

Abstracts

This paper investigates OFDMA and SC-FDMA techniques combined with the Orthogonal Frequency Division Multiplexing (OFDM). Single carrier frequency Division Multiple Access (SC-FDMA) is a notable application of Multiple Input Multiple Output (MIMO) system. SC-FDMA is one of the most promising techniques aiming at solving the capacity problem of wireless communication systems and achieving higher spectral efficiency, depending on multiplexing signals based on their spatial signature. On the other hand most third generation mobile phone systems are using Code Division Multiple Access (CDMA) as their modulation technique. CDMA is not so complicated to implement as OFDM based systems. As CDMA has a wide bandwidth, it is difficult to equalize the overall spectrum - significant levels of processing would be needed for this as it consists of a continuous signal and not discrete carriers. Not as easy to aggregate spectrum as for OFDM. For this reason, CDMA is also investigating so that the performance of OFDM-SC-FDMA can be compared. Various OFDMA techniques are investigated including LTE or Long Term Evolution is the brand name given to the efforts of 3GPP 4th Generation technology development efforts mostly in Europe and UMB (Ultra-Mobile Broadband) is the brand name for similar efforts by 3GPP2, linear detection schemes, minimum mean square error, ordered successive cancellation, and maximum likelihood methods. Promising results are obtained to enhance spectral efficiency on the expense of computational complexity which needs to be addressed.

Keywords: Single carrier frequency division Multiple Access (SC-FDMA); Orthogonal Frequency Division Multiple Access (OFDMA); Multiple input multiple output (MIMO); Signal-to-noise ratio (SNR); (UMB) Ultra-Mobile Broadband; Long Term Evolution (LTE).

Introduction

Wireless technology overview

Wireless technologies enable one or more devices to communicate without an actual wired connection. Radio frequency is used to transmit the data. From simple to complex wireless communications needs can all be classified in one of three ways, based on the distance they are meant to cover. These include: wireless personal area networks (WPAN), wireless local area networks (WLAN), and wireless wide area networks

(WWAN). The evolution is stated in figure: 1.1 [9]

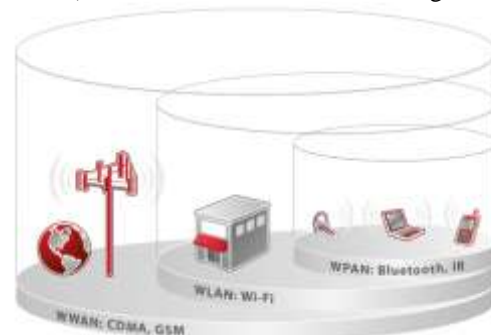


Figure: 1.1 Evolution of wireless technology

Verizon wireless and LTE mobile broadband technology

Wireless carriers are keenly interested in choosing the best technology for their customers—for both today and

information bits (more powerful coding), or reduces the modulation level (better Euclidean distance), or increases the spreading rate (longer spreading code) for lower data rate transmission. Therefore, instead of fixed information rate for all levels of channel quality, variable rates of information transfer can be used to maximize system resource utilization with high quality of user experience.

One particular interest for SNR estimation is to use it for Adaptive Orthogonal Frequency Division Multiplexing (AOFDM) based wireless communication systems. Adaptive modulation that employs different level of modulation for each (or a group) of sub-carriers depends strongly on accurate estimation of SNR value [1]-[3]. There are many other applications that can exploit SNR information, like channel estimation through interpolation and optimal soft information generation for high performance decoding algorithms[4],[5].

In previous SNR estimation techniques, the SNR measurement is considered as an indication of long-term fading statistics due to shadowing and log-normal fading. This long-term SNR estimate is often calculated using regularly. Transmitted training (or pilot) sequences. Instead of using training sequences, the data symbols can also be used for this purpose. For example, Balachandran, who uses SNR information as a channel quality indicator for rate adaptation, exploits the cumulative Euclidean metric corresponding to the decoded trellis path for channel quality information [6]. Jacobsmeier describes another method for channel quality measurement. He proposes the use of the difference between the maximum likelihood decoder metrics for the best path and the second best path [7]. In a sense, he uses some sort of soft information for channel quality indication. But, this approach does not provide any information about the strength of the interferer or the desired signal. There are several other SNR measurement techniques which can be found in [8] and reference listed therein.[12]

Comparison of parameters of UMTS, HSPA, HSPA+ and LTE

	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

Figure:4.1 Comparison of UMTS, HSPA, HSPA+ and LTE

What is OFDM?

Orthogonal frequency division multiplexing (OFDM) is a widely used modulation and multiplexing technology, which has become the basis of many telecommunications standards including wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting in much of the world.[3]

In the past, as well as in the present, the OFDM is referred in the literature as Multi-carrier, Multi-tone and Fourier Transform. The OFDM concept is based on spreading the data to be transmitted over a large number of carriers, each being modulated at a low rate. The carriers are made orthogonal to each other by appropriately choosing the frequency spacing between them. A multicarrier system, such as FDM (aka: Frequency Division Multiplexing), divides the total available bandwidth in the spectrum into sub-bands for multiple carriers to transmit in parallel.[15] It combines a large number of low data rate carriers to construct a composite high data rate communication system. Orthogonality gives the carriers a valid reason to be closely spaced with overlapping without ICI. [16]

Why OFDM?

In contrast to conventional Frequency Division Multiplexing, the spectral overlapping among subcarriers are allowed in OFDM since orthogonality will ensure the subcarrier separation at the receiver, providing better spectral efficiency and the use of steep band pass filter was eliminated. OFDM transmission system offers possibilities for alleviating many of the problems encountered with single carrier systems. It has the advantage of spreading out a frequency selective fade over many symbols. This effectively randomizes burst errors caused by fading or impulse interference so that instead of several adjacent symbols being Completely destroyed, many symbols are only slightly distorted. This allows successful reconstruction of majority of them even without forward error correction. Because of dividing an entire signal bandwidth into many narrow sub-bands, the frequency response over individual sub-bands is relatively flat due to sub-band are smaller than coherence bandwidth of the channel. Thus, equalization is potentially simpler than in a single carrier system and even equalization may be avoided altogether if Differential encoding is implemented.[3]

Principle of OFDM

In digital communications, information is expressed in the form of bits. The term symbol refers to a collection, in various sizes, of bits [17]. OFDM data are generated by taking symbols in the spectral space using M-PSK,

QAM, etc, and convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT). Since Inverse Fast Fourier Transform (IFFT) is more cost effective to implement, it is usually used instead [16]. The main features of a practical OFDM system are as follows:

- Some processing is done on the source data, such as coding for correcting errors, interleaving and mapping of bits onto symbols. An example of mapping used is QAM.
- The symbols are modulated onto orthogonal sub-carriers. This is done by using IFFT.
- Orthogonality is maintained during channel transmission. This can be achieved by adding a cyclic prefix to the OFDM frame to be sent. The cyclic prefix consists of the L last samples of the frame, which are copied and placed in the beginning of the frame. It must be longer than the channel impulse response.
- Synchronization: cyclic prefix can be used to detect the start of each frame. This is done by using the fact that the L first and last samples are the same and therefore correlated.
- Demodulation of the received signal by using FFT.
- Channel equalization: the channel can be estimated either by using a training sequence or sending known so-called pilot symbols at predefined sub-carriers. Decoding and de-interleaving.

Basic OFDM system

The OFDM signal generated by the system in Fig 1 & 2 is at baseband ; in order to generate a radio frequency (RF) signal at the desired transmit frequency filtering and mixing is required. OFDM allows for a high spectral efficiency as the carrier power and modulation scheme can be individually controlled for each carrier. However in broadcast systems these are fixed due to the one-way communication.

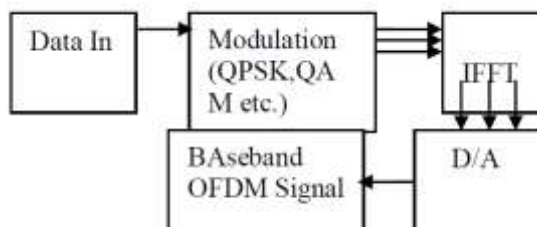


fig. 1: Transmitter

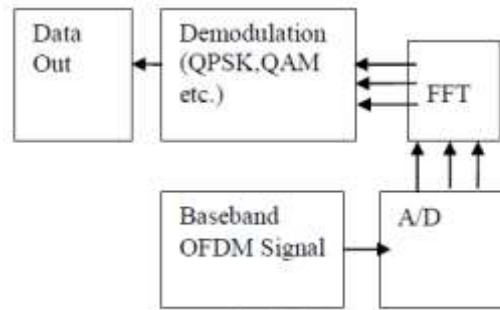


fig.2: Receiver

The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. The block diagram showing a simplified configuration for an OFDM transmitter and receiver is given in Fig.1 & Fig. 2. [3]

Orthogonality

The main aspect in OFDM is maintaining orthogonality of the carriers. If the integral of the product of two signals is zero over a time period, then these two signals are said to be orthogonal to each other. Two sinusoid with frequencies that are integer multiples of a common frequency can satisfy this criterion.

$$\int_0^T \cos(2\pi n f_o t) \cos(2\pi m f_o t) dt = 0 \quad (n \neq m)$$

Therefore, orthogonality is defined by: Where n and m are two unequal integers; fo is the fundamental frequency; T is the period over which the integration is taken. For OFDM, T is one symbol period and fo set to 1/T for optimal effectiveness [15][16].

OFDM applications

OFDM technique is the most prominent technique of this era .Some of its applications is given below.

- DAB: DAB - OFDM forms the basis for the Digital Audio Broadcasting (DAB) standard in the European market [18]. Digital Audio Broadcasting (DAB) using OFDM has been standardized in Europe [19] and is the next step in evolution beyond FM radio broadcasting providing interference free transmission.
- HDTV
- Wireless LAN Networks
- 5.3.1 HIPERLAN/2
- IEEE 802.11g
- IEEE 802.16 Broadband Wireless Access System.
- Wireless ATM transmission system
- IEEE 802.11a

SC-FDMA

Single-carrier FDMA (SC-FDMA) was chosen to reduce Peak to Average Ratio (PAR), which has been identified as a critical issue for use of OFDMA in the uplink where power-efficient amplifiers are required in mobile devices. Another important requirement was to maximize the coverage. For each time interval, the base station scheduler assigns a unique time-frequency interval to a terminal for the transmission of user data, thereby ensuring intracell orthogonality. Slow power control, for compensating path loss and shadow fading, is sufficient as no near-far problem is present due to the orthogonal uplink transmissions. Transmission parameters, coding, and modulation are similar to the downlink transmission.

The chosen SC-FDMA solution is based on using a cyclic prefix to allow high-performance and low-complexity receiver implementation in the e-Node B. As such, the receiver requirements are more complex than in the case of OFDMA for similar link performance, but this is not considered to be a problem in the base station. The terminal is only assigned with contiguous spectrum blocks in the frequency domain to maintain the single-carrier properties and thereby ensure power-efficient transmission. This approach is often referred to as blocked or localized SC-FDMA.[9]

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. 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 15.1.

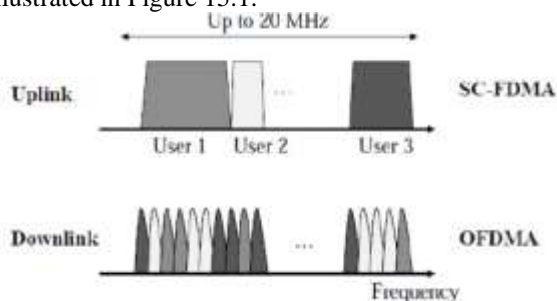


Figure:15.1 Physical layer in LTE

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 wide band(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.[19]

Transceiver result

This simulates model of OFDMA and SC-FDMA in Matlab. The block diagrams of OFDMA and SC-FDMA are shown in Figure 16.1 and Figure 16.2 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.[19]

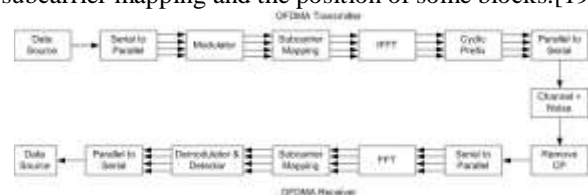


Figure:16.1 Transmitter

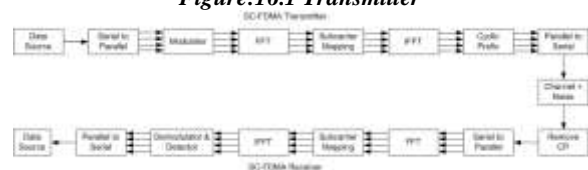


Figure: 16.2 Receiver

BER vs SNR of OFDMA and SC-FDMA

The BER vs SNR of OFDMA and SC-FDMA are shown in Figures 17.1 & 17.2 and the corresponding values in Tables 4.2 and 4.3 respectively. In Tables 18.1 and 18.2, the observations are taken for a specific value of BER (1e-3). In both OFDMA and SC-International FDMA, the BPSK and QPSK have same SNR values of 6.8 and 6.5 respectively, but a sudden change occur in 16 (16.4) which shows that 64

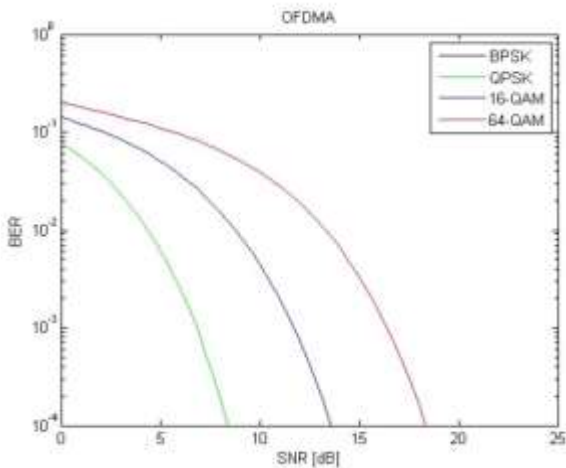


Figure 17.1: BER vs SNR of OFDMA with Adaptive Modulation.

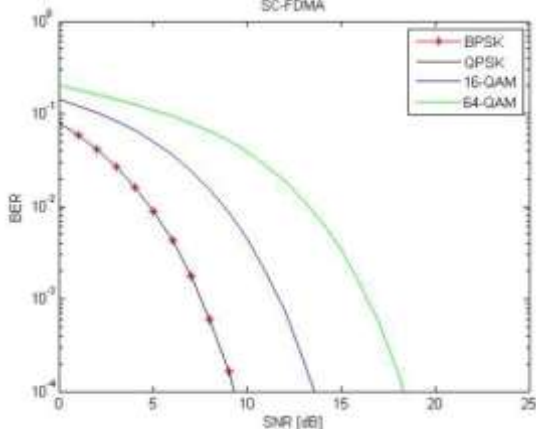


Figure 17.2 BER vs SNR of SC-FDMA with Adaptive Modulation

BER VS SNR for OFDMA

Error Probability of OFDMA and SC-FDMA for Adaptive Modulation The error probability graphs of OFDMA and SC-FDMA are shown in Figures 18.1 and 18.2, and the corresponding values in Tables 18.3 and 18.4 respectively.

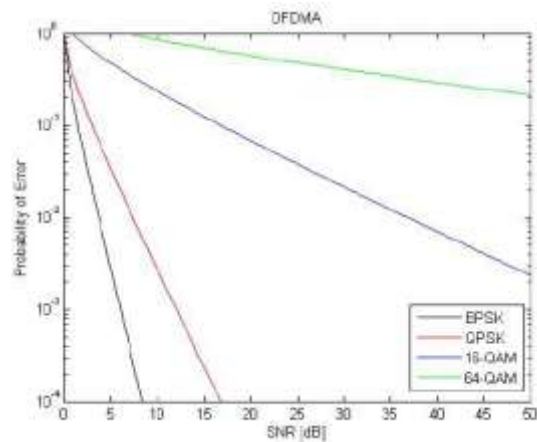


Figure 18.1: Power Spectral Density of OFDMA

Table 18.3: Error probability of OFDMA Table 18.4: Error probability of SC-FDMA From Tables 18.3 and 18.4, it can be seen that for a specific value of P_e ($1e-0.5$) the BPS modulation has less value of SNR as compared to other modulations.

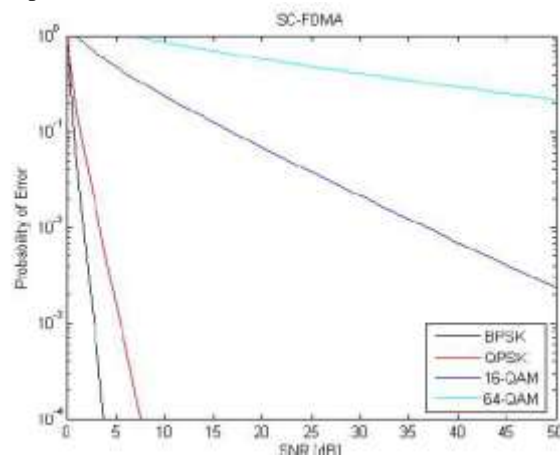


Figure 18.2: Power Spectral Density of SC-FDMA

$P_e = 1e-0.5$		
Modulation Scheme	Bits per Symbol	SNR (dB)
BPSK	1	1
QPSK	2	2.6
16-QAM	4	8.4
64-QAM	6	53

Table 18.3: 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 18.4: Error probability of SC-FDMA

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 19.1 and figure 19.2 respectively.

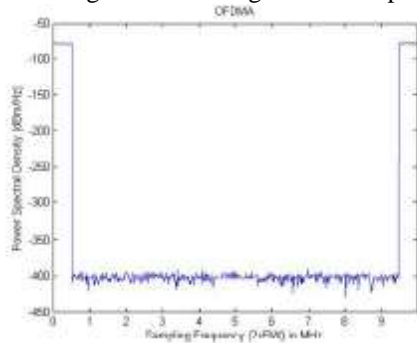


Figure 19.1: Power Spectral Density of OFDMA

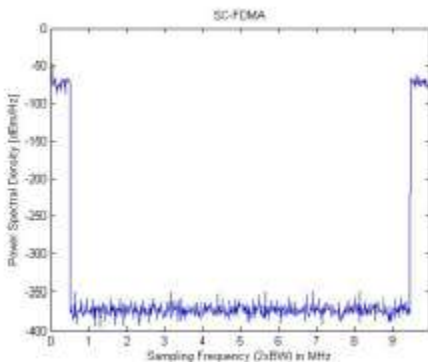


Figure 19.2: Power Spectral Density of SC-FDMA

Figure 19.1 and 19.2 shows the power spectral density of the OFDMA and SCFDMA 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 20.1 and Figure 20.2 respectively.

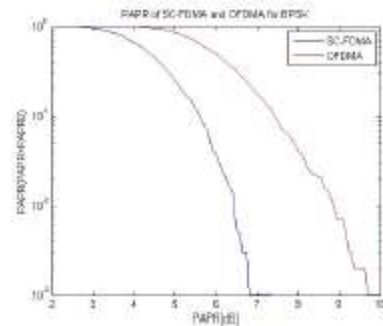


Figure 20.1: PAPR of OFDMA and SC-FDMA for BPSK.

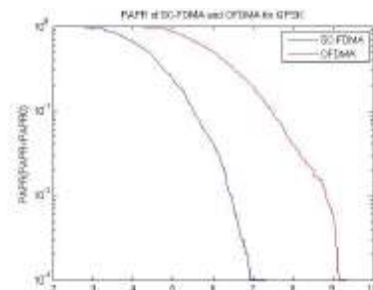


Figure 20.2: PAPR of OFDMA and SC-FDMA for QPSK

- b) **16-QAM and 64-QAM:** The PAPR of OFDMA and SC-FDMA for 16-QAM and 64-QAM are shown in Figures 20.3 and 20.4 respectively.

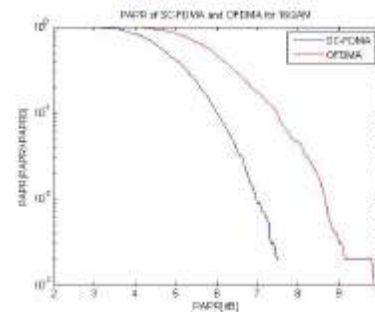


Figure 20.3: PAPR of OFDMA and SC-FDMA for 16-QAM

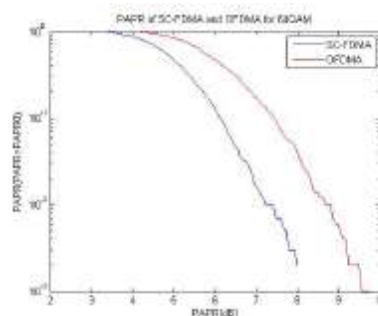


Figure 20.4: PAPR of OFDMA and SC-FDMA for 64-QAM.

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

LTE and 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. Here our future work is focused toward the study of achievable "Enhancement Survey on Security in 4G".

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