AMERICAN INTERNATIONAL UNIVERSITY BANGLADESH

Faculty of Engineering

Laboratory Report Cover Sheet

Students must complete all details except the faculty use part.

Please submit all reports to your subject supervisor or the office of the concerned faculty.

Laboratory Title: Study of Nyquist bit rate and Shannon capacity using MATLAB

Experiment Number: 3 Due Date: 19/10/2022 Semester: Fall 2022-23

Subject Code: COE3103 Subject Name: Data Communication Section: K

Course Instructor: Dr. Shuvra Mondal Degree Program: B.Sc. in CSE

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Group Number (if applicable): 01 ☐ Individual Submission ☐ Group Submission

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Total Marks: _______ Marks Obtained: _______

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American International University- Bangladesh

Department of Computer Engineering

Data Communication Laboratory

Title of the experiment: Study of Nyquist bit rate and Shannon capacity using MATLAB

Abstract: This experiment is designed to understand the use of MATLAB for solving communication engineering problems and also develop understanding of Nyquist bit rate and Shannon capacity using MATLAB.

Introduction:

I. Nyquist Bit Rate: The Nyquist bit rate formula defines the theoretical maximum bit rate for a noiseless channel.

$$\mathbf{BitRate = 2 \times bandwidth \times \log_2 L}$$

In this formula, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, and BitRate is the bit rate in bits per second.

II. Shannon capacity: Shannon capacity formula was introduced to determine the theoretical highest data rate for a noisy channel:

$$\mathbf{Capacity = bandwidth \times \log_2(1 + SNR)}$$

In this formula, bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity is the capacity of the channel in bits per second.

III. Signal-to-noise ratio (SNR): To find the theoretical bit rate limit, we need to know the ratio of the signal power to the noise power. The signal-to-noise ratio is defined as

$$\mathbf{SNR = \frac{Average\ Signal\ Power}{Average\ Noise\ Power}}$$

We need to consider the average signal power and the average noise power because these may change with time. A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.

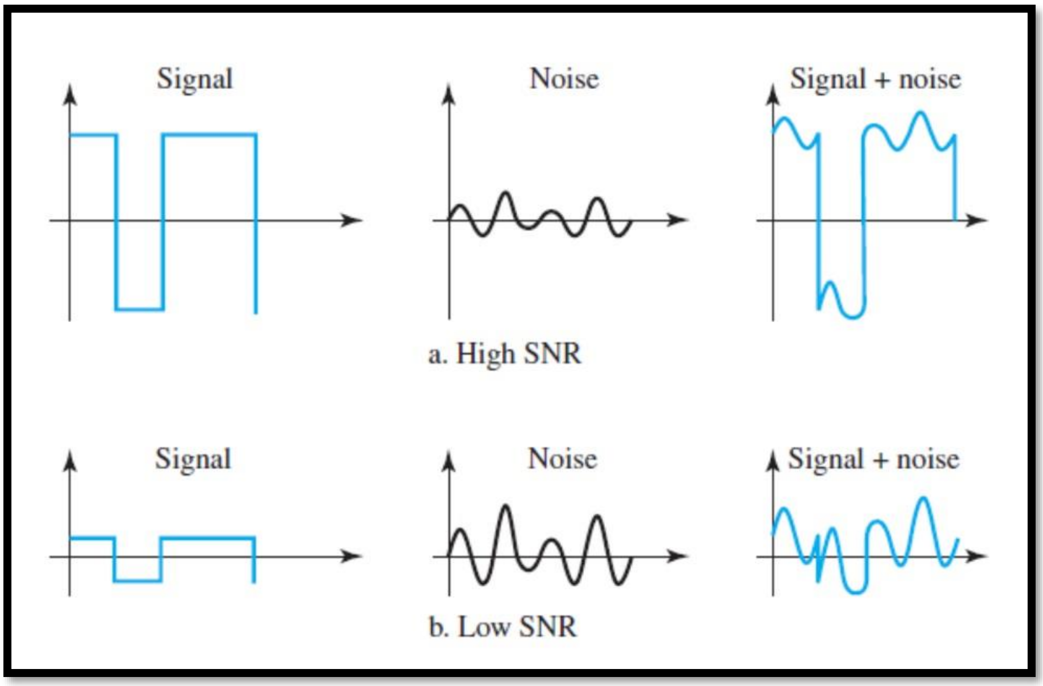

Fig.: Two cases of SNR, high and low

Because SNR is the ratio of two powers, it is often described in decibel units, SNRdB, defined as

$$\mathbf{SNR_{dB} = 10log_{10}(\mathit{SNR})}$$

Simulation:

Example of Nyquist bit rate calculation for a noiseless channel:

code:

```
close all;

clc;
fs = 8000; % Sampling frequency
t = 0:1/fs:1-1/fs; % Time duration
cx = 1.5*sin(2*pi*300*t) + 1.6*cos(2*pi*400*t) + 1.7*sin(2*pi*500*t); % Composite signal
bandwidth = obw(cx,fs); % Bandwidth of the signal
L=2; % Level of the signal

BitRate = 2*bandwidth*log2(L)
```

Command Window Output:

```
BitRate =

  401.9391
```

Calculation of SNR:

code:

```
close all;
clc;
%Define number of samples to take
fs = 8000; % Sampling frequency
f = 300; %Hz
%Defining the signal
t = 0:1/fs:1-1/fs;
A = 4.0;
powfund = A^2/2  %Average power of the signal

s = 0.2;
varnoise = s^2; %Average power of the noise

signal = A*sin(2*pi*f*t); %Setting up the signal
noise = s*randn(size(signal)); %noise
noisySignal = signal + noise; %noisy signal

SNR = snr(noisySignal) %Calculation of SNR using snr function
defSNR = 10*log10(powfund/varnoise) %Calculation of SNR following the definition
```

Command Window Output:

```
SNR =

   23.1452


defSNR =

   23.0103
```

Example of Shannon capacity calculation for a noisy channel:

code:

```
clc
close all
fs = 8000; % Sampling frequency
f = 4; %Hz
%Define signal
t = 0:1/fs:1-1/fs;
A = 3;
s = 0.3;
%signal
x = A*sin(2*pi*f*t);
%noise
ns = s*randn(size(signal));
S_N_R = snr(x,ns);
bandwidth = obw(x,fs); % Bandwidth of the signal
%capacity
capacity = bandwidth*log2(1+SNR) % Shannon capacity of the channel
```

Command Window Output:

capacity =

2.4087

<u>Performance Task for Lab Report</u>

a) Here, Student ID=20-41840-1
So, A=2; B=0; C=4; D=1; E=8; F=4; G=0; H=1;

Now, $A_1 = A + B + H = 3;$ $C + D + H = 6;$ $s = \frac{C+D+H}{30} = \frac{6}{30} = \frac{1}{5};$

$A_2 = B + C + H = 5;$ $D + E + H = 10;$

b) Generating a noisy signal and finding the SNR value for it:

<u>code:</u>

```
clc;

close all;

fs = 100000; % Sampling frequency
t = 0:1/fs:1-1/fs; % Time duration

A=2;B=0;C=4;D=1;E=8;F=4;G=0;H=1; %Constants from student id

A1=A+B+H; %calculating from student id
A2=B+C+H;
s=(C+D+H)/30;

% Making a composite signal and adding noise to it
x=A1*sin(2*pi*((C+D+H)*100)*t) + A2*cos(2*pi*((D+E+H)*100)*t) + s*randn(size(t));
% The noise will be generated from random normal distribution values

powfund = (A1^2)/2 + (A2^2)/2; %Average power of the signal
varnoise=s^2; %Average power of the noise

plot(t,x); %Plotting the noisy signal
xlabel('time');
ylabel('amplitude');
title('Generating a noisy signal');
axis([0 0.005 -10 10]);


SNR = snr(x)
%Using the built in MATLAB %function to generate SNR value
defSNR = 10*log10(powfund/varnoise) %SNR value in dB unit
```

<u>Command window output:</u>

```
SNR =

   4.4006

defSNR =

   26.2839
```

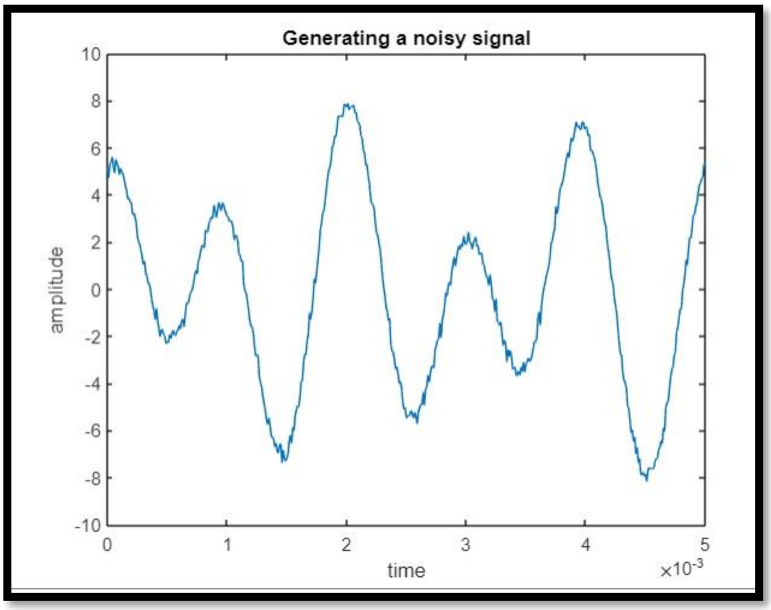

Fig.: Noisy composite signal created using student ID

c) Finding the bandwidth and maximum capacity of the signal:

code:

```
clc;

close all;

fs = 100000; % Sampling frequency

t = 0:1/fs:1-1/fs; % Time duration

A=2;B=0;C=4;D=1;E=8;F=4;G=0;H=1; %Constants from student id
A1=A+B+H; %calculating from student id
A2=B+C+H;
s=(C+D+H)/30;

% Making a composite wave and adding noise to it
x=A1*sin(2*pi*((C+D+H)*100)*t) + A2*cos(2*pi*((D+E+H)*100)*t) + s*randn(size(t));
% The noise will be generated from random normal distribution values

powfund = (A1^2)/2 + (A2^2)/2; %Average power of the signal
varnoise=s^2; %Average power of the noise

SNR = snr(x); %Using the built in MATLAB function to generate SNR value

bandwidth = obw(x,fs) %Using othe obw(occupied bandwidth) function to calculate badwidth
capacity = bandwidth*log2(1+SNR) %using the equation for Shannon capacity
                                 %unit of Shannon capacity is bits per sec
```

Command window output:

```
bandwidth =
    400.9775

capacity = 975.6855
```

d) Finding the suitable level for this signal:

We know,

$$\mathrm{BitRate} = 2 \times \mathrm{bandwidth} \times \log_2 \mathrm{L}$$

or,

$$\log_2 \mathrm{L} = \frac{\mathrm{BitRate}}{2 \times \mathrm{bandwidth}}$$

or,

$$\mathrm{L} = 2^{\left(\frac{\mathrm{BitRate}}{2 \times \mathrm{bandwidth}}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (\mathrm{i})$$

code:

```
clc;
close all;

fs = 100000; % Sampling frequency
t = 0:1/fs:1-1/fs; % Time duration

A=2;B=0;C=4;D=1;E=8;F=4;G=0;H=1; %Constants from student id

A1=A+B+H; %calculating from student id
A2=B+C+H;
s=(C+D+H)/30;

% Making a composite wave and adding noise to it
x=A1*sin(2*pi*((C+D+H)*100)*t) + A2*cos(2*pi*((D+E+H)*100)*t) + s*randn(size(t));
% The noise will be generated from random normal distribution values

powfund = (A1^2)/2 + (A2^2)/2; %Average power of the signal
varnoise=s^2; %Average power of the noise

SNR = snr(x); %Using the built in MATLAB function to generate SNR value
defSNR = 10*log10(powfund/varnoise) ;

bandwidth = obw(x,fs); %Using othe obw(occupied bandwidth) function to calculate badwidth
capacity = bandwidth*log2(1+SNR); %using the equation for Shannon capacity

apprx_data_rate=floor(bandwidth*log2(1+SNR)) %Bitrate or Data rate has to be integer
%apprx_data_rate_2=floor(bandwidth*log2(1+defSNR));

level=floor(2^(apprx_data_rate_1/(2*bandwidth))) %using equation(i)
%level2=floor(2^(apprx_data_rate_2/(2*bandwidth)))
```

Command window output:

```
apprx_data_rate =

   975


level =

     2
```

So to achieve this data rate we need a signal level of 2.

Results and Discussion: For the lab performance task we have successfully created a composite noisy signal in time domain, determined the SNR value for it, determined the bandwidth, maximum capacity and suitable level for it.

An issue we faced was with the double quotations when representing text, because MATLAB identifies these symbols (“ ”) as errors. This issue was resolved by replacing the double quotations with single quotations(‘ ’),

Overall meticulous care was taken to avoid errors and the outputs were obtained perfectly during experiment time. We therefore believe the experiment has been completed successfully.

Conclusion: Through this experiment we have successfully simulated and demonstrated the study of nyquist bit rate, shannon capacity and Signal to noise ratio using MATLAB

References:

1. MATLAB user guide.
2. Prof. Dr.-Ing. Andreas Czylwik, “MATLAB for Communications”
3. AIUB Student Lab Manual