission, LTE utilize SC-FDMA for multiple access for either Frequency Division Duplex (FDD) or Time Division Duplex (TDD) schemes for work. The fundamental structure of SC-FDMA can be considered to be similar to QAM, where every symbol is transmitted one by one, in a similar manner to Time Division Multiple Access (TDMA) schemes like GSM. Generation of frequency domain for signal adds the OFDMA feature of good spectral efficiency instead of a time domain signal with modulation scheme. Hence, the requirement for protector bands between several clients can be not considered, like to the downlink side of the OFDMA system. The cyclic prefix in OFDMA scheme is added irregularly in the time domain to combat ISI and in order to streamline the design of the receiver. The receiver tends to deal with ISI as the cyclic prefix for combating ISI among symbols. Therefore, the receiver operates the equalizer to obtain symbols, even arriving the cyclic prefix that limits the additional spread of ISI [20]. SC-FDMA method is suitable for transmitting high data rate in uplink side and has been utilized by 4G for its new broadcast technology, known as LTE. SC-FDMA scheme is a developed form of OFDM technology with related quantity execution and complication. This is frequently observed as a Discreet Fourier Transform OFDM where the data symbols are transformed to the frequency domain via an Inverse Fast Fourier Transform (FFT) in the time domain. Thus, SC-FDMA overcomes the existing difficulties of OFDM over other comprehended systems like as TDMA and CDMA. Versus OFDM, SC-FDMA has the additional benefit of lower PAPR that making it available for uplink communication by end users. In a similar method to the OFDM, SC-FDMA splits the transmission band of data transmission into different subcarriers in a parallel form, with orthogonality between subcarriers within frequency selective fading channel via utilizing a guard time or cyclic prefix. Using the cyclic prefix lead to combating the ISI between SC-FDMA data for easier channel equalization. In this method, the linear convolution of the different channel converts to a circular convolution [21].

B. *Channel Equalization in SC-FDMA*

SC-FDMA is affected by inter-symbol interference in cases where the transmission is across a fading channel. Hence, for cellular mobile applications, SC-FDMA needs equalization at the receiver side. GP is used for recovering difficulties of the coming mobile wireless technology due to the decrease of spectral efficiency.

The important part of an LTE receiver is channel equalization. It is one of the essential components of radio receivers which use synchronize detection. For having efficient LTE techniques, the systems pilots and their device complexities and device computational should be low, and equalization system should be utilized to decrease the complexities. An equalizer is required inside a receiver for medium band of required characteristics of delay and channel amplitude. When the characteristic of a channel is unknown and is time-varying, the equalizer should be adaptive to those changes. In most communication systems, channel equalization can be implemented in both time and frequency domains. For traditional FDM schemes, the equalization is essential in the time domain. Adjusting channel components in the receiver performs by equalizer. Therefore, to decrease ISI by the time-changing multi-path channel the equalizer gives the inverse components of channel balance. Performing equalization on frequency domain is the appropriate way for reducing the linear equalization's complexity. The process of equalization is implemented with block size *N*. FFT converts all samples of the acquired signal to the frequency domain. Subsequently, equalization process is conducted in the frequency domain. In [22] the frequency domain and it's block diagram is shown. On the receiver side, before transmitting the results to block inverse of FFT, SC-FDMA uses an equalizer system. The impact of the block FFT is eliminated by using Inverse FFT. Thus, frequency domain, equalizes the received signal. So, equalized signal transmitted to the time-domain by using IFFT. The time domain equalized signal $k\ (n)$ can be defined as (2) [23]:

$$k(n) = \frac{1}{N_{FFT}} \sum_{m=0}^{N_{FFT}-1} E(m).G(m) e^{\frac{i2\pi mn}{N_{FFT}}} \qquad (2)$$

Where *n* and *m* = 0, 1, 2….. $N_{FFT} - 1$ and $E(m)$ is the equalizer coefficient for the M^{th} sub carrier. The equalizer coefficients *E(m)* are defined to reduce the mean square error between the primary signal and the equalized signal. The *E(m)* can be computed based on the frequency domain equalizer (FDE) in two ways [19] which are ZFE and MMSE. Equation (3) illustrates computation of *E(m)* based-MMSE domain [18].

$$E(m) = H^*(m)/[|H(m)|^2 + (E_b/N_0)^{-1}] \qquad (3)$$

In this Equation, * indicates the conjugate complexity and $H(m)$ is the function transmission of channel. The average energy is indicated as E_b/N_0. Equalization employs to reduce the result of ISI. In [14] the transmitter of SC-FDMA can use an easier power amplifier in order to decrease the power consumption, but this is very complex on the receiver side. SC-FDMA has been chosen by LTE system on uplink communication. Also, PAPR plays an important role in the design of wireless communication systems. A bandlimited signal with high PAPR requires a large back-off to ensure that the power amplifier operates inside its linear region in order not to distort signals.

The importance of power efficiency for the end user cause using SC-FDMA [3]. The most well-known kind of channel equalizer that utilizes an application to decrease ISI is a linear equalizer with adaptive coefficients. In this study, two different schemes are utilized for linear equalization.

V. SYSTEM MODEL

For evaluating the channel equalization efficiency with SC-FDMA and for investigating the response of an uplink transmitter, MATLAB framework, is applied in this study. The multiple access technique is used at the uplink of LTE physical layer on SC-FDMA. Performance evaluation will be done based on four channel models such as AWGN, Rayleigh, Pedestrian *A* and Vehicular *A* channels.

Two types of linear equalization have been applied that are used in SC-FDMA, namely Minimum Mean Square Error (MMSE), and Zero Forcing Equalizer (ZFE). According to BER and SNR variations, the connection of SC-FDMA quality of performance with channel equalization is used here. Moreover, a modulation scheme such as QPSK is utilized to analyze and perform the channel equalization of SCFDMA over LTE system. Both ZFE and MMSE methods are simulated with two schemes of subcarrier mapping as LFDMA and IFDMA to assess performance of SC-FDMA scheme in term of BER and SNR.

This section discussed the results of the simulation that have been obtained from channel equalization with SC-FDMA. Also, the simulation parameters that are used in this study are shown in Table II.

Table- II: Simulation Parameters

Parameters	Values
Simulation method	Monte Carlo
System bandwidth	5 MHz
Modulation type	QPSK
CP length	20 samples
FFT size	512
Subcarriers mapping technique	Localized and interleaved
Types of channels	AWGN, Rayleigh fading, Pedestrian A, Vehicular A
Input Block Size	256
SNR	0:20
Equalization	MMSE, ZFE
Doppler Frequency	100 Hz
Channel estimation	Perfect
Detection	Hard decision
Number of iterations	$> 10^4$

Reduction the ISI impact is an important aim of equalization. Nevertheless, balancing this purpose in a way that noise power does not increase in received signal while dispelling ISI, should be considered. The frequency domain filter can be computed based on assessing the response of channel frequency which is inverted by linear digital equalizer. This inverting lead to noise enhancement while non-linear equalizer does not invert the response of channel frequency. The object of ZF is to force ISI to zero without noise state, and the ZF equalizer frequency response can be shown as following [3]:

$$Z(f) = \frac{1}{H(f)} \qquad (4)$$

Where $H(f)$ is the channel frequency response and *Z(f)* denotes the f transform of the Z_j.

The transfer function of the equalizer according to the MMSE equalizer is [3]:

$$Z(f) = \frac{H^*(f^{-1})}{H(f)H^*(f)+N_0} \quad (5)$$

In (5), the noise-whitening filter is joined into $Z(f)$. Therefore, we get an equivalent equalizer having the transfer like [3]:

$$Z'(f) = \frac{1}{H(f)H(f^{-1})+N_0} = \frac{1}{X(f)+N_0} \quad (6)$$

Note that the N_0 is small, then the equalizer will be like ZFE.

Development of DFT's error probabilities on OFDM and SC-FDMA schemes have analyzed and derivation for fading and multipath channel, fading AWGN and AWGN have been considered for the channel models, in case of utilizing MMSE and ZF equalizers. It was mentioned that condition of AWGN channel and BER is similar for MMSE and ZF [25]:

$$P_{ZF} = P_{MMSE} = \mathrm{Q}\left(\sqrt{\frac{2E_s}{N_0}}\right) \quad (7)$$

Where E_s represents symbol energy and N_0 is noise spectral density. In case of considering Rayleigh channel, the channel response remains low and value of amplitude doesn't stay constant at 1. Practically, these factors differ from one channel to another. Also, the BER of ZF and MMSE can be seen in the below equation that utilized for OFDM system [25]:

$$P_{ZF} = P_{MMSE} = E_H\left(Q\left(\sqrt{\frac{2E_s|H_i|^2}{N_0}}\right)\right) \quad (8)$$

The performance of MMSE and ZF will be changed in situation frequency selective channel. The probability of error for ZF can be found as [25]:

$$P_{ZF} = \mathrm{Q}\left(\sqrt{\frac{2E_s}{\beta_{ZF}N_0}}\right) \quad (9)$$

Where β_{ZF} represents the noise improvement factor of the Zero Forcing Equalizer ZFE [20]:

$$\beta_{ZF} = \frac{1}{M}\sum_{i=0}^{M-1}\frac{1}{|H_i|^2} \quad (10)$$

However, in the MMSE equalizer, the factor of noise improvement is seen to be very small compared to ZF equalizer. The probability of error can be calculated as [25]:

$$P_{MMSE} = Q\left(\sqrt{\frac{1}{\sqrt{\frac{1}{\alpha_{MMSE}}}-1}}\right) \quad (11)$$

Also;

$$\alpha_{MMSE} = \beta_{ZF} = \frac{1}{M}\sum_{i=0}^{M-1}\frac{|H_i|^2}{|H_i|^2+\sigma n^2/\sigma s^2} \quad (12)$$

Where σs^2 is the signal power and σn^2 is the noise power.

The International Telecommunication Union (ITU) suggested a multipath channel which designs to cover all states based on user movement. There are two schemes of these models, which are pedestrian *A* and vehicular *A*. the result of comparison between these modules is less delay on Pedestrian *A* channel. Therefore, the frequency selectivity for the Vehicular channel is very high. Table III illustrates the simulation parameters of both channel models which adapted from [26]. The sampling rate of this system is 5MHz/s, and a delay of channel quantization on adjacent is multiples and we have 5 paths for (Vehicular A) channel and 3 paths for Pedestrian A channel. Every path has a different power (dB).

Table- III: Pedestrian *A* and Vehicular *A* Channel Parameters.

Pedestrian *A* Channel Model			Vehicular *A* channel model		
Path No	***Delay (nsec)***	***Power (db)***	***Path No***	***Delay (nsec)***	***Power (dB)***
Path 1	0	0	Path 1	310	-1.0
Path 2	110	-9.7	Path 2	710	-9.1
Path 3	190	-19.2	Path 3	1090	-10.0
Path 4	410	-22.8	Path 4	1730	-15.0
Path 5	_	_	Path 5	2510	-1.0

The cyclic prefix length (CP) is 20 samples. In the last stage, instead of the (pedestrian A) channel and (vehicular A) channel, a time variant channel has been added that is modeled as a Rayleigh fading channel and is a beneficial model for practical events in cellular communications. These events introduce multipath fading effects, time scattering, and Doppler frequency that occur due to mobility between the receiver and transmitter. Thus, the main paths arrive at the receiver without delay. However, the radio signal of other paths exposed to dispersion on local scale. This dispersion gives rise to many reflections by objects adjacent to the mobile device. These paths arrive at the receiver and produce "multiple fading". Because of these events (phenomenon), every path takes as a separate fading. Usually, the process of fading has Rayleigh distribution follows for both line of sight (LOS), and non- line of sight (NLOS). On the other hand, "Doppler frequency" is the outcome of mobility between the receiver and transmitter, i.e. the frequency is changed at the receiver.

Often, the local dispersion comes due to a lot of angle nearby the mobile station. The maximum Doppler frequency relates to the dispersion and multipath components whose direction exactly compete against the mobile path. The factors of the Rayleigh channel are shown in Table IV.

Table- IV: Parameters of Rayleigh Channel Fading

Parameters	***Values***
Sampling time (T_s)	10e-4
Doppler frequency (F_d)	100
Delay of path(tau)	[0 1.5e-4 2.5e 4]
Power in each path (dB)	[0 -2 -6]

The proposed methodology follows these steps:

1) Implementing linear equalizers (MMSE, ZFE) on SC-FDMA on MATLAB.
2) Applying linear equalizers on both subcarrier mapping methods (IFDMA, LFDMA) for evaluating BER and SNR performance.

3) Applying above mentioned implementations individually on all four channel models (AWGN, Rayleigh, Pedestrian *A* and Vehicular *A* channels).
4) BER updating automatically as the simulation progresses for comparing between equalization methods.
5) Evaluating the quality of received signal on SC-FDMA.

VI. RESULT AND DISCUSSION

A. *Performance evaluation of SC-FDMA under AWGN Channel*

Upon completion of designing the simulation code and adjusting all parameters perfectly, the next step is to run the simulations and to obtain the results that express the BER performance of the SC-FDMA without equalization system. The relationship between the BER and the SNR for SC-FDMA under AWGN are investigated. In this simulation, two schemes of subcarrier mapping have been applied, which are "Interleaved frequency division multiple access" (IFDMA) and "localized frequency division multiple access"(LFDMA). From the results, it can be observed that when the SNR increases, the performance of BER decreases, which generates better performance. Also, both schemes of subcarrier mapping give the same performance. In order to obtain BER at 10^{-6} in both IFDMA and LFDMA, we need to increase a value of SNR to (14dB) while FFT size is 256 as shown in Fig. 1, but when size of FFT is increased to 512 and 1024, significant improvements to the received signal were noted as shown in Fig. 2. In the same figure, ZFE and MMSE hase been applied to the AWGN channel. The results showed the same performance as before applying the equalization; the reason for that is because there is no noise or multipath and only white noise is generated from this channel (AWGN). As previously mentioned, this model of channel is used to evaluate the current system.

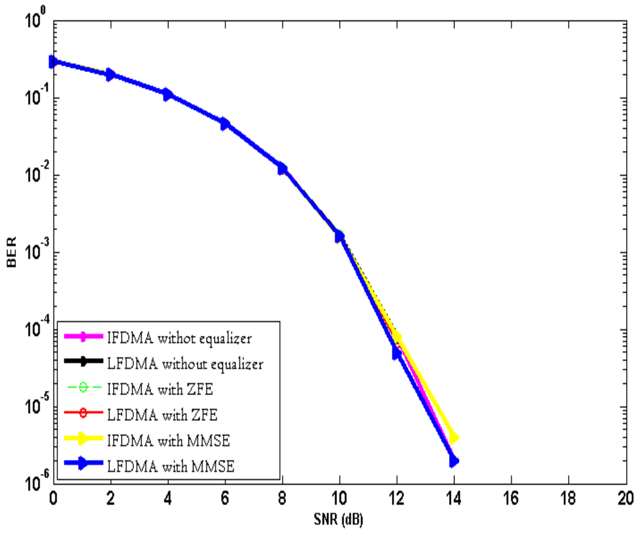

Fig. 1. Performance evaluation of AWGN and with ZFE and MMSE with FFT size 256.

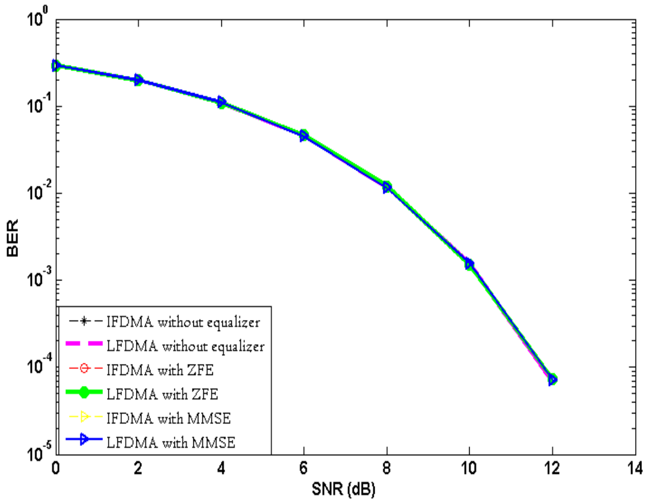

Fig. 2. Performance Evaluation of AWGN and with ZFE and MMSE with FFT size 1024.

B. *Performance evaluation SC-FDMA under Pedestrian A channel*

Fig. 3 shows the performance of BER under the (pedestrian *A)* channel. As this channel model has different multipath and each path has different delay, the BER for this model has low performance d which causes the distortion and inter-symbol interference (ISI). The performance of IFDMA exhibits better result than LFDMA as can be noted from figure, because in the scheme of IFDMA, the frequencies are distributed regally across entire band. To achieve the BER of 10^{-6}, it is necessary to increase the value of SNR to (18dB) for IFDMA and more than 18dB for LFDMA. However, when the number of FFT increases, the received signal is improved, as shown in Fig. 4. Additionally, the block size number and the iterations number can increase the reliability of BER. However, after applying two types of equalization for SC-FDMA with (pedestrian A) channel, it was observed that the received signal was significantly improved. Now, in order to investigate BER at $10^{-6,}$ the SNR requires 14dB for both equalizations. This means that the number of errors decreased.

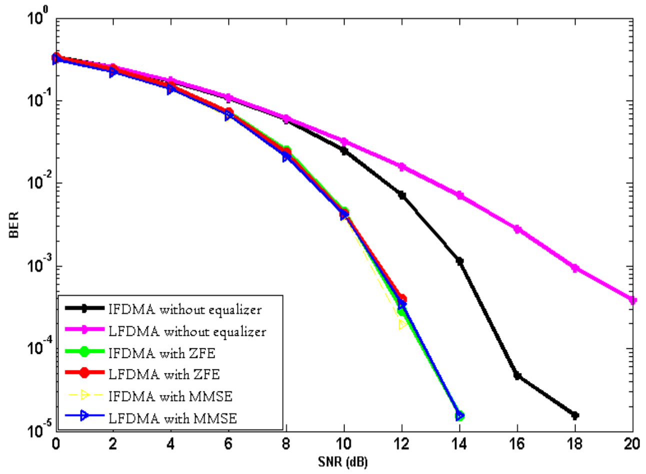

Fig. 3. Performance evaluation of pedestrian *A* channel with ZFE and MMSE with FFT size 256.

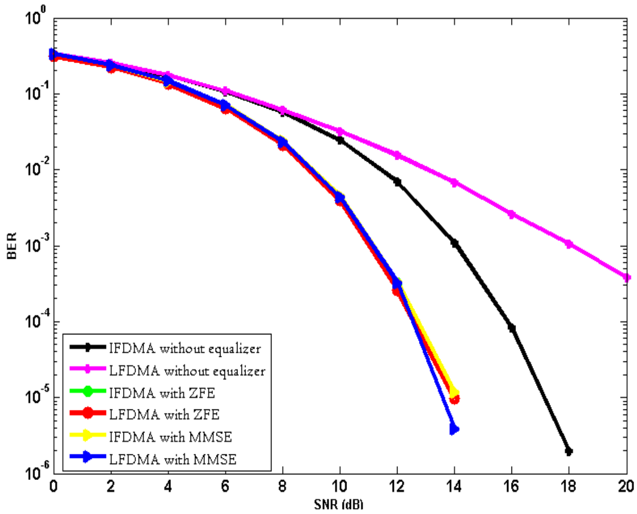

Fig. 4. Performance evaluation of pedestrian *A* channel with ZFE and MMSE with FFT size 1024.

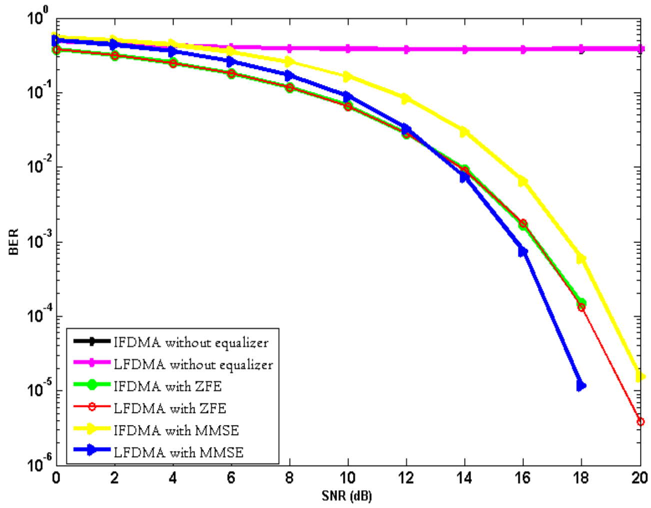

Fig. 6. Performance evaluation of Vehicular *A* channel with ZFE and MMSE with FFT size 1024.

C. *Performance evaluation of SC-FDMA with Vehicular A channel.*

Next, instead of the (pedestrian A) channel, the (Vehicular A) channel has been tested. This channel has more delay and many paths. Fig. 5 shows the performance evaluation of BER under this channel. As we can see, there is distortion for the received signal due to multipath delay in a channel. Both IFDMA and LFDMA exhibit bad performance, which means that all bits that were sent have errors, and it can be considered in following figure compared to AWGN channel. However, after applying the equalizations ZFE and MMSE, the errors in received signal have been reduced and performance is increased. Nevertheless, the performance of ZFE was improved in comparison to MMSE because the equalization of ZFE removes most of ISI in the received signal, whereas it is minimized by MMSE. To achieve the BER at 10^{-6} the ZFE requires approximately 20 dB, but MMSE requires more than 25 dB. When the FFT size increased the BER is improved, as seen in Fig. 6.

D. *Performance evaluation of SC-FDMA with Rayleigh channel*

Finally, Rayleigh fading channel has been added with Doppler frequency of 100Hz to the signal. The results of SCFDMA for LFDMA and IFDMA can be seen in Fig. 7. We note that there are several factors that affect the signal like delay, Doppler frequency and the power of each path. This channel is different from previous channels as it is variant with time, i.e. every path has special power and changes with time. Due to the Doppler frequency and delay, the received signal became distortion, as shown in the following figures. When the Doppler frequency is high, the distortion and ISI both increases. The performance of BER is constant at 10^{-1} when no equalization is applied. However, when two types of equalizations are added, the performance of the received signal is improved. Size of FFT has an effect on improving the received signal, as shown in Fig. 8.

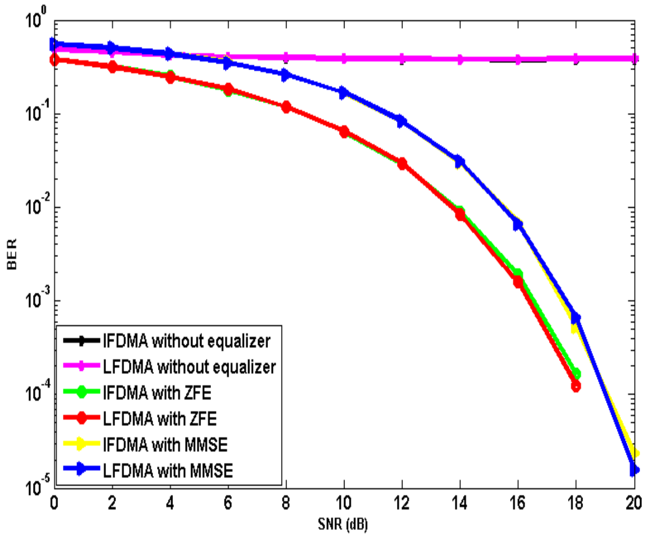

Fig. 5. Performance evaluation of Vehicular *A* channel with ZFE and MMSE with FFT 256.

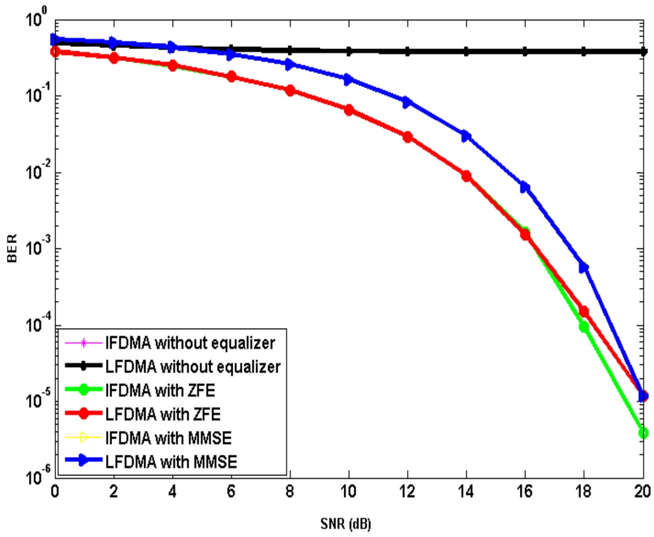

Fig. 7. Performance evaluation of Rayleigh fading with ZFE and MMSE with FFT size 256.

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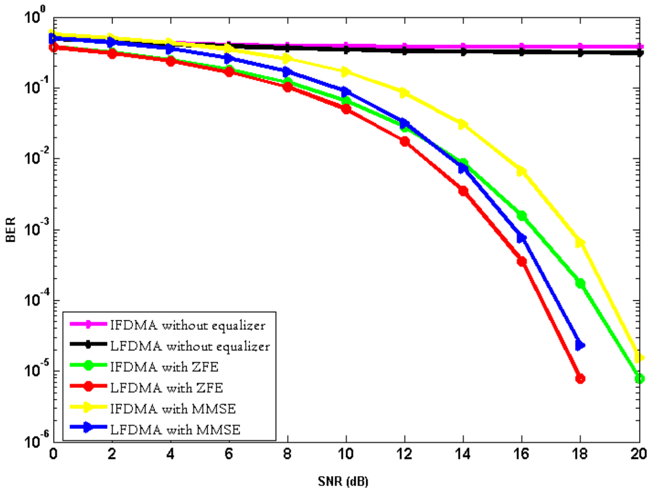

Fig. 8. Performance evaluation of Rayleigh fading with ZFE and MMSE with FFT size 1024.

The bellow table shows experimented results under four different channel model by applying two linear equalizer.

Table- V: Evaluation of BER performance on SC-FDMA.

Channel models	Required power to obtain ideal BER at 10^{-6}	
	IFDMA	LFDMA
AWGN	14 dB	14 dB
Pedestrian *A*	18 dB	< 18 dB
Vehicular *A*	< 25 dB	20 dB
Rayleigh	100 Hz Doppler frequency	

VII. CONCLUSION AND FUTURE WORK

LTE is a developing technology that is suggested in order to achieve a higher speed and higher data rate. One of the important features of this technology is that it uses two schemes of access modes, namely OFDMA and SC-FDMA that apply in the downlink and uplink direction respectively. The most vital factor in SC-FDMA is the channel equalization. This paper examined and analyzed BER performance for SC-FDMA under four different channel equalization such as AWGN, Rayleigh, Pedestrian *A* and Vehicular *A* channels. Based on this examination we analyzed the performance and distortion of the received signal after applying ZFE and MMSE equalizers. As a result of this experiment, we observed that by applying these two equalizers on SC-FDMA the performance of the received signal has significantly enhanced. Also, the size of FFT has a direct effect on improving the received signal. Both ZFE and MMSE equalizer methods are simulated with two schemes of subcarrier mapping as LFDMA and IFDMA to assess performance of SC-FDMA scheme in term of BER and SNR. Consequently, simulation results have revealed that BER performance can be maintained in the SC-FDMA scenario by executing an authentic channel equalization and estimation approach. In order to enrich and improve this work, our future studies can be conducted by examining the effect of non-linear equalization (Maximum–Likelihood Sequence Estimation and Decision–Feedback Equalization) on SC-FDMA. Also, channel coding and decoding can be designied and implemented to provide more effective model for SC-FDMA.

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AUTHORS PROFILE

Sahar Ebadinezhad received the B.S. degree in Computer engineering from the Azad University of Islamshahr, Tehran, Iran, in 2011, and the M.S. degrees in Computer engineering from the Eastern Mediterranean University (EMU), North Cyprus, in 2014. She achieved the Ph.D degree at Computer engineering from the Cyprus International University (CIU), North Cyprus. In 2017, she joined the Department of Computer Information System, University of Near East, as a Lecturer. Her current research interests include Wireless communications system, Millimeter wave communication, Vehicular communication (v2x), Body Centric Communications and Wearable Communication.

Saddam Hasan received his B.Sc degree in Electronic engineering from College of Electronic Technology, Bani walid, Libya in 2014 and He received M.Sc degree in electrical and electronic engineering from Cyprus international university (CIU), Nicosia , Cyprus, in 2018, He is interested in the field of Communications Networks, where he gets Cisco certification (CCNA) . His research interests include Mobile Communication Technique.