CWN lab1:

Result:

Distance=50(m)

```
Distance: 50
Prx in dBm: -64.0254
Prx in Watt: 3.9579e-10
Empirical average noise power in Watt: 1.9963e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -86.9978
Theoretical average noise power in dBm: -90
Empirical SNRdB: 22.9724
Theoretical SNRdB: 25.9746
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 0
Empirical Throughput of QPSK(bps): 625000
Theoretical Throughput of QPSK(bps): 625000
Empirical BER of 16-QAM: 0
Empirical Throughput of 16-QAM(bps): 1250000
Theoretical Throughput of 16-QAM(bps): 1250000
Empirical BER of 64-QAM: 0
Empirical Throughput of 64-QAM(bps): 1875000
Theoretical Throughput of 64-QAM(bps): 1875000
Optimal modulation scheme: 64-QAM
```

Distance=100(m)

```
Distance: 100
Prx in dBm: -70.046
Prx in Watt: 9.8946e-11
Empirical average noise power in Watt: 1.9946e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.0014
Theoretical average noise power in dBm: -90
Empirical SNRdB: 16.9554
Theoretical SNRdB: 19.954
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 0
Empirical Throughput of QPSK(bps): 625000
Theoretical Throughput of QPSK(bps): 625000
Empirical BER of 16-QAM: 0
Empirical Throughput of 16-QAM(bps): 1250000
Theoretical Throughput of 16-QAM(bps): 1250000
Empirical BER of 64-QAM: 0.0014633
Empirical Throughput of 64-QAM(bps): 75000
Theoretical Throughput of 64-QAM(bps): 5358.8196
Optimal modulation scheme: 16-QAM
```

Distance=150(m)

```
Distance: 150
Prx in dBm: -73.5678
Prx in Watt: 4.3976e-11
Empirical average noise power in Watt: 1.9739e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.0466
Theoretical average noise power in dBm: -90
Empirical SNRdB: 13.4788
Theoretical SNRdB: 16.4322
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 0
Empirical Throughput of QPSK(bps): 625000
Theoretical Throughput of QPSK(bps): 625000
Empirical BER of 16-QAM: 5.6667e-05
Empirical Throughput of 16-QAM(bps): 1050000
Theoretical Throughput of 16-QAM(bps): 996476.6837
Empirical BER of 64-QAM: 0.02288
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 1.1604e-34
Optimal modulation scheme: 16-QAM
```

Distance=200(m)

```
Distance: 200
Prx in dBm: -76.0666
Prx in Watt: 2.4737e-11
Empirical average noise power in Watt: 1.9385e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.1253
Theoretical average noise power in dBm: -90
Empirical SNRdB: 11.0587
Theoretical SNRdB: 13.9334
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 0
Empirical Throughput of QPSK(bps): 625000
Theoretical Throughput of QPSK(bps): 625000
Empirical BER of 16-QAM: 0.0013533
Empirical Throughput of 16-QAM(bps): 33333.3333
Theoretical Throughput of 16-QAM(bps): 5550.5619
Empirical BER of 64-QAM: 0.065187
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 1.488e-111
Optimal modulation scheme: QPSK
```

Distance=250(m)

```
Distance: 250
Prx in dBm: -78.0048
Prx in Watt: 1.5831e-11
Empirical average noise power in Watt: 1.9021e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.2077
Theoretical average noise power in dBm: -90
Empirical SNRdB: 9.2029
Theoretical SNRdB: 11.9952
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 0
Empirical Throughput of QPSK(bps): 625000
Theoretical Throughput of QPSK(bps): 625000
Empirical BER of 16-QAM: 0.00786
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 2.4476e-08
Empirical BER of 64-QAM: 0.11039
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 1.1971e-197
Optimal modulation scheme: QPSK
```

Distance=300(m)

```
Distance: 300
Prx in dBm: -79.5884
Prx in Watt: 1.0994e-11
Empirical average noise power in Watt: 1.8669e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.2888
Theoretical average noise power in dBm: -90
Empirical SNRdB: 7.7004
Theoretical SNRdB: 10.4116
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 3.3333e-06
Empirical Throughput of QPSK(bps): 616666.6667
Theoretical Throughput of QPSK(bps): 616721.9624
Empirical BER of 16-QAM: 0.022123
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 1.711e-33
Empirical BER of 64-QAM: 0.15075
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 2.6427e-278
Optimal modulation scheme: QPSK
```

Distance=350(m)

```
Distance: 350
Prx in dBm: -80.9274
Prx in Watt: 8.0773e-12
Empirical average noise power in Watt: 1.8338e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.3665
Theoretical average noise power in dBm: -90
Empirical SNRdB: 6.4391
Theoretical SNRdB: 9.0726
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 7e-05
Empirical Throughput of QPSK(bps): 475000
Theoretical Throughput of QPSK(bps): 472360.209
Empirical BER of 16-QAM: 0.04253
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 3.9592e-70
Empirical BER of 64-QAM: 0.18386
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 0
Optimal modulation scheme: QPSK
```

Distance=400(m)

```
Distance: 400
Prx in dBm: -82.0872
Prx in Watt: 6.1842e-12
Empirical average noise power in Watt: 1.804e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.4377
Theoretical average noise power in dBm: -90
Empirical SNRdB: 5.3505
Theoretical SNRdB: 7.9128
Empirical BER of BPSK: 0
Empirical Throughput of BPSK(bps): 312500
Theoretical Throughput of BPSK(bps): 312500
Empirical BER of QPSK: 0.00041333
Empirical Throughput of QPSK(bps): 91666.6667
Theoretical Throughput of QPSK(bps): 119590.8739
Empirical BER of 16-QAM: 0.06585
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 5.7994e-113
Empirical BER of 64-QAM: 0.21036
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 0
Optimal modulation scheme: BPSK
```

Distance=450(m)

```
Distance: 450
Prx in dBm: -83.1102
Prx in Watt: 4.8862e-12
Empirical average noise power in Watt: 1.7773e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.5024
Theoretical average noise power in dBm: -90
Empirical SNRdB: 4.3921
Theoretical SNRdB: 6.8898
Empirical BER of BPSK: 6.6667e-06
Empirical Throughput of BPSK(bps): 304166.6667
Theoretical Throughput of BPSK(bps): 304276.7696
Empirical BER of QPSK: 0.0013633
Empirical Throughput of QPSK(bps): 0
Theoretical Throughput of QPSK(bps): 2666.3156
Empirical BER of 16-QAM: 0.090387
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 3.3433e-159
Empirical BER of 64-QAM: 0.23201
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 0
Optimal modulation scheme: BPSK
```

Distance=500(m)

```
Distance: 500
Prx in dBm: -84.0254
Prx in Watt: 3.9579e-12
Empirical average noise power in Watt: 1.7532e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.5617
Theoretical average noise power in dBm: -90
Empirical SNRdB: 3.5363
Theoretical SNRdB: 5.9746
Empirical BER of BPSK: 5.6667e-05
Empirical Throughput of BPSK(bps): 245833.3333
Theoretical Throughput of BPSK(bps): 249119.1709
Empirical BER of QPSK: 0.00347
Empirical Throughput of QPSK(bps): 0
Theoretical Throughput of QPSK(bps): 0.57199
Empirical BER of 16-QAM: 0.11424
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 2.3319e-205
Empirical BER of 64-QAM: 0.24925
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 0
Optimal modulation scheme: BPSK
```

Distance=550(m)

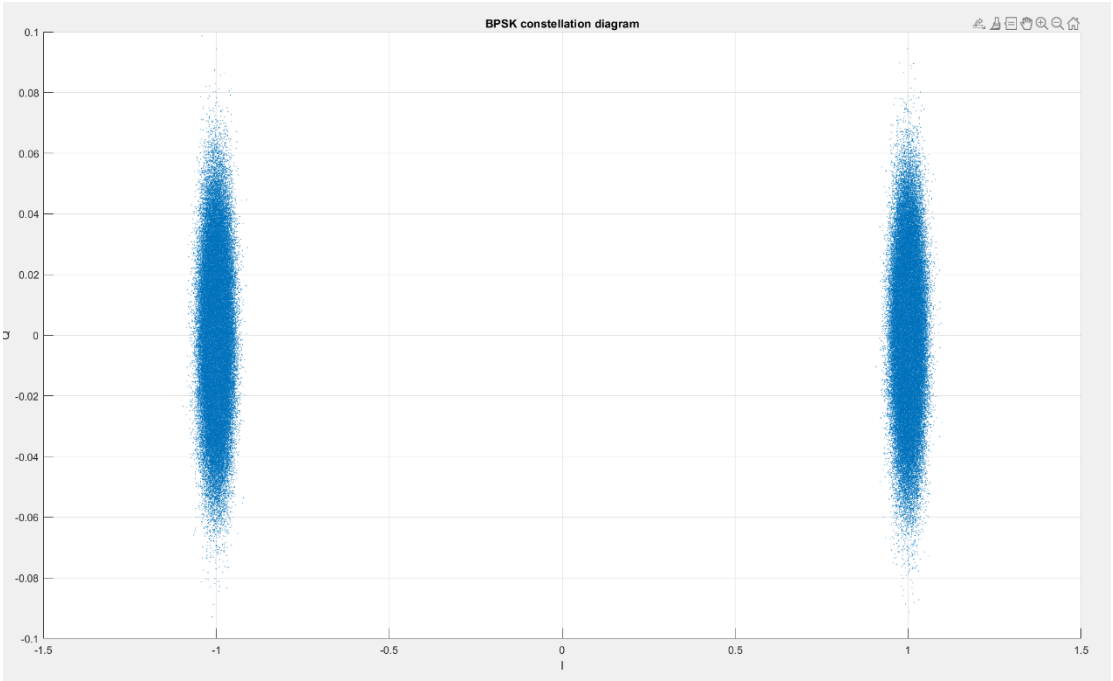
```
Distance: 550
Prx in dBm: -84.8533
Prx in Watt: 3.271e-12
Empirical average noise power in Watt: 1.7308e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.6176
Theoretical average noise power in dBm: -90
Empirical SNRdB: 2.7643
Theoretical SNRdB: 5.1467
Empirical BER of BPSK: 0.00027333
Empirical Throughput of BPSK(bps): 100000
Theoretical Throughput of BPSK(bps): 104702.3629
Empirical BER of QPSK: 0.0069067
Empirical Throughput of QPSK(bps): 0
Theoretical Throughput of QPSK(bps): 5.7036e-07
Empirical BER of 16-QAM: 0.1367
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 5.5446e-250
Empirical BER of 64-QAM: 0.26448
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 0
Optimal modulation scheme: BPSK
```

Distance=600(m)

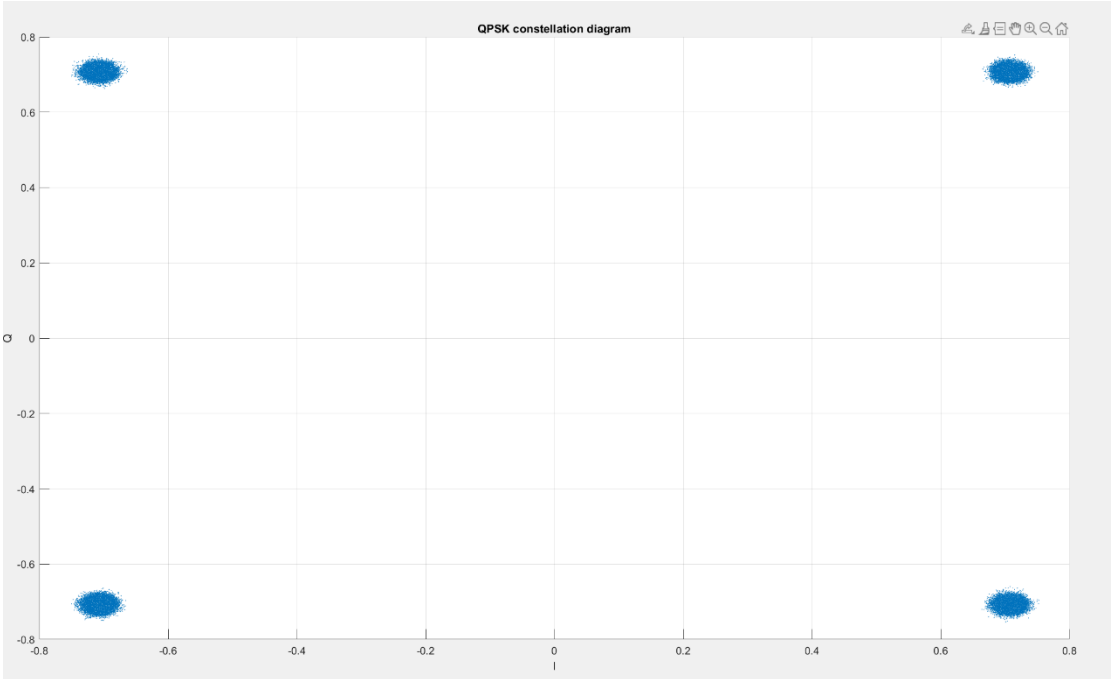
```
Distance: 600
Prx in dBm: -85.609
Prx in Watt: 2.7485e-12
Empirical average noise power in Watt: 1.7089e-12
Theoretical average noise power in Watt: 1e-12
Empirical average noise power in dBm: -87.6728
Theoretical average noise power in dBm: -90
Empirical SNRdB: 2.0638
Theoretical SNRdB: 4.391
Empirical BER of BPSK: 0.00087
Empirical Throughput of BPSK(bps): 4166.6667
Theoretical Throughput of BPSK(bps): 9612.7447
Empirical BER of QPSK: 0.012187
Empirical Throughput of QPSK(bps): 0
Theoretical Throughput of QPSK(bps): 3.1291e-16
Empirical BER of 16-QAM: 0.15767
Empirical Throughput of 16-QAM(bps): 0
Theoretical Throughput of 16-QAM(bps): 1.0786e-292
Empirical BER of 64-QAM: 0.27743
Empirical Throughput of 64-QAM(bps): 0
Theoretical Throughput of 64-QAM(bps): 0
Optimal modulation scheme: BPSK
```

Constellation Diagram:

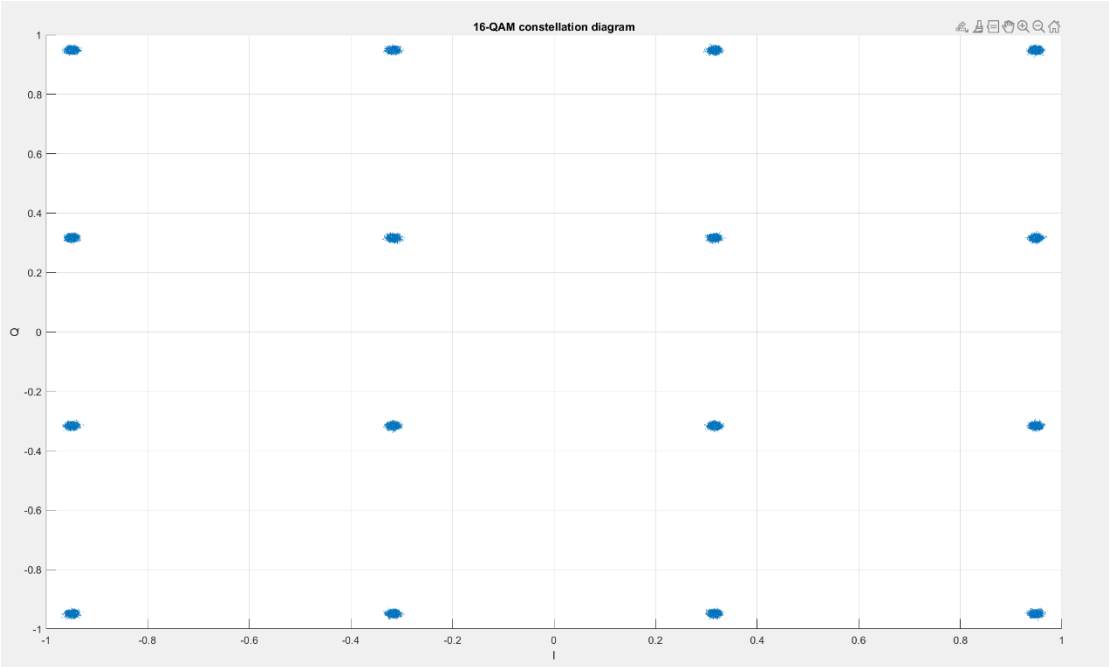
BPSK with 40m:



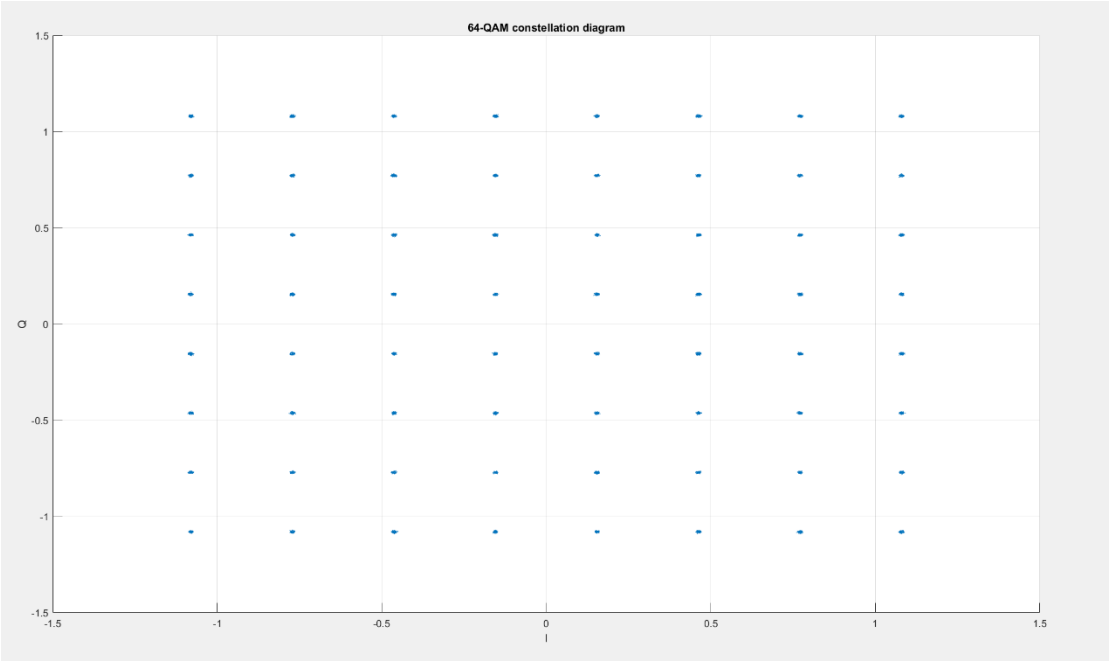
QPSK with 20m:



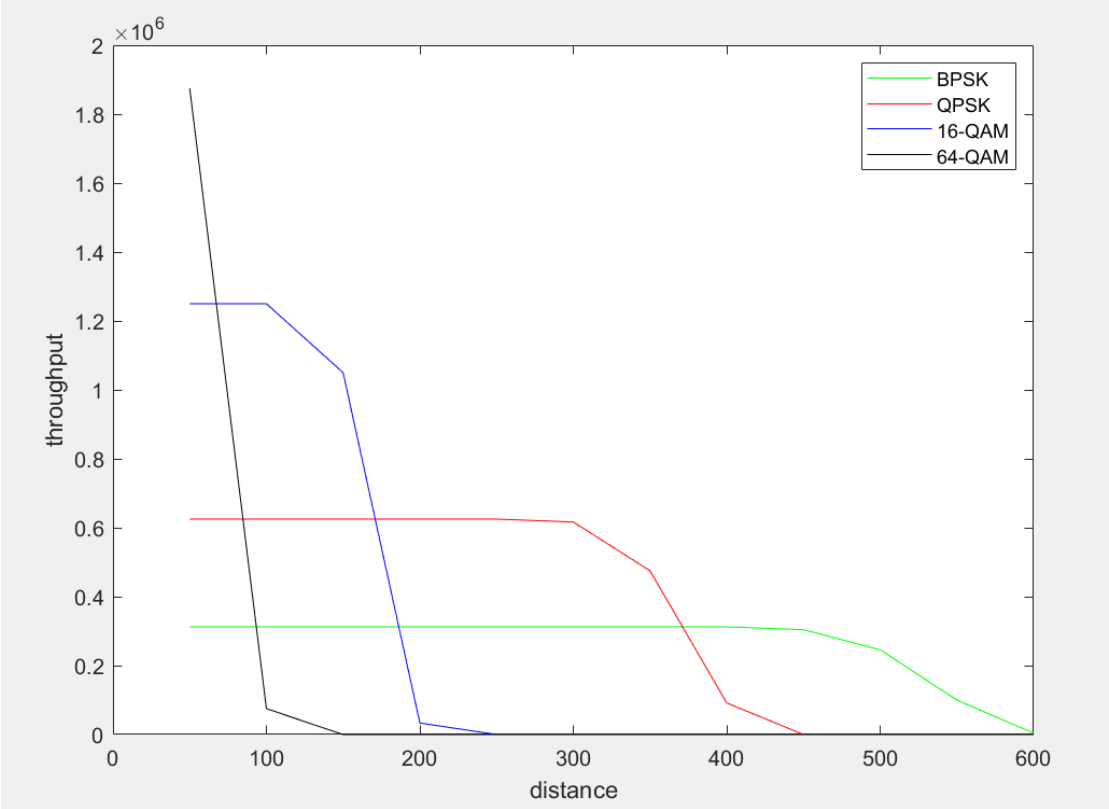
16-QAM with 10m:



64-QAM with 5m:



Throughput v.s. Distance:



Answer the following questions:

Assume there exists a theoretical modulation table given in SNR_BER.mat(also in Appendix 1).

What is the theoretical optimal modulation scheme for link distance *d* and packet size *l*? (You can write a Matlab code to output the answer)

```
Distance: 50
I(packet size in bits): 100
Optimal modulation scheme: 64-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 100
I(packet size in bits): 100
Optimal modulation scheme: 64-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 150
I(packet size in bits): 100
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 200
I(packet size in bits): 100
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 250
I(packet size in bits): 100
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 300
I(packet size in bits): 100
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: QPSK
```

```
Distance: 350
I(packet size in bits): 100
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 400
I(packet size in bits): 100
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 450
I(packet size in bits): 100
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 500
I(packet size in bits): 100
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 550
I(packet size in bits): 100
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 600
I(packet size in bits): 100
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
```

```
Distance: 50
I(packet size in bits): 2000
Optimal modulation scheme: 64-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 100
I(packet size in bits): 2000
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 150
I(packet size in bits): 2000
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 200
I(packet size in bits): 2000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: QPSK
Distance: 250
I(packet size in bits): 2000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 300
I(packet size in bits): 2000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
```

```
Distance: 350
I(packet size in bits): 2000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 400
I(packet size in bits): 2000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 450
I(packet size in bits): 2000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 500
I(packet size in bits): 2000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 550
I(packet size in bits): 2000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 600
I(packet size in bits): 2000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
```

```
Distance: 50
I(packet size in bits): 4000
Optimal modulation scheme: 64-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 100
I(packet size in bits): 4000
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 150
I(packet size in bits): 4000
Optimal modulation scheme: 16-QAM
Optimal theoretical modulation scheme: QPSK
Distance: 200
I(packet size in bits): 4000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: QPSK
Distance: 250
I(packet size in bits): 4000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 300
I(packet size in bits): 4000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
```

```
Distance: 350
I(packet size in bits): 4000
Optimal modulation scheme: QPSK
Optimal theoretical modulation scheme: BPSK
Distance: 400
I(packet size in bits): 4000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 450
I(packet size in bits): 4000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 500
I(packet size in bits): 4000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 550
I(packet size in bits): 4000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
Distance: 600
I(packet size in bits): 4000
Optimal modulation scheme: BPSK
Optimal theoretical modulation scheme: BPSK
```

I write this part of code in lab1_111550175_q1code.m file. In this file, you can adjust the “packet_size_bits” variable to change the packet size you want.
The Optimal modulation scheme is the empirical rate selection, and the Optimal theoretical modulation scheme is the optimal selection gained by the chart SNR/BER and empirical SNR.

Compare your empirical rate selection with the optimal selection and describe your observation

1. The empirical rate selection is really different compare with optimal selection, the reason might be the number in given file might underestimate the accuracy when transmitting the signal. On the other side, the other reason might be the condition of the lab is too ideal. There are much more error will occur in the reality that we do not consider and leads to a total different output.

2. As the distance become longer, the modulation of lower order will often have a higher throughput. But at the short distance, higher order modulation will actually produce higher throughput.
3. Under the same distance, more bits one packet contains, the more the higher order modulation’s throughput will decrease. So, if the packet size is small, it will be well to select a higher order modulation.

What have you learned from this lab?

1. I learned how to write some basic MATLAB code.

2. I reviewed the whole process of transmitting the bitstream involves modulation, produce noise, demodulation, and calculate the throughput.

3. I have gained a greater understanding of the transformation of dBm, Watt, and calculation of Friss Transmission Formula.

4. I have done more deeper learning on how to implement the modulation and demodulation process using MATLAB, and this let me clearly know the difference between various modulation methods.

What difficulty have you met in this lab?
One of the difficulties I have met in this lab is to set every parameter correct. For instance, the first time I plot the figure was very weird. Though the distance of suddenly decrease of the four different modulation methods have the same order as the picture shown in the slide, but the distance is wrong. For example, the distance that the 64-QAM decrease quickly is approximately 100m, but the result of my code is around 150-200m. And I start to go through each session of my code; however, it turns out that the output of each session is just perform as what I expected. Then I turn to thinking about the meaning of each parameter and adjust them. The first bug I found is that I didn't use same channel(h) over different distances, after I make it a constant through the whole trial, the output of the throughput becomes more closer to the given picture. The second bug is that I didn't scale the noise correctly. I directly multiply the noise by the received power. However, when I notice the scales, I adjust was a and b (noise is a+bi), so when calculating the power of the noise need to square both a and b, then directly multiply them will be obviously wrong. So, I square root the power before I multiply it by a and b. And it turns out that I'm right, the output is almost same as the given picture.