

# 112-2 CWN Lab 1 Report

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## Output Results

- d=50

distance:50  
Prx (Watt): 3.9579e-10  
Prx (dbm): -64.0254  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:395.7859  
theoretical SNR(dB):25.9746

BPSK:  
empirical average noise power:0.032935(Watt) = 15.1766(dbm)  
empirical SNR:30.363  
empirical SNR(dB):14.8234  
empirical BER:0  
empirical throughput:312500 (bit/s)  
theoretical throughput:312500 (bit/s)

QPSK:  
empirical average noise power:0.032938(Watt) = 15.1769(dbm)  
empirical SNR:30.3604  
empirical SNR(dB):14.8231  
empirical BER:0  
empirical throughput:625000 (bit/s)  
theoretical throughput:625000 (bit/s)

16QAM:  
empirical average noise power:0.032969(Watt) = 15.181(dbm)  
empirical SNR:28.7141  
empirical SNR(dB):14.581  
empirical BER:0  
empirical throughput:1250000 (bit/s)  
theoretical throughput:1250000 (bit/s)

64QAM:  
empirical average noise power:0.032963(Watt) = 15.1803(dbm)  
empirical SNR:28.7141  
empirical SNR(dB):14.5505  
empirical BER:0  
empirical throughput:1875000 (bit/s)  
theoretical throughput:1875000 (bit/s)

optimal modulation scheme: 64QAM

- d=100

distance:100  
Prx (Watt): 9.8946e-11  
Prx (dbm): -70.046  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:98.9465  
theoretical SNR(dB):19.954

BPSK:

empirical average noise power:0.06587(Watt) = 18.1869(dbm)  
empirical SNR:15.1815  
empirical SNR(dB):11.8131  
empirical BER:0  
empirical throughput:312500 (bit/s)  
theoretical throughput:312500 (bit/s)

QPSK:

empirical average noise power:0.065875(Watt) = 18.1872(dbm)  
empirical SNR:15.1802  
empirical SNR(dB):11.8128  
empirical BER:0  
empirical throughput:625000 (bit/s)  
theoretical throughput:625000 (bit/s)

16QAM:

empirical average noise power:0.065937(Watt) = 18.1913(dbm)  
empirical SNR:14.357  
empirical SNR(dB):11.5707  
empirical BER:0  
empirical throughput:1250000 (bit/s)  
theoretical throughput:1250000 (bit/s)

64QAM:

empirical average noise power:0.065927(Watt) = 18.1906(dbm)  
empirical SNR:14.357  
empirical SNR(dB):11.5402  
empirical BER:0.0015633  
empirical throughput:50000 (bit/s)  
theoretical throughput:3589.9472 (bit/s)

optimal modulation scheme: 16QAM

- d=150

distance:150  
 Prx (Watt): 4.3976e-11  
 Prx (dbm): -73.5678  
 theoretical noise power:1e-12(Watt) = -90(dbm)  
 theoretical SNR:43.9762  
 theoretical SNR(dB):16.4322

BPSK:

empirical average noise power:0.098805(Watt) = 19.9478(dbm)  
 empirical SNR:10.121  
 empirical SNR(dB):10.0522  
 empirical BER:0  
 empirical throughput:312500 (bit/s)  
 theoretical throughput:312500 (bit/s)

QPSK:

empirical average noise power:0.098813(Watt) = 19.9481(dbm)  
 empirical SNR:10.1201  
 empirical SNR(dB):10.0519  
 empirical BER:0  
 empirical throughput:625000 (bit/s)  
 theoretical throughput:625000 (bit/s)

16QAM:

empirical average noise power:0.098906(Watt) = 19.9522(dbm)  
 empirical SNR:9.5714  
 empirical SNR(dB):9.8097  
 empirical BER:1e-05  
 empirical throughput:1216666.6667 (bit/s)  
 theoretical throughput:1200986.5587 (bit/s)

64QAM:

empirical average noise power:0.09889(Watt) = 19.9515(dbm)  
 empirical SNR:9.5714  
 empirical SNR(dB):9.7793  
 empirical BER:0.023117  
 empirical throughput:0 (bit/s)  
 theoretical throughput:4.4035e-35 (bit/s)

optimal modulation scheme: 16QAM

- d=200

distance:200  
Prx (Watt): 2.4737e-11  
Prx (dbm): -76.0666  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:24.7366  
theoretical SNR(dB):13.9334

BPSK:

empirical average noise power:0.13174(Watt) = 21.1972(dbm)  
empirical SNR:7.5907  
empirical SNR(dB):8.8028  
empirical BER:0  
empirical throughput:312500 (bit/s)  
theoretical throughput:312500 (bit/s)

QPSK:

empirical average noise power:0.13175(Watt) = 21.1975(dbm)  
empirical SNR:7.5901  
empirical SNR(dB):8.8025  
empirical BER:0  
empirical throughput:625000 (bit/s)  
theoretical throughput:625000 (bit/s)

16QAM:

empirical average noise power:0.13187(Watt) = 21.2016(dbm)  
empirical SNR:7.1785  
empirical SNR(dB):8.5604  
empirical BER:0.0013333  
empirical throughput:33333.3333 (bit/s)  
theoretical throughput:6013.499 (bit/s)

64QAM:

empirical average noise power:0.13185(Watt) = 21.2009(dbm)  
empirical SNR:7.1785  
empirical SNR(dB):8.5299  
empirical BER:0.065527  
empirical throughput:0 (bit/s)  
theoretical throughput:3.4726e-112 (bit/s)

optimal modulation scheme: QPSK

- d=250

distance:250  
Prx (Watt): 1.5831e-11  
Prx (dbm): -78.0048  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:15.8314  
theoretical SNR(dB):11.9952

BPSK:

empirical average noise power:0.16467(Watt) = 22.1663(dbm)  
empirical SNR:6.0726  
empirical SNR(dB):7.8337  
empirical BER:0  
empirical throughput:312500 (bit/s)  
theoretical throughput:312500 (bit/s)

QPSK:

empirical average noise power:0.16469(Watt) = 22.1666(dbm)  
empirical SNR:6.0721  
empirical SNR(dB):7.8334  
empirical BER:0  
empirical throughput:625000 (bit/s)  
theoretical throughput:625000 (bit/s)

16QAM:

empirical average noise power:0.16484(Watt) = 22.1707(dbm)  
empirical SNR:5.7428  
empirical SNR(dB):7.5913  
empirical BER:0.0081933  
empirical throughput:0 (bit/s)  
theoretical throughput:6.3827e-09 (bit/s)

64QAM:

empirical average noise power:0.16482(Watt) = 22.17(dbm)  
empirical SNR:5.7428  
empirical SNR(dB):7.5608  
empirical BER:0.11061  
empirical throughput:0 (bit/s)  
theoretical throughput:4.4512e-198 (bit/s)

optimal modulation scheme: QPSK

- d=300

distance:300  
 Prx (Watt): 1.0994e-11  
 Prx (dbm): -79.5884  
 theoretical noise power:1e-12(Watt) = -90(dbm)  
 theoretical SNR:10.9941  
 theoretical SNR(dB):10.4116

BPSK:

empirical average noise power:0.19761(Watt) = 22.9581(dbm)  
 empirical SNR:5.0605  
 empirical SNR(dB):7.0419  
 empirical BER:0  
 empirical throughput:312500 (bit/s)  
 theoretical throughput:312500 (bit/s)

QPSK:

empirical average noise power:0.19763(Watt) = 22.9584(dbm)  
 empirical SNR:5.0601  
 empirical SNR(dB):7.0416  
 empirical BER:6.6667e-06  
 empirical throughput:608333.3333 (bit/s)  
 theoretical throughput:608553.5393 (bit/s)

16QAM:

empirical average noise power:0.19781(Watt) = 22.9625(dbm)  
 empirical SNR:4.7857  
 empirical SNR(dB):6.7994  
 empirical BER:0.022277  
 empirical throughput:0 (bit/s)  
 theoretical throughput:9.1375e-34 (bit/s)

64QAM:

empirical average noise power:0.19778(Watt) = 22.9618(dbm)  
 empirical SNR:4.7857  
 empirical SNR(dB):6.769  
 empirical BER:0.1505  
 empirical throughput:0 (bit/s)  
 theoretical throughput:8.5773e-278 (bit/s)

optimal modulation scheme: QPSK

- $d=350$

distance:350  
 Prx (Watt):  $8.0773e-12$   
 Prx (dbm):  $-80.9274$   
 theoretical noise power: $1e-12$ (Watt) =  $-90$ (dbm)  
 theoretical SNR: $8.0773$   
 theoretical SNR(dB): $9.0726$

BPSK:

empirical average noise power: $0.23054$ (Watt) =  $23.6275$ (dbm)  
 empirical SNR: $4.3376$   
 empirical SNR(dB): $6.3725$   
 empirical BER: $0$   
 empirical throughput: $312500$  (bit/s)  
 theoretical throughput: $312500$  (bit/s)

QPSK:

empirical average noise power: $0.23056$ (Watt) =  $23.6279$ (dbm)  
 empirical SNR: $4.3372$   
 empirical SNR(dB): $6.3721$   
 empirical BER: $6.3333e-05$   
 empirical throughput: $475000$  (bit/s)  
 theoretical throughput: $485126.797$  (bit/s)

16QAM:

empirical average noise power: $0.23078$ (Watt) =  $23.632$ (dbm)  
 empirical SNR: $4.102$   
 empirical SNR(dB): $6.13$   
 empirical BER: $0.043173$   
 empirical throughput: $0$  (bit/s)  
 theoretical throughput: $2.6915e-71$  (bit/s)

64QAM:

empirical average noise power: $0.23074$ (Watt) =  $23.6313$ (dbm)  
 empirical SNR: $4.102$   
 empirical SNR(dB): $6.0995$   
 empirical BER: $0.18393$   
 empirical throughput: $0$  (bit/s)  
 theoretical throughput: $0$  (bit/s)

optimal modulation scheme: QPSK

- d=400

distance:400  
Prx (Watt): 6.1842e-12  
Prx (dbm): -82.0872  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:6.1842  
theoretical SNR(dB):7.9128

BPSK:

empirical average noise power:0.26348(Watt) = 24.2075(dbm)  
empirical SNR:3.7954  
empirical SNR(dB):5.7925  
empirical BER:3.3333e-06  
empirical throughput:308333.3333 (bit/s)  
theoretical throughput:308360.9812 (bit/s)

QPSK:

empirical average noise power:0.2635(Watt) = 24.2078(dbm)  
empirical SNR:3.7951  
empirical SNR(dB):5.7922  
empirical BER:0.00040667  
empirical throughput:66666.6667 (bit/s)  
theoretical throughput:122824.209 (bit/s)

16QAM:

empirical average noise power:0.26375(Watt) = 24.2119(dbm)  
empirical SNR:3.5893  
empirical SNR(dB):5.5501  
empirical BER:0.06646  
empirical throughput:0 (bit/s)  
theoretical throughput:4.2524e-114 (bit/s)

64QAM:

empirical average noise power:0.26371(Watt) = 24.2112(dbm)  
empirical SNR:3.5893  
empirical SNR(dB):5.5196  
empirical BER:0.21102  
empirical throughput:0 (bit/s)  
theoretical throughput:0 (bit/s)

optimal modulation scheme: BPSK



- d=450

distance:450  
Prx (Watt): 4.8862e-12  
Prx (dbm): -83.1102  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:4.8862  
theoretical SNR(dB):6.8898

BPSK:

empirical average noise power:0.29641(Watt) = 24.719(dbm)  
empirical SNR:3.3737  
empirical SNR(dB):5.281  
empirical BER:2e-05  
empirical throughput:287500 (bit/s)  
theoretical throughput:288473.6275 (bit/s)

QPSK:

empirical average noise power:0.29644(Watt) = 24.7193(dbm)  
empirical SNR:3.3734  
empirical SNR(dB):5.2807  
empirical BER:0.00134  
empirical throughput:0 (bit/s)  
theoretical throughput:2927.5247 (bit/s)

16QAM:

empirical average noise power:0.29672(Watt) = 24.7234(dbm)  
empirical SNR:3.1905  
empirical SNR(dB):5.0385  
empirical BER:0.09093  
empirical throughput:0 (bit/s)  
theoretical throughput:3.0635e-160 (bit/s)

64QAM:

empirical average noise power:0.29667(Watt) = 24.7227(dbm)  
empirical SNR:3.1905  
empirical SNR(dB):5.008  
empirical BER:0.23253  
empirical throughput:0 (bit/s)  
theoretical throughput:0 (bit/s)

optimal modulation scheme: BPSK

- $d=500$

distance:500  
Prx (Watt):  $3.9579 \times 10^{-12}$   
Prx (dbm): -84.0254  
theoretical noise power: $1 \times 10^{-12}$ (Watt) = -90(dbm)  
theoretical SNR:3.9579  
theoretical SNR(dB):5.9746

BPSK:  
empirical average noise power: $0.32935$ (Watt) = 25.1766(dbm)  
empirical SNR:3.0363  
empirical SNR(dB):4.8234  
empirical BER: $7.3333 \times 10^{-5}$   
empirical throughput:229166.6667 (bit/s)  
theoretical throughput:233051.7145 (bit/s)

QPSK:  
empirical average noise power: $0.32938$ (Watt) = 25.1769(dbm)  
empirical SNR:3.036  
empirical SNR(dB):4.8231  
empirical BER: $0.0034067$   
empirical throughput:0 (bit/s)  
theoretical throughput:0.73755 (bit/s)

16QAM:  
empirical average noise power: $0.32969$ (Watt) = 25.181(dbm)  
empirical SNR:2.8714  
empirical SNR(dB):4.581  
empirical BER:0.11508  
empirical throughput:0 (bit/s)  
theoretical throughput: $5.242 \times 10^{-207}$  (bit/s)

64QAM:  
empirical average noise power: $0.32963$ (Watt) = 25.1803(dbm)  
empirical SNR:2.8714  
empirical SNR(dB):4.5505  
empirical BER:0.2494  
empirical throughput:0 (bit/s)  
theoretical throughput:0 (bit/s)

optimal modulation scheme: BPSK

- d=550

distance:550  
Prx (Watt):  $3.271e-12$   
Prx (dbm): -84.8533  
theoretical noise power: $1e-12$ (Watt) = -90(dbm)  
theoretical SNR:3.271  
theoretical SNR(dB):5.1467

BPSK:

empirical average noise power: $0.36228$ (Watt) = 25.5905(dbm)  
empirical SNR:2.7603  
empirical SNR(dB):4.4095  
empirical BER: $0.00032$   
empirical throughput:100000 (bit/s)  
theoretical throughput:86868.86 (bit/s)

QPSK:

empirical average noise power: $0.36231$ (Watt) = 25.5908(dbm)  
empirical SNR:2.76  
empirical SNR(dB):4.4092  
empirical BER: $0.0071633$   
empirical throughput:0 (bit/s)  
theoretical throughput: $2.0282e-07$  (bit/s)

16QAM:

empirical average noise power: $0.36265$ (Watt) = 25.5949(dbm)  
empirical SNR:2.6104  
empirical SNR(dB):4.167  
empirical BER:0.1377  
empirical throughput:0 (bit/s)  
theoretical throughput: $5.4597e-252$  (bit/s)

64QAM:

empirical average noise power: $0.3626$ (Watt) = 25.5942(dbm)  
empirical SNR:2.6104  
empirical SNR(dB):4.1365  
empirical BER:0.26465  
empirical throughput:0 (bit/s)  
theoretical throughput:0 (bit/s)

optimal modulation scheme: BPSK

- d=600

distance:600  
Prx (Watt): 2.7485e-12  
Prx (dbm): -85.609  
theoretical noise power:1e-12(Watt) = -90(dbm)  
theoretical SNR:2.7485  
theoretical SNR(dB):4.391

**BPSK:**

empirical average noise power:0.39522(Watt) = 25.9684(dbm)  
empirical SNR:2.5302  
empirical SNR(dB):4.0316  
empirical BER:0.00084667  
empirical throughput:8333.3333 (bit/s)  
theoretical throughput:10553.9828 (bit/s)

**QPSK:**

empirical average noise power:0.39525(Watt) = 25.9687(dbm)  
empirical SNR:2.53  
empirical SNR(dB):4.0313  
empirical BER:0.012547  
empirical throughput:0 (bit/s)  
theoretical throughput:7.2812e-17 (bit/s)

**16QAM:**

empirical average noise power:0.39562(Watt) = 25.9728(dbm)  
empirical SNR:2.3928  
empirical SNR(dB):3.7891  
empirical BER:0.15804  
empirical throughput:0 (bit/s)  
theoretical throughput:1.8313e-293 (bit/s)

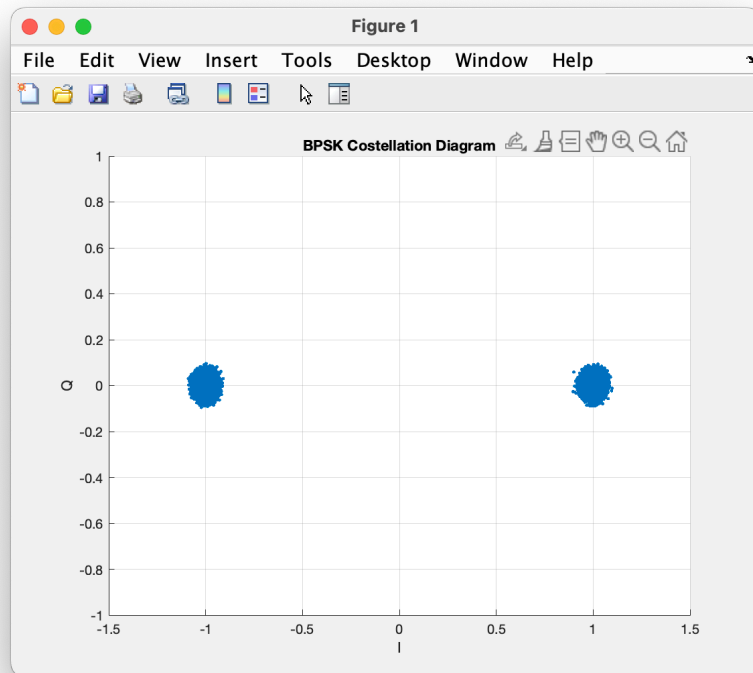
**64QAM:**

empirical average noise power:0.39556(Watt) = 25.9721(dbm)  
empirical SNR:2.3928  
empirical SNR(dB):3.7587  
empirical BER:0.27739  
empirical throughput:0 (bit/s)  
theoretical throughput:0 (bit/s)

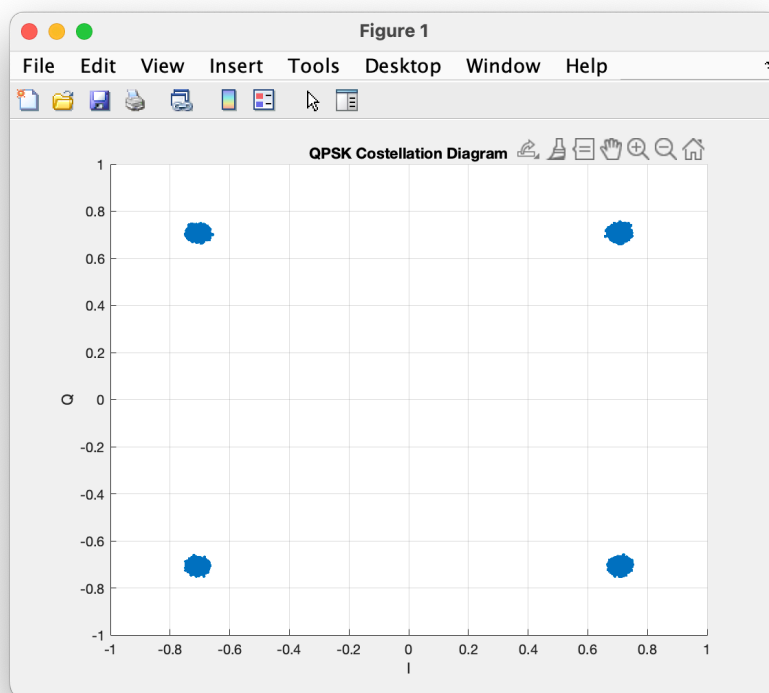
optimal modulation scheme: BPSK

# Diagrams

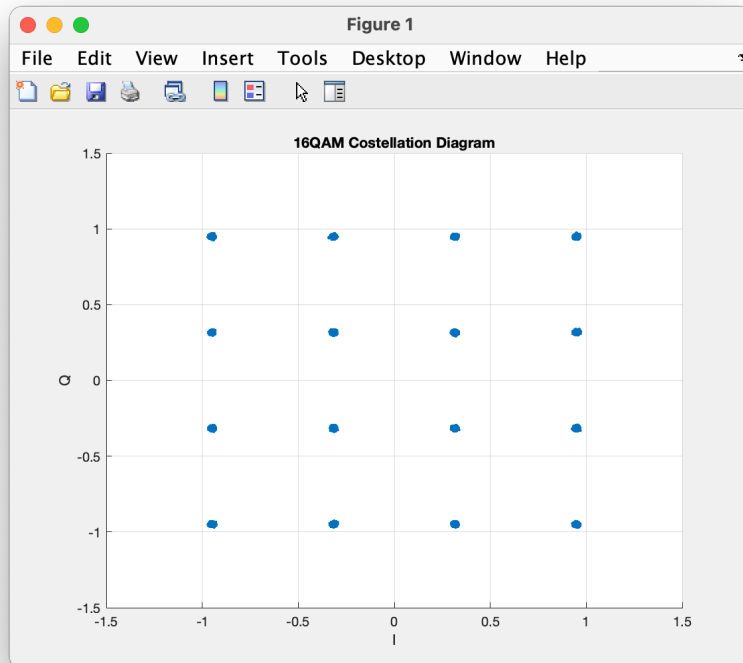
- BPSK,  $d=40$



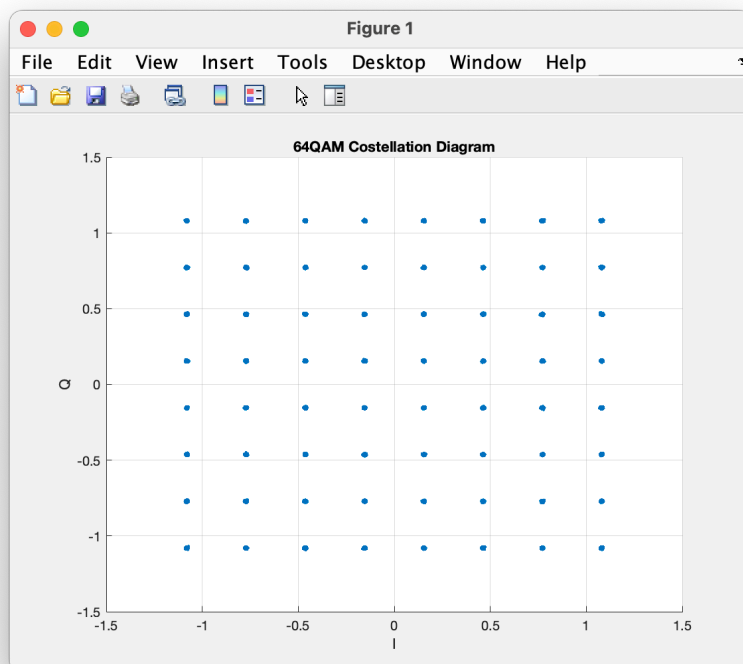
- QPSK,  $d=20$



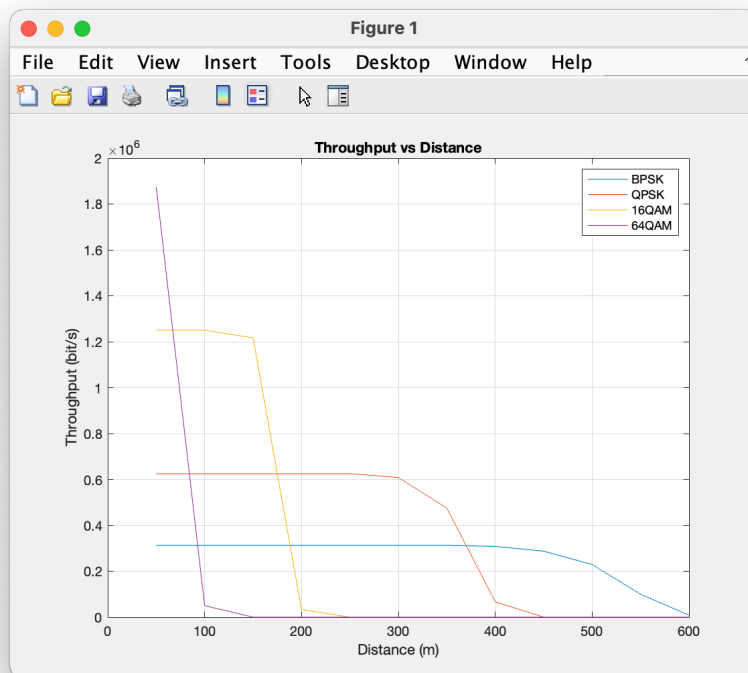
- 16QAM,  $d=10$



- 64QAM,  $d=5$



- Throughput vs distance



## Questions

1. Assume there exists a theoretical modulation table given in [SNR\\_BER.mat](#)
  - What is the theoretical optimal modulation scheme for link distance  $d$  and packet size  $l$ ? ( $d=[50:50:600]$ ,  $l=100,2000,4000$  bits)

distance \ packet size	100	2000	4000
50	QPSK	QPSK	QPSK
100	QPSK	QPSK	QPSK
150	QPSK	QPSK	QPSK
200	QPSK	BPSK	BPSK
250	QPSK	BPSK	BPSK
300	QPSK	BPSK	BPSK
350	BPSK	BPSK	BPSK
400	BPSK	BPSK	BPSK
450	BPSK	BPSK	BPSK
500	BPSK	BPSK	BPSK
550	BPSK	BPSK	BPSK
600	BPSK	BPSK	BPSK

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

distance	optimal selection	empirical selection
50	QPSK	64QAM
100	QPSK	16QAM
150	QPSK	16QAM
200	BPSK	QPSK
250	BPSK	QPSK
300	BPSK	QPSK
350	BPSK	QPSK
400	BPSK	BPSK
450	BPSK	BPSK
500	BPSK	BPSK
550	BPSK	BPSK
600	BPSK	BPSK

The optimal selection selects more preservative method than the empirical selection. This might due to the amount of data we calculated are too little. Also, we only considered AWGN, but there might be other kinds of interferences and noises in reality, making BER higher.

2. What have you learned from this lab?

I learned how modulation is done and how to add AWGN to signals. In addition, I get a clearer picture of how the noise and throughput is calculated while a signal is transmitted through a channel.

3. What difficulty have you met in this lab?

I struggled on how to scale channels and noises. I also have difficulty deciding which signal power to use while calculating SNR. I think most of the difficulties are related to power scaling. Thankfully, the TAs gave us a lot of assistance.