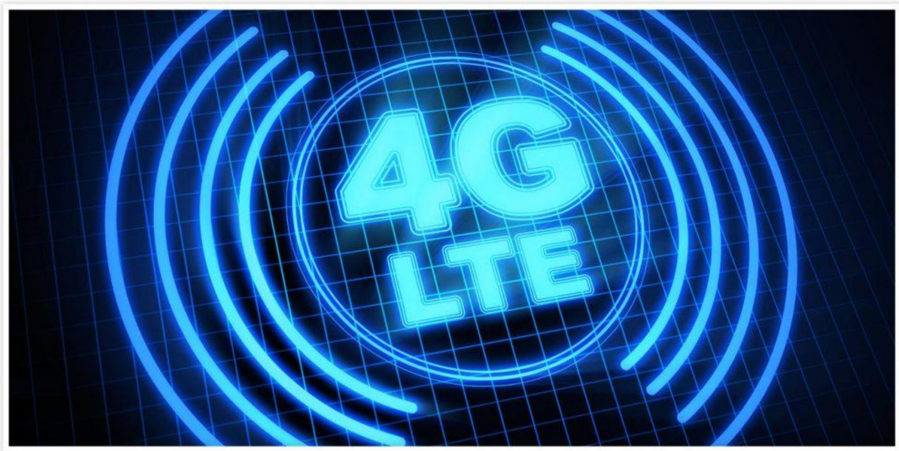
Efficiency Analysis of LTE Physical Layer using OFDMA and SC-FDMA



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COMMUNICATION SYSTEMS-II

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Abstract

LTE basically "Long Term Evolution" is what it stands for. LTE is a fourth-generation telecommunications technology for data transmission via cellular networks. It has a downstream data transmission rate of up to 100 Mbps and an upstream data transfer rate of up to 50 Mbps. Although the names "4G" and "LTE" are frequently used interchangeably, LTE is a subset of 4G technology.

LTE's physical layer's primary signal format is OFDM, including OFDMA in the downlink and SC-FDMA in the uplink, and different modulation schemes. OFDM is suited for high-speed data transmission because it is resistant to narrow band fading caused by reflections and the general propagation qualities at these frequencies. It works by using numerous carriers, each carrying a low data rate.

Several modulation techniques, including PSK and QAM, are employed inside the core LTE OFDM signal format. To obtain larger data rates, higher order modulation is employed, with the modulation order dictated by signal quality.

The adoption of OFDM in LTE is a natural decision. While the essential concepts of OFDM have been retained, it has been adapted to meet the specific needs of LTE. However, it continues to employ many carriers, each with a poor data rate.

In this paper, performance results of LTE Physical Layer using OFDMA and SC-FDMA will be studied by using QPSK and 16-QAM modulation schemes. PAPR, BER and PSD of SC-FDMA and OFDMA will be evaluated.

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1 Introduction

Long Term Evolution has first launched by 3GPP in 2004. There were a huge amount of benefits of LTE to cellular networks such as bandwidth efficiency, reduced latency and higher data rates. OFDM is the main signal format which is used in LTE physical layer as a multiplexing scheme. OFDMA is used for downlink transmission and SC-FDMA is used for uplink transmission in LTE. SC-FDMA is another scheme which is used to save power from uplink transmission.

The multiple access schemes OFDMA and SC-FDMA which is used in LTE has to meet specific requirements to provide good quality of service. These requirements would be high throughput, good robustness, low bit error rate (BER), high spectral efficiency, low delays, low PAPR an so on.

In this paper evaluation of performance of LTE physical layer using OFDMA and SC-FDMA will be done.

2 Background

Date Rate, Bandwidth, Peak Spectral Efficiency, Spectral Efficiency of Cell Edge, Average Cell Spectral Efficiency, and latency are the primary requirements for constructing LTE systems. The peak data rate for 20 MHz spectrum is 50 Mbps (uplink) and 100 Mbps (downlink) (for downlink). [1]

Both wideband (WCDMA with 5MHz) and narrowband (3GPP technology) were examined in the 3GPP technology family (GSM with 200 kHz). As a result, with frequency allocation flexibility of 1.25/2.5, 5, 10, 15, and 20 MHz, the new system is now necessary.

PAPR requirement for downlink is 5 bps/Hz or higher, and for uplink is 2.5 bps/Hz or higher. 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.

The high peak-to-average power ratio of OFDM is a major flaw (PAPR). Because many of the subcarriers are in phase for some input sequences, the transmitted signal is the total of all modulated subcarriers, and strong amplitude peaks are unavoidable. The power amplifier of a transmitter is put under a lot of strain by the amplitude peaks. OFDM is also more susceptible to frequency offset and frequency selective fading than time-domain transmission systems.

Performance evaluation and comparison of OFDMA and SC-FDMA in terms of different modulations and metrics such as (PAPR, BER, SNR, Error probability, and PSD), and SC-FDMA was utilized on uplink transmission to solve the limitations of OFDMA, particularly the PAPR.

The study's goal is to assess the performance of the LTE physical layer using the following performance metrics: SNR, BER, PSD, PAPR, and Probability of Error. Using a variety of modulation methods (BPSK, QPSK, 16-QAM and 64-QAM)

2.1 LTE Frequency and Bandwidth

LTE is capable of operating in both existing and newer cellular frequencies. Depending on the country of operation and the nature of their spectrum holdings, different carriers employ different bands. The majority of LTE phones use two of these bands, which differ from provider to carrier.

LTE is a broadband wireless technology that achieves high data rates and can support a large number of users by using wide channels. The standard allows for bandwidths of 1.4, 3, 5, 10, 15, and 20 MHz to be used. The carrier chooses the bandwidth based on its spectrum holdings and the sort of service it will provide. The most typical widths are 5 and 10 MHz. Some bandwidths are incompatible with other bands.

2.2 Multiple in Multiple out (MIMO)

MIMO is effectively a radio antenna technique since it uses multiple antennas at the transmitter and receiver to provide a variety of signal paths to transfer the data. Each antenna is assigned to a different signal path, allowing for numerous signal paths to be used.

2.3 LTE Multiple Access Schemes and Physical Layer

The adoption of a multicarrier strategy for numerous access techniques was the first important design in LTE. WCDMA, OFDMA, and SC-FDMA were the contenders for downlink once this step was proposed, while WCDMA, OFDMA, and SC-FDMA were the candidates for uplink. Finally, in 2005, the decision was made to use OFDMA as the downlink multiple access technique and SC-FDMA as the uplink multiple access system.

By altering the amplitude, phase, or both of the carrier signal, the information is modulated to only one carrier. The frequency can also be changed, although frequency changes in LTE are unaffected.

LTE (Long-Term Evolution) The physical layers for downlink and uplink are significantly different. The downlink and uplink are treated individually, hence they are explained separately here.

LTE frame structure can be two types : LTE Frequency Division Duplex (FDD) mode systems and LTE Time Division Duplex (TDD) mode systems.

2.3.1 LTE Frequency Division Duplex Mode Systems (Type-1)

Both half-duplex and full-duplex FDD modes can use the Type-1 frame structure. This sort of radio frame has a duration of 10 milliseconds and is made up of 20 slots, each with a duration of 0.5 milliseconds [2]. Because a subframe is made up of two slots, one radio frame has ten subframes, as seen in Figure 2-3. In FDD mode, downlink and uplink transmission are split in the frequency domain, with half of the total sub-frames used for downlink and half utilized for uplink in each 10ms radio frame interval.

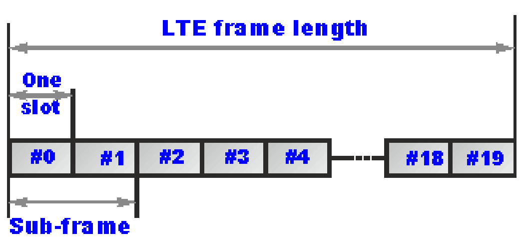

Figure 1 : LTE Type-1 Frame Structure

2.3.2 LTE Time Division Duplex Mode Systems

Avoid any further divisions under the sub-subheading. Otherwise, the number of divisions becomes distracting and difficult to follow. Two identical half frames of 5ms each make up the Type-2 frame structure. Figure 2-4 [2] shows that both half frames have a total of 5 sub-frames of 1ms duration.

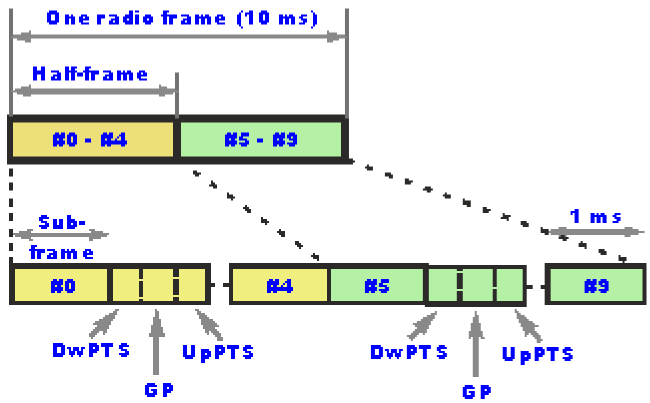

Figure 2 : LTE Type-2 Frame Structure

2.4 Adaptive Modulation in LTE

If the channel is influenced by fading, noise, or changes, adaptive modulation is an intelligent strategy for selecting the right modulation scheme for the channel. When signal conditions deteriorate, LTE takes advantage of this by switching from one modulation scheme to another that best suits the signal. When the modulation method is changed, the degree of variance in throughput and spectral efficiency changes as well. When compared to BPSK and QPSK, 64-QAM has a high throughput. In order to obtain high spectral efficiency and transmission throughput, higher modulation techniques must be used. Lower order modulation methods, on the other hand, are less susceptible to noise and interference in the channel.

2.5 Multiple Access Schemes

Multiple access is a radio transmission system that allows multiple senders to send signals at the same time while avoiding interference.

2.5.1 Orthogonal Frequency Division Mulitple Access (OFDMA)

OFDMA is a frequency division multiplexing (FDM) technique in which a frequency band is split into a number of orthogonal frequency subcarriers. The data is transformed into parallel bit streams before being modulated on each subcarrier using standard modulation methods. OFDMA provides for a modest data flow from a large number of users while maintaining a short and consistent latency. It may be deployed over multiple frequency bands with minimum modification to the air interface. Because each user's data is modulated over numerous orthogonal frequencies rather than a single frequency for the duration of the connection, the effect of multipath fading is lessened when utilizing OFDMA. Furthermore, OFDMA not only facilitates capacity sharing in available bandwidth, but it also boosts each user's capacity.

2.5.2 Single Carrier Frequency Division Mulitple Access (SC-FDMA)

Multiple users sharing a communication resource are likewise addressed by SC-FDMA. It has an OFDMA-like structure with the addition of a Discrete Fourier Transform (DFT) block. The data symbols are modulated on subcarriers after passing through the DFT block. Fast Fourier Transform (FFT) calculations are used to equalize the signal at the receiver. Because SC-FDMA is derived from OFDMA and has the same basic structure, it boosts user capacity by employing several frequencies to convey a single user's data.

SC-FDMA is used for uplink transmission while OFDMA is used for downlink transmission in LTE. We will go over the basics of OFDMA and SC-FDMA in the following sections.

2.6 System Model

2.6.1 OFDMA Transmitter and Receiver

The available spectrum in an OFDMA transmitter is divided into a number of orthogonal subcarriers [3].

The LTE system uses a 15 KHz subcarrier spacing with a 66.67s OFDMA symbol time. Adaptive modulation methods such as (BPSK, QPSK, 16-QAM, 64-QAM) are applied to the high-bit-rate data stream as it passes through the modulator. A serial to parallel converter converts this hierarchical sequence of modulated symbols into parallel frequency components (subcarriers). The IFFT stage generates OFDM signals by converting these complex data symbols into time domain. Between OFDMA symbols, a guard band is utilized to cancel inter-symbol interference at the receiver. This guard band is known as Cyclic Prefix (CP) in LTE, and its duration should be longer than the channel impulse response or delay spread.

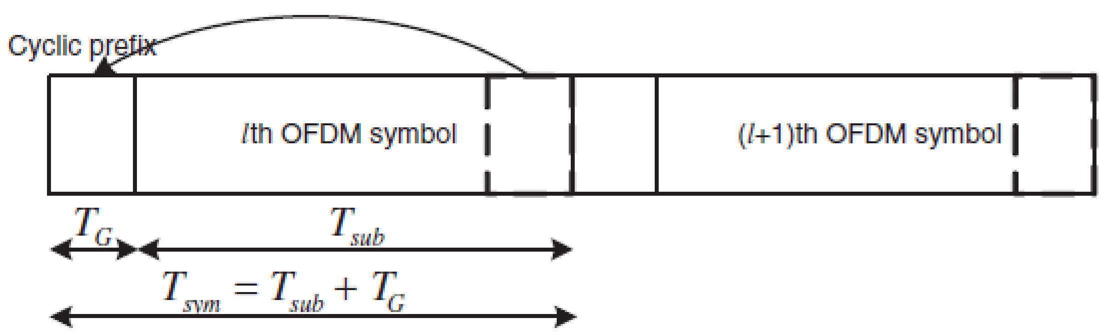

Figure 3 : Cyclic Prefix

2.6.2 OFDMA System Model

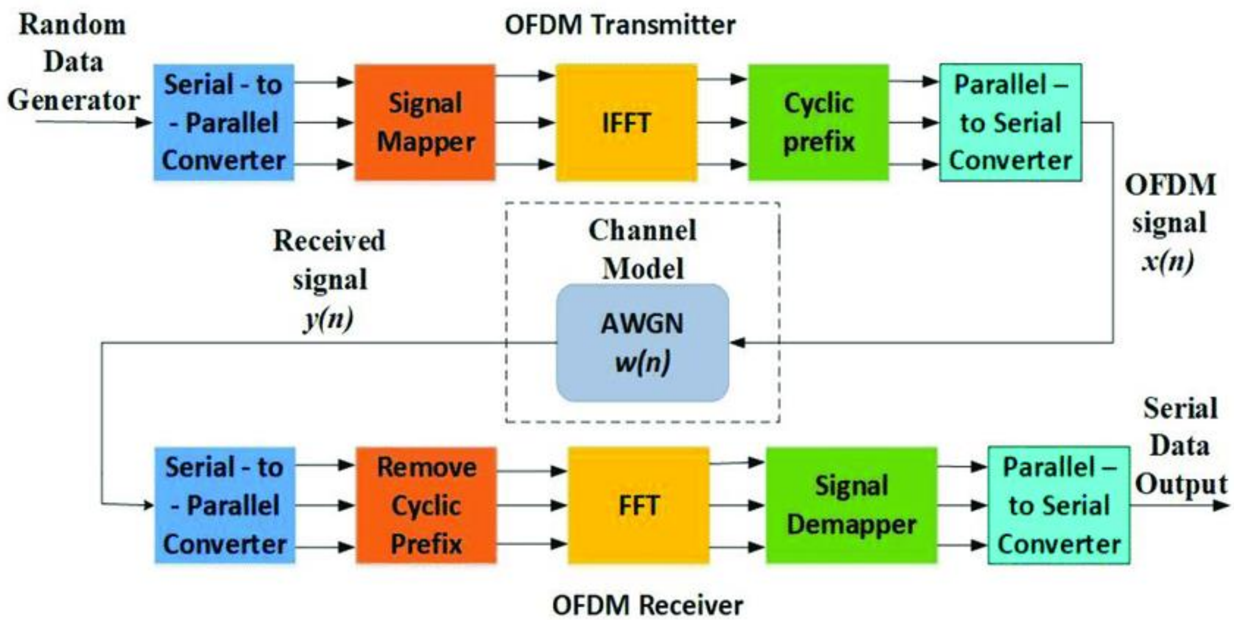

Figure 4 : OFDMA System Model

2.6.3 SC-FDMA Transmitter and Receiver

At the transmitter, SC-FDMA employs an additional N-point DFT stage, as well as an N-point IDFT stage at the receiver. Figure 5 depicts the fundamental block diagram of a SC-FDMA transmitter. A stream of modulated symbols is fed into the transmitter. Similarly to OFDMA, data is mapped into signal constellations using QPSK, 16-QAM, or 64-QAM modulation depending on channel conditions in SC-FDMA. The subcarriers are not directly modulated by the QPSK/QAM symbols. These symbols are passed through a serial to parallel converter and then a discrete frequency domain representation of the QPSK/QAM symbols is produced by a DFT block. DFT element follows pulse shaping, but it is optional and is occasionally required to shape the output signal from DFT. If pulse shaping is enabled, bandwidth expansion happens in the actual signal. In the subcarrier mapping block, the discrete Fourier symbols from the output of the DFT block are mapped to the subcarriers. The frequency domain modulated subcarriers are then converted to time domain via IDFT. The rest of the transmitter's operation is identical to that of OFDMA.

The SC-FDMA transmitter relies heavily on sub-carrier mapping. It transfers each of the N DFT outputs to a single subcarrier out of M subcarriers, where M is the total number of accessible bandwidth subcarriers. There are two approaches for subcarrier mapping: localized subcarrier mapping and distributed subcarrier mapping. In localized subcarrier mapping, the modulation symbols are assigned to M contiguous subcarriers, whereas in scattered mode, the symbols are evenly spaced across the entire channel bandwidth.

Distributed subcarrier mapping is also known as distributed SCFDMA (LFDMA), and localized subcarrier mapping is known as localized SCFDMA (LFDMA) (DFDMA). In both forms of subcarrier mapping, the IDFT assigns zero amplitude to the vacant subcarriers in the transmitter. In SC-FDMA, IFDMA is more efficient because the transmitter can modulate the signal in the time domain instead of using DFT and IDFT. Interleaved FDMA (IFDMA) [4] is the distributed mode with equidistance between subcarriers when Q = MN. Where M is the number of subcarriers, Q denotes the number of users, and N denotes the number of subcarriers assigned to each user. N-discrete frequency signals are mapped uniformly spaced sub-carriers in distributed mapping, whereas N-discrete frequency signals are mapped on N consecutive subcarriers in localized mapping.

Figure 5 depicts a SC-FDMA receiver. It's nearly identical to standard OFDMA, but with the addition of subcarrier demapping, IDFT, and an optional shaping filter. This filter corresponds to the transmitter's spectral shape. M-mapped subcarrier subcarrier demapping yields N- discrete signals. IDFT translates the SC-FDMA signal to the signal constellation in the end.

2.6.4 SC-FDMA System Model

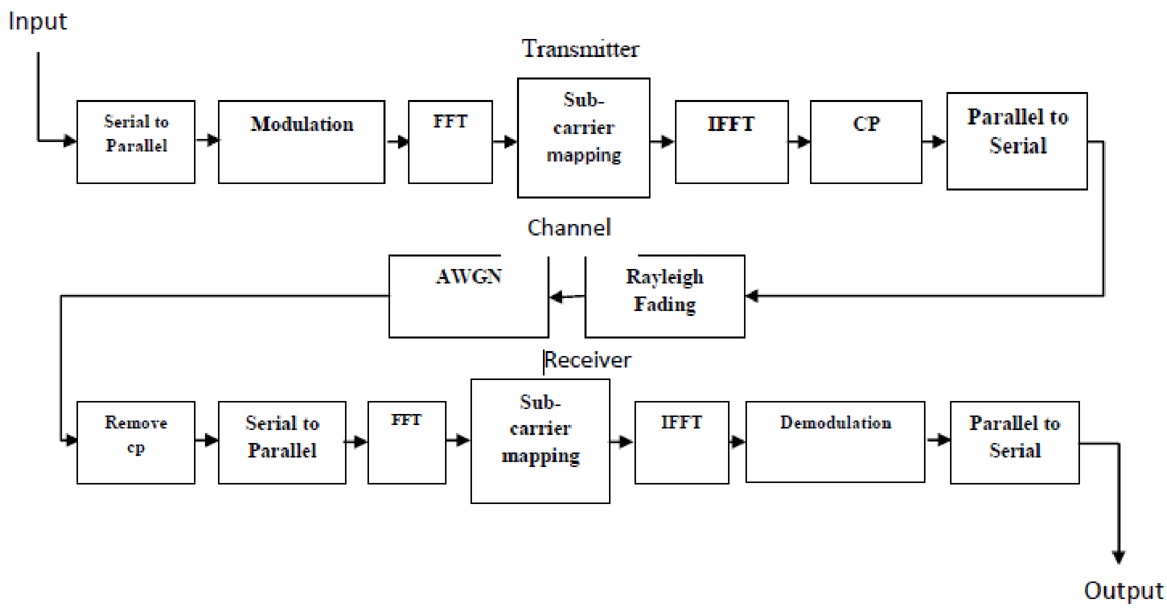

Figure 5 : SC-FDMA System Model

2.7 Brief Information on some definitions

2.7.1 PAPR

Because power conservation in transmission is a significant concern for the LTE multiple access approaches, we consider PAPR as an important transmission element for both OFDMA and SC-FDMA. A CCDF (Complementary Cumulative Distribution Function) of PAPR is used to determine the PAPR. The probability that the PAPR is higher than a specific PAPR value PAPR0 (Pr PAPR>PAPR0) [4] is the CCDF of PAPR. It's a crucial metric that's extensively utilized to describe the full range of signal power characteristics.

2.7.2 BER

The BER is the ratio of error bits to total bits sent over a given time frame.

Error Bits/Number of Transmitted Bits = BER

2.7.3 SNR

The SNR is defined as the ratio of bit energy (Eb) to noise power spectral density (N0) in decibels.

Eb / N0 = SNR

The BER is represented in terms of SNR for any modulation scheme. The error counts over the entire amount of bits transferred are computed by comparing the transmitted and received signals.

The rate at which errors occur in a received signal is known as the probability of error (Pe). The symbol error probability of M-ary PSK and M-ary QAM in the AWGN channel is determined by the following formulas for coherent detection.

For M-ary PSK :

$$P_e = 2\mathrm{Q}\left[\sqrt{\frac{2\,\mathrm{E_b}\log_2 \mathrm{M}}{\mathrm{N_o}}}\sin\left(\frac{\pi}{\mathrm{M}}\right)\right]$$

For M-ary QAM :

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

2.7.4 Power Spectral Density

The power spectral density (PSD) is a useful function for describing a signal's power distribution in terms of frequency. In mobile communication, the PSD is critical for making accurate radio resource management (RRM) decisions at the base station, particularly for transmission format allocation, which includes modulation and bandwidth. If the PSD of the base station terminal is unknown, it may result in the utilization of more transmission bandwidth than the maximum UE power capability [5].

3 Methodology

MATLAB was used to model SC-FDMA and OFDMA systems, including transmission and reception processes using adaptive modulation schemes like as BPSK, QPSK, 16-QAM, and 64-QAM, under the name PAPR. To analyze the performance of the LTE physical layer for both uplink and downlink, SNR, BER, PSD, bit error probability, and PAPR characteristics were used.

4 Results and discussion

Using ofdma.m, we have plotted OFDMA BER/SNR, Pe/SNR and Power Spectral Density. Plots are shown below.

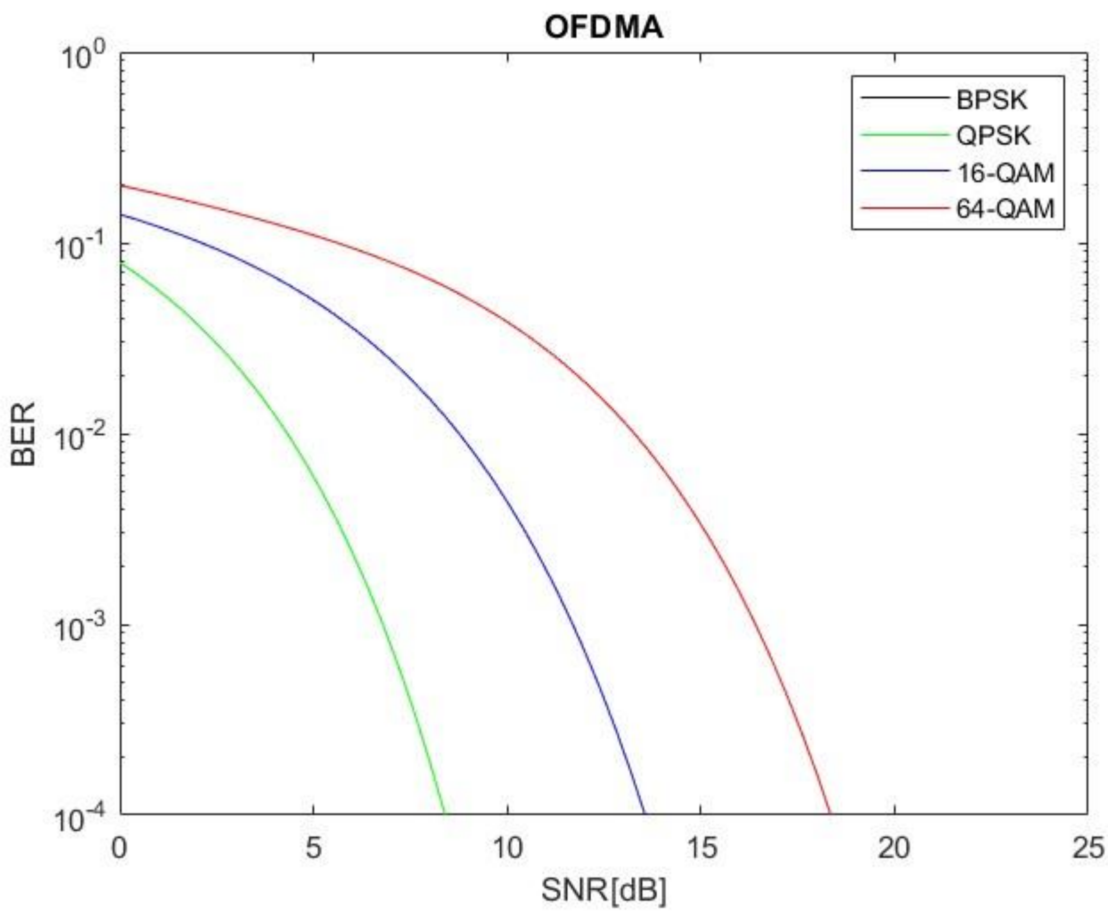

Figure 6: OFDMA BER/SNR Plot

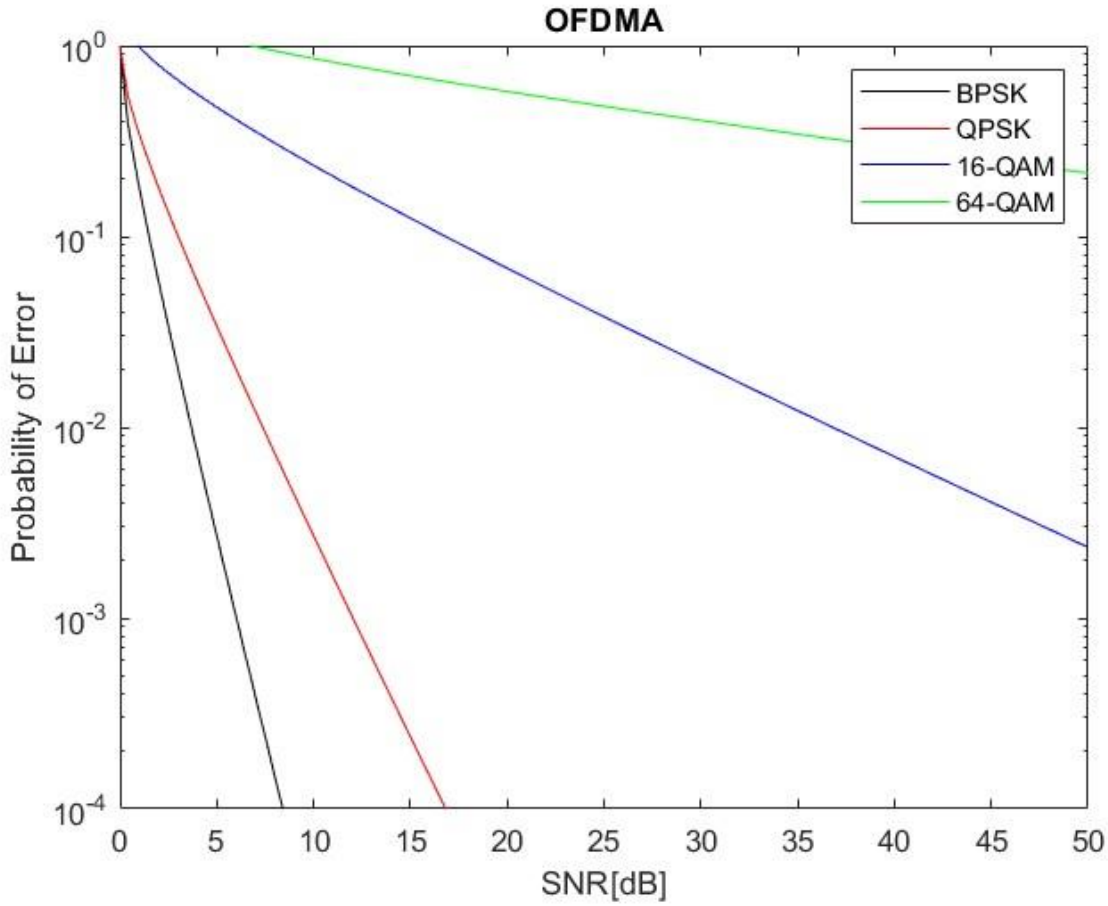

Figure 7 : OFDMA Pe/SNR Plot

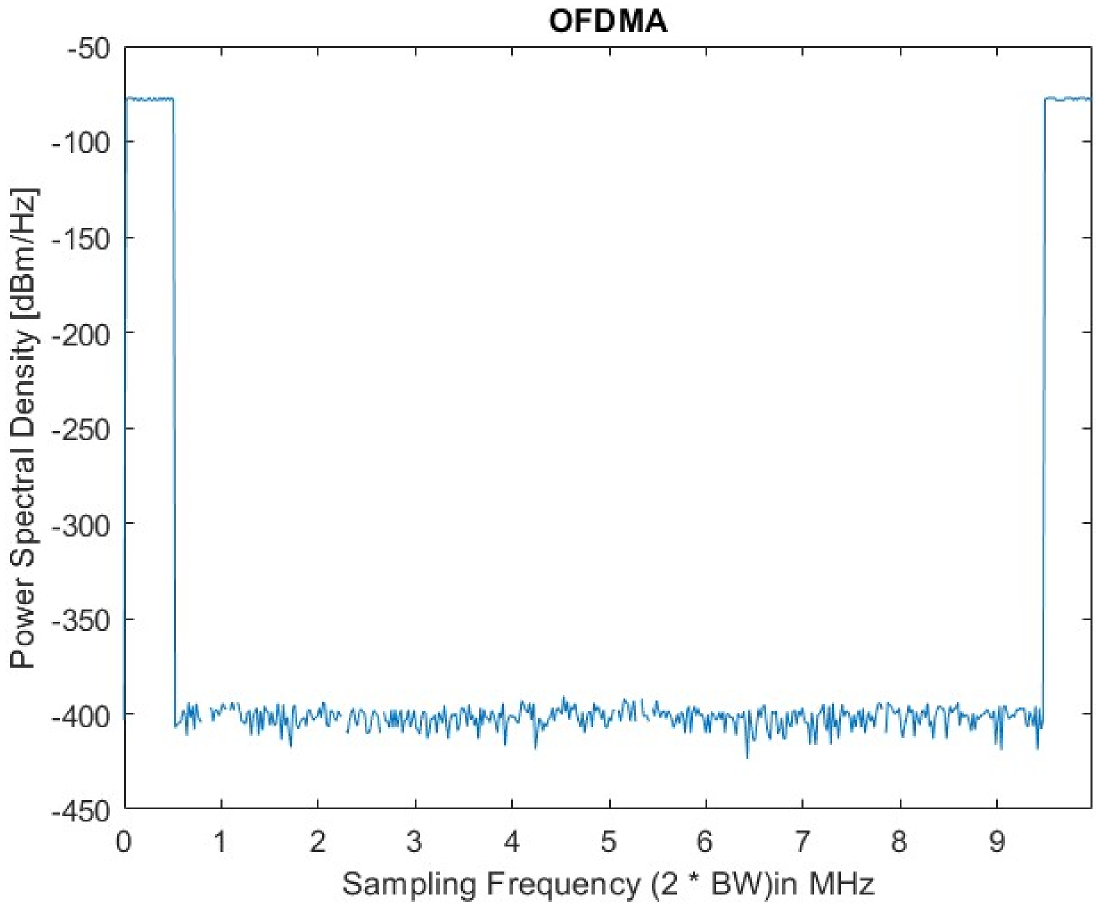

Figure 8 : OFDMA PSD Plot

Using scfdma.m, we have plotted SC-FDMA BER/SNR, Pe/SNR, PSD and PAPR of both SC-FDMA and OFDMA.

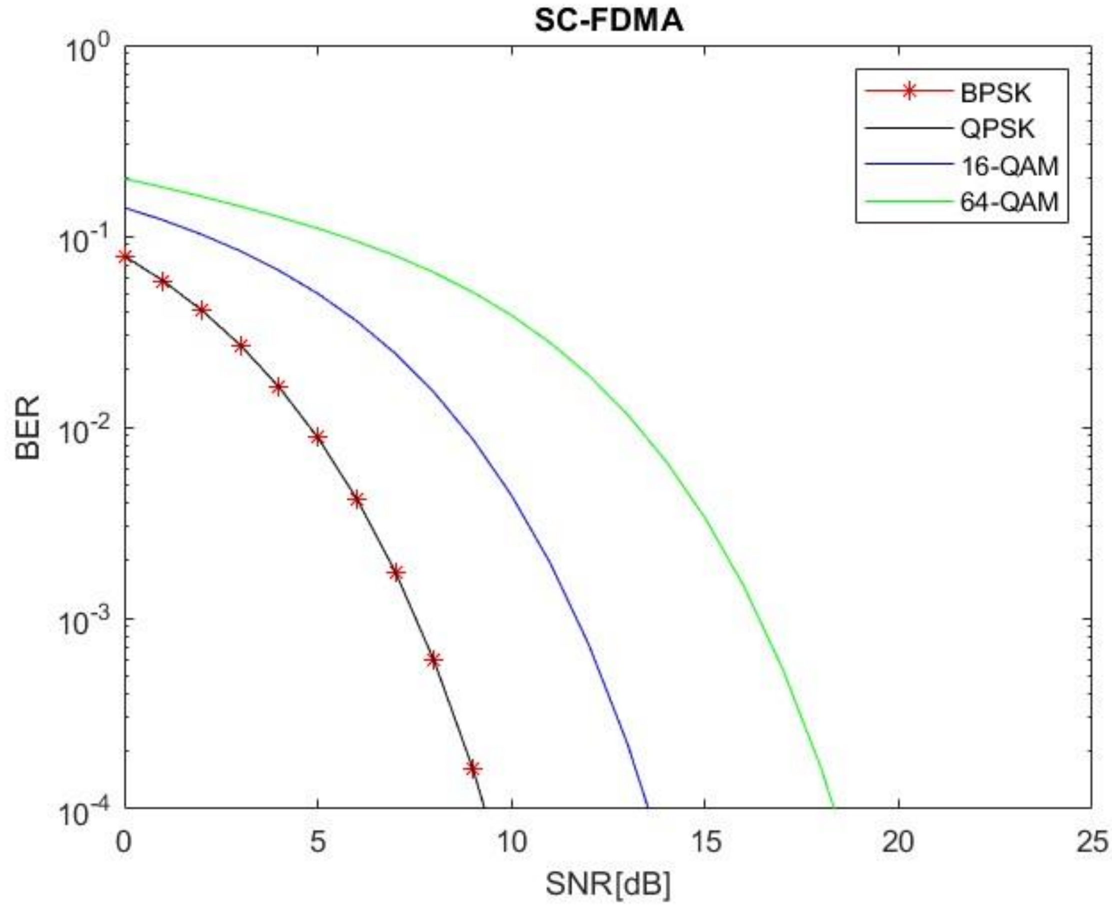

Figure 9 : SC-FDMA BER/SNR Plot

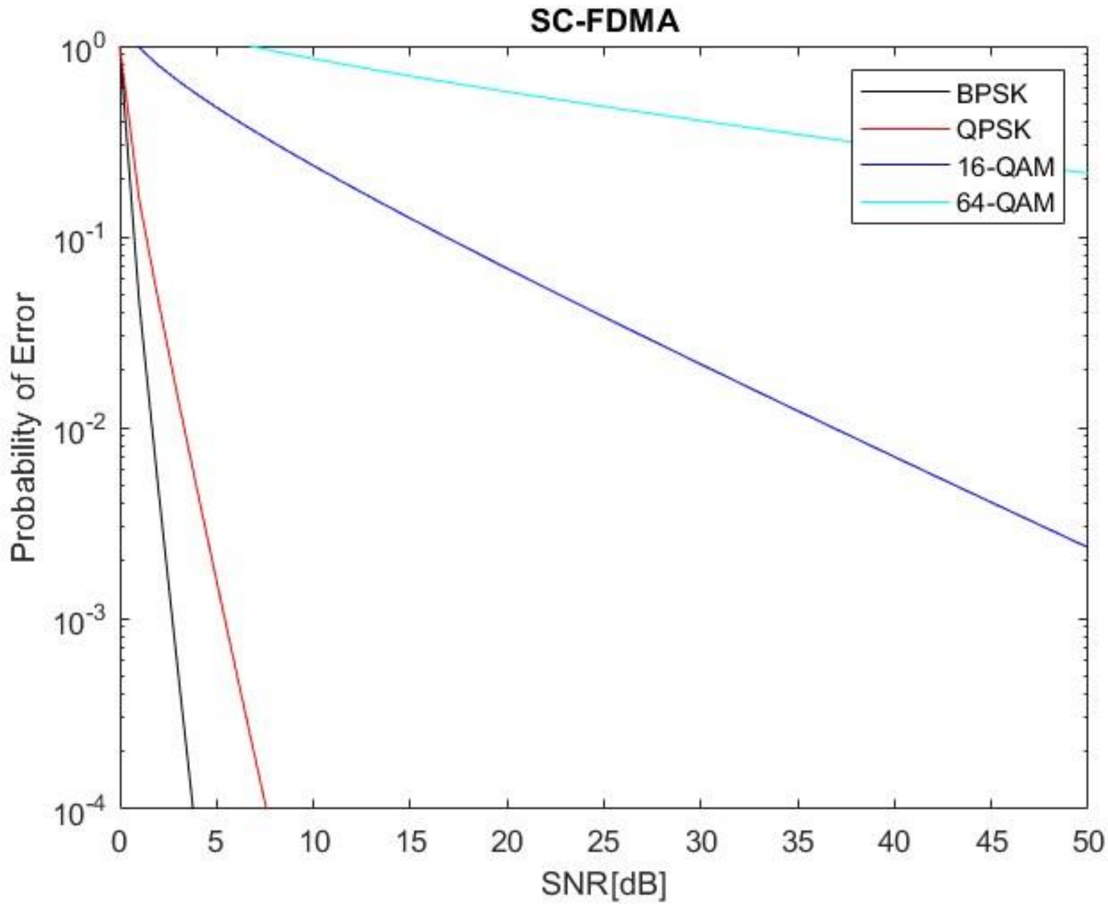

Figure 10 : SC-FDMA Pe/SNR Plot

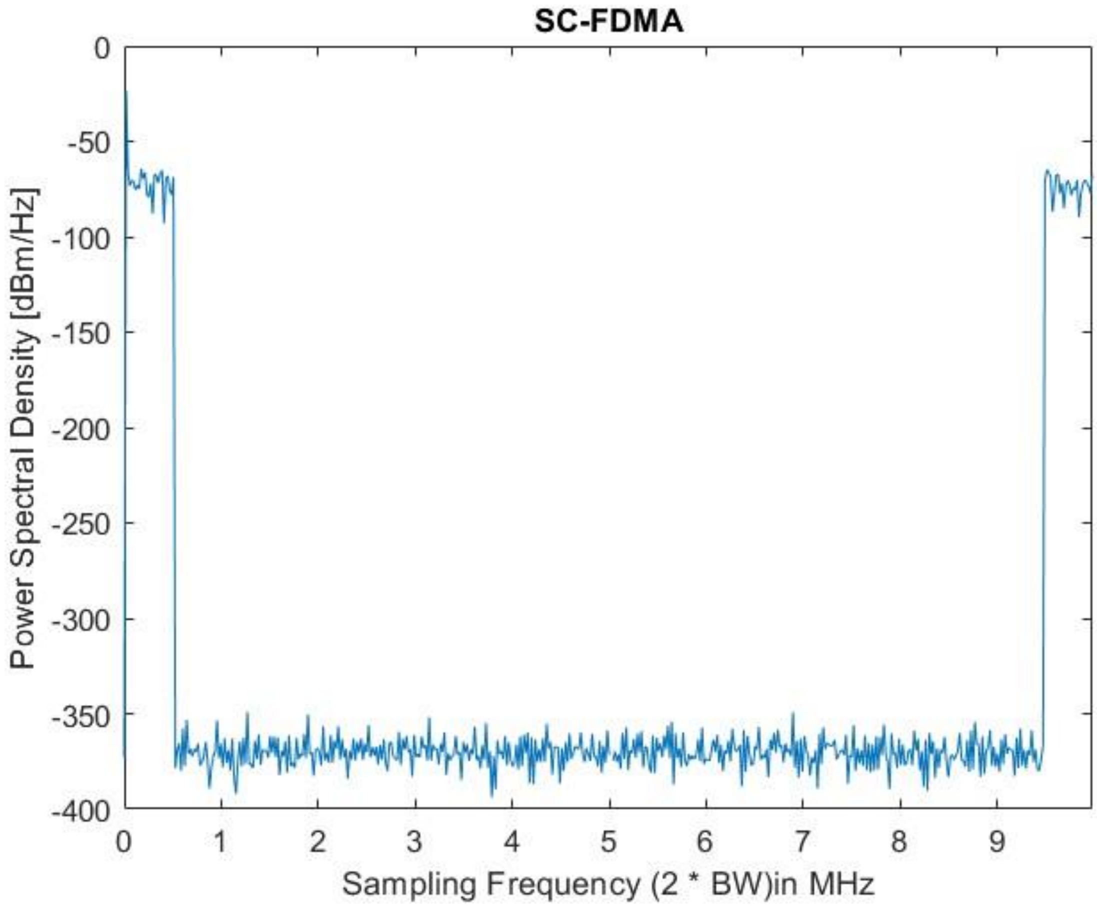

Figure 11 : SC-FDMA PSD Plot

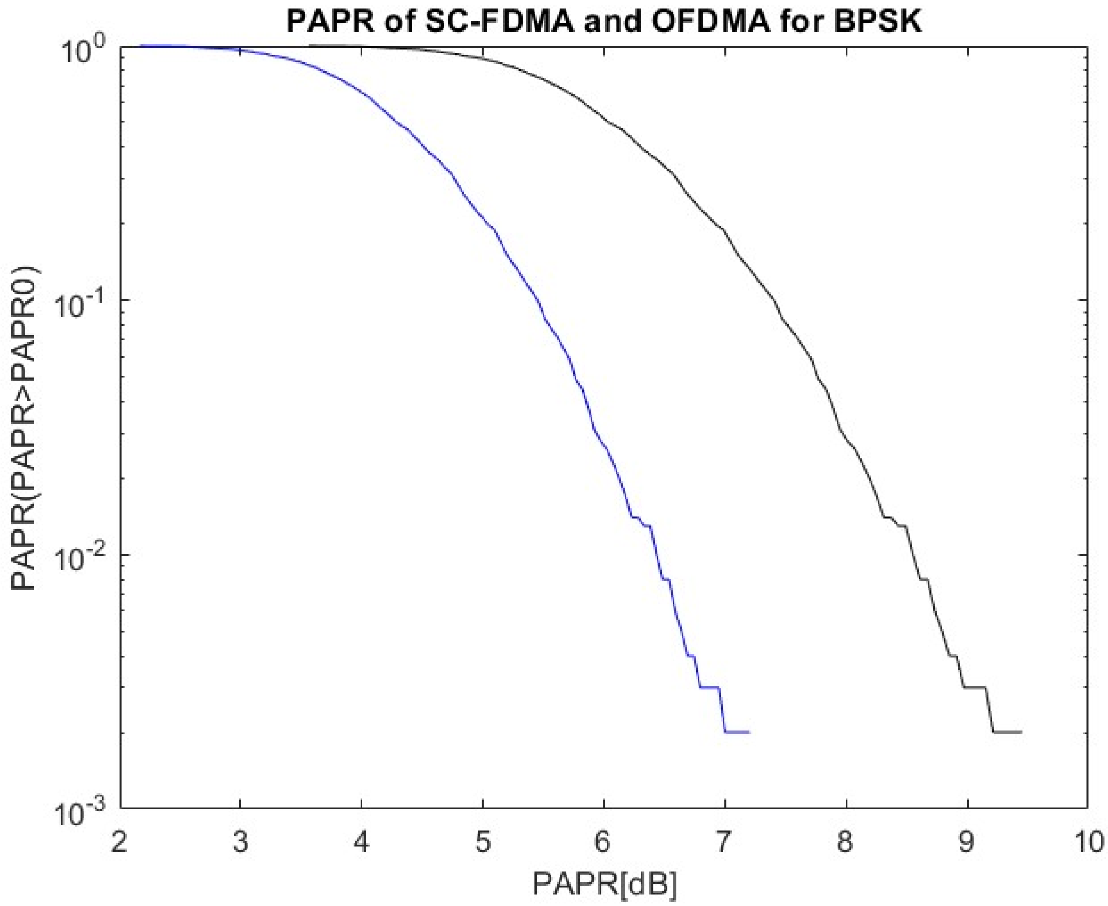

Figure 12 : OFDMA and SC-FDMA PAPR Plot

5 Conclusions and recommendations

We discovered that the BER value in SC-FDMA is less and more efficient than OFDMA, which is one of the most essential metrics to evaluate system performance. Because SC-FDMA divides all data into a single subcarrier, unlike OFDMA, which divides data into many subcarriers.

In all modulation types, OFDMA is more efficient than SC-FDMA in terms of SNR. Because it uses many frequencies (subcarriers), high order modulation is increased.

Because the SC-FDMA value is lower than that of OFDMA in terms of probability of error, SC-FDMA is more efficient than OFDMA (in all modulation schemes).

In terms of power spectral density, OFDMA symbols (512) have a higher average power than SC-FDMA symbols (512) at all frequencies, indicating that OFDMA is more efficient than SC-FDMA.

In all modulation schemes, the overall value of PAPR in SC-FDMA is still smaller than that of OFDMA, which is why it has been adopted for uplink transmission in the LTE system. Based on our findings, we recommend using low order modulation schemes for uplink, such as BPSK, QPSK, 16-QAM, and 64QAM, to reduce PAPR at the user end.

In conclusion, we have evaluated the LTE Physical layer performance in this work.

7 References

[1] Erik Dahlman and et al, “3G Evolution HSPA and LTE for Mobile Broadband”.

[2] T.S. Rappaport and et al, Wireless communications: principles and practice, Prentice Hall PTR New Jersey, 1996.

[3] 3GPP, „Further discussion on delay enhancements in Rel7‟, 3GPP R2-061189, August 2006.

[4] H.G. Myung, J. Lim, and D.J. Goodman, “Peak-to-average power ratio of single carrier FDMA signals with pulse shaping,” Proc. of PIMRC06.

[5] H. Holma and A. Toskala, LTE for UMTS: OFDMA and SC-FDMA based radio access, John Wiley & Sons Inc, 2009.

Appendix A: MATLAB codes

ofdma.m

```
%% OFDMA
 % Subcarrier sayisi
 NS=512;
 % Giris sinyali olusturulmasi
 x=rand(1,NS)>0.5;
 fftlength=512;
 nd=6;
 BW=5e6;
 FS=2*BW;%Sampling Frekansi
 pathDelays = [0 2e-5]; %comm.RayleighChannel fonksiyonunu kullanabilmek için
 pathPower = [0 -9]; %dB cinsinden. Rayleigh channel için.
 fD = 100; %Hz cinsinden. Maximum doppler shift.
 fs = 1000; %Hz cinsinden. Input sample rate.
 %gelen data'nin seriden paralele cevrimi
 p=series2parallel(x,NS);
 % M-ary PSK & QAM Modulasyon
 M=2;
 X=0;
 for count1=2:1:7
    if(M==2||M==4||M==16||M==64)
      M=M+X;
        %M-ary modulasyon
      if(M<=8)
        %PSK modulasyon
        y = pskmod(p,M);
      else
        %QAM modulasyon
        y = qammod(p,M);
      end
      ylen=length(y);
      %Mapping fonksiyonu
      q_out=ofdma_mapping(y,ylen);
      %Inverse Fast Fourier Transform
      outifft=ifft(q_out);
      %Cyclic Prefix eklenmesi
      cp(count1,:)=cyclicpad(outifft,64);
      %CP uzunlugu
      cplength=length(cp);
      %Datanin paralelden seriye cevrimi
      out=reshape(cp(count1,:),1,cplength);
      %AWGN kanali
      ynoisy=awgn(out,100,'measured');
      % Rayleigh fading eklenmesi
      c=comm.MIMOChannel('SampleRate',fs,'PathDelays',pathDelays, ...

'AveragePathGains',pathPower,'MaximumDopplerShift',fD,'NumTransmitAntennas',576,'Spat
ialCorrelationSpecification','None');
      rf=c(ynoisy);
      %Data'nin seriden paralele cevrimi
      p2=series2parallel(ynoisy,cplength);
```

```
        re_par=real(p2);
        %Cyclic prefix kaldirilmasi
        rcp(count1,:)=decyclicpad(p2,64);
        rcplength=length(rcp);
        %Fast Fourier Transform
        zzfft=fft(rcp(count1,:),fftlength);
        %Demapping fonksiyonu
        qq_out=ofdma_demapping(zzfft);
        outfft=qq_out;
        if(M<=8)
          %Receiver'da PSK Demodulasyonu
          z=pskdemod(outfft,M);
        else
          %Receiver'da QAM Demodulasyonu
          z=qamdemod(outfft,M);
        end
        %Data'nin paralelden seriye cevrimi
        xdash=reshape(z,1,NS);
        berr=0;
        for a=1:1:NS
          if(xdash(:,a)==x(:,a))
              berr=0;
          else
              berr=berr+1;
          end
        end
        tberr(count1,:)=berr;
        Eb_No=0:1:NS-1;
        Eb_No=0.4*Eb_No;
        if(M<=8)

ber(count1,:)=berawgn(Eb_No,'psk',M,'nondiff');
          Pe(count1,:)=erfc(sqrt(0.9*Eb_No)*sin(pi/M));
        else
          ber1(count1,:)=berawgn(0.9*Eb_No,'qam',M);
          Pe(count1,:)=2*((1-(1/sqrt(M)))*erfc(sqrt((1.5*Eb_No)/(M-1))));
        end
        for init=1:1:32
            switch M
            end
        end
    end
    M=2^count1;
end
 figure()
 %SNR ve BER Plot

semilogy(Eb_No,ber(2,:),'k',Eb_No,ber(3,:),'g',Eb_No,ber1(5,:),'b',Eb_No,ber1(7,:),'r
');
    axis([0 25 0.0001 1]);
    xlabel('SNR[dB]')
    ylabel('BER')
    legend('BPSK','QPSK','16-QAM','64-QAM')
    title('OFDMA')
    figure()
```

```
    %Error Probability Plot
 semilogy(Eb_No,Pe(2,:),'k',Eb_No,Pe(3,:),'r',Eb_No,Pe(5,:),'b',Eb_No,Pe(7,:),'g');
    axis([0 50 0.0001 1]);
    xlabel('SNR[dB]')
    ylabel('Probability of Error')
    legend('BPSK','QPSK','16-QAM','64-QAM')
    title('OFDMA')
    h=spectrum.periodogram;
    figure()

HS=psd(h,outifft,'SpectrumType','twosided','NFFT',512,'FS',FS);
    plot(HS)
    xlabel('Sampling Frequency (2 * BW)in MHz')
    ylabel('Power Spectral Density [dBm/Hz]')
    title('OFDMA')
    grid off;
```

sc_fdma.m

```
%% SC-FDMA:
%Subcarrier sayisi
   NS=512;
   %Giris sinyalinin olusturulmasi
   x=rand(1,NS)>0.5;
   fftlength=512;
   nd=6;
   BW=5e6;
   FS=2*BW;%Sampling Frekansi
   pathDelays = [0 2e-5]; %comm.RayleighChannel fonksiyonunu kullanabilmek için
   pathPower = [0 -9]; %dB cinsinden. Rayleigh channel için.
   fD = 100; %Hz cinsinden. Maximum doppler shift.
   fs = 1000; %Hz cinsinden. Input sample rate.
   %Data'nin seriden paralele cevrimi
   p=series2parallel(x,NS);
   %M-ary PSK & QAM Modulasyon
   M=2;
   X=0;
   for count1=2:1:7
      if(M==2||M==4||M==16||M==64)
      M=M+X;
      %M-ary Modulasyon
        if(M<=8)
          %PSK Modulasyon
          y = pskmod(p,M);
        else
          %QAM Modulasyon
          y = qammod(p,M);
        end
        out_fft = fft(y,fftlength);
        %Mapping fonksiyonu
        q_out=ofdma_mapping(out_fft,fftlength);
        %Inverse Fast Fourier Transform
        outifft=ifft(q_out);
        %Cyclic Prefix eklenmesi
        cp(count1,:)=cyclicpad(outifft,64);
```

```
        %CP uzunlugu
        cplength=length(cp);
        %Data'nin paralelden seriye cevrimi
        out=reshape(cp(count1,:),1,cplength);
        %Rayleigh fading eklenmesi
        c=comm.MIMOChannel('SampleRate',fs,'PathDelays',pathDelays, ...

'AveragePathGains',pathPower,'MaximumDopplerShift',fD,'NumTransmitAntennas',576,'Spat
ialCorrelationSpecification','None');
        rf = c(out);
        %AWGN kanal
        ynoisy=awgn(out,100,'measured');
        %Data'nin seriden paralele cevrimi
        p2=series2parallel(ynoisy,cplength);
        re_par=real(p2);
        %Cyclic Prefix kaldirilmasi
        rcp(count1,:)=decyclicpad(p2,64);
        rcplength=length(rcp);
        %FFT
        zzfft=fft(rcp(count1,:),fftlength);
        %Demapping fonksiyonu
        qq_out=ofdma_demapping(zzfft);
        outfft=ifft(qq_out);
         %% IFFT
        %zfft=ifft(qq_out);
        if(M<=8)
          %Receiver'da PSK Demodulasyonu
          z=pskdemod(outfft,M);
        else
          %Receiver'da QAM Demodulasyonu
          z=qamdemod(outfft,M);
        end
        %Data'nin paralelden seriye cevrimi
        xdash=reshape(z,1,NS);
        berr=0;
        for a=1:1:NS
          if(xdash(:,a)==x(:,a))
            berr=0;
          else
            berr=berr+1;
          end
        end
        tberr(count1,:)=berr;
        Eb_No=0:1:NS-1;
        if(M<=8)

ber(count1,:)=berawgn(0.9*Eb_No,'psk',M,'nondiff');
            Pe(count1,:)=erfc(sqrt(2*Eb_No)*sin(pi/M));
        else
            ber1(count1,:)=berawgn(0.9*Eb_No,'qam',M);
            Pe(count1,:)=2*((1-(1/sqrt(M)))*erfc(sqrt((1.5*Eb_No)/(M-1))));
        end
        for init=1:1:32
            switch M
            end
```

```
        end
    end
    M=2^count1;
 end
   figure()
   %SNR ve BER Plot
   semilogy(Eb_No,ber(2,:),'*-
r',Eb_No,ber(3,:),'k',Eb_No,ber1(5,:),'b',Eb_No,ber1(7,:),'g');
   axis([0 25 0.0001 1]);
   xlabel('SNR[dB]')
   ylabel('BER')
   legend('BPSK','QPSK','16-QAM','64-QAM')
   title('SC-FDMA')
   figure()
   %Error Probability Plot
   semilogy(Eb_No,Pe(2,:),'-k',Eb_No,Pe(3,:),'-r',Eb_No,Pe(5,:),'-b',Eb_No,Pe(7,:),'-
c');
   axis([0 50 0.0001 1]);
   xlabel('SNR[dB]')
   ylabel('Probability of Error')
   legend('BPSK','QPSK','16-QAM','64-QAM')
   title('SC-FDMA')
   h=spectrum.periodogram;
   figure()

HS=psd(h,outifft,'SpectrumType','twosided','NFFT',512,'FS',FS);
 plot(HS)
 xlabel('Sampling Frequency (2 * BW)in MHz')
 ylabel('Power Spectral Density [dBm/Hz]')
 title('SC-FDMA')
 grid off;
 paprSCFDMA();
```

cyclicpad.m

```
function y=cyclicpad(X,L)
 N=length(X(:,1));
 %N-L+1
 Y=[X(N-L+1:N,:);X];
 y=Y;
end
```

decyclicpad.m

```
function y=decyclicpad(X,L)
 N=length(X(:,1));
 Y=X(L+1:N,:);
 y=Y;
end
```

ofdma_mapping.m

```
function [qout]=ofdma_mapping(qdata,fftlength)
 qout=zeros(fftlength,1);
 qout(2:27,:) = qdata(1:26,:);
 qout(487:end,:)= qdata(27:52,:);
end
```

ofdma_demapping.m

```
function [qout]=ofdma_demapping(qdata)
 qdata = qdata';
 qout=zeros(length(qdata),1);
 qout(1:26,:)=qdata(2:27,:);
 qout(27:52,:)=qdata(487:end,:);
end
```

paprSCFDMA.m

```
function paprSCFDMA()
   dataType = 'B-PSK'; % Modulation format.
   NS = 512; % Number of total subcarriers.
   Symbols = 16; % Data block size.
   Q = NS/Symbols; % Bandwidth spreading factor of SC-FDMA.
   BW = 5e6; % System bandwidth.
   Ts = 1/BW; % sampling rate.
   osf = 4; % Oversampling factor.
   Nsub = NS;
   Fsub = (0:Nsub-1)*BW/Nsub; % Subcarrier spacing of OFDMA.
   Runs = 1e3; % Number of iterations.
   papr1 = zeros(1,Runs); % Initialize the PAPR results for sc-fdma.
   papr3 = zeros(1,Runs); % Initialize the PAPR results for OFDMA
   for n = 1:Runs,
    % Generate random data.
    if strcmp(dataType , 'B-PSK') == 1
        tmp = round(rand(Symbols,2));
        tmp = tmp*2 - 1;
        data = (tmp(:,1) + 1i*tmp(:,2))/sqrt(2);
    elseif strcmp(dataType, '16QAM') == 1
        dataSet = [-3+3i -1+3i 1+3i 3+3i ...
                   -3+1i -1+1i 1+1i 3+1i ...
                   -3-1i -1-1i 1-1i 3-1i ...
                   -3-3i -1-3i 1-3i 3-3i];
        dataSet = dataSet / sqrt(mean(abs(dataSet).^2));
        tmp = ceil(rand(Symbols,1)*16);
        for k = 1:Symbols,
            if tmp(k) == 0
                tmp(k) = 1;
            end
            data(k) = dataSet(tmp(k));
```

```
        end
        data = data';
    end
    % Convert data to frequency domain.
    Z1 = fft(data);
    Z2 = fft(data);
    % Initialize the subcarriers.
    Y1 = zeros(NS,1);
    Y2 = zeros(NS,1);
    % Subcarrier mapping for SC-FDMA
    Y1(1:Symbols) = Z1;
    Y2(1:Symbols) = Z2;
    % Convert data back to time domain.
    y1 = ifft(Y1);
    y2 = ifft(Y2);
    % OFDMA modulation.
    % Time range of the OFDMA symbol.
    t = 0:Ts/osf:Nsub*Ts;
    y3 = 0;
    for k = 1:Symbols,
        y3= y3 + data(k)*exp(1i*2*pi*Fsub(k)*t);
    end
    % Calculate PAPR.
    papr3(n) = 10*log10(max(abs(y3).^2) /mean(abs(y3).^2));
    papr1(n) = 10*log10(max(abs(y1).^2) /mean(abs(y1).^2));
    papr2(n) = 10*log10(max(abs(y2).^2) /mean(abs(y2).^2));
end
% Plot CCDF.
figure
[N,Z3] = hist(papr3, 100);
[N,Z1] = hist(papr1, 100);
[N,Z2] = hist(papr2, 100);
semilogy(Z1,1-cumsum(N)/max(cumsum(N)),'b')
hold on
semilogy(Z3,1-cumsum(N)/max(cumsum(N)),'black')
hold off
title ('PAPR of SC-FDMA and OFDMA for BPSK')
xlabel ('PAPR[dB]')
ylabel ('{PAPR(PAPR>PAPR0)}')
grid off;
% Save data.
% save paprSCFDMA
% QPSK:
if strcmp(dataType, 'QPSK') == 1
    tmp = round(rand(Symbols,4));
    tmp = tmp*2 - 1;
    data = (tmp(:,1) + 1i*tmp(:,2))/sqrt(2);
% 16-QAM:
elseif strcmp(dataType , '16QAM') == 1
dataSet = [-3+3i -1+3i 1+3i 3+3i ...
           -3+1i -1+1i 1+1i 3+1i ...
           -3-1i -1-1i 1-1i 3-1i ...
           -3-3i -1-3i 1-3i 3-3i];
% 64-QAM:
elseif strcmp(dataType , '64QAM') == 1
```

```
 dataSet = [-5+5i -1+5i 1+5i 5+5i ...
            -5+1i -1+1i 1+1i 5+1i ...
            -5-1i -1-1i 1-1i 5-1i ...
            -5-5i -1-5i 1-5i 5-5i];
    end
end
```

series2parallel.m

```
function y = series2parallel(x,NS)
 L=length(x);
 q=floor(L/NS);
 newvec=zeros(NS,q);
 for i=1:q
 newvec(1:NS,i)=x((1+(i-1)*NS):i*NS);
 end
 y=newvec;
end
```