A report

on

DESIGN OF SDR FOR HD VIDEO COMMUNICATION

Sashank Krishna S 2019A8PS0184P

Aditya Soni 2019A8PS1282H

Prepared in Partial Fulfillment of Practice School - 1
(Course No: BITS F221)
at
Department of Communications
Military College of Electronics and Mechanical Engineering
a Practice School - 1 Station
of

Birla Institute of Technology and Science, Pilani

June, 2021

Birla Institute of Technology and Science, Pilani
Rajasthan
Practice School Division

Station: Military College of Electronics and Mechanical Engineering, Secundrabad
Duration: Seven Weeks **Date of Start:** May 31, 2021
Date of Submission: June 27, 2021
Title: Design of SDR for HD Video communication

Students:
Sashank Krishna S
2019A8PS0184P
B.E. Electronics and Instrumentation

Aditya Soni
2019A8PS1282H
B.E. Electronics and Instrumentation

Mentors:
AEE Naveen Reddy
Military college of Electronics and Mechanical Engineering

Dr. Rahul Singhal
Assistant professor,
BITS Pilani, Pilani Campus

Keywords:
MIMO-OFDM, Polar codes, USRP, HD Video communication, DVB, H.264, H.265

Project Areas:
Wireless communications, Digital communications, Software defined Radio, Video codecs

Abstract:
The project aims to implement a MIMO-OFDM + Polar coding system using USRP for HD video communication. The video is processed using the H.264 / H.265 codecs, and the system supports both transfer and streaming of the video. A power amplifier is also selected in order to improve the system's performance.

Student Signature **Mentor Signature**

Contents

1 About the Organization

The Military College of Electronics and Mechanical Engineering (M.C.E.M.E.), Secunderabad (Hyderabad, Telangana) is an institution of technical education in the Army. The College was awarded the Golden Peacock National Training Award (1997) as well as the Golden Peacock National Quality Award.

M.C.E.M.E. offers graduate and post-graduate engineering courses in computer science, communications, radars, missiles, aeronautics and mechanical engineering. It also conducts management courses for middle and senior-level officers and diploma courses in various engineering disciplines for other ranks. In addition, large numbers of officers and other ranks from friendly foreign countries come to the M.C.E.M.E. for training.

2 About the Project

2.1 Objectives

The project aims to implement a MIMO-OFDM system using USRP n210s and b210s. The link will employ polar coding as the channel coding scheme. The video is compressed using the H.264 / H.265 standards and transmitted through the implemented link. The receiving end must be able to both store the video as well as stream the same. Lastly, a power amplifier is to be selected for extending the range of the wireless link.
The project involved the following sub-problems:

- Modelling of a MIMO-OFDM link
- Implementation of Polar coding
- Translation of the above models into HDL, and configuring the SDR
- Incorporation of H.264 and H.265 codecs
- Selection of suitable power amplifier

2.2 Expected Learning outcomes

1. Proficiency with MATLAB, and the communications toolbox
2. A background in wireless communications
3. A strong background in digital communications
4. A better understanding of 4G, and 5G communication standards
5. A strong understanding of MIMO-OFDM
6. A strong understanding of Polar coding
7. Insight into video codecs
8. Familiarity with SDRs
9. Selection of electronic components via market surveys

2.3 Project work plan & progress

The project was decoupled into two independent sets of problem statements, and the work was done as shown below :

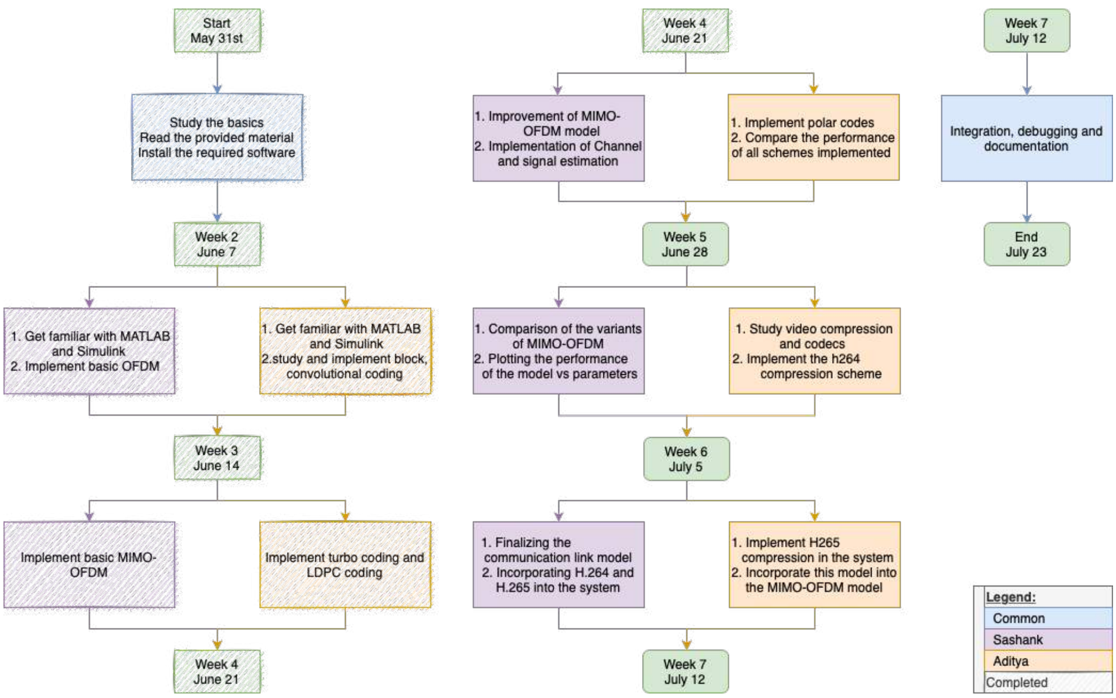

Figure 1: The work split and plan followed by the team

3 Theoretical Background

3.1 QPSK and QAM

Chunks of bits are translated into symbols on a constellation diagram and are transmitted. The bits can be recovered by inverting the mapping from the constellation diagram at the receiver end. Here, the received symbol gets mapped to the nearest meaningful point on the constellation diagram.

The constellation diagram has two axes: the I (in-phase) and Q (Quadrature-phase) axes. The (I, Q) coordinates together map to a superposition of a cosine wave and a sine wave of corresponding amplitudes. Effectively, the information is encoded in the amplitude level and the phase shift of the resulting sinusoid.

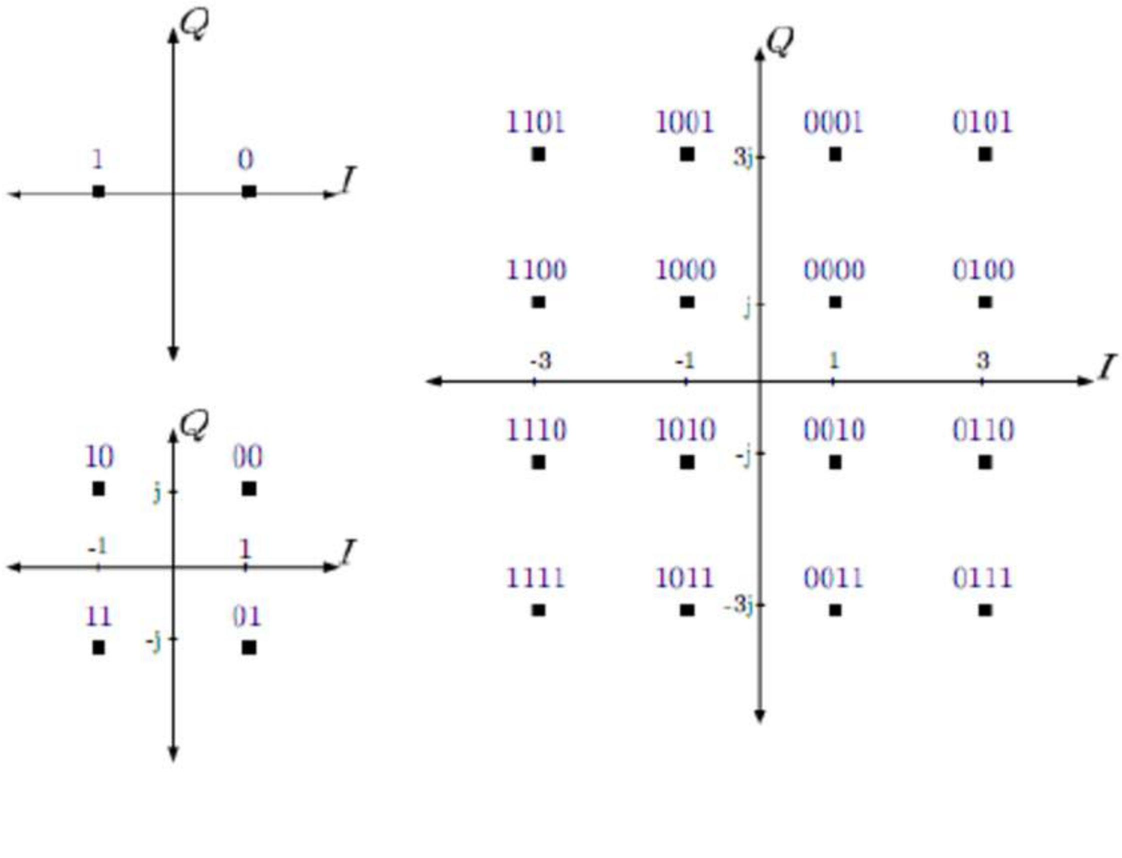

Figure 2: Mapping of bits to constellation (gray code)

3.2 Wireless channels and channel estimation

The waves transmitted through a wireless channel undergo reflections, refractions, scattering and even diffraction due to the miscellaneous obstacles making up the channel. We even get constructive and destructive interference of the waves, and can get both significant increases as well as significant drops in amplitude. Effectively, the receiver receives a superposition of time-shifted, phase-shifted, amplitude scaled copies of the signal transmitted. Wireless channels hence necessitate heavy signal processing in order to estimate the transmitted signal.

3.2.1 Rayleigh fading channel

First, we assume that the time-shifting is very small relative to the time taken to transmit each symbol. If not, we would also face Inter Symbol Interference. With the assumption that it is small, we ignore the time shift. We are now left with a superposition of phase and amplitude shifted versions of the signal. What we receive is now equivalent to receiving the signal but scaled by a sum of a large number of random complex numbers.

Applying Central Limit Theorem, one can approximate the sum as a complex number with both its real and imaginary parts following normal distributions. It translates to the amplitude of the complex number following a Rayleigh distribution and the phase following a uniform distribution.

$$ae^{i\Phi} : P(a) = 2ae^{-a^2}; P(\phi) = \frac{1}{2\pi}$$

This result poses a significant problem since we encoded the information in the phase and amplitude of a sinusoid. Hence, to recover the information, we must invert the effects of the channel at the receiver end. i.e. We must estimate the channel.

Another problem faced stems from the shape of the Rayleigh distribution. There is a chance that the scaling factor a will be uncomfortably close to zero. When this happens, the noise will dominate the signal, and the information will be lost forever. This condition is known as a deep fade. The problem of a deep fade can be alleviated by increasing the diversity order.

3.3 MIMO

MIMO stands for Multiple-Input Multiple-Output. The channel in the system will receive inputs from multiple transmitters, and will have outputs extracted via multiple receivers.

One would like to use multiple receivers because, for the deep fade of the new system, the links to both receivers must suffer from deep fade. If even one link survives, the message can still get through. Note that this assumes that the several links are independent. For this to hold, the receivers must be placed at least half a wavelength apart. The assumption is stronger if the receivers are placed further apart. Else the two links would interfere with each other. We say the system has a diversity order of R for a system with one transmitter and R receivers.

When we use multiple receivers, an issue that crops up is that now we have multiple copies of the signal and need to estimate the initially transmitted signal from them. For this purpose, we perform beamforming. A simple example of a beamforming technique is the maximal ratio combiner, where we weigh the various receivers by their channel coefficients.

Similarly, we would like to have multiple transmitters so that we can have multiple links as well. However, the signal processing this time is different. However, the primary reason is to improve the data rate through transmission via parallel links. We would do this by optimally pre-coding the message such that the system can be decoupled into many parallel systems. This approach would allow us to reach a diversity order of RT for a system containing T transmitters.

Furthermore, we can employ orthogonal space-time block coding (OSTBC) techniques to improve our performance. Space-time block coding refers to making the retrieval of the symbols easier by utilizing redundancies spread across antennas and time. i.e. across space and time. An example of the same is the Alamouti code.

3.4 OFDM

Orthogonal Frequency Division Multiplexing is a multi-carrier modulation technique that employs frequency division multiplexing but using orthogonal frequencies. I.e. with pulses of duration such that in the frequency domain, when any of the corresponding sync functions are peaking, all others are at zero. Hence, as we can pack more peaks using lower bandwidth, OFDM allows for spectrally efficient multiplexing.

3.5 Polar Codes

In information theory, a polar code is a linear block error-correcting code. The code construction is based on a multiple recursive concatenation of a short kernel code which transforms the physical channel into virtual outer channels. When the number of recursions becomes large, the virtual channels tend to either have high reliability or low reliability (in other words, they polarize or become sparse), and the data bits are allocated to the most reliable channels.

Consider a polar code where K information bits are being sent in a block of N bits. Polar code encoding will polarize the channel into reliable and unreliable bit-channels. The information bits will be transmitted on the most reliable K bit-channels. The remaining N-K channels are unreliable are usually set to 0 as they are not reliable for data transmission.

It is the first code with an explicit construction to provably achieve the channel capacity for symmetric binary-input, discrete, memoryless channels (B-DMC) with polynomial dependence on the gap to capacity.

Polar codes have modest encoding and decoding complexity $O(nlogn)$, which renders them attractive for many applications.

4 Research Methodologies

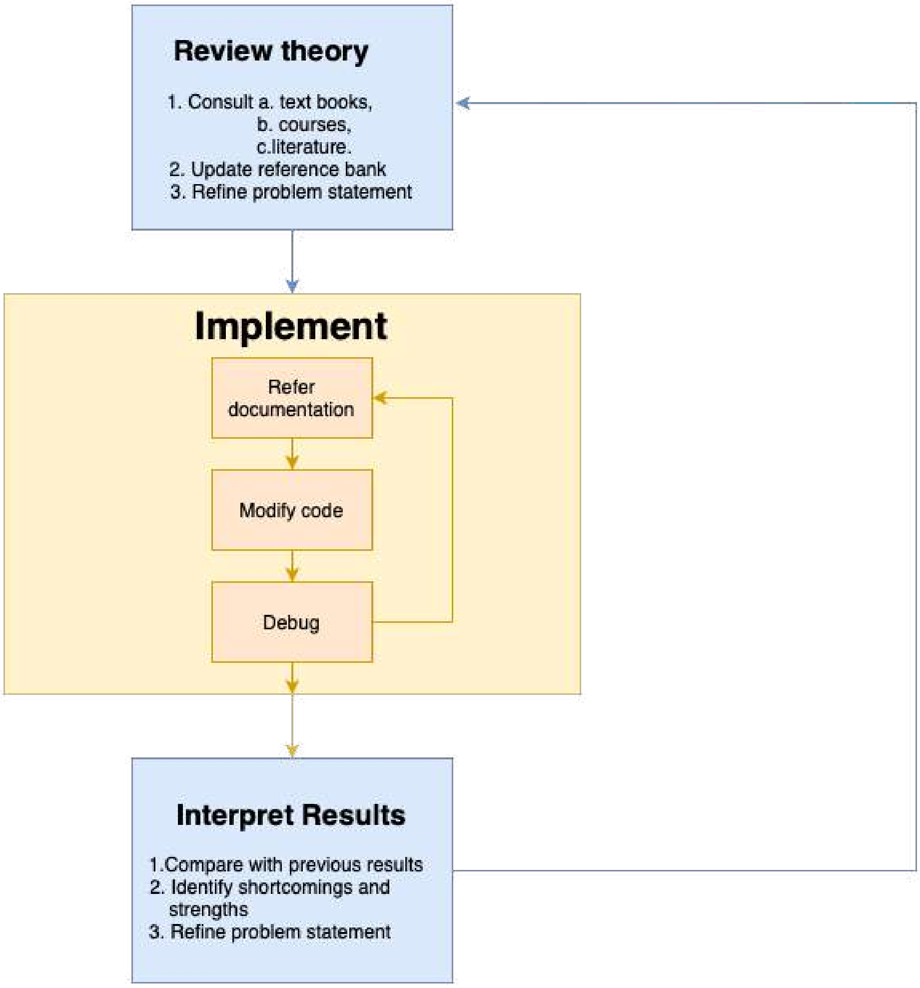

Figure 3: Research Methodology followed

5 Results

As of the writing of the mid-term report, a simple test bench was implemented for the comparative study of the various schemes available. A simple setup for varying parameters and extracting BER plots was established, and the BER for different MIMO-OFDM schemes were plotted. A similar test bench was implemented for the study of different channel coding schemes at standard parameters.

6 Conclusions and Future Scope

The project aims to implement a MIMO-OFDM system with Polar coding using a USRP for HD video communication. This report lists the objectives we have covered so far, the research methodology we are following, and the results we have obtained so far.

The system we have designed has shown acceptable results so far in our simulations. However, there is a lot that we can do to improve the system to achieve competitive results.

Our projects' future goals and scopes are :

1. implementing video compression and transmitting it with polar coding into the MIMO-OFDM system.
2. Deployment of the system on the target hardware
3. Field testing and extending the range by selecting a suitable power amplifier

7 Acknowledgements

We thank A.E.E. Naveen Reddy and Dr Rahul Singhal for all their guidance and support throughout the project. We also thank BITS and M.C.E.M.E. for providing us with such a rich opportunity.

8 References

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9 Appendix

9.1 MIMO-OFDM implementation

The following implementation implements baseband MIMO-OFDM modulation, passes the signal through a Rayleigh fading channel, adds noise, performs signal estimation using the **ideal** channel estimate, and followed by ideal baseband demodulation.
The upgrade to incorporate the RF carrier, and to incorporate channel estimation from the pilot carriers is pending.

The key contents of the script can be duplicated, and the same operations can be performed twice in the same loop, but for different setups. This way, one can compare the performance of the various setups.

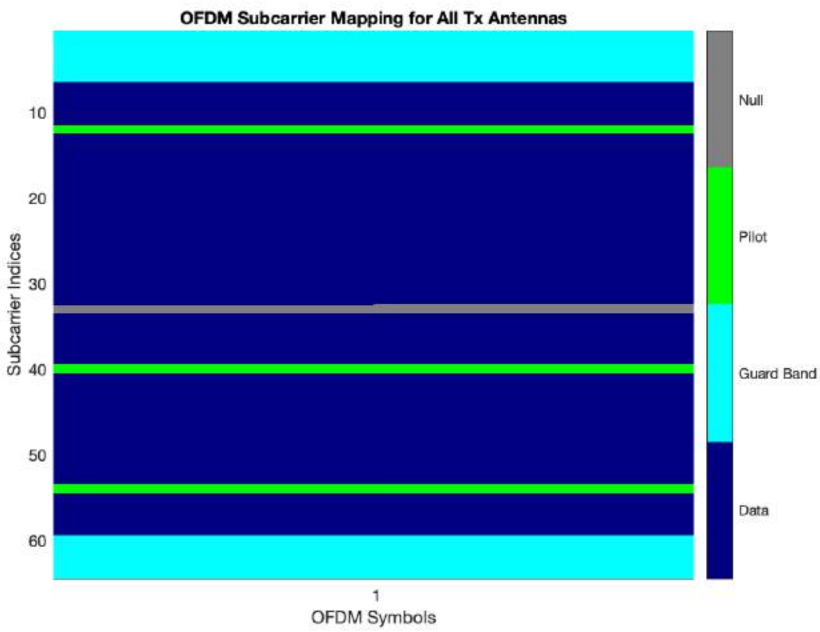

Figure 4: Resource allocation for a simple OFDM system

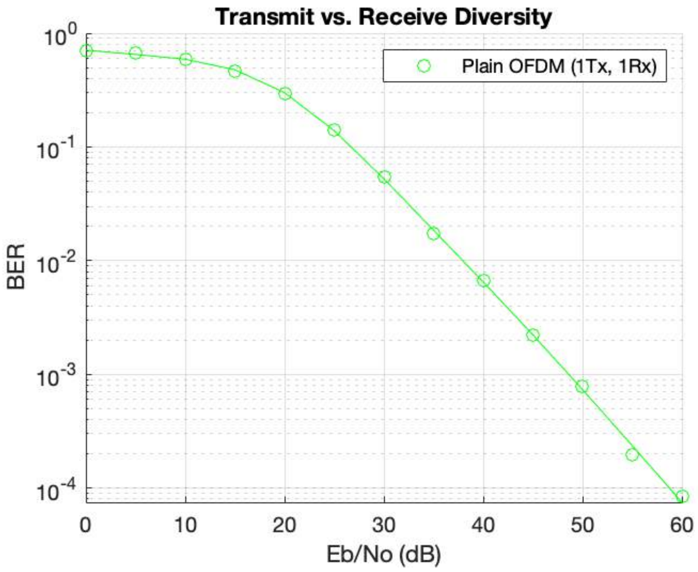

Figure 5: BER for a simple OFDM system

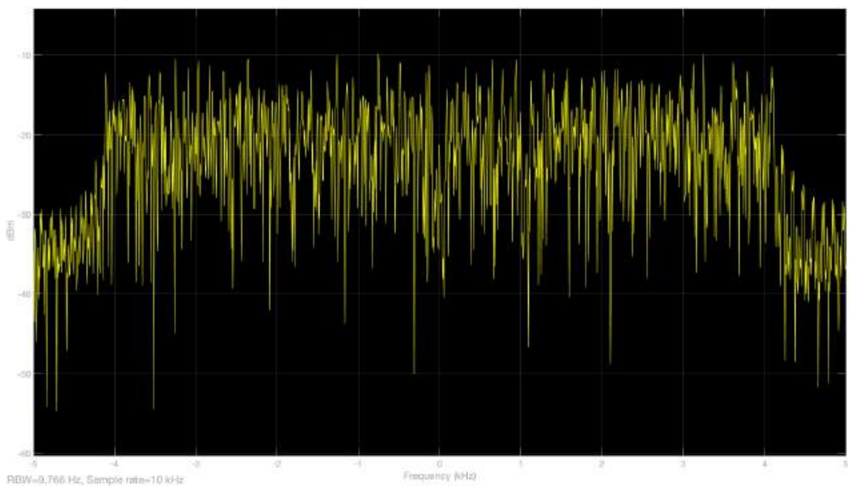

Figure 6: frequency spectrum of a simple OFDM system

Resource allocation for a 2 Tx MIMO-OFDM system :

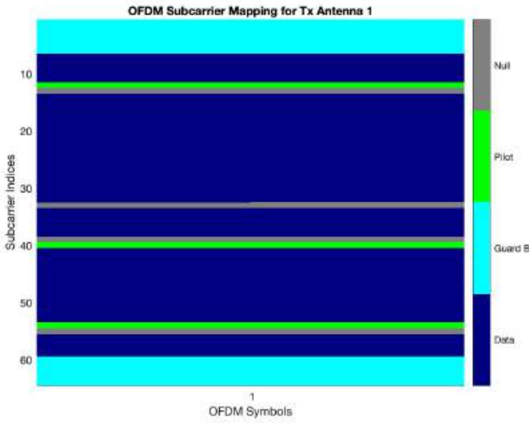

Figure 7: part 1

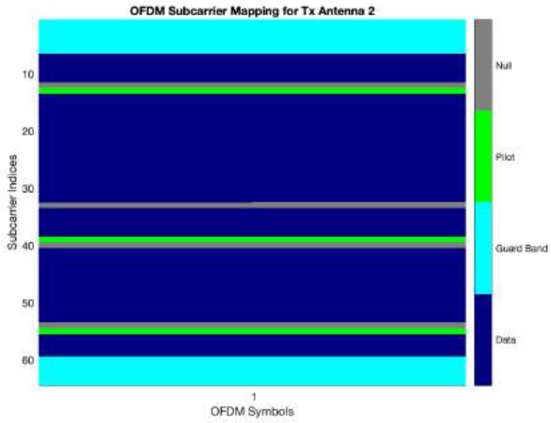

Figure 8: part 2

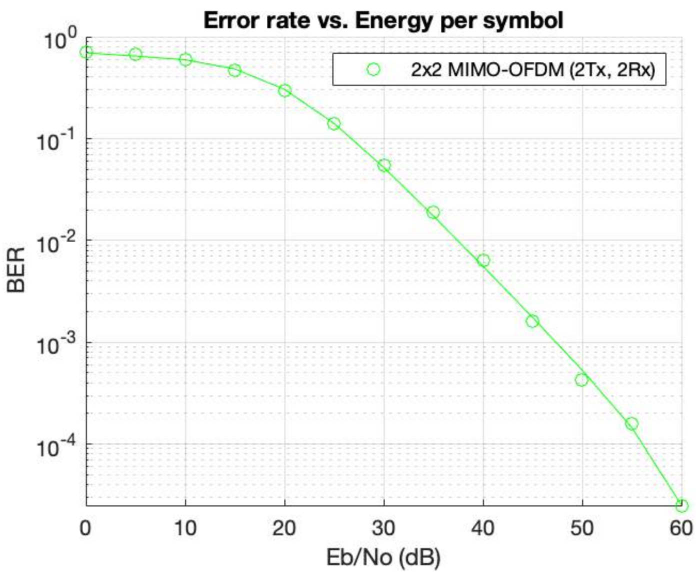

Figure 9: BER for a 2x2 MIMO-OFDM system

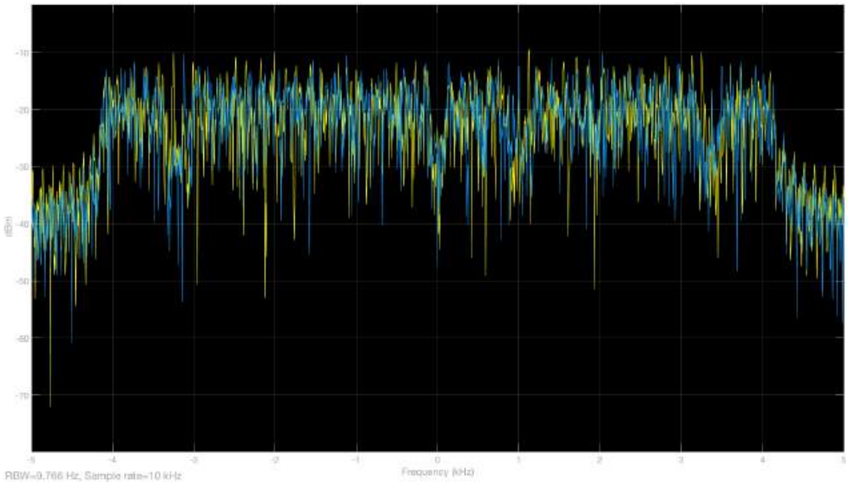

Figure 10: Frequency spectrum of a 2x2 MIMO-OFDM system

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The purpose of this script is to vary Eb/No and plot ...
    variation of BER
% for various diversity orders
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

close all; clear; clc;

qpskMod = comm.QPSKModulator;
qpskDemod = comm.QPSKDemodulator;
Tx = 1;
Rx = 1;

scope1 = dsp.SpectrumAnalyzer;
scope2 = dsp.SpectrumAnalyzer;

ofdmMod = ...
    comm.OFDMModulator('FFTLength',64,'PilotInputPort',true,...
     'PilotCarrierIndices',cat(3,[12; 40; ...
         54]),'InsertDCNull',true,...
     'NumTransmitAntennas',Tx, 'CyclicPrefixLength', 16);

%For 2x2 MIMO, set Tx, Rx to 2, and handle the dimensions of ...
    the pilot carrier indices
% eg for 2x2, use 'PilotCarrierIndices',cat(3,[12; 40; 54],[13; ...
    39; 55])

ofdmDemod = comm.OFDMDemodulator(ofdmMod);
```

```
ofdmDemod.NumReceiveAntennas = Rx;

showResourceMapping(ofdmMod)

ofdmModDim = info(ofdmMod);

numData = ofdmModDim.DataInputSize(1);  % Number of data ...
    subcarriers
numSym = ofdmModDim.DataInputSize(2);     % Number of OFDM symbols
numPilots = ofdmModDim.PilotInputSize;
LenFrame = ofdmMod.FFTLength + ofdmMod.CyclicPrefixLength;


EbNo = 0:5:60;

nframes = 10000;
data = randi([0 3],nframes*numData,numSym,Tx);

modData = qpskMod(data(:));
modData = reshape(modData,nframes*numData,numSym,Tx);

errorRate = comm.ErrorRate;
RxSignalFull = zeros(nframes*LenFrame,Tx);
RxOFDMDataFull = zeros(numData*nframes,1,Tx);

% Set up the figure to be plotted
BER   = zeros(3,length(EbNo));

fig = figure;
grid on;
ax = fig.CurrentAxes;
hold(ax,'on');

ax.YScale = 'log';
xlim(ax,[EbNo(1), EbNo(end)]);
ylim(ax,[1e-4 1]);
xlabel(ax,'Eb/No (dB)');
ylabel(ax,'BER');
fig.NumberTitle = 'off';
fig.Renderer = 'zbuffer';
fig.Name = 'Transmit vs. Receive Diversity';
title(ax,'Transmit vs. Receive Diversity');
set(fig, 'DefaultLegendAutoUpdate', 'off');
fig.Position = figposition([15 50 25 30]);
```

```
% Generating the plots
for idx = 1:length(EbNo)

    reset(errorRate)

    for k = 1:nframes
        % Find row indices for kth OFDM frame
        indData = (k-1)*numData+1:k*numData;

        % Generate random OFDM pilot symbols
        pilotData = complex(rand(numPilots), ...
            rand(numPilots));

        % Modulate QPSK symbols using OFDM
        dataOFDM = ofdmMod(modData(indData,:,:),pilotData);

        % Create flat, i.i.d., Rayleigh fading channel
        chGain = complex(randn(Rx,Tx),randn(Rx,Tx))/sqrt(2); % ...
            Random 2x2 channel

        % Pass OFDM signal through Rayleigh and AWGN channels
        receivedSignal = awgn(dataOFDM*chGain,EbNo(idx));

        % Apply least squares solution to remove effects of ...
            fading channel
        rxSigMF = chGain.' \ receivedSignal.';      % Solves H' ...
            x = y'

        RxSignalFull((k-1)*LenFrame+1:k*LenFrame,:) = rxSigMF.';

        % Demodulate OFDM data
        [receivedOFDMData,receivedPilotData] = ...
            ofdmDemod(rxSigMF.');
        [x,dummy] = ofdmDemod(receivedSignal);
        RxOFDMDataFull(indData,:,:) = receivedOFDMData;

        % Demodulate QPSK data
        receivedData = qpskDemod(receivedOFDMData(:));

        % Compute error statistics
        dataTmp = data(indData,:,:);
        BER(:,idx) = errorRate(dataTmp(:),receivedData);
    end
```

```
    fprintf('\nSymbol error rate = %d from %d errors in %d ...
       symbols\n',BER(:,idx));
    semilogy(ax,EbNo(1:idx), BER(1,1:idx), 'go');
    legend(ax,'Plain OFDM (1Tx, 1Rx)');
    drawnow;
end

fitBER = berfit(EbNo, BER(1,:));
semilogy(ax,EbNo, fitBER, 'g');
hold(ax,'off');

scope2(RxSignalFull);
release(scope2);
```

9.2 Polar codes implementation

Given below is a sample program for the implementation of polar codes in MATLAB using the 5G Toolbox.

```
nVar = 1.5;
chan = comm.AWGNChannel('NoiseMethod','Variance','Variance',nVar);

bpskMod = comm.BPSKModulator;
bpskDemod = comm.BPSKDemodulator('DecisionMethod', ...
    'Approximate log-likelihood ratio','Variance',nVar);

K = 132;
E = 256;
msg = randi([0 1],K,1,'int8');
enc = nrPolarEncode(msg,E);

mod = bpskMod(enc);
rSig = chan(mod);
rxLLR = bpskDemod(rSig);

L = 8;
rxBits = nrPolarDecode(rxLLR,K,E,L);

numBitErrs = biterr(rxBits,msg);
disp(['Number of bit errors: ' num2str(numBitErrs)])
```

The following figure compares the theoretical performances of Hamming, Reed-Solomon and Convolutional codes at standard parameters. This plot will soon be updated to reflect the performances of Turbo, LDPC, and Polar Codes.

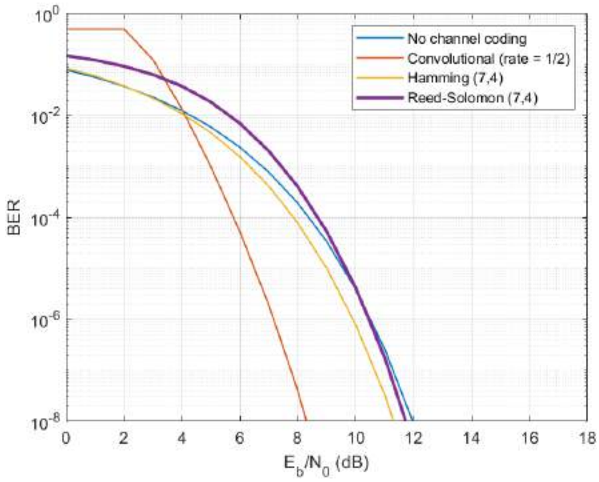

Figure 11: The Bit Error Rate performance of various channel coding schemes