Simulation of Modulation Techniques in LTE

B04901098 電機四 陳立富 / B04701242 電機三 蔡舜宇

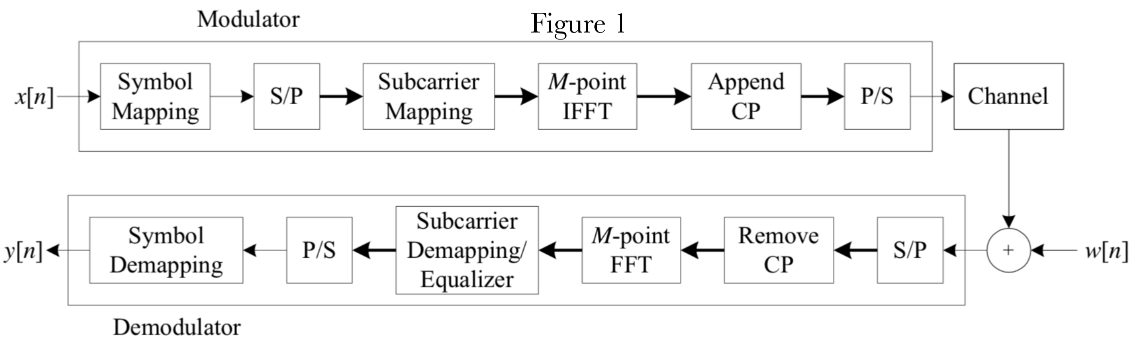
OFDMA

Introduction

As a popular modulation technique, Orthogonal Frequency Division Multiple Access (OFDMA) is adopted in the downlink of Long-Term Evolution(LTE). The basic concept of OFDMA is to combine Orthogonal Frequency Division Multiplexing(OFDM) with Multiple Access methods. OFDMA is very similar to OFDM with the main difference being that instead of being allocated all of the available subcarriers, the subcarrier mapping in OFDMA allocates a subset of carriers to each user in order to accommodate multiple transmissions simultaneously.

The block diagram of OFDMA is shown in Figure 1. In this report, we will follow the flow in Figure 1 and perform simulations concerning PAPR and SER for OFDMA.

Figure 1



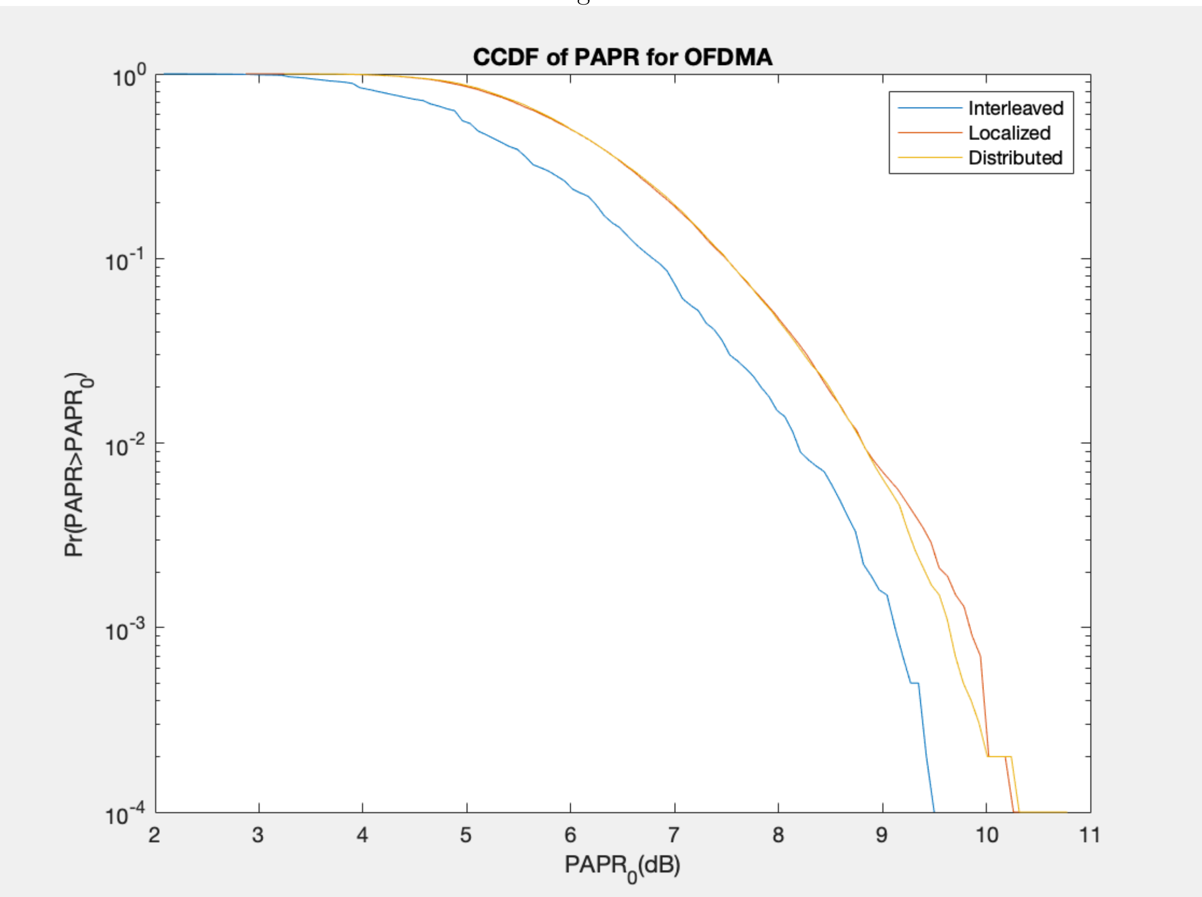
Simulation

There are two ways to do subcarrier mapping for transmission; distributed subcarrier mapping and localized subcarrier mapping. In the distributed subcarrier mapping mode, the modulated input data are allocated over the entire bandwidth with zeros occupying the unused subcarriers. In the localized subcarrier mapping mode, consecutive subcarriers are occupied by the modulated input data. In a special case of distributed subcarrier mapping mode, also known as interleaved mapping, subcarriers are occupied with equidistance Q by the modulated input data, where $Q = \dfrac{M}{N}$ is the spreading factor.

PAPR[1]:

Figure 2 - Parameter of PAPR Simulation			
	OFDMA	**OFDMA**	**OFDMA**
System Bandwidth	5MHz	5MHz	5MHz
Sampling Rate	5M samples/s	5M samples/s	5M samples/s
Subcarrier Mapping	Interleaved	Localized	Distributed
Modulation	QPSK	QPSK	QPSK
M	512	512	512
N	16	16	16
Bandwidth Spreading Factor	32	X	31
Pulse Shaping	Raised-Cosine with α =0.2	Raised-Cosine with α =0.2	Raised-Cosine with α =0.2
Iteration Times	10000	10000	10000

Figure 3

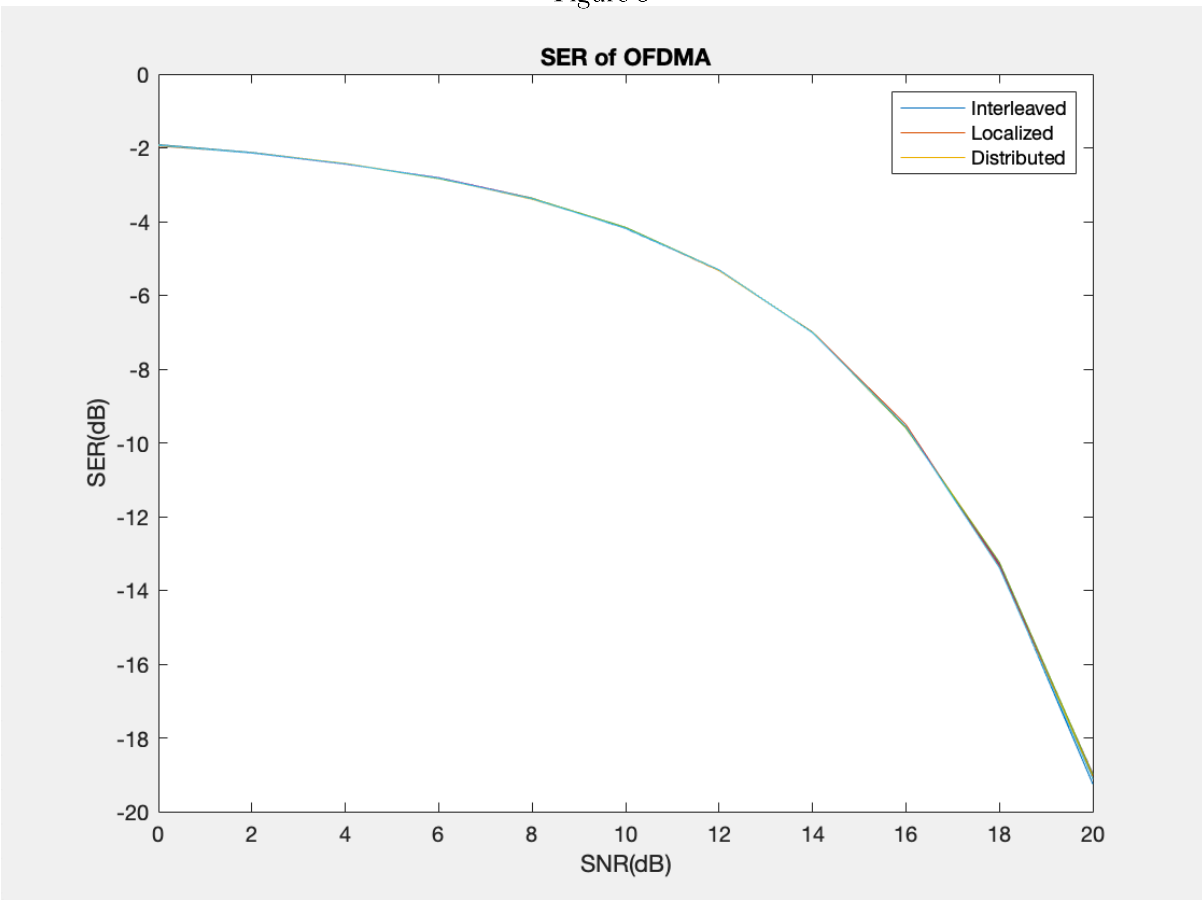


[1] The peak-to-average power ratio (PAPR) is the peak amplitude squared (giving the peak power) divided by the RMS value squared (giving the average power).

SER:

Figure 4 - Parameter of SER			
	OFDMA	**OFDMA**	**OFDMA**
Subcarrier Mapping	Interleaved	Localized	Distributed
Modulation	QPSK	QPSK	QPSK
M	512	512	512
N	16	16	16
Bandwidth Spreading Factor	32	X	31
Cyclic Prefix Size	20	20	20
Pulse Shaping	None	None	None
Channel	AWGN	AWGN	AWGN
SNR	0~20dB	0~20dB	0~20dB
Equalization	Zero-forcing	Zero-forcing	Zero-forcing
Detection	Hard	Hard	Hard

Figure 5



SC-FDMA

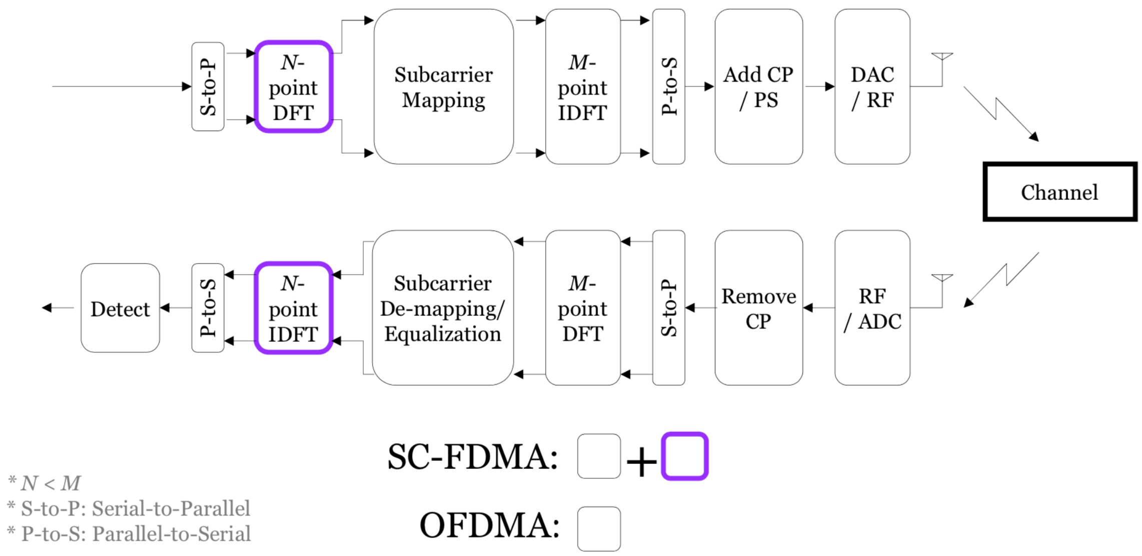
Introduction

Single carrier frequency division multiple access (SC- FDMA) is a technique utilizing single carrier modulation at the transmitter and frequency domain equalization at the receiver. It has similar performance and structure as those of an OFDMA system. However, it has a prominent advantage over OFDMA, which is the lower peak-to-average power ratio (PAPR). Consequently, SC-FDMA has served as an attractive and efficient alternative to OFDMA in the uplink multiple access scheme in LTE where lower PAPR greatly benefits the mobile terminal in terms of transmit power efficiency.

Figure 6 shows a block diagram of an SC-FDMA system. The transmitter of an SC-FDMA system first groups the modulation symbols into blocks each consisting of N symbols. Next, it performs an N-point DFT to produce a frequency domain representation of the input signals. It then maps each of the N-DFT outputs to one of the M ($> N$) subcarriers. After that, it adds a copy of the last part of the block, which is referred to as a cyclic prefix (CP) to provide a guard time to prevent inter-block interference (IBI) due to multi-path propagation and then performs pulse shaping to reduce out-of-band signal energy. When the receiver gets the signal, it removes the cyclic prefix, transforms the received signal into the frequency domain via DFT, de-maps the subcarriers, and then performs frequency domain equalization. The equalized symbols are transformed back to the time domain via IDFT, and detection and decoding take place in the time domain.

In this report, we will simulate SC-FDMA for different subcarrier mappings and show the simulation results on PAPR characteristics for the transmitter and error performance for the receiver. Hence, we can see whether SC-FDMA indeed achieves a lower PAPR than that of OFDMA and the overall performance of SC-FDMA.

Figure 6 - Scheme of SC-FDMA



Simulation

A. Subcarrier Mapping

There are two methods to choose the subcarriers for transmission; distributed subcarrier mapping and localized subcarrier mapping. In the distributed subcarrier mapping mode, referred to as DFDMA, DFT outputs of the input data are allocated over the entire bandwidth with zeros occupying the unused subcarriers. In the localized subcarrier mapping mode, referred to as LFDMA, consecutive subcarriers are occupied by the DFT outputs of the input data. In a special case of distributed subcarrier mapping mode, referred to as IFDMA, subcarriers are occupied with equidistance Q by the DFT outputs of the input data, where $Q = \frac{M}{N}$ is the spreading factor.

Figure 7 shows subcarrier allocation methods for $M = 12$, $N = 4$, $Q = 3$, and $Q_{dfdma} = 2$ and the time domain representations. For IFDMA, the modulated time symbols are a repetition of the original input symbols with a scaling factor of $1/Q$. For DFDMA and LFDMA, they have exact copies of input time symbols with a scaling factor of $1/Q$ in the Q-multiple sample positions and in-between values are sum of all the time input symbols in the input block with different complex-weighting.

Figure 8 & 9 show our simulation result of the outputs of M-point IDFT with $M = 64$, $N = 16$, $Q = 4$, and $Q_{dfdma} = 3$. QPSK and 16QAM are adopted for the simulation and then it can be easily justified that the simulated time symbol structures indeed follow the pattern shown in Figure 4. Moreover, we can clearly see more fluctuation and higher peak in amplitude for DFDMA and LFDMA in Figure 8 & 9.

Figure 7

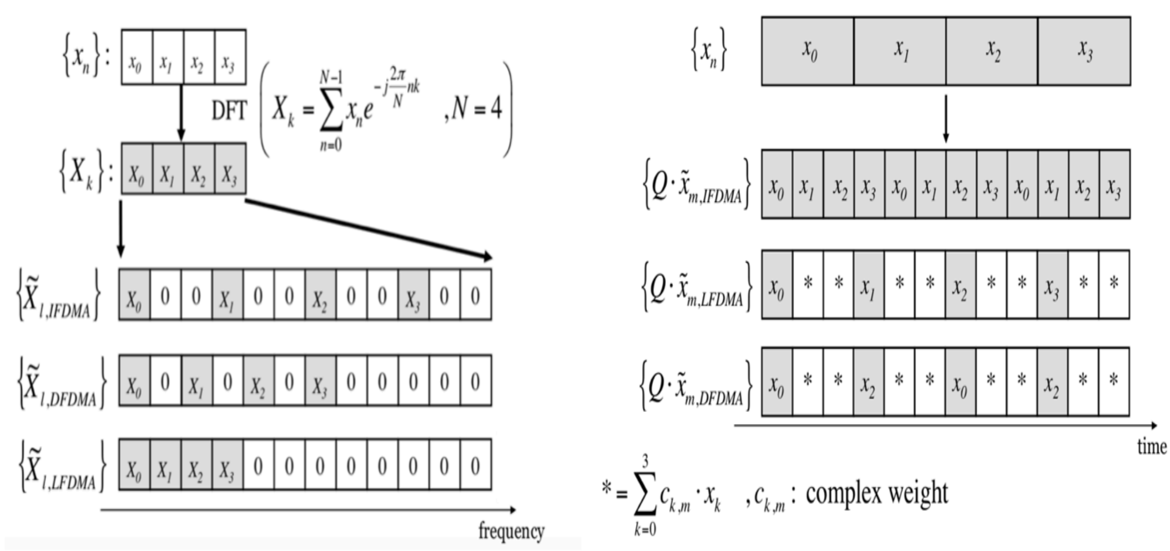


Figure 8

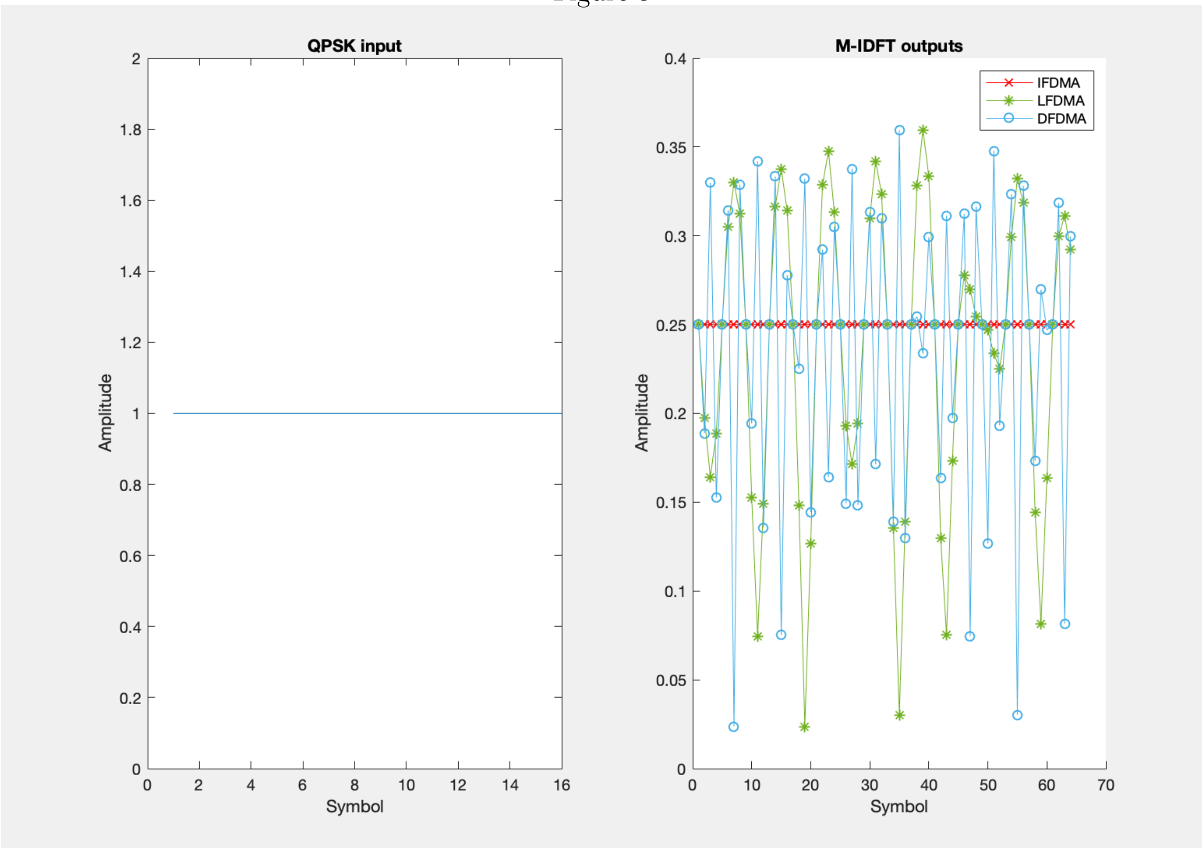
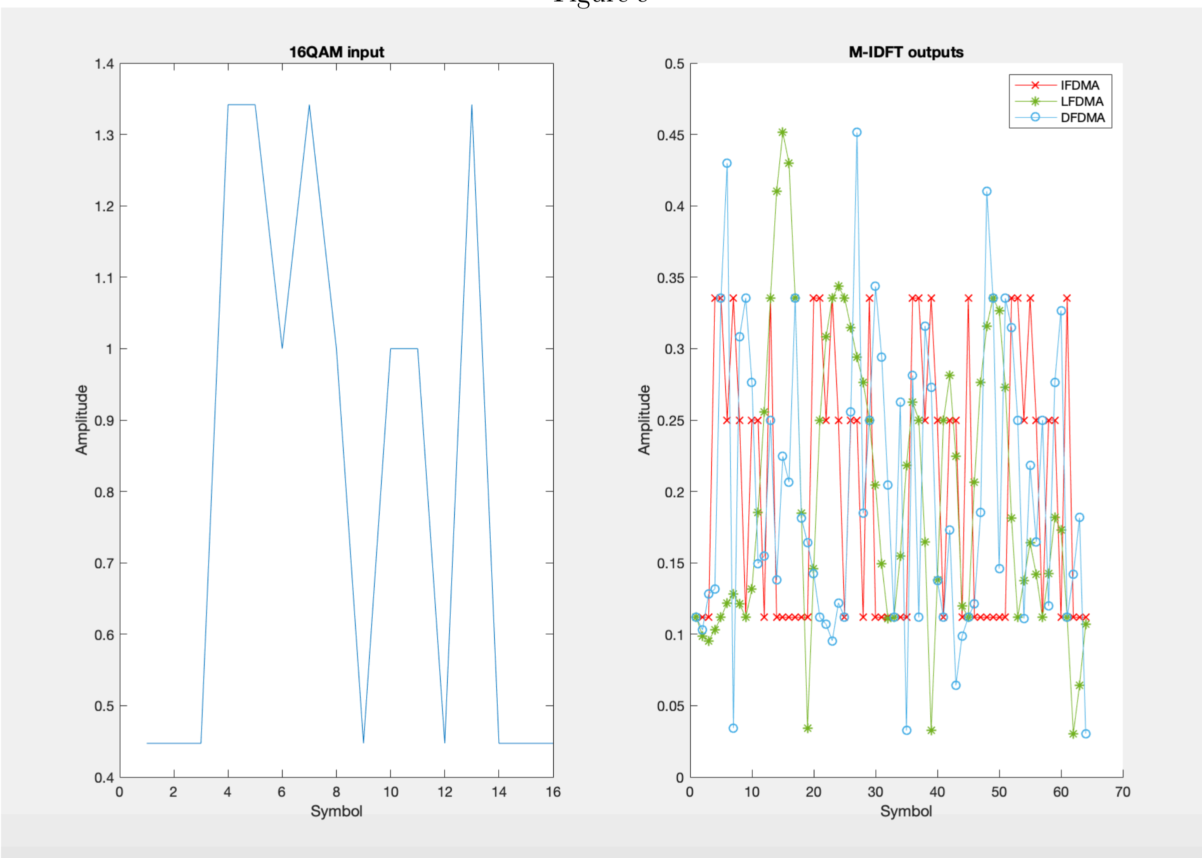


Figure 9



B. PAPR

The peak-to-average power ratio is defined by PAPR $= \frac{\max |x(t)|^2}{E[\,|x(t)|^2\,]}$, where $x(t)$ is the transmitted signal. It is a measure for the power efficiency of the transmitter. For an ideal linear power amplifier where we achieve linear amplification up to the saturation point, we reach the maximum power efficiency when the amplifier is operating at the saturation. Thus, a positive PAPR in dB means that we need a power backoff to operate in the linear region of the power amplifier and degrades the transmit power efficiency performance.

Figure 10 shows the parameters we used for the simulation of PAPR and Figure 11~14 show the distributions and complementary cumulative distributions of PAPR for different modulations respectively. It can be seen that for SC-OFDMA, PAPR is concentrated around 6dB; for SC-IFDMA, PAPR is concentrated around 4dB; for SC-LFDMA, PAPR is concentrated around 4~5dB; for SC-DFDMA, PAPR is concentrated around 5~6dB

Figure 15 shows the overall complementary cumulative distributions of PAPR for different modulations. We can see that all the cases for SC-FDMA have indeed lower PAPR than that of OFDMA. Moreover, for SC-FDMA, IFDMA has the lowest PAPR, and DFDMA and LFDMA have similar levels of PAPR.

Figure 10 - Parameter of PAPR Simulation

	OFDMA	SC-IFDMA	SC-LFDMA	SC-DFDMA
System Bandwidth	5MHz	5MHz	5MHz	5MHz
Sampling Rate	5M samples/s	5M samples/s	5M samples/s	5M samples/s
Subcarrier Mapping	Localized	Interleaved	Localized	Distributed
Modulation	QPSK	QPSK	QPSK	QPSK
M	512	512	512	512
N	16	16	16	16
Bandwidth Spreading Factor	X	32	X	31
Pulse Shaping	Raised-Cosine with α=0.2	Raised-Cosine with α=0.2	Raised-Cosine with α=0.2	Raised-Cosine with α=0.2
Iteration Times	10000	10000	10000	10000

Figure 11

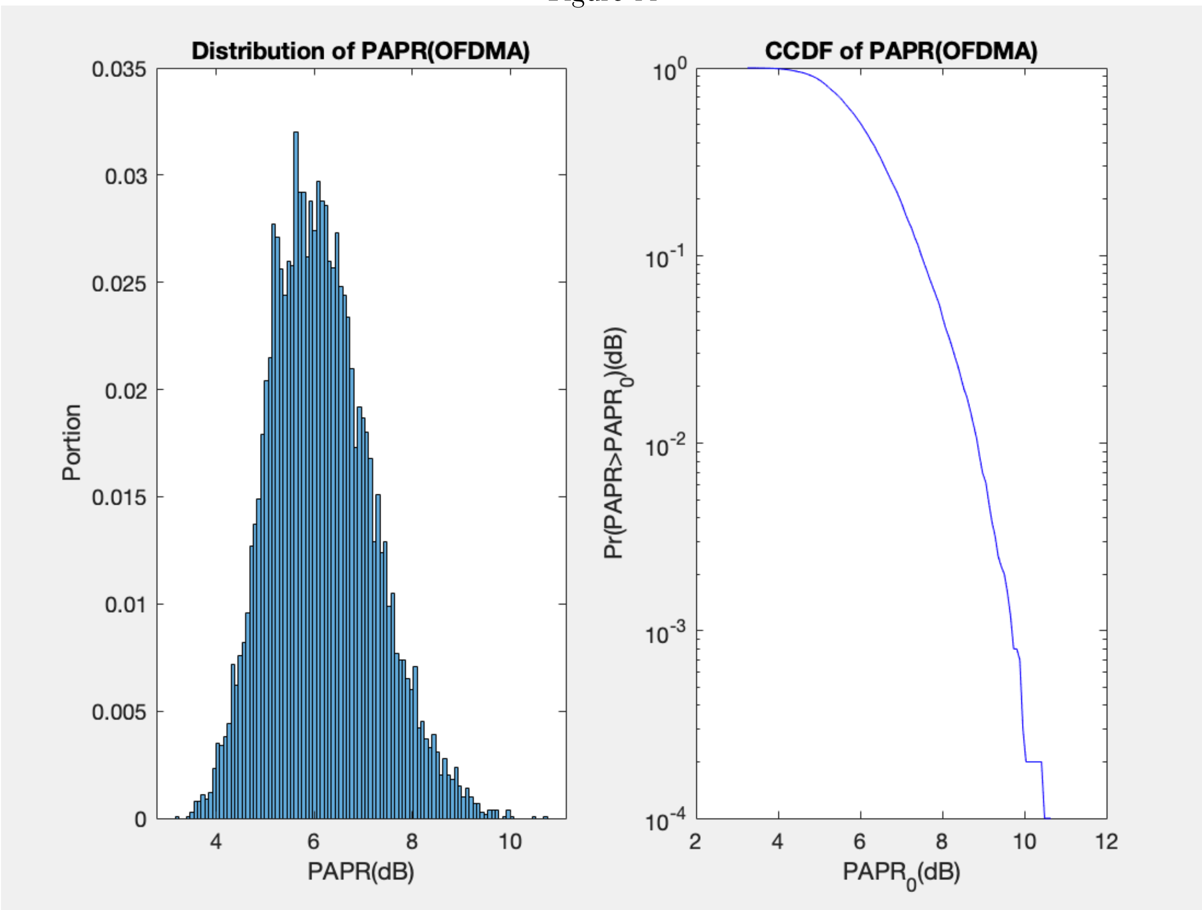


Figure 12

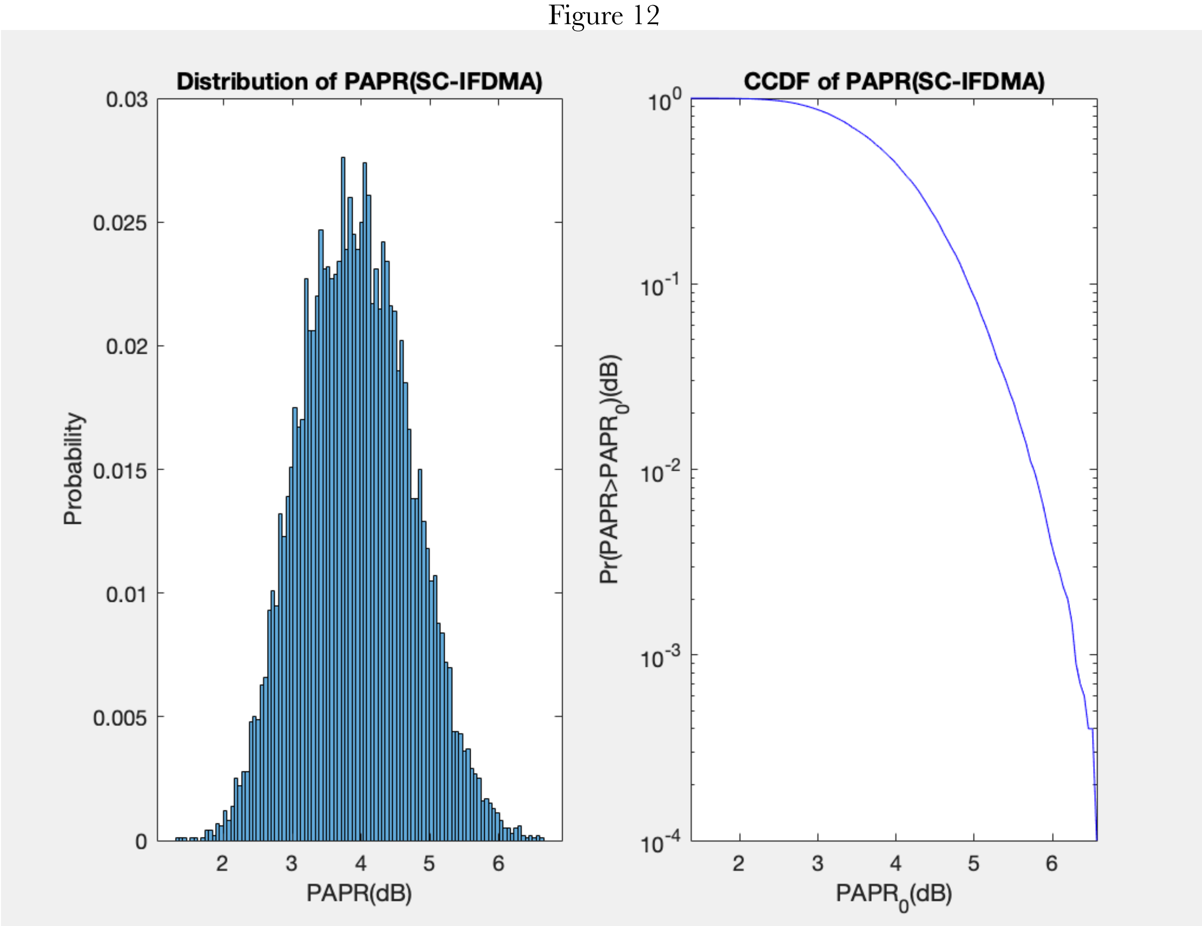


Figure 13

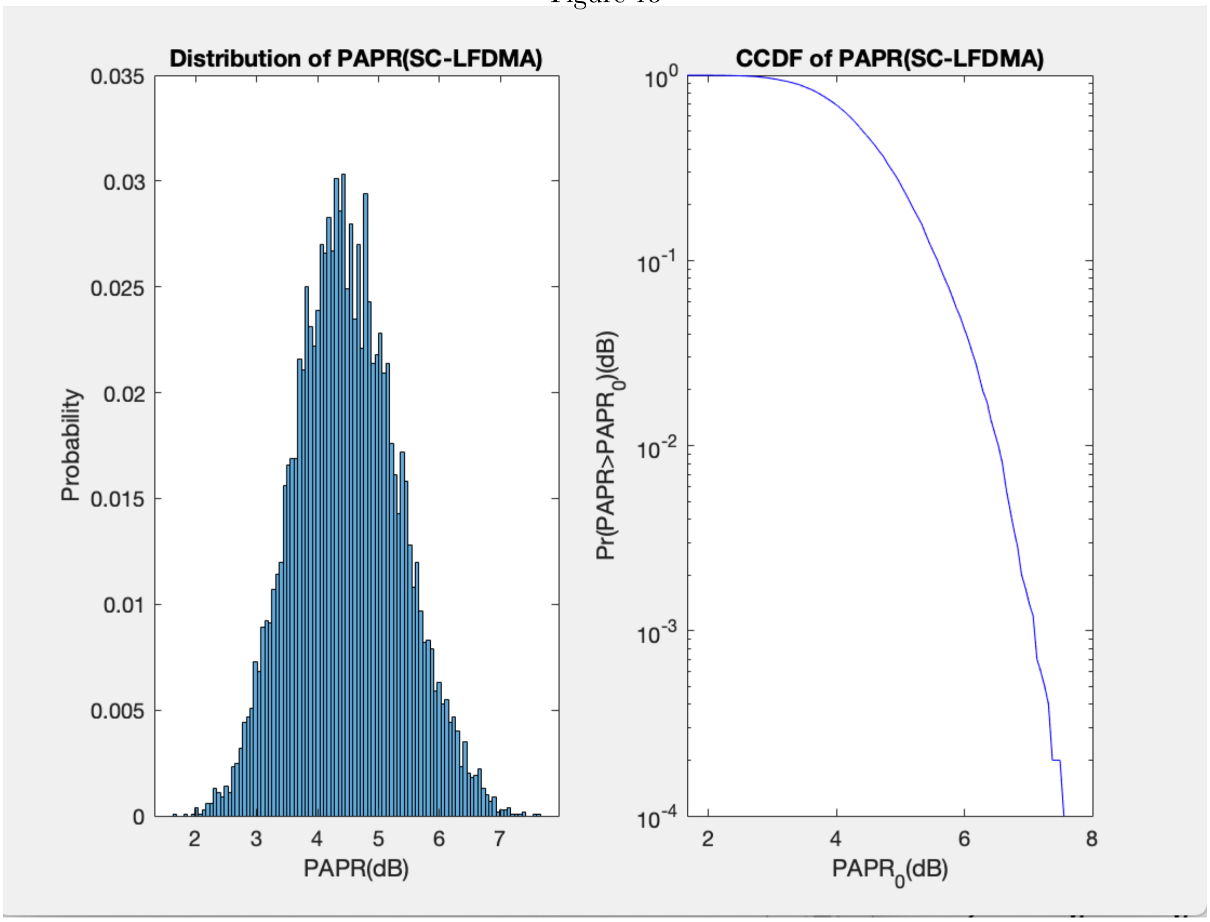


Figure 14

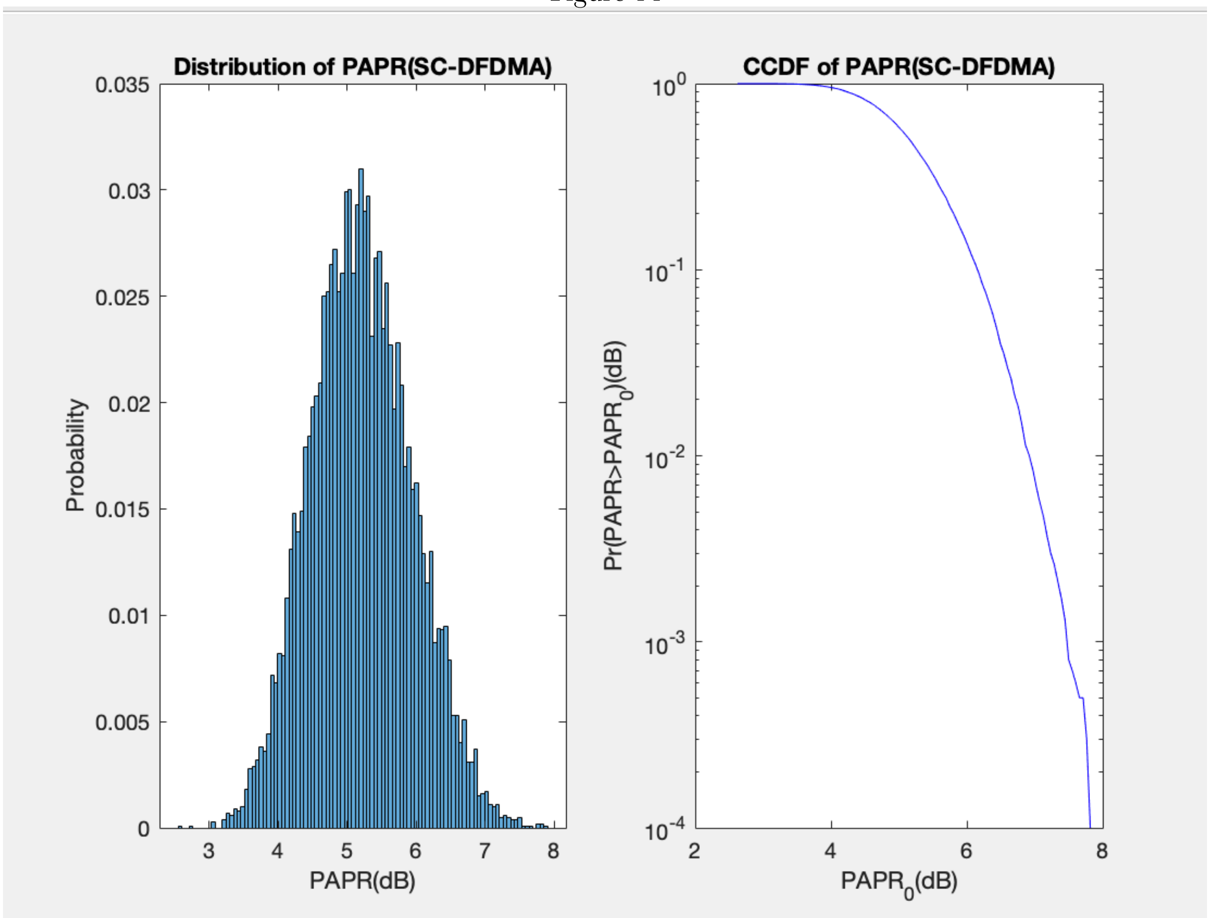
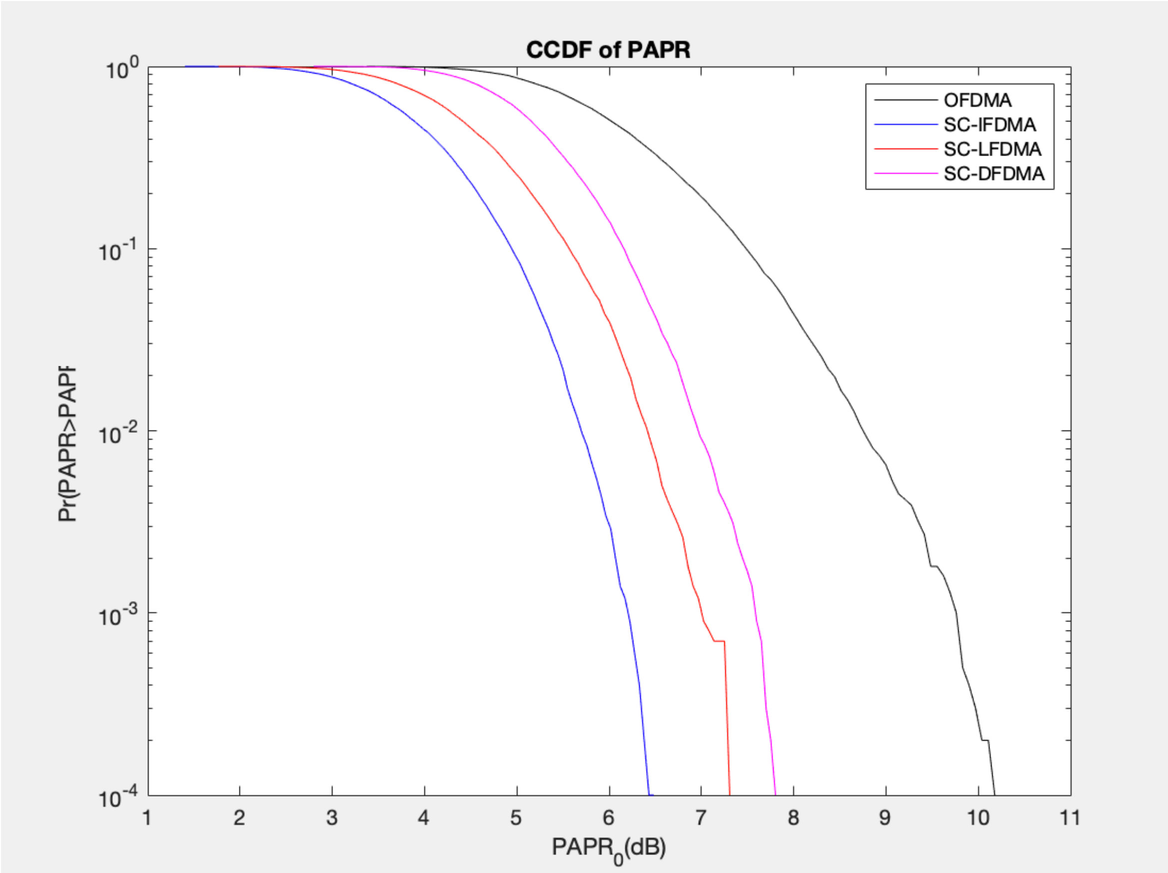


Figure 15



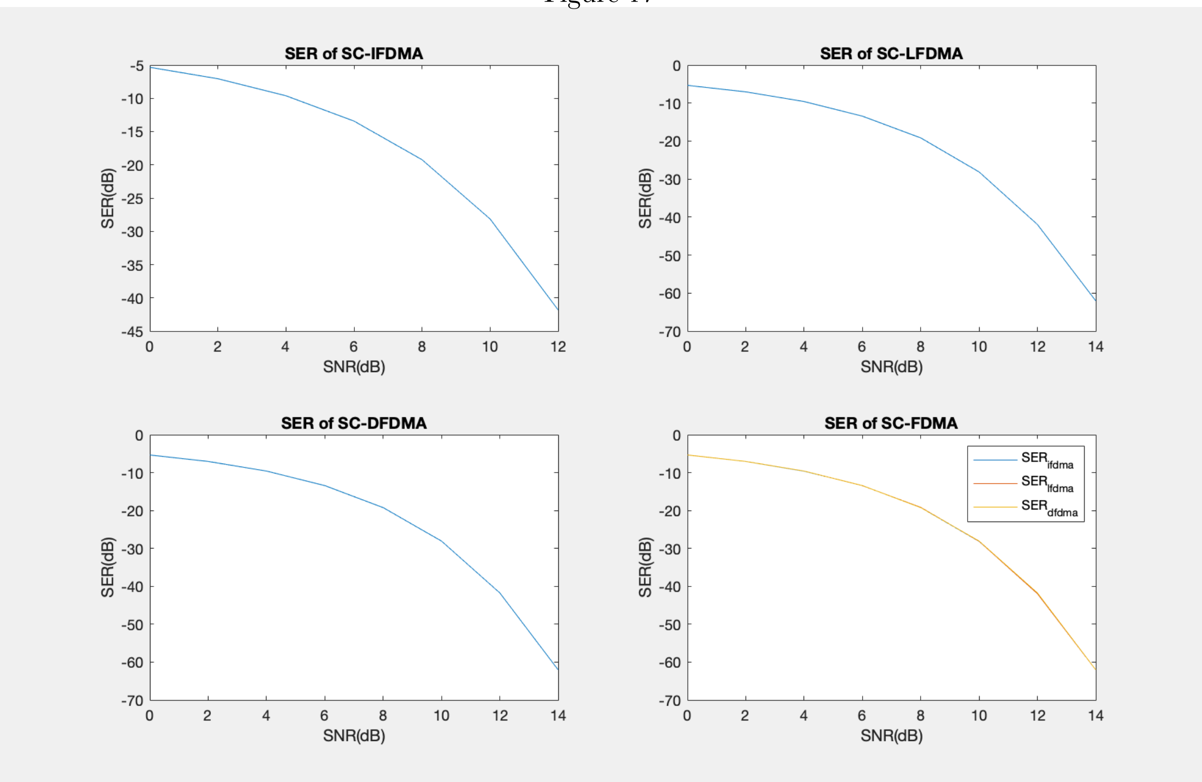
C. SER

In this part, we go through the scheme shown in Figure 6. We first map the bits to QPSK symbols and perform DFT to do subcarrier mapping. After, we do IDFT and add cyclic prefix to it. For simplicity, we exclude pulse shaping and assume the channel is AWGN. Receiving the noisy signals, we remove the cyclic prefix, do equalization in the frequency domain and perform detection based on hard decision.

Figure 16 shows the parameters we used in the simulation of SER. Figure 17 shows the overall SER curves for different modulations. We can see that SER decays as SNR increases and all the cases of SC-FDMA have almost the same SER curves. It tells us that the different subcarrier mappings have little impact on the SER performance although they have much to do with the PAPR.

Figure 16 - Parameter of SER Simulation for SC-FDMA			
	SC-IFDMA	**SC-LFDMA**	**SC-DFDMA**
Sampling Rate	5M samples/s	5M samples/s	5M samples/s
Modulation	QPSK	QPSK	QPSK
M	512	512	512
N	16	16	16
Bandwidth Spreading Factor	32	X	31
Cyclic Prefix Size	$20(4\mu s)$	$20(4\mu s)$	$20(4\mu s)$
Pulse Shaping	None	None	None
Channel	AWGN	AWGN	AWGN
SNR	0~20dB	0~20dB	0~20dB
Equalization	Zero-forcing	Zero-forcing	Zero-forcing
Detection	Hard	Hard	Hard

Figure 17



Reference

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