main

November 20, 2020

1 KNN-Modulation-Classification

1.1

kNN AMC

1.2

kNN kNN

1.3

1.3.1

- `BPSK`: $u(i) = \frac{1}{\sqrt{2}}(1-2b(i)) + j(1-2b(i))$
- `QPSK`: $u(i) = \frac{1}{\sqrt{2}}[(1-2b(i)) + j(1-2b(2i+1))]$
- `16QAM`: $u(i) = \frac{1}{\sqrt{10}}\{(1-4b(i))[2-(1-2b(4i+2))] + j(1-2b(4i+1))[2-(1-2b(4i+3))]\}$
- `64QAM`: $u(i) = \frac{1}{\sqrt{42}}\{(1-2b(6i))[4-(1-2b(6i+2))[2-(1-2b(6i+4))]] + j(1-2b(6i+1))[4-(1-2b(6i+3))[2-(1-2b(6i+5))]]\}$

1.3.2 AMC

/ /

1.3.3

- : $M_{pq} = E[X(t)^{(p-q)}X^*(t)^q]$
- : $C_pq = \text{cum}\{X(t), \cdots, X(t), X^*(t), \cdots, X^*(t)\}$
  - $X(t)$ $p-q$ $X^*(t)$ q

1.3.4 kNN

kNN (k-nearest neighbors algorithm) k

1.
2.
3. k
4. k
5.

1.4

- OS: Manjaro Linux x86_64
- Kernel: 5.4.78-1-MANJARO
- Python: 3.8.6
- Jupyter Notebook: 6.1.4
- Scikit-learn: 0.23.2
- Matplotlib: 3.3.3
- Numpy: 1.19.4

1.5

1. data_generation Matlab data
   - : getSample.m kNN
   - : getTest16QAM.m getTestBPSK.m getTestQPSK.m test[process]-[N]-[snr].dat
     - process: BPSK QPSK 16QAM
     - N: 200 500
     - snr:
2. modulation_recognition main.ipynb

1.5.1

[1]:
```
import collections
from collections import defaultdict
from os.path import join

import matplotlib.pyplot as plt
import numpy as np  #  numpy
from sklearn.neighbors import KNeighborsClassifier  #   knn


def file2matrix(filename, n_features):
    """       .

    Args:
        filename (string):
        n_features (int)):

    Returns:
        any, any:
    """
    filepath = join("..", "data", filename)
    fr = open(filepath)
    number_of_lines = len(
        fr.readlines()
    )  # get the number of lines in the file
    # prepare matrix to return the number of features
    return_mat = np.zeros((number_of_lines, n_features))
```

```
    class_label_vector = []  # prepare labels return
    fr = open(filepath)
    for index, line in enumerate(fr.readlines()):
        line = line.strip()
        list_from_line = line.split("\t")
        return_mat[index, :] = list_from_line[0:n_features]  # chose features
        class_label_vector.append(float(list_from_line[-1]))
        # classLabelVector.append(float(0))
    return return_mat, class_label_vector
```

1.5.2 KNN

[2]:
```
Ls = (5, 9) #
Ks = (3, 10, 24) # kNN
kNN_classifiers = ([], [])

for i, L in enumerate(Ls):

    for K in Ks:
        kNN_classifiers[i].append(KNeighborsClassifier(n_neighbors=K))

    data_x, data_y = file2matrix("sample.dat", L)

    #
    for kNN_classifier in kNN_classifiers[i]:
        kNN_classifier.fit(data_x, data_y)
```

1.5.3 kNN

[3]:
```
def ModulationClassTest(n_features, SNR, method, n, labels, kNN_classifier):
    """          .

    Args:
        n_features (int):
        SNR (List[int]):
        method (int):
        n (int):
        labels (Tuple[str]):
        kNN_classifier (any): kNN

    Returns:
        defaultdict[_KT, list]:
    """
    accuracy = defaultdict(list)
    #    BPSK, QPSK, 16QAM, 64QAM
    numbers = (
        defaultdict(list),
```

```
        defaultdict(list),
        defaultdict(list),
        defaultdict(list),
    )
    for snr in SNR:
        filename = (
            "test" + labels[method] + "-" + str(n) + "-" + str(snr) + ".dat"
        )
        testDataMat, _ = file2matrix(filename, n_features)
        numTestVecs = testDataMat.shape[0]
        for i in range(4):
            numbers[i][snr] = 0.0
        for i in range(numTestVecs):

            X_predict = testDataMat[i, :].reshape(1, -1)
            y_predict = kNN_classifier.predict(X_predict)

            if y_predict == 2:
                numbers[0][snr] += 1.0
            elif y_predict == 4:
                numbers[1][snr] += 1.0
            elif y_predict == 16:
                numbers[2][snr] += 1.0
            elif y_predict == 64:
                numbers[3][snr] += 1.0

        accuracy[snr] = numbers[method][snr] / numTestVecs
        print("the total correct rate on %d dB SNR is:" % snr, (accuracy[snr]))
        accuracy = collections.OrderedDict(sorted(accuracy.items()))
        for i in range(4):
            print(
                (" " if i == method else "") + "  ",
                labels[i] + ":",
                numbers[i][snr],
            )
    return accuracy


Ns = (200, 500)
labels = ("BPSK", "QPSK", "16QAM", "64QAM")


def ModulationClassTests(SNR, method):
    """              .

    Args:
        SNR (List[int]):
```

```
        method (int):
    """
    fig, axs = plt.subplots(2, figsize=(20, 16))
    fig.suptitle("SNR vs Accuracy - " + labels[method], fontsize=32)
    x = SNR

    for i, L in enumerate(Ls):
        for N in Ns:
            for j, K in enumerate(Ks):
                label = "N = " + str(N) + ", K = " + str(K)
                print(label + ":")
                accuracy = ModulationClassTest(
                    L, SNR, method, N, labels, kNN_classifiers[i][j]
                )
                print(accuracy)

                axs[i].plot(
                    x,
                    list(accuracy.values()),
                    label=label,
                    marker="o",
                    linewidth=2.0,
                    linestyle="dashed",
                )

        axs[i].set_title("L =" + str(L), fontsize=24)
        axs[i].legend(loc="upper left", frameon=False, fontsize=14)
        axs[i].grid()

    for ax in axs.flat:
        ax.set(
            xticks=np.arange(min(x), max(x) + 1, 2.0),
            yticks=np.arange(0, 1, 0.10),
            xlabel="SNR (dB)",
            ylabel="Test accuracy",
        )

    plt.show()
```

1.5.4 BPSK ModulationClassTest

[4]:
```
SNR = [2 * x for x in range(-2, 6)]
ModulationClassTests(SNR, 0)
```

```
N = 200, K = 3:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
```

```
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 402.0
   16QAM: 0.0
   64QAM: 598.0
the total correct rate on 4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.638
    BPSK: 638.0
   QPSK: 362.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.638), (8,
1.0), (10, 1.0)])
N = 200, K = 10:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 2.0
   64QAM: 998.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
```

```
   QPSK: 0.0
   16QAM: 68.0
   64QAM: 932.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 620.0
   64QAM: 380.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 90.0
   16QAM: 890.0
   64QAM: 20.0
the total correct rate on 4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 984.0
   16QAM: 15.0
   64QAM: 1.0
the total correct rate on 6 dB SNR is: 0.81
    BPSK: 810.0
   QPSK: 190.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.81), (8,
1.0), (10, 1.0)])
N = 200, K = 24:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
```

```
   QPSK: 1.0
   16QAM: 999.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 357.0
   16QAM: 643.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.953
    BPSK: 953.0
   QPSK: 47.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.953), (8,
1.0), (10, 1.0)])
N = 500, K = 3:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
```

```
   QPSK: 287.0
   16QAM: 0.0
   64QAM: 713.0
the total correct rate on 4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.685
    BPSK: 685.0
   QPSK: 315.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.685), (8,
1.0), (10, 1.0)])
N = 500, K = 10:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 10.0
   64QAM: 990.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 663.0
   64QAM: 337.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 7.0
   16QAM: 987.0
   64QAM: 6.0
the total correct rate on 4 dB SNR is: 0.0
    BPSK: 0.0
```

```
   QPSK: 999.0
   16QAM: 1.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.893
    BPSK: 893.0
   QPSK: 107.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.893), (8,
1.0), (10, 1.0)])
N = 500, K = 24:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 246.0
   16QAM: 754.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.996
    BPSK: 996.0
```

```
   QPSK: 4.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.996), (8,
1.0), (10, 1.0)])
N = 200, K = 3:
the total correct rate on -4 dB SNR is: 0.004
    BPSK: 4.0
   QPSK: 235.0
   16QAM: 167.0
   64QAM: 594.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 513.0
   16QAM: 48.0
   64QAM: 439.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 933.0
   16QAM: 3.0
   64QAM: 64.0
the total correct rate on 2 dB SNR is: 0.005
    BPSK: 5.0
   QPSK: 995.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.171
    BPSK: 171.0
   QPSK: 829.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.92
    BPSK: 920.0
   QPSK: 80.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
```

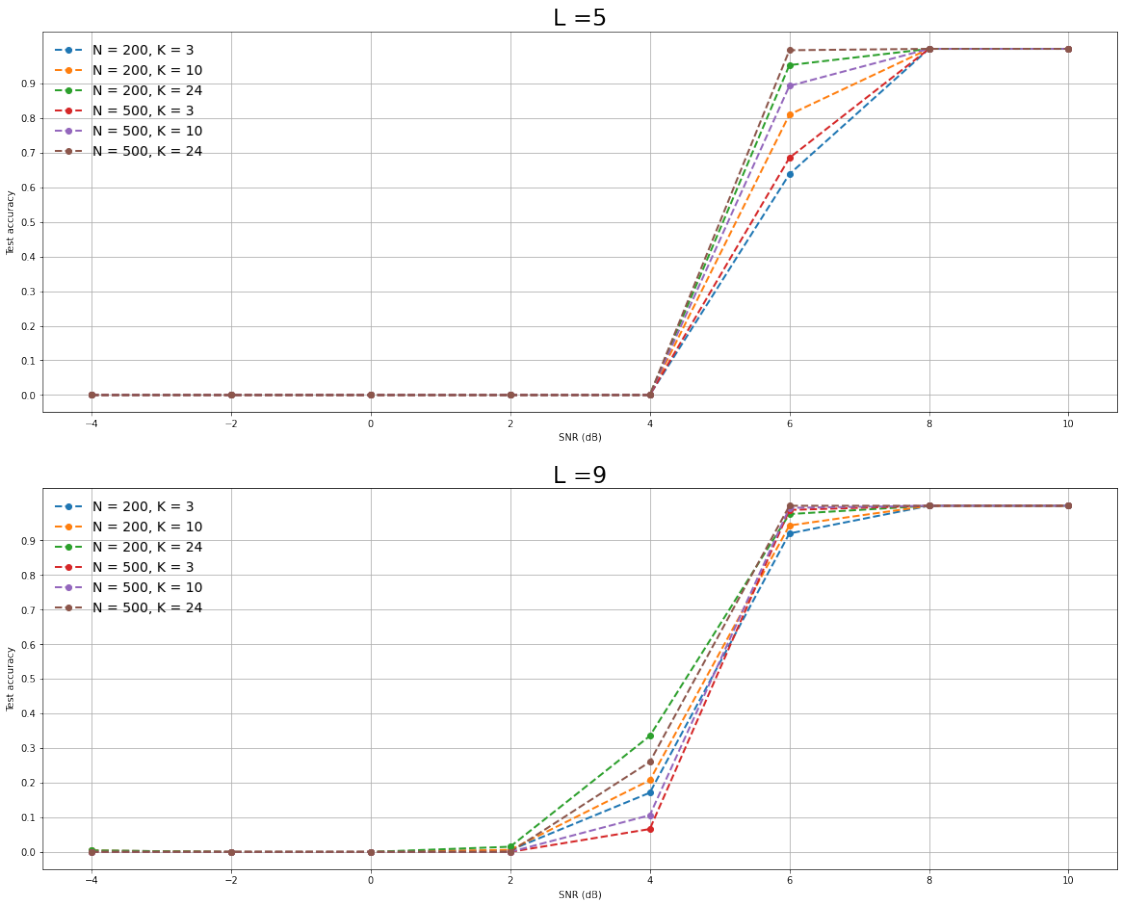
```
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.004), (-2, 0.0), (0, 0.0), (2, 0.005), (4, 0.171), (6,
0.92), (8, 1.0), (10, 1.0)])
N = 200, K = 10:
the total correct rate on -4 dB SNR is: 0.004
    BPSK: 4.0
   QPSK: 110.0
   16QAM: 418.0
   64QAM: 468.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 313.0
   16QAM: 508.0
   64QAM: 179.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 827.0
   16QAM: 162.0
   64QAM: 11.0
the total correct rate on 2 dB SNR is: 0.006
    BPSK: 6.0
   QPSK: 994.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.207
    BPSK: 207.0
   QPSK: 793.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.943
    BPSK: 943.0
   QPSK: 57.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
```

```
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.004), (-2, 0.0), (0, 0.0), (2, 0.006), (4, 0.207), (6,
0.943), (8, 1.0), (10, 1.0)])
N = 200, K = 24:
the total correct rate on -4 dB SNR is: 0.004
    BPSK: 4.0
   QPSK: 189.0
   16QAM: 807.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 452.0
   16QAM: 548.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 905.0
   16QAM: 95.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.015
    BPSK: 15.0
   QPSK: 985.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.335
    BPSK: 335.0
   QPSK: 665.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.976
    BPSK: 976.0
   QPSK: 24.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.004), (-2, 0.0), (0, 0.0), (2, 0.015), (4, 0.335), (6,
0.976), (8, 1.0), (10, 1.0)])
```

```
N = 500, K = 3:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 83.0
   16QAM: 104.0
   64QAM: 813.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 425.0
   16QAM: 13.0
   64QAM: 562.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 986.0
   16QAM: 0.0
   64QAM: 14.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.066
    BPSK: 66.0
   QPSK: 934.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.988
    BPSK: 988.0
   QPSK: 12.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.066), (6, 0.988),
(8, 1.0), (10, 1.0)])
N = 500, K = 10:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 24.0
   16QAM: 376.0
```

```
   64QAM: 600.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 186.0
   16QAM: 722.0
   64QAM: 92.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 906.0
   16QAM: 88.0
   64QAM: 6.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.106
    BPSK: 106.0
   QPSK: 894.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.994
    BPSK: 994.0
   QPSK: 6.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.106), (6, 0.994),
(8, 1.0), (10, 1.0)])
N = 500, K = 24:
the total correct rate on -4 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 55.0
   16QAM: 945.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 334.0
   16QAM: 666.0
```

```
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 965.0
   16QAM: 35.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.0
    BPSK: 0.0
   QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.26
    BPSK: 260.0
   QPSK: 740.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
    BPSK: 1000.0
   QPSK: 0.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.26), (6, 1.0), (8,
1.0), (10, 1.0)])
```



1.5.5 QPSK ModulationClassTest

[5]:
```
SNR = [2 * x for x in range(-2, 6)]
ModulationClassTests(SNR, 1)
```

```
N = 200, K = 3:
the total correct rate on -4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on -2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 0 dB SNR is: 0.0
```

```
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 24.0
   64QAM: 976.0
the total correct rate on 8 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 735.0
   64QAM: 265.0
the total correct rate on 10 dB SNR is: 0.19
   BPSK: 0.0
    QPSK: 190.0
   16QAM: 810.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0), (8,
0.0), (10, 0.19)])
N = 200, K = 10:
the total correct rate on -4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 5.0
   64QAM: 995.0
the total correct rate on -2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 2 dB SNR is: 0.0
```

```
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 2.0
   64QAM: 998.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 69.0
   64QAM: 931.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 739.0
   64QAM: 261.0
the total correct rate on 8 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.308
   BPSK: 0.0
    QPSK: 308.0
   16QAM: 692.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0), (8,
0.0), (10, 0.308)])
N = 200, K = 24:
the total correct rate on -4 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 999.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.0
```

```
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 0.005
   BPSK: 0.0
    QPSK: 5.0
   16QAM: 995.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.735
   BPSK: 0.0
    QPSK: 735.0
   16QAM: 265.0
   64QAM: 0.0
OrderedDict([(-4, 0.001), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0), (8,
0.005), (10, 0.735)])
N = 500, K = 3:
the total correct rate on -4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on -2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 6 dB SNR is: 0.0
```

```
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 6.0
   64QAM: 994.0
the total correct rate on 8 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 832.0
   64QAM: 168.0
the total correct rate on 10 dB SNR is: 0.055
   BPSK: 0.0
    QPSK: 55.0
   16QAM: 945.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0), (8,
0.0), (10, 0.055)])
N = 500, K = 10:
the total correct rate on -4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on -2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 8.0
   64QAM: 992.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 731.0
   64QAM: 269.0
the total correct rate on 8 dB SNR is: 0.0
```

```
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.308
   BPSK: 0.0
    QPSK: 308.0
   16QAM: 692.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0), (8,
0.0), (10, 0.308)])
N = 500, K = 24:
the total correct rate on -4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.881
```

```
   BPSK: 0.0
    QPSK: 881.0
   16QAM: 119.0
   64QAM: 0.0
OrderedDict([(-4, 0.0), (-2, 0.0), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0), (8,
0.0), (10, 0.881)])
N = 200, K = 3:
the total correct rate on -4 dB SNR is: 0.063
   BPSK: 4.0
    QPSK: 63.0
   16QAM: 222.0
   64QAM: 711.0
the total correct rate on -2 dB SNR is: 0.012
   BPSK: 0.0
    QPSK: 12.0
   16QAM: 121.0
   64QAM: 867.0
the total correct rate on 0 dB SNR is: 0.003
   BPSK: 0.0
    QPSK: 3.0
   16QAM: 82.0
   64QAM: 915.0
the total correct rate on 2 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 140.0
   64QAM: 859.0
the total correct rate on 4 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 428.0
   64QAM: 571.0
the total correct rate on 6 dB SNR is: 0.029
   BPSK: 0.0
    QPSK: 29.0
   16QAM: 759.0
   64QAM: 212.0
the total correct rate on 8 dB SNR is: 0.413
   BPSK: 0.0
    QPSK: 413.0
   16QAM: 531.0
   64QAM: 56.0
the total correct rate on 10 dB SNR is: 0.975
   BPSK: 0.0
    QPSK: 975.0
   16QAM: 24.0
   64QAM: 1.0
OrderedDict([(-4, 0.063), (-2, 0.012), (0, 0.003), (2, 0.001), (4, 0.001), (6,
```

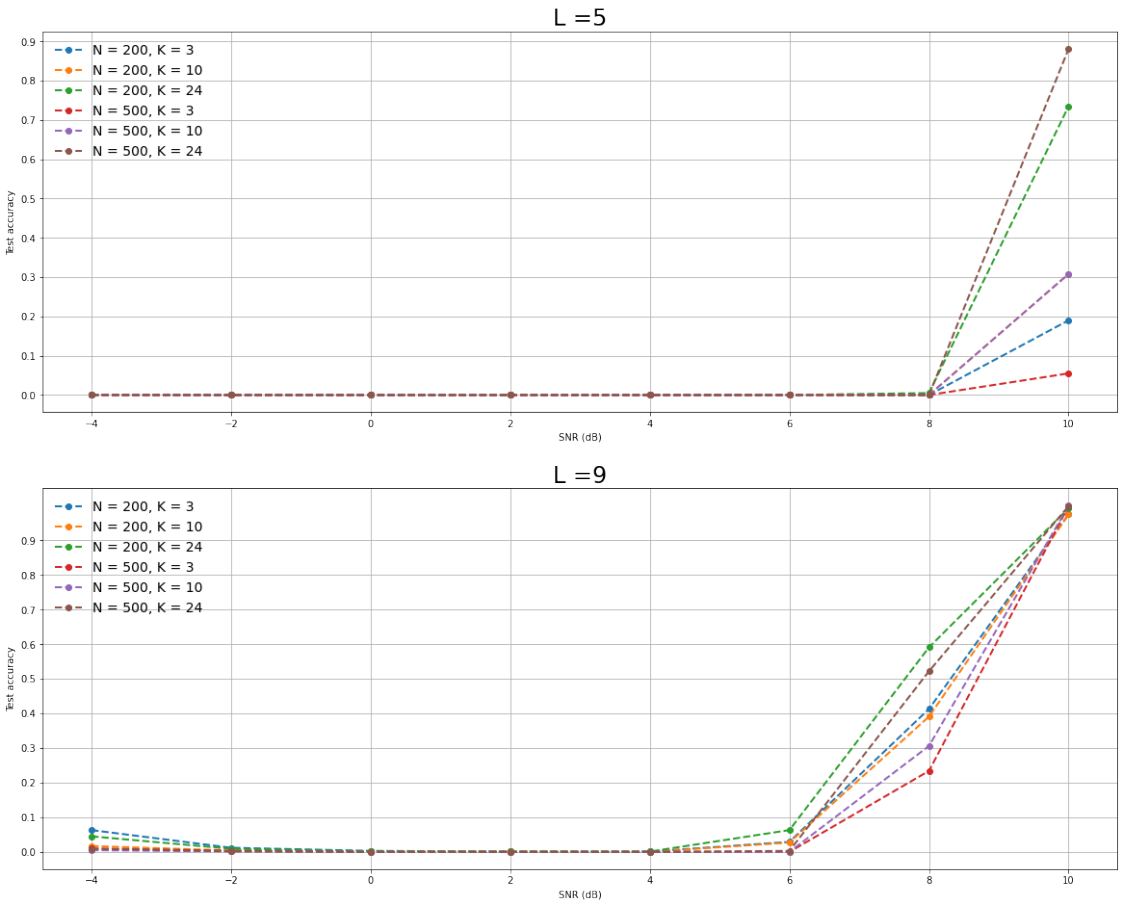
```
0.029), (8, 0.413), (10, 0.975)])
N = 200, K = 10:
the total correct rate on -4 dB SNR is: 0.017
   BPSK: 4.0
    QPSK: 17.0
   16QAM: 160.0
   64QAM: 819.0
the total correct rate on -2 dB SNR is: 0.004
   BPSK: 0.0
    QPSK: 4.0
   16QAM: 71.0
   64QAM: 925.0
the total correct rate on 0 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 79.0
   64QAM: 920.0
the total correct rate on 2 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 247.0
   64QAM: 752.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 802.0
   64QAM: 198.0
the total correct rate on 6 dB SNR is: 0.027
   BPSK: 0.0
    QPSK: 27.0
   16QAM: 972.0
   64QAM: 1.0
the total correct rate on 8 dB SNR is: 0.391
   BPSK: 0.0
    QPSK: 391.0
   16QAM: 609.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.975
   BPSK: 0.0
    QPSK: 975.0
   16QAM: 25.0
   64QAM: 0.0
OrderedDict([(-4, 0.017), (-2, 0.004), (0, 0.001), (2, 0.001), (4, 0.0), (6,
0.027), (8, 0.391), (10, 0.975)])
N = 200, K = 24:
the total correct rate on -4 dB SNR is: 0.045
   BPSK: 4.0
    QPSK: 45.0
```

```
   16QAM: 951.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.009
   BPSK: 0.0
    QPSK: 9.0
   16QAM: 991.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.002
   BPSK: 0.0
    QPSK: 2.0
   16QAM: 998.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 999.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 999.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.063
   BPSK: 0.0
    QPSK: 63.0
   16QAM: 937.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 0.591
   BPSK: 0.0
    QPSK: 591.0
   16QAM: 409.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.993
   BPSK: 0.0
    QPSK: 993.0
   16QAM: 7.0
   64QAM: 0.0
OrderedDict([(-4, 0.045), (-2, 0.009), (0, 0.002), (2, 0.001), (4, 0.001), (6,
0.063), (8, 0.591), (10, 0.993)])
N = 500, K = 3:
the total correct rate on -4 dB SNR is: 0.01
   BPSK: 0.0
    QPSK: 10.0
   16QAM: 81.0
   64QAM: 909.0
the total correct rate on -2 dB SNR is: 0.003
   BPSK: 0.0
    QPSK: 3.0
```

```
   16QAM: 24.0
   64QAM: 973.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 10.0
   64QAM: 990.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 46.0
   64QAM: 954.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 489.0
   64QAM: 511.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 919.0
   64QAM: 81.0
the total correct rate on 8 dB SNR is: 0.234
   BPSK: 0.0
    QPSK: 234.0
   16QAM: 760.0
   64QAM: 6.0
the total correct rate on 10 dB SNR is: 0.999
   BPSK: 0.0
    QPSK: 999.0
   16QAM: 1.0
   64QAM: 0.0
OrderedDict([(-4, 0.01), (-2, 0.003), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0),
(8, 0.234), (10, 0.999)])
N = 500, K = 10:
the total correct rate on -4 dB SNR is: 0.005
   BPSK: 0.0
    QPSK: 5.0
   16QAM: 35.0
   64QAM: 960.0
the total correct rate on -2 dB SNR is: 0.001
   BPSK: 0.0
    QPSK: 1.0
   16QAM: 13.0
   64QAM: 986.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
```

```
   16QAM: 9.0
   64QAM: 991.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 76.0
   64QAM: 924.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 879.0
   64QAM: 121.0
the total correct rate on 6 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 0.306
   BPSK: 0.0
    QPSK: 306.0
   16QAM: 694.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
   BPSK: 0.0
    QPSK: 1000.0
   16QAM: 0.0
   64QAM: 0.0
OrderedDict([(-4, 0.005), (-2, 0.001), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.0),
(8, 0.306), (10, 1.0)])
N = 500, K = 24:
the total correct rate on -4 dB SNR is: 0.009
   BPSK: 0.0
    QPSK: 9.0
   16QAM: 991.0
   64QAM: 0.0
the total correct rate on -2 dB SNR is: 0.002
   BPSK: 0.0
    QPSK: 2.0
   16QAM: 998.0
   64QAM: 0.0
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 2 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
```

```
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 4 dB SNR is: 0.0
   BPSK: 0.0
    QPSK: 0.0
   16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 6 dB SNR is: 0.003
   BPSK: 0.0
    QPSK: 3.0
   16QAM: 997.0
   64QAM: 0.0
the total correct rate on 8 dB SNR is: 0.522
   BPSK: 0.0
    QPSK: 522.0
   16QAM: 478.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 0.999
   BPSK: 0.0
    QPSK: 999.0
   16QAM: 1.0
   64QAM: 0.0
OrderedDict([(-4, 0.009), (-2, 0.002), (0, 0.0), (2, 0.0), (4, 0.0), (6, 0.003),
(8, 0.522), (10, 0.999)])
```



1.5.6 16QAM ModulationClassTest

[6]:
```
SNR = [5 * x for x in range(0, 9)]
ModulationClassTests(SNR, 2)
```

```
N = 200, K = 3:
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 5 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 10 dB SNR is: 0.004
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 4.0
   64QAM: 996.0
the total correct rate on 15 dB SNR is: 0.284
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 284.0
   64QAM: 716.0
the total correct rate on 20 dB SNR is: 0.767
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 767.0
   64QAM: 233.0
the total correct rate on 25 dB SNR is: 0.844
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 844.0
   64QAM: 156.0
the total correct rate on 30 dB SNR is: 0.877
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 877.0
   64QAM: 123.0
the total correct rate on 35 dB SNR is: 0.906
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 906.0
   64QAM: 94.0
the total correct rate on 40 dB SNR is: 0.895
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 895.0
   64QAM: 105.0
OrderedDict([(0, 0.0), (5, 0.0), (10, 0.004), (15, 0.284), (20, 0.767), (25,
0.844), (30, 0.877), (35, 0.906), (40, 0.895)])
N = 200, K = 10:
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 5 dB SNR is: 0.001
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1.0
   64QAM: 999.0
the total correct rate on 10 dB SNR is: 0.119
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 119.0
   64QAM: 881.0
the total correct rate on 15 dB SNR is: 0.652
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 652.0
   64QAM: 348.0
the total correct rate on 20 dB SNR is: 0.886
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 886.0
   64QAM: 114.0
the total correct rate on 25 dB SNR is: 0.928
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 928.0
   64QAM: 72.0
the total correct rate on 30 dB SNR is: 0.948
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 948.0
   64QAM: 52.0
the total correct rate on 35 dB SNR is: 0.955
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 955.0
   64QAM: 45.0
the total correct rate on 40 dB SNR is: 0.959
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 959.0
   64QAM: 41.0
OrderedDict([(0, 0.0), (5, 0.001), (10, 0.119), (15, 0.652), (20, 0.886), (25,
0.928), (30, 0.948), (35, 0.955), (40, 0.959)])
N = 200, K = 24:
the total correct rate on 0 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 5 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 15 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 20 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 25 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 30 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 35 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 40 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
OrderedDict([(0, 1.0), (5, 1.0), (10, 1.0), (15, 1.0), (20, 1.0), (25, 1.0),
(30, 1.0), (35, 1.0), (40, 1.0)])
N = 500, K = 3:
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 5 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 10 dB SNR is: 0.001
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1.0
   64QAM: 999.0
the total correct rate on 15 dB SNR is: 0.232
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 232.0
   64QAM: 768.0
the total correct rate on 20 dB SNR is: 0.904
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 904.0
   64QAM: 96.0
the total correct rate on 25 dB SNR is: 0.964
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 964.0
   64QAM: 36.0
the total correct rate on 30 dB SNR is: 0.983
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 983.0
   64QAM: 17.0
the total correct rate on 35 dB SNR is: 0.974
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 974.0
   64QAM: 26.0
the total correct rate on 40 dB SNR is: 0.984
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 984.0
   64QAM: 16.0
OrderedDict([(0, 0.0), (5, 0.0), (10, 0.001), (15, 0.232), (20, 0.904), (25,
0.964), (30, 0.983), (35, 0.974), (40, 0.984)])
N = 500, K = 10:
the total correct rate on 0 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 5 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 10 dB SNR is: 0.012
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 12.0
   64QAM: 988.0
the total correct rate on 15 dB SNR is: 0.664
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 664.0
   64QAM: 336.0
the total correct rate on 20 dB SNR is: 0.958
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 958.0
   64QAM: 42.0
the total correct rate on 25 dB SNR is: 0.984
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 984.0
   64QAM: 16.0
the total correct rate on 30 dB SNR is: 0.991
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 991.0
   64QAM: 9.0
the total correct rate on 35 dB SNR is: 0.983
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 983.0
   64QAM: 17.0
the total correct rate on 40 dB SNR is: 0.984
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 984.0
   64QAM: 16.0
OrderedDict([(0, 0.0), (5, 0.0), (10, 0.012), (15, 0.664), (20, 0.958), (25,
0.984), (30, 0.991), (35, 0.983), (40, 0.984)])
N = 500, K = 24:
the total correct rate on 0 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 5 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 15 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 20 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 25 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 30 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 35 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 40 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
OrderedDict([(0, 1.0), (5, 1.0), (10, 1.0), (15, 1.0), (20, 1.0), (25, 1.0),
(30, 1.0), (35, 1.0), (40, 1.0)])
N = 200, K = 3:
the total correct rate on 0 dB SNR is: 0.03
   BPSK: 0.0
   QPSK: 2.0
    16QAM: 30.0
   64QAM: 968.0
the total correct rate on 5 dB SNR is: 0.02
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 20.0
   64QAM: 980.0
the total correct rate on 10 dB SNR is: 0.2
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 200.0
   64QAM: 800.0
the total correct rate on 15 dB SNR is: 0.487
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 487.0
   64QAM: 513.0
the total correct rate on 20 dB SNR is: 0.587
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 587.0
   64QAM: 413.0
the total correct rate on 25 dB SNR is: 0.618
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 618.0
   64QAM: 382.0
the total correct rate on 30 dB SNR is: 0.65
   BPSK: 0.0
   QPSK: 1.0
    16QAM: 650.0
   64QAM: 349.0
the total correct rate on 35 dB SNR is: 0.689
   BPSK: 0.0
   QPSK: 1.0
    16QAM: 689.0
   64QAM: 310.0
the total correct rate on 40 dB SNR is: 0.673
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 673.0
   64QAM: 327.0
OrderedDict([(0, 0.03), (5, 0.02), (10, 0.2), (15, 0.487), (20, 0.587), (25,
0.618), (30, 0.65), (35, 0.689), (40, 0.673)])
N = 200, K = 10:
the total correct rate on 0 dB SNR is: 0.018
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 18.0
   64QAM: 982.0
the total correct rate on 5 dB SNR is: 0.031
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 31.0
   64QAM: 969.0
the total correct rate on 10 dB SNR is: 0.373
```

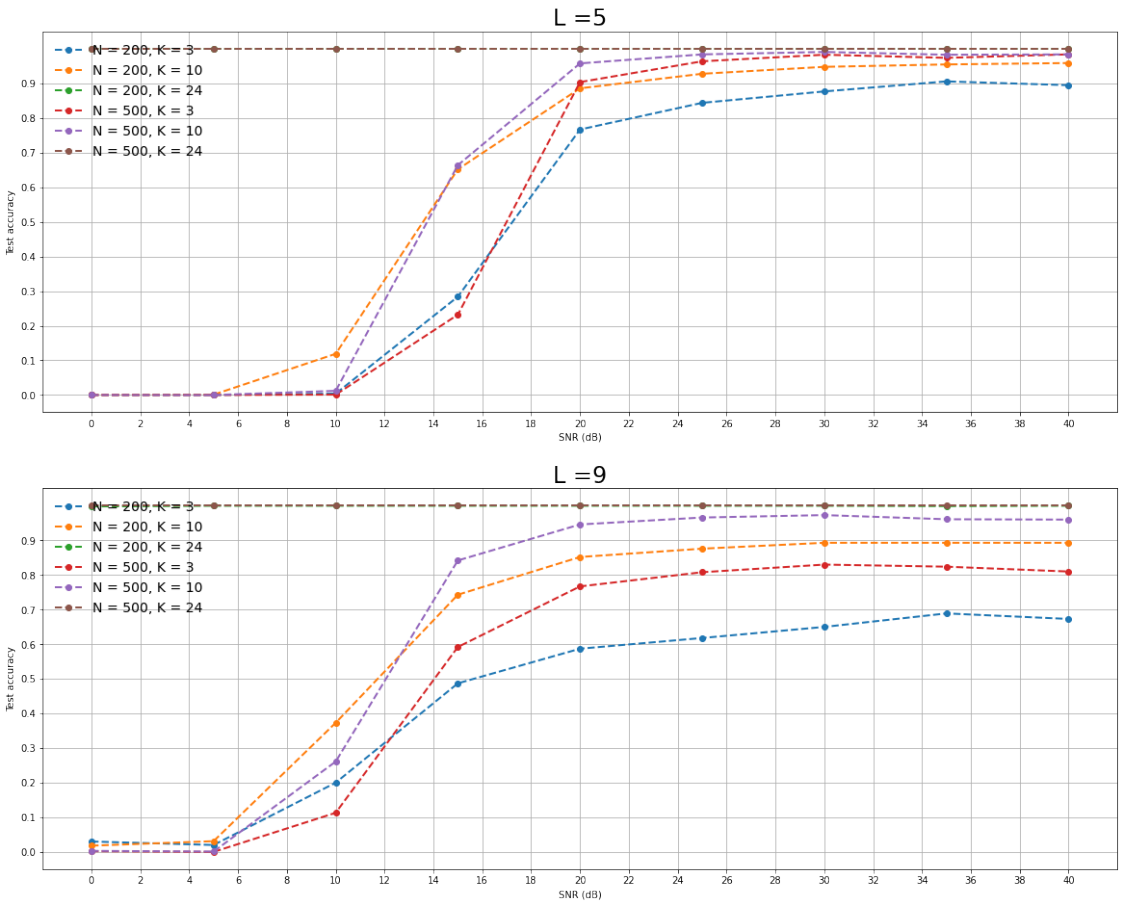
```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 373.0
   64QAM: 627.0
the total correct rate on 15 dB SNR is: 0.743
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 743.0
   64QAM: 257.0
the total correct rate on 20 dB SNR is: 0.852
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 852.0
   64QAM: 148.0
the total correct rate on 25 dB SNR is: 0.876
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 876.0
   64QAM: 124.0
the total correct rate on 30 dB SNR is: 0.893
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 893.0
   64QAM: 107.0
the total correct rate on 35 dB SNR is: 0.893
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 893.0
   64QAM: 107.0
the total correct rate on 40 dB SNR is: 0.893
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 893.0
   64QAM: 107.0
OrderedDict([(0, 0.018), (5, 0.031), (10, 0.373), (15, 0.743), (20, 0.852), (25,
0.876), (30, 0.893), (35, 0.893), (40, 0.893)])
N = 200, K = 24:
the total correct rate on 0 dB SNR is: 0.998
   BPSK: 0.0
   QPSK: 2.0
    16QAM: 998.0
   64QAM: 0.0
the total correct rate on 5 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 15 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 20 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 25 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 30 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 35 dB SNR is: 0.999
   BPSK: 0.0
   QPSK: 1.0
    16QAM: 999.0
   64QAM: 0.0
the total correct rate on 40 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
OrderedDict([(0, 0.998), (5, 1.0), (10, 1.0), (15, 1.0), (20, 1.0), (25, 1.0),
(30, 1.0), (35, 0.999), (40, 1.0)])
N = 500, K = 3:
the total correct rate on 0 dB SNR is: 0.002
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 2.0
   64QAM: 998.0
the total correct rate on 5 dB SNR is: 0.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 0.0
   64QAM: 1000.0
the total correct rate on 10 dB SNR is: 0.113
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 113.0
   64QAM: 887.0
the total correct rate on 15 dB SNR is: 0.592
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 592.0
   64QAM: 408.0
the total correct rate on 20 dB SNR is: 0.767
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 767.0
   64QAM: 233.0
the total correct rate on 25 dB SNR is: 0.808
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 808.0
   64QAM: 192.0
the total correct rate on 30 dB SNR is: 0.83
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 830.0
   64QAM: 170.0
the total correct rate on 35 dB SNR is: 0.824
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 824.0
   64QAM: 176.0
the total correct rate on 40 dB SNR is: 0.81
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 810.0
   64QAM: 190.0
OrderedDict([(0, 0.002), (5, 0.0), (10, 0.113), (15, 0.592), (20, 0.767), (25,
0.808), (30, 0.83), (35, 0.824), (40, 0.81)])
N = 500, K = 10:
the total correct rate on 0 dB SNR is: 0.003
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 3.0
   64QAM: 997.0
the total correct rate on 5 dB SNR is: 0.001
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1.0
   64QAM: 999.0
the total correct rate on 10 dB SNR is: 0.261
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 261.0
   64QAM: 739.0
the total correct rate on 15 dB SNR is: 0.842
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 842.0
   64QAM: 158.0
the total correct rate on 20 dB SNR is: 0.946
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 946.0
   64QAM: 54.0
the total correct rate on 25 dB SNR is: 0.966
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 966.0
   64QAM: 34.0
the total correct rate on 30 dB SNR is: 0.973
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 973.0
   64QAM: 27.0
the total correct rate on 35 dB SNR is: 0.961
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 961.0
   64QAM: 39.0
the total correct rate on 40 dB SNR is: 0.96
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 960.0
   64QAM: 40.0
OrderedDict([(0, 0.003), (5, 0.001), (10, 0.261), (15, 0.842), (20, 0.946), (25,
0.966), (30, 0.973), (35, 0.961), (40, 0.96)])
N = 500, K = 24:
the total correct rate on 0 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 5 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 10 dB SNR is: 1.0
```

```
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 15 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 20 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 25 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 30 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 35 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
the total correct rate on 40 dB SNR is: 1.0
   BPSK: 0.0
   QPSK: 0.0
    16QAM: 1000.0
   64QAM: 0.0
OrderedDict([(0, 1.0), (5, 1.0), (10, 1.0), (15, 1.0), (20, 1.0), (25, 1.0),
(30, 1.0), (35, 1.0), (40, 1.0)])
```



1.6

1. SNR
2.
3. 1 SNR
4.