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IMPLEMENTING SC-FDMA &OFDMA IN MATLAB

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Abstract

It is very challenging to design an efficient wireless communication system. It is because of many factors, affecting the performance of a typical wireless communication system. Single Carrier Frequency Division Multiple Access (SC-FDMA) & Orthogonal Division Multiple Access (OFDMA) are a major part of future mobile communication standards like Long Term Evolution (LTE), LTE-Advanced and Ultra Mobile Broadband (UMB). OFDMA is well utilized for achieving high spectral efficiency in communication systems. SC-FDMA was recently introduced for uplink multiple access scheme. The multiple access schemes in an advanced mobile radio system have to meet the challenging requirements, such as high throughput, good robustness, low Bit Error Rate (BER), high spectral efficiency, low delays, low computational complexity, low Peak to Average Power Ratio (PAPR) and low error probability. Therefore, this project focuses on implementing the two multiple access techniques (SC-FDMA and OFDMA) with adaptive modulation techniques BPSK, QPSK, 16-QAM and 64-QAM; in order to evaluate the performance of LTE physical layer. An introduction to LTE systems is presented in this manuscript.

Keywords : OFDMA, SC- FDMA, LTE, BER, PAPR, MATLAB.

Introduction

To globally standardize the telecommunication, an organization known International Telegraph Union (ITU) (presently, International Telecommunication Union), was established in Switzerland in 1865 [1]. Since then, ITU has been involved in developing global standards; from telegraphs to modern age 4G systems. Recently, in 2000, to satisfy the ITU's 3rd generation mobile system standards, an organization 3rd Generation Partnership Project (3GPP) was formed. 3GPP is a collaboration of groups of telecom associations working on Global System for Mobile Communication (GSM) [1]. 3GPP published and introduced the various standards for IP based system in Release 8, which was also termed Long Term Evolution and abbreviated as LTE. Recently in 2011, LTE was further developed through Release 10 to satisfy ITU's IMT-Advanced requirements for 4G cellular systems. LTE radio transmission and reception specifications are documented in TS 36.101 for the UE (User Equipment) and TS 36.104 for the eNB (Evolved Node B). As per these specifications, LTE is capable of supporting up to 1Giga Bits per second (1Gbps) for fixed user and up to 100 Mega Bits per second (100 Mbps) for high speed user [1]. The prime cause of this high speed of LTE systems is the advancement in physical layer.

Although there are major step changes between LTE and its 3G predecessors, it is nevertheless looked upon as an evolution of the UMTS/3GPP 3G standards as shown in the Table 1.1. Although LTE uses a different form of radio interface using OFDMA/SC-FDMA instead of CDMA; yet there are many similarities with the earlier forms of 3G architecture and there is scope for much re-use. LTE can, therefore, be seen to provide a further evolution of functionality, increased speeds and general improved performance.

	WCDMA (UMTS)	**HSPA HSDPA/HSUPA**	**HSPA+**	**LTE**
Max downlink speed	384Kbps	14Mbps	28Mbps	100Mbps
Max uplink speed	128Kbps	5.7Mbps	11Mbps	50Mbps
Latency round trip time	150ms	100ms	50ms (max)	~10ms
3GPP releases	Rel 99/4	Rel 5/6	Rel 7	Rel 8/10
Approx years of initial roll out	2003/04	2005/06 (HSDPA) 2007/08 (HSUPA)	2008/09	2009/10
Access technology	CDMA	CDMA	CDMA	OFDMA/ SC-FDMA

Table 1.1: Comparison of parameters of UMTS, HSPA, HSPA+ and LTE [1-3].

In addition to this, LTE is an all IP based network, supporting both IPv4 and IPv6. There is also no basic provision for voice; although, this can be carried as VoIP.

LTE Specifications

The detailed specification of LTE is given in Table 1.2.

Specification	**Details**
Peak downlink speed 64QAM (Mbps)	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak uplink speed (Mbps)	50 (QPSK), 57 (16QAM), 86 (64QAM)
Data type	All packet switched data (voice and data). No circuit switched.
Channel bandwidths	1.4, 3, 5, 10, 15 and 20 MHz
Duplex schemes	FDD and TDD
Mobility	0-15 Km/h optimized 15 - 120 Km/hr (high performance)

Latency	Idle to active less than 100 ms Small packets ~10 ms
Spectral Efficiency	Downlink: 3 to 4 x HSDPA Rel. 6 Uplink: 2 to 3 x HSUPA Rel. 6
Supported antenna configurations	Downlink: 4x2, 2x2, 1x2, 1x1 Uplink: 1x2, 1x1
Access schemes	OFDMA (downlink) SC-FDMA (uplink)
Modulation types supported	QPSK, 16QAM, 64QAM (Uplink and downlink)
Coverage	Full performance up to 5 Km Slight degradation 5 Km – 30 Km Operation up to 100 Km should not be precluded by standard

Table 1.2: Specification of LTE [1-3].

Review of Literature

The LTE physical layer is designed for maximum efficiency of the packet-based transmission; thus only shared channels exist in the physical layer to enable dynamic resource utilization. Different bandwidths ranging from 1.4 MHz to 20MHz are used and parameters are chosen in such a way that FFT lengths as well as sampling rates are obtained easily for all operation modes. All resource allocations are usually short-term. The downlink transmission also contains the control information required for the uplink resources.

The LTE frame structure in the physical layer is comprised of two types:

- Type-1 LTE Frequency Division Duplex (FDD) mode systems
- Type-2 LTE Time Division Duplex (TDD) mode systems

Type-1 frame structure works on both half duplex and full duplex FDD modes. This type of radio frame has duration of 10ms and consists of 20 slots, each slot has equal duration of 0.5ms [9]. A sub-frame consists of two slots; therefore, one radio frame has 10 sub-frames as shown in Figure 2.1. In FDD mode, downlink and uplink transmission is divided in frequency domain; such that, half of the total sub-frames are used for downlink and half for uplink, in each radio frame interval of 10ms.

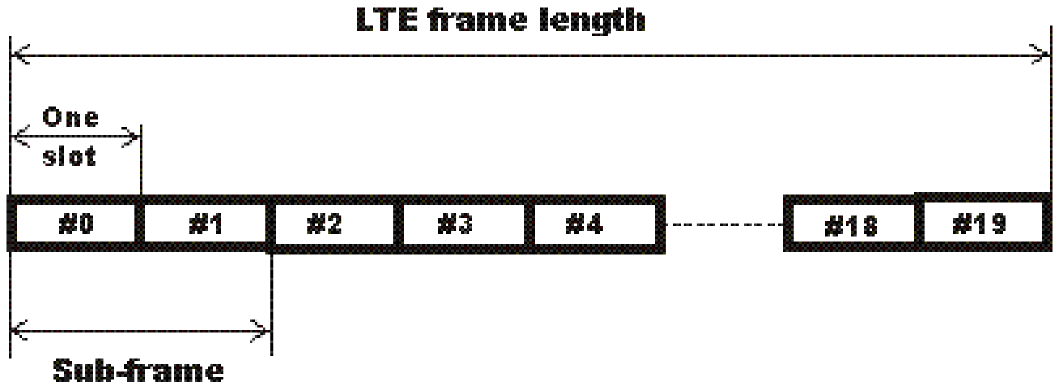

Figure 2.1: Type-1 LTE frame structure [7].

Type-2 frame structure is composed of two identical half frames of 5ms duration each. Both half frames have further 5 sub-frames of 1ms duration as illustrated in Figure 2.2.

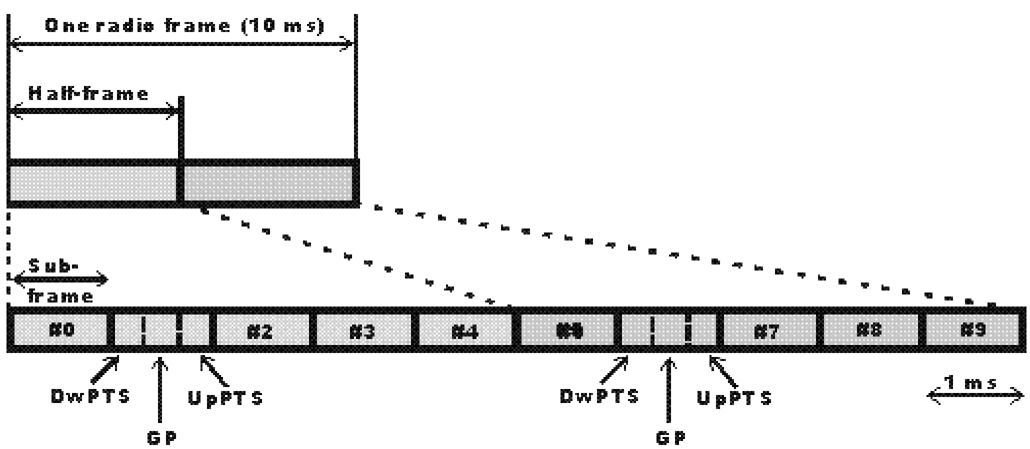

Figure 2.2: Type-2 LTE frame structure [7].

One sub-frame consists of two slots and each slot has duration of 0.5ms. There are some special sub-frames which consist of three fields; Guard Period (GP), Downlink Pilot Timeslot (DwPTS) and Uplink Pilot Timeslot (UpPTS). In terms of length these three fields are configurable individually, but each sub-frames must have total length of

1ms. There are seven uplink/downlink configurations used for either 5ms or 10ms switch-point periodicities. A special sub-frame exists in both half frames in case of 5ms switch-point periodicity; whereas, for 10ms switch-point periodicity the special frame exists only in the first half-frame.

Time and frequency resources of the available bandwidth are divided into smaller blocks to support multiuser configuration and improve overall system efficiency. As LTE DownLink (DL) uses OFDMA and UpLink (UL) supports SC-OFDMA, the available bandwidth is divided into number of orthogonal frequencies with a spacing of Δf = 15KHz called subcarriers [8]. This subcarrier spacing of 15KHz helps keeping Inter Carrier Interference (ICI) to the lower level even the mobile is moving with high speed and causing high Doppler shifts in the frequency [8].

A Resource Block (RB) or sub-frame (Figure 2.3) is formed of a length 1ms using 12 subcarriers and 12 or 14 OFDM symbols (depending on the Cyclic Prefix (CP) length).

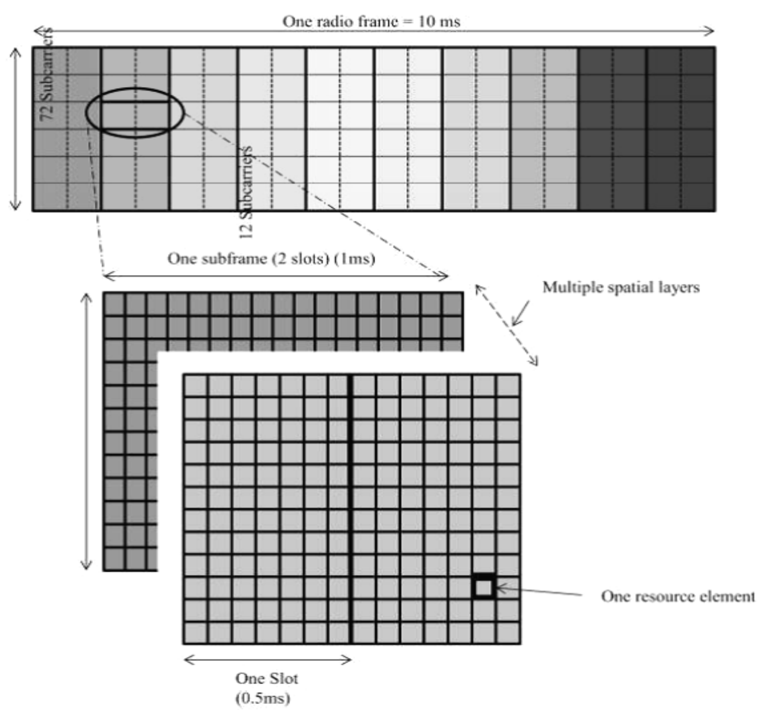

Figure 2.3: LTE radio frame structure with 72 subcarriers with Δf = 15KHz [10].

Furthermore, the RB is subdivided into two slots of 0.5 ms each containing 6 or 7 OFDM symbols over 12 subcarriers. Such fine granularity of the time and frequency resources helps network to assign one or more RBs to different active users simultaneously depending upon the channel conditions and other factors. These building blocks are grouped together to form the radio resources.

SC-FCDMA & OF-DMA in LTE Physical Layer

The multiple access scheme in LTE downlink uses Orthogonal Frequency Division Multiple Access and uplink uses Single Carrier Frequency Division Multiple Access. These multiple access solutions provide orthogonality between the users, reducing the interference and improving the network capacity. The multiple access schemes are illustrated in Figure 3.1.

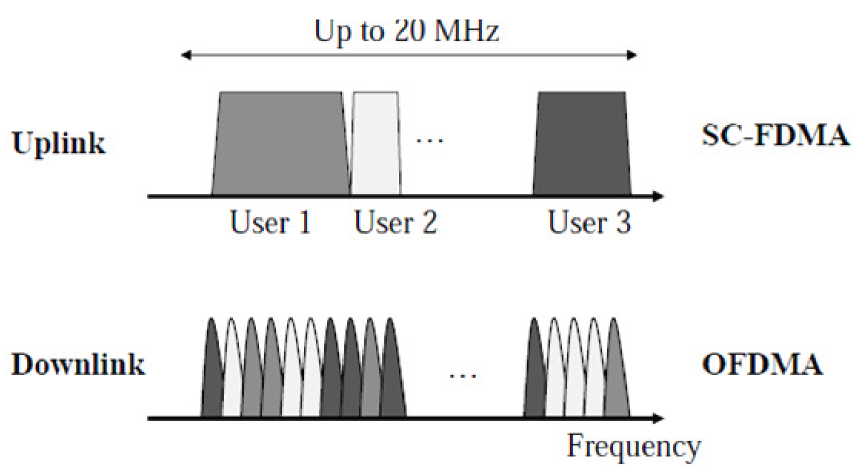

Figure 3.1: LTE multiple access schemes [16].

The resource allocation in the frequency domain takes place with a resolution of 180 kHz resource blocks both in uplink and downlink. The frequency dimension in the packet scheduling is one reason for the high LTE capacity. The uplink user specific allocation is continuous to enable single carrier transmission while the downlink can use resource blocks freely from different parts of the spectrum. The uplink single carrier solution is also designed to allow efficient terminal power amplifier design, which is relevant for the terminal battery life. The LTE solution enables spectrum flexibility where the transmission bandwidth can be selected between 1.4 MHz and 20 MHz depending on the available spectrum. The 20 MHz bandwidth can provide up to 150 Mbps downlink user data rate with 2 × 2 MIMO, and 300 Mbps with 4 × 4 MIMO. The uplink peak data rate is 75 Mbps.

LTE increases the system capacity and widens the spectrum from existing technology up to 20MHz. It can be deployed in any bandwidth combination because of its flexible usage of spectrum (1.4 MHz to 20 MHz). It uses Frequency Division Duplex (FDD) and Time Division Duplex (TDD) to suit all types of spectrum resources. The main requirements for designing the LTE systems are summarized as:

- **Date Rate:** For 20 MHz spectrum, the target for peak data rate is 50 Mbps (for uplink) and 100 Mbps (for downlink).
- **Bandwidth:** In 3GPP technology family, there were considered both the wideband (WCDMA with 5MHz) and the narrowband (GSM with 200 kHz). Therefore, the new system is now required to facilitate frequency allocation flexibility with 1.25/2.5, 5, 10, 15 and 20 MHz allocations [7].
- **Peak Spectral Efficiency:** The peak spectral efficiency requirement for downlink is 5 bps/Hz or higher, and for uplink is 2.5 bps/Hz or higher.
- **Spectral Efficiency of Cell Edge:** The requirement for spectral efficiency of cell edge is 0.04-0.06 bps/Hz/user for downlink and 0.02-0.03 bps/Hz/user for uplink, with assumption of 10 users/cell.
- **Average Cell Spectral Efficiency:** The average cell spectral efficiency required for downlink is 1.6-2.1 bps/Hz/cell and for uplink it is 0.66-1.0 bps/Hz/cell.
- **Latency:** The LTE control-plane latency (transition time to active state) is less than 100 ms (for idle to active), and is less than 50 ms (for dormant to active). The user-plane latency is less than 10 ms from UE (user end) to server.

- **Security & Mobility:** Security and mobility in 3GPP technology is used at good level with the earlier systems starting from GSM and it is sustained at that level and higher.

Simulation Results

This simulates model of OFDMA and SC-FDMA in Matlab. The block diagrams of OFDMA and SC-FDMA are shown in Figure 4.1 and Figure 4.2 respectively, below. The block diagrams of OFDMA and SC-FDMA are similar to OFDM system, except the additional subcarrier mapping and the position of some blocks**.**

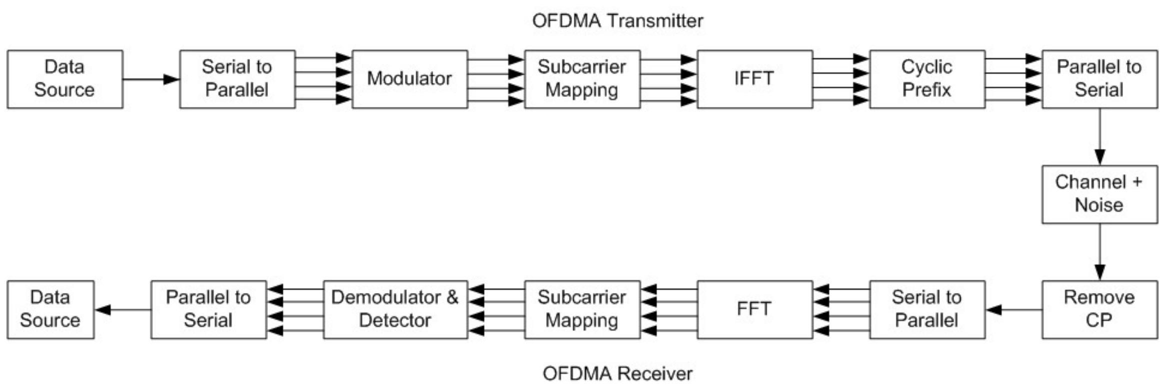

Figure 4.1: Block diagram of an OFDMA system.

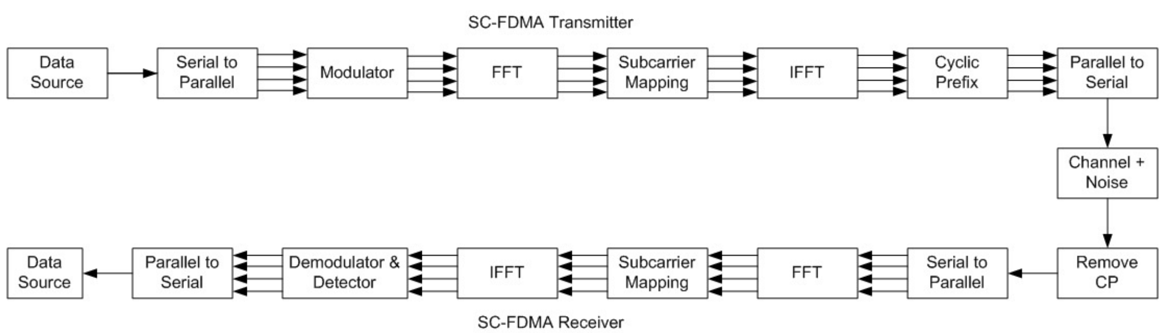

Figure 4.2: Block diagram of a SC-FDMA system.

BER vs SNR of OFDMA and SC-FDMA

The BER vs SNR of OFDMA and SC-FDMA are shown in Figures 4.3 & 4.4 and the corresponding values in Tables 4.2 and 4.3 respectively. In Tables 4.1 and 4.2, the observations are taken for a specific value of BER (1e-3). In both OFDMA and SC-

FDMA, the BPSK and QPSK have same SNR values of 6.8 and 6.5 respectively, but a sudden change occur in 16-QAM and 64-QAM. The 64-QAM has highest value of SNR (16.4) which shows that 64-QAM is more efficient in terms BER.

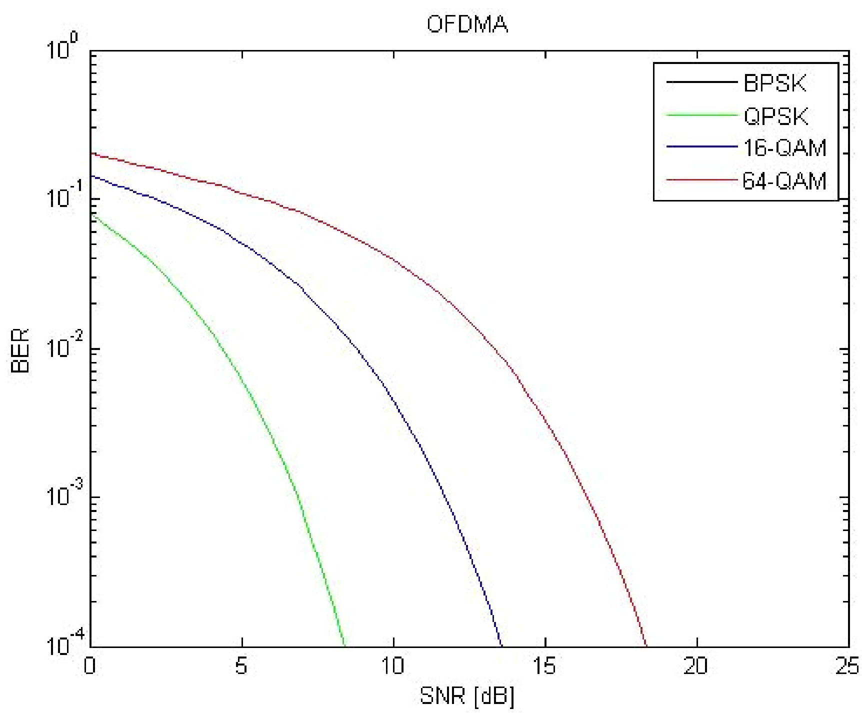

Figure 4.3: BER vs SNR of OFDMA with Adaptive Modulation.

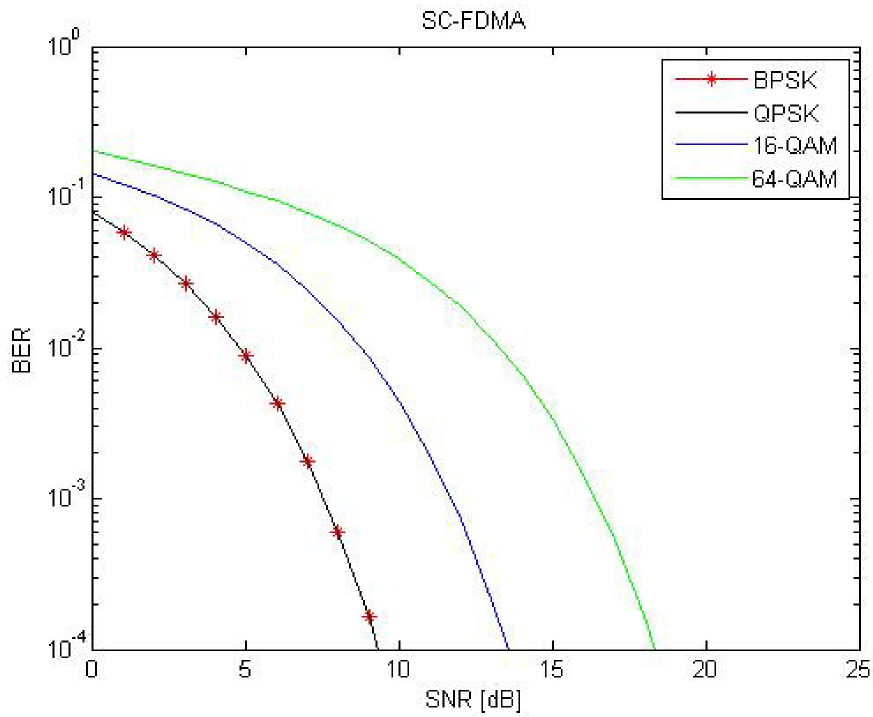

Figure 4.4: BER vs SNR of SC-FDMA with Adaptive Modulation.

BER =1e-3		
Modulation Scheme	**Bits per Symbol**	**SNR (dB)**
BPSK	1	6.8
QPSK	2	6.8
16-QAM	4	11.6
64-QAM	6	16. 4

Table 4.2: BER vs SNR for OFDMA.

BER =1e-3		
Modulation Scheme	**Bits per Symbol**	**SNR (dB)**
BPSK	1	6.5
QPSK	2	6.5

16-QAM	4	11.7
64-QAM	6	16. 4

Table 4.3: BER vs SNR for SC-FDMA.

Error Probability of OFDMA and SC-FDMA for Adaptive Modulation

The error probability graphs of OFDMA and SC-FDMA are shown in Figures 4.5 and 4.6, and the corresponding values in Tables 4.4 and 4.5 respectively.

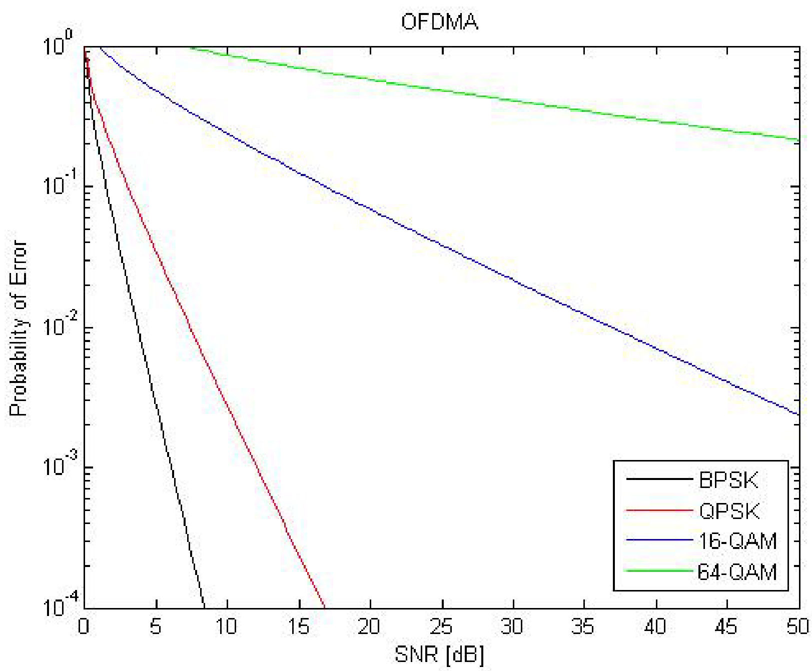

Figure 4.5: Error probability of OFDMA.

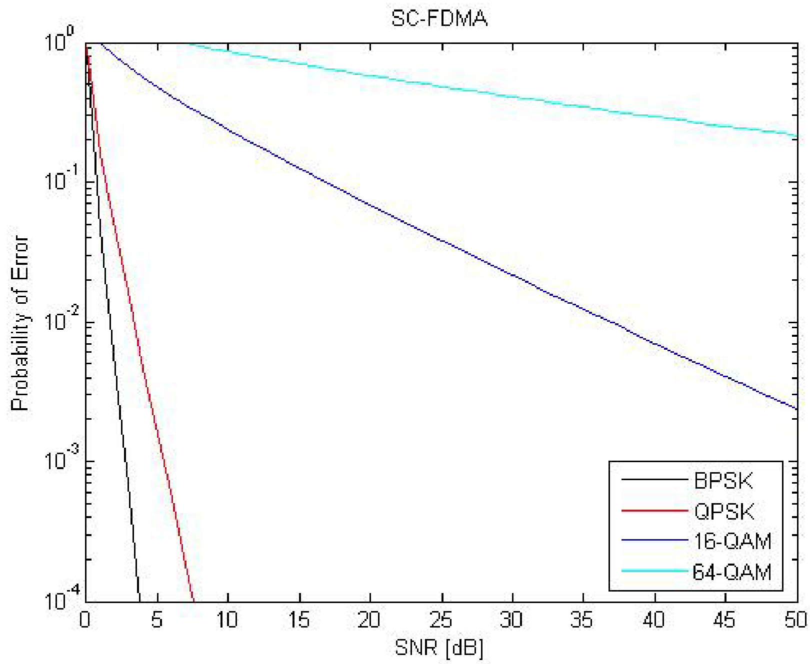

Figure 4.6: Error probability of SC-FDMA.

P_e =1e-0.5		
Modulation Scheme	**Bits per Symbol**	**SNR (dB)**
BPSK	1	1
QPSK	2	2.6
16-QAM	4	8. 4
64-QAM	6	53

Table 4.4: Error probability of OFDMA.

P_e =1e-0.5		
Modulation Scheme	**Bits per Symbol**	**SNR (dB)**
BPSK	1	1
QPSK	2	2
16-QAM	4	7.8
64-QAM	6	37

Table 4.5: Error probability of SC-FDMA.

From Tables 4.4 and 4.5, it can be seen that for a specific value of Pe (1e-0.5) the BPSK modulation has less value of SNR as compared to other modulations. The 64-QAM has higher SNR values in both OFDMA and SC-FDMA.

Power Spectral Density of OFDMA and SC-FDMA:

The power spectral density of OFDMA and SC-FDMA are shown in figure 4.7 and figure 4.8 respectively.

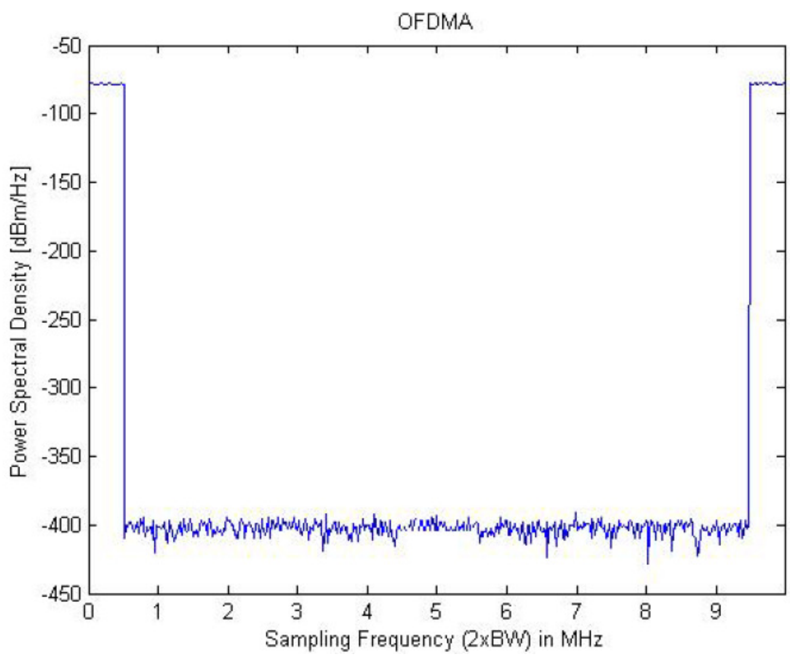

Figure 4.7: Power Spectral Density of OFDMA

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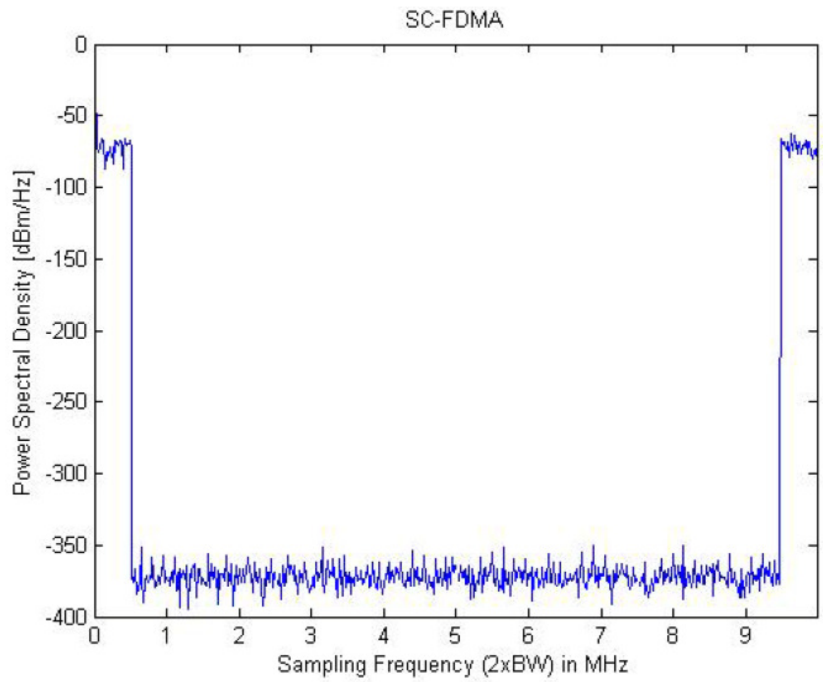

Figure 4.8: Power Spectral Density of SC-FDMA

Figure 4.7 and Figure 4.8 shows the power spectral density of the OFDMA and SC-FDMA respectively. We can observe that the average power of all SC-FDMA symbols (512) is nearly -375dB, whereas, in case of OFDMA the average power of all symbols is nearly -400dB. This shows that the SC-FDMA symbols have inherently more average power as compared to OFDMA at all frequencies. This result also shows the transmit power requirements of OFDMA and SC-FDMA symbols which is covered in next section of PAPR.

PAPR of OFDMA and SC-FDMA for Adaptive Modulation

a) BPSK and QPSK: The PAPR of OFDMA and SC-FDMA for BPSK and QPSK modulations are shown in Figure 4.9 and Figure 4.10 respectively.

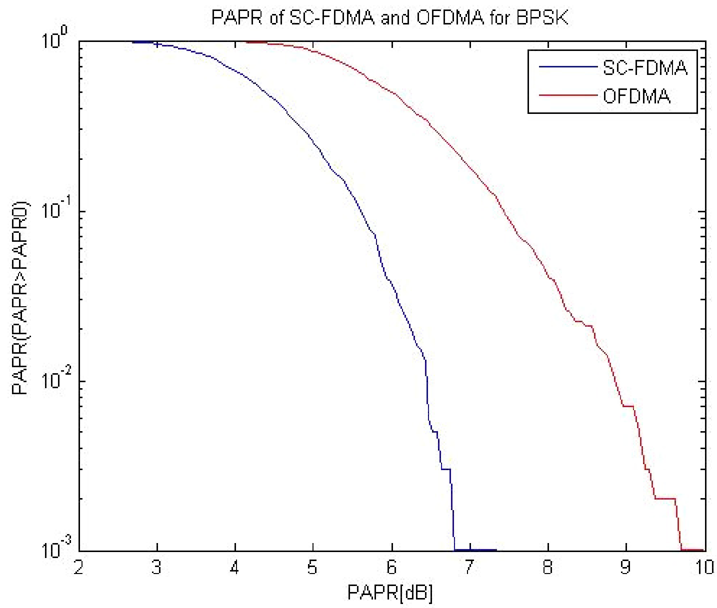

Figure 4.9: PAPR of OFDMA and SC-FDMA for BPSK.

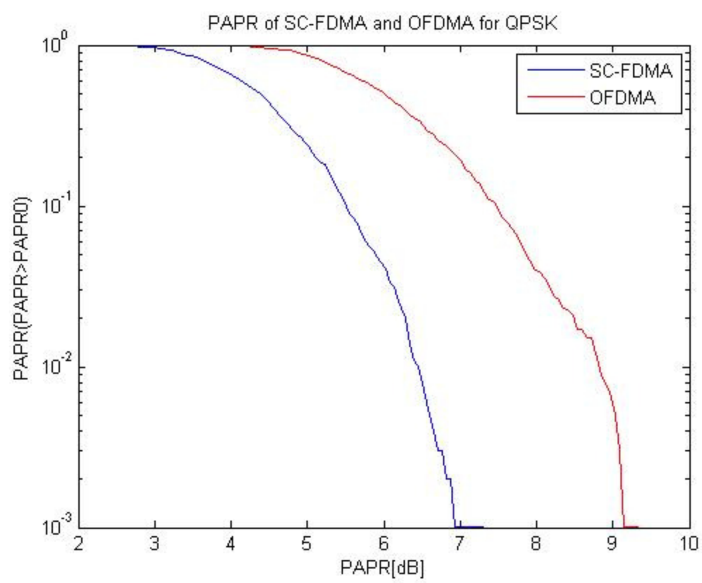

Figure 4.10: PAPR of OFDMA and SC-FDMA for QPSK

From Figure 4.9 and Figure 4.10, it can be observed that the PAPR value of SC-FDMA is almost similar for both modulation schemes; whereas, the PAPR value of OFDMA slightly decreases in case of QPSK modulation.

b) 16-QAM and 64-QAM: The PAPR of OFDMA and SC-FDMA for 16-QAM and 64-QAM are shown in Figures 4.11 and 4.12 respectively.

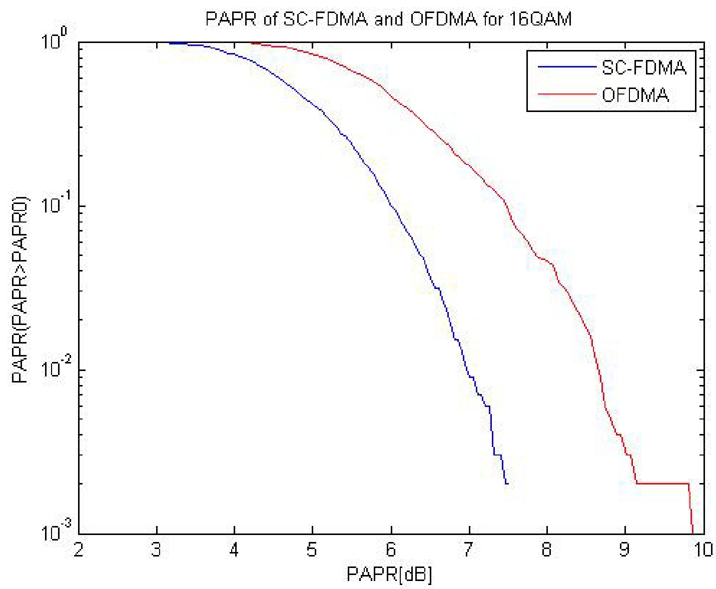

Figure 4.11: PAPR of OFDMA and SC-FDMA for 16-QAM.

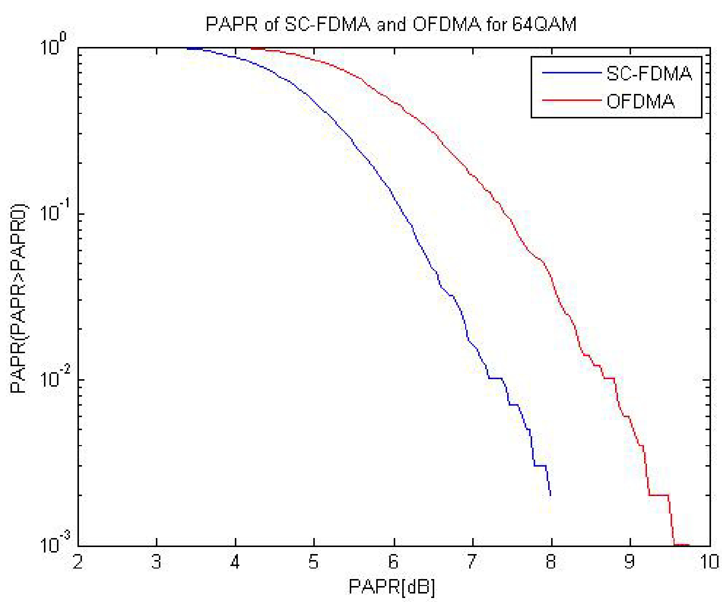

Figure 4.12: PAPR of OFDMA and SC-FDMA for 64-QAM.

From Figures 4.11 and 4.12, it can be observed that by increasing the order of modulation, the PAPR of SC-FDMA increases from 7.5 dB to 8 dB (in case of 16-QAM) and becomes 9.8 db (in case of 64-QAM). Thus, for SC-FDMA the PAPR increases for higher order modulation.

Conclusion and Future work

BER is a key parameter for indicating the system performance of any data link. From the simulated results, it can be observed that for a fix value of SNR, the BER increases for high order modulation (16-QAM and 64-QAM) in both the multiple access techniques (OFDMA and SC-FDMA) used in LTE system. On the other hand, the lower order modulation schemes (BPSK and QPSK) experience less BER at receiver thus lower order modulations improve the system performance in terms of BER and SNR. If the bandwidth efficiency of these modulation schemes is considered, the higher order modulation accommodates more data within a given bandwidth and is more bandwidth efficient as compared to lower order modulation. Thus, there exists a tradeoff between BER and bandwidth efficiency among these modulation schemes used in LTE. It is also concluded from the results that, the error probability 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 the simulation results, it can be concluded that the higher order modulation schemes have an impact on the PAPR of both OFDMA and SC-FDMA. The PAPR increases in SC-FDMA and slightly decreases in OFDMA for higher order modulation schemes. The overall value of PAPR in SC-FDMA is still less than that of OFDMA in all modulation schemes, and that is why it has been adopted for uplink transmission in LTE system. Based on the results obtained, it can be concluded to adopt low order modulation scheme i.e. BPSK, QPSK and 16-QAM for uplink in order to have less PAPR at user end. In nutshell, SC-FDMA is more power efficient. our future work is focused toward the study of achievable "Enhancement Survey on Security Aspects for LTE and LTE-A Networks in 4G".

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