

Performance Evolution of SC-FDMA for Mobile Communication System

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Abstract

The main aim of this work is to investigate the performance of Single Carrier Frequency Division Multiple Access (SC-FDMA) in mobile communication system. Nowadays there is increase in demand for high speed data transfer in mobile communication. Different multiple access schemes like Orthogonal Frequency Division Multiplexing (OFDM) and SC-FDM are the two important schemes of Long Term Evolution (LTE) for next generation communication. In this paper, we observe the evolution of SC-FDMA in LTE by showing bit error rate variation and PAPR ratio comparison between OFDMA system and SC-OFDMA system.

Keyword: SC-FDMA, OFDMA, 3GPP-LTE, PAPR, BPSK, MATLAB

1. Introduction

In next generation wireless communication there is a demand for high data rate transfer with long battery life of user equipment. The SC-FDM is a simplified version of OFDM with low Peak-to-Average Power Ratio (PAPR). SC-FDMA is the uplink transmission scheme in the 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 PAPR compared to OFDMA [1]. It has become broadly accepted mainly because of its high resistance to frequency selective fading channels [2].

The 3rd Generation Partnership Project (3GPP) is currently specifying the minimum requirements for Long Term Evolution-Advanced (LTE-A) systems. To cope with this ambitious requirement, advanced multiple-antenna techniques, providing high spectral efficiency values and very large spectrum allocations, in the order of 100 MHz, are expected to be deployed.

In the previous LTE Release-8 standard [3], OFDMA has been selected for the downlink due to its ability to easily cope with the frequency selectivity of wide-band channels and its high spectral efficiency. In this scheme, the modulated symbols are split over low-rate narrow-band orthogonal subcarriers and a proper Cyclic Prefix (CP) is inserted allowing simple equalization at the receiver [4]. In this paper performance of SC-FDMA is shown along with the pilot mapping instead of subcarrier mapping. The performances of our proposed SC-FDMA system are evaluated in both local and wide area scenarios.

2. Long Term Evolution (LTE)

Next generation wireless system proposed by 3GPP is known as LTE. LTE implemented using OFDMA system in downlink and SC-FDMA in uplink communication. This system support both Time and Frequency division duplexing (TDD & FDD). The example as shown in Figure 1, the generic radio frame has time duration of 10 ms, consisting of 20 slots of each 0.5 ms [9].

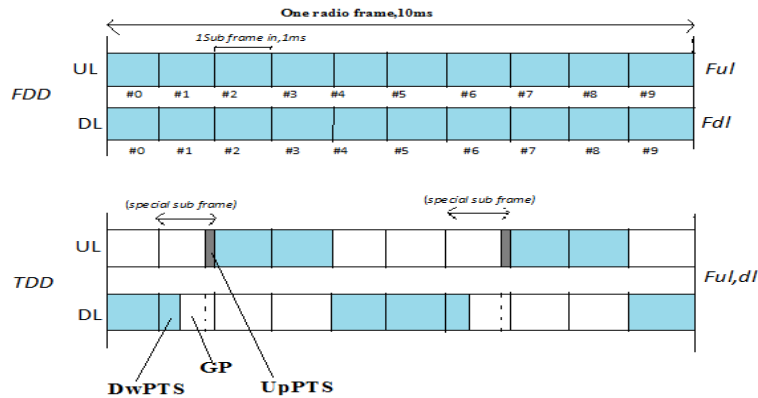


Figure 1. LTE Frame Structure in FDD and TDD Modes [9]

3. Problem Identification

Most of the previous communication system based on TDMA, CDMA, FDMA are provides less speed with complex network. The OFDMA system provides high speed but power consumption in devices is more for transmitting data from device in *uplink*. So we designed SC-FDMA system to whose advantages are listed bellow

- Next generation mobile communication needs high rate of data transfer.
- SC-FDMA allows for the possibility for low-complexity but high-quality equalization in the frequency domain.
- Flexible bandwidth assignments with SC-FDMA.
- Maximizing the utilization of current and future cellular networks. Low sensitivity to carrier frequency offset.
- Less sensitive to non linear distortion and hence, it allows the use of low-cost power amplifiers, low-PAPR (single-carrier property). Greater robustness against spectra nulls.

4. OFDMA vs. FDMA

SC-FDMA system contains the advantage of better PAPR. This is, because the DFT block is added at the transmitter to transmit data.

a. OFDM vs Most Used for Broadband Systems

TDMA & CDMA technologies are implemented in 2nd and 3rd generation mobile system. Time dispersion depends on multipath fading effect due to transmission of signal through wireless network. In a TDMA and CDMA system, it is the ratio of the channel dispersion to signal symbol time and number of channel taps with strong energy at chip-time resolution over the channel dispersion period respectively. In OFDMA system, channel time dispersion is viewed as the frequency selective or non-selective in the frequency domain called *flat fading*. In the time domain, the channel is not dispersive relative to its symbol time, and hence, there is no ISI in OFDM system.

b. Sc-Fdma Modulation System:-

Single carrier modulation, DFT spread orthogonal frequency multiplexing, and frequency domain equalization used in SC-FDMA as OFDMA. In transmitter section block of data are transmitted through modulation block, frequency domain which is the basic property of SC-FDMA using FFT at input, then power & amplitude levels are assigned using pilot insertion in FFT output signal, IFFT applied, and CP are added for

error correction, to transmit data through channel P/S converter is used at last, serially data transmitted through AWGN channel with Rayleigh fading and inverse operation performed at receiver and get the data which was transmitted at input.

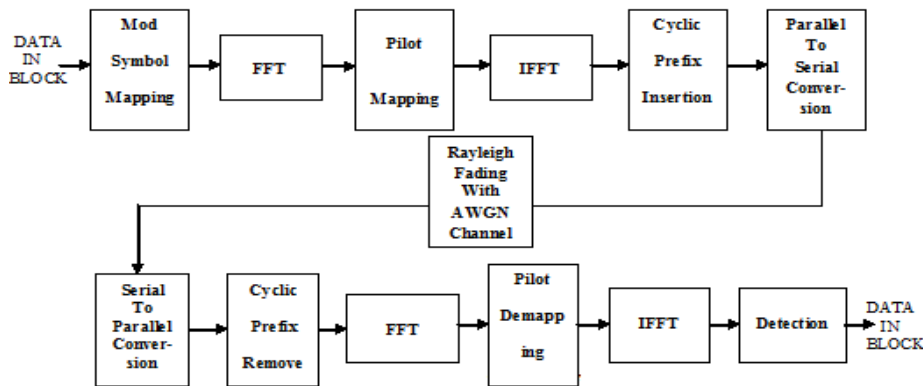


Figure 2. SC-FDMA Transmitter and Receiver

c. OFDMA System

As SC-FDMA is built over OFDMA modulation, we will look at OFDMA system structure. Typical OFDMA transmitter and receiver structure is shown in Figure 3. An OFDMA symbol is the time used to transmit all of subcarriers that are modulated by block of input data symbols. The modulator transforms the input binary bits into a set of multi-level complex numbers that corresponds to different adaptive modulations formats such as BPSK, QPSK, 16-or 64-QAM. These modulated symbols are then mapped to subcarriers (pilot mapping). An IFFT is used to transform the modulated frequency domain subcarriers into time domain samples.

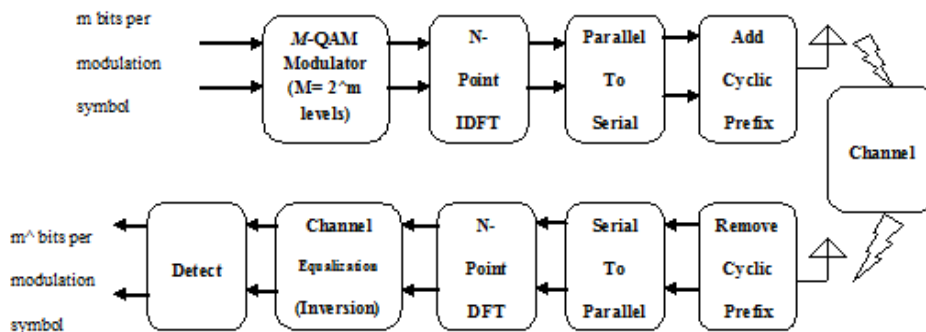


Figure 3. Ofdma System

Having an appropriate modulation format on subcarriers would help to maximize the overall system throughput. A cyclic prefix block copies a portion of the symbol at the end of the time domain samples block to the beginning. Since FFT outputs are periodic hence, copying the samples to the beginning will make the signal continuous. The CP length depends on the channel delay spread, and is longer than the length of the channel response. At the receiver, the prefix part of the symbol is removed because it may contain ISI from its previous symbol.

5. Parameters in OFDMA Based Wireless System

The SC-FDMA system which we are designed here is based on these parameters of OFDMA system [12].

a. Pilot Placement Scheme:-

For a time-varying system, pilot symbols become especially important to achieve reliable transmission. Since high information transmission rate makes low percentage of training. Let $\hat{\mathbf{h}}$ be the channel estimate and MSE is defined as $E\{\|\hat{\mathbf{h}} - \mathbf{h}\|^2\}$. In [15], $(L+1)$ pilot symbols is optimal. Therefore, in considering the pilot placement schemes

- 1) The percentage of pilot symbols in the data stream, denoted as η , is fixed.
- 2) Each OFDM block size $N = k(l + 1), k \geq 1$.
- 3) $(L+1)$ out of N subchannels are selected periodically as *training subchannels* from the set $\left\{i, i + \frac{N}{L+1}, \dots, i + \frac{LN}{L+1}\right\}, i = 0, 1, \dots, \frac{N}{L+1} - 1$. During a training period, pilot symbols in each OFDM block, denoted as $S_{p,m} = [S_{p,m}[0], \dots, S_{p,m}[L]]^t$, are sent over the selected $(L+1)$ training subchannel.
- 4) *Pilot symbols have equal power, $|S_{p,m}[i]|^2 = \sigma_p^2$, for any m and i .*

Since the channel state changes from block to block, we consider the type of periodical placement with equal training cluster size, as shown in Figure 4. For fixed pilot percentage η , it is not hard to see that given the pilot cluster r , the transmission period length T is the given $T = \frac{(L+1)r}{N\eta}$.

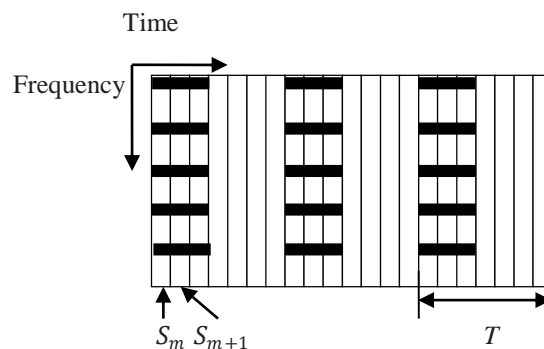


Figure 4. Input OFDM Blocks With Training Period T [15]

b. The Cyclic Prefix Length

The increase in CP length reduces ISI affect at the expense of higher transmitted power loss. In LTE standard, normal cyclic prefix (around $5.7 \mu\text{s}$) and extended cyclic prefix (around $16.67 \mu\text{s}$) which corresponds to seven and six OFDM symbols per slot respectively [12].

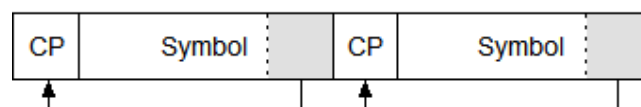


Figure 5. Cyclic Prefix

c. Performance Calculations

The performance analysis of OFDMA and SC-FDMA in LTE are characterized by following parameters [10, 14].

a. Bit Error Rate (Ber)

The BER is ratio of errors bits to the total number of bits transmitted during the time interval

$$BER = \frac{(\text{error bits})}{(\text{number of transmitted bits})} \quad (1)$$

b. Signal to Noise Ratio (Snr)

The SNR is the ratio of bit energy (Eb) to the noise power spectral density (N0) and is expressed in db.

$$SNR = \frac{E_b}{N_0} \quad (2)$$

c. Ber Vs Snr Process

For any modulation scheme, the BER is expressed in terms of SNR. BER is measured by comparing the transmitted signal with received signal, and compute the error counts over the total number of bits transmitted.

d. Probability Of Error (Pe)

The probability of error or error probability (Pe) is the rate of errors occurs in the received signal. For the coherent detection the symbol error probability of M-ary PSK and M-ary QAM in the AWGN channel is determined by following expressions,

For M-ary PSK the Pe is given by

$$Pe \cong 2Q \left[\sqrt{\frac{2E_b \log_2 M}{N_0}} \sin\left(\frac{\pi}{M}\right) \right] \quad (3)$$

Where,

$E_b \log_2 M = E$ (Transmitted signal energy per symbol)

N_0 = Noise density in AWGN

Q = Q-Function

Therefore

$$Pe \cong 2Q \left[\sqrt{\frac{2E}{N_0}} \sin\left(\frac{\pi}{M}\right) \right] \quad (4)$$

The complementary error function (erfc) used instead of Q. Therefore, the symbol error probability in terms of erfc is

$$Pe \cong \text{erfc} \left[\sqrt{\frac{E}{N_0}} \sin\left(\frac{\pi}{M}\right) \right] \quad (5)$$

Whereas, the relationship between erfc and Q is given by

$$Q(x) = \frac{1}{2} \operatorname{erfc} \left[\frac{x}{\sqrt{2}} \right] \quad (6)$$

For M-ary QAM the P_e is given by,

$$P_e \cong 4 \left(1 - \frac{1}{\sqrt{M}} \right) Q \left[\sqrt{\frac{3E_{av}}{(M-1)N_0}} \right] \quad (7)$$

Similarly in terms of erfc, the P_e of M-ary QAM is given by

$$P_e \cong 2 \left(1 - \frac{1}{\sqrt{M}} \right) \operatorname{erfc} \left(\sqrt{\frac{3E_{av}}{2(M-1)N_0}} \right) \quad (8)$$

Where,

N_0 = Noise density in AWGN

E_{av} = Average value of transmitted symbol energy in M-ary QAM or M-ary PSK

e. Peak To Average Power Ratio (Papr)

The Complementary Cumulative Distribution Function (CCDF) of PAPR is the probability of the PAPR is higher than a certain PAPR value $PAPR_0$ ($\Pr\{PAPR > PAPR_0\}$).

f. Power Spectral Density

The power spectral density (PSD) is an important function that describes the power distribution of a signal with respect to frequency.

$$P_{xx}(m) = \frac{1}{f_s} \left\{ \frac{1}{N} |DFT_N\{x(N)\}|^2 \right\} \quad (9)$$

Where,

f_s = Sampling Frequency (10 MHz)

N = Number of FFT points (256 = total subcarriers)

We calculate the PSD at the output of IFFT block in the transmitter of both SC-FDMA.

g. Results and Stimulation

The stimulation of performance evolution of SC-OFDMA system is implemented in MATLAB.

Table 1. Parameters

Parameters	Value
Number of Subcarrier	256
CP length	64 (4 symbol)
Modulation Scheme	BPSK, QPSK, 16-QAM, 64-QAM
Data Block size	16 symbol
Bandwidth	5MHz

Channel	AWGN (SNR 100db)
Fading	Rayleigh (frequency Selective)
Rayleigh fading parameter	Input sample period = 1.00e-3 sec Maximum Doppler shift = 100 Hz Vector path delays = [0 2.00e-5] sec Average path gain vector = [0 -9] db
FFT and IFFT Size	64

h. Stimulation Results are Given Below

Stimulation results are based on different modulation techniques and parameters given in the above table. The results are shown below

g. SC-FDMA and OFDMA Paper Comparison for Different Modulation Scheme

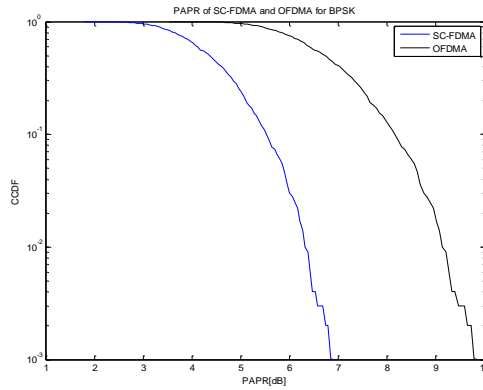


Figure 6. PAPR Comparison for BPSK Scheme

From above Figure 6 we can say that the BPSK modulation scheme have an impact on the PAPR of both OFDMA and SC-FDMA. The overall value of PAPR in SC-FDMA (is shown in figure as blue line) is less than that of OFDMA (is shown in figure as black line).

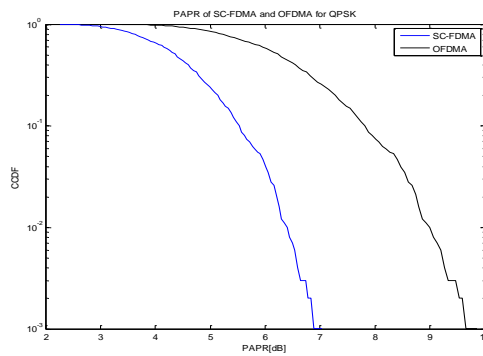


Figure 7. PAPR Comparison for QPSK Scheme

From above Figure 7 we can conclude that the QPSK modulation schemes have PAPR (6.8db) of SC-FDMA and (9.6db) OFDMA system. As the modulation bits increases here than QPSK system that's why it consist of higher PAPR.

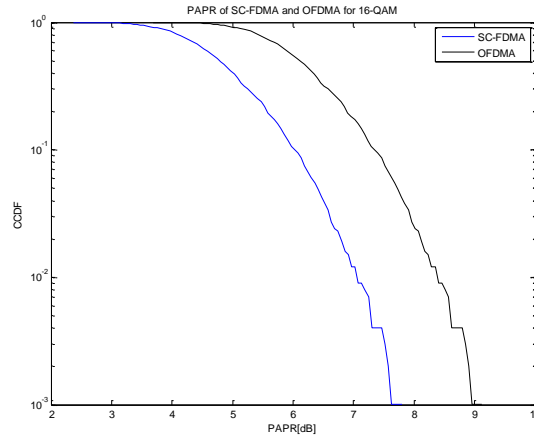


Figure 8. PAPR Comparison for 16-QAM Scheme

Figure 8 shows that there is sharp increase in PAPR of 16-QAM system as the bits transmitted in a system are more than BPSK and QPSK system and have PAPR 7.6db for SC-FDMA system.

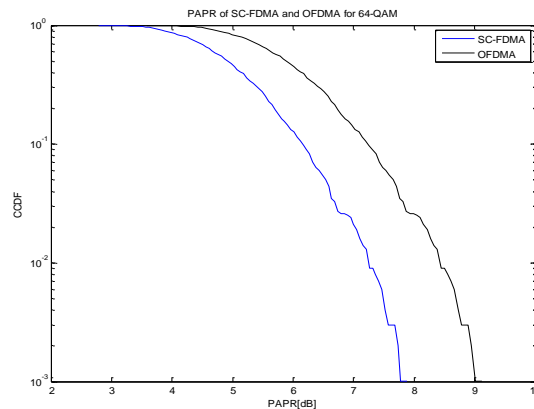


Figure 9. PAPR Comparison for 64-QAM Scheme

From above Figure 9 we can say that the 64-QAM modulation scheme have PAPR than other modulation schemes is 9db but nearly equal to 16- QAM system.

Table 2. PAPR Comparison

Modulation scheme	SC-FDMA		OFDMA	
	PAPR (dB)	CC DF	PAPR (dB)	CC DF
BPSK	6.8	1e-3	9.7	1e-3
QPSK	6.85	1e-3	9.6	1e-3
16QAM	7.6	1e-3	9	1e-3
64QAM	7.7	1e-3	9	1e-3

From Table 2, for OFDMA system the PAPR is decreasing continuously if we do for increasing the order of PSK or QAM. But overall PAPR of SC-FDMA is less than that of the OFDMA system. PAPR is the factor which shows power consumption in mobile system. Hence, SC-FDMA is more efficient for uplink communication system than OFDMA

i. Sc-Fdma Ber And Snr For Different Modulation Scheme:-

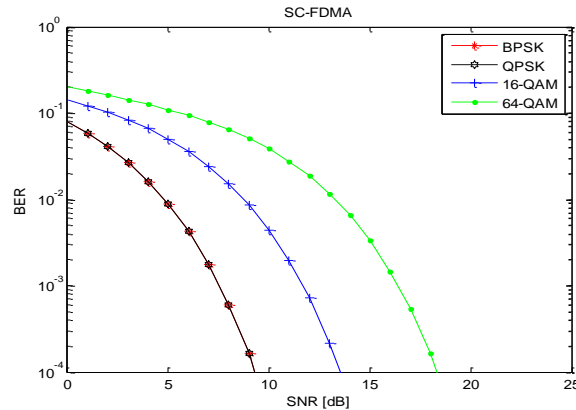


Figure 10. Sc-Fdma Ber Vs Snr

Above Figure10 is the representation of Bit Error Rate along with the Signal to Noise Ratio for SC-OFDMA representing the working of different modulation schemes. Performance of BPSK and QPSK modulation scheme are same as compared to 16-QAM and 64-QAM. When SNR is increasing there is less variation in BPSK and QPSK scheme than that of other modulation scheme.

Table 3. BER vs SNR

Modulation scheme	Bits per symbol	SC-FDMA	
		SNR	BER
<i>BPSK</i>	1	6.8	1e-3
<i>QPSK</i>	2	6.8	1e-3
<i>16QAM</i>	4	11.7	1e-3
<i>64QAM</i>	6	16.5	1e-3

Table III is the representation of BERVs SNR for SC-FDMA representing the working of different modulation schemes. For large value of SNR, there is increasing there is less variation in BPSK and QPSK scheme than that of other modulation scheme.

j. Probability of Error Occurred in Different Modulation Scheme

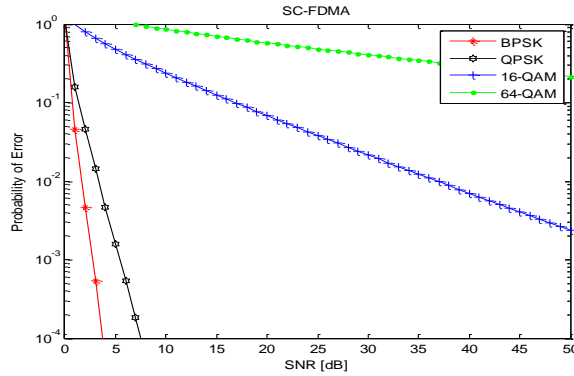


Figure 11. Probability of Error Vs SNR in SC-FDMA System

Figure 11 shows the probability of error occurred in different modulation scheme. The probability of error is high in case of 64-QAM than 16-QAM and QPSK scheme. We can see that BPSK scheme there is very less probability of error when there is change of SNR ratio.

Table 4. Probability of Error

Modulation scheme	Bits per symbol	SC-FDMA	
		SNR	P_e
<i>BPSK</i>	1	1	$1e-0.5$
<i>QPSK</i>	2	2	$1e-0.5$
<i>16QAM</i>	4	8	$1e-0.5$
<i>64QAM</i>	6	39	$1e-0.5$

Probability of error increases with increase in modulation scheme we can see that from Table IV it shows the comparison between all the modulation schemes, where as the bits transmission over symbol increase the probability of error increase.

k. Required Power Spectral Density

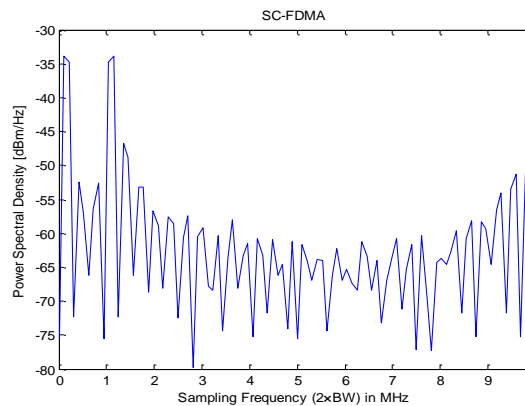


Figure 12. Sampling Frequency Vs Spectral Density

This Figure 12 shows different sampling frequency required for different power spectral density for of SC-FDMA.

6. Conclusion

The PAPR ratio for both the BPSK and QPSK modulation techniques nearly equal for SC-FDMA is varies in the range from 6.5db to 7db. If we increase the size of QAM the PAPR ratio increases. For SC-FDMA, the PAPR value for 16-QAM & 64-QAM is in the range 8.5db to 9db. But the overall value of SC-FDMA is less than OFDMA. Hence SC-FDMA must be used for uplink communication system.

The BPSK modulation scheme is having better performance there in performance evolution of SC-FDMA & QAM modulation schemes are not suitable for uplink communication because there is maximum amount of probability of error increase with increase in SNR. So, they require more power for error correction, hence low order modulation i.e. BPSK, QPSK are adopted in the uplink in order to have less PAPR at user end as observed in result analysis.

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