American International University- Bangladesh
Department of Electrical and Electronic Engineering
COE 3201: Data Communication Laboratory

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

Abstract:

This experiment is designed to-

1.To understand the use of MATLAB for solving communication engineering problems.
2.To 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.

$$BitRate = 2 \times bandwidth \times log_2 L$$

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:

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

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.

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

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

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.

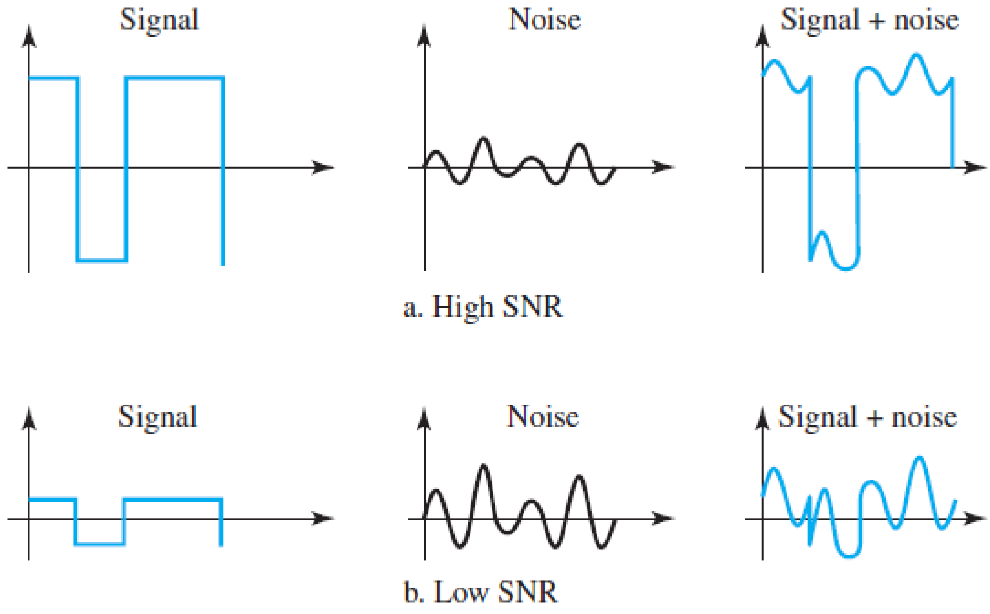

Fig: Two cases of SNR: a high SNR and a low SNR

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

$$SNR_{dB} = 10log_{10}(SNR)$$

Example of Nyquist bit rate calculation for a noiseless channel:

```
close all;
clc;
fs = 8000; % Sampling frequency
t = 0:1/fs:1-1/fs; % Time duration
cx = 1.1*sin(2*pi*100*t) + 1.3*cos(2*pi*300*t) +
1.5*sin(2*pi*2000*t);
bandwidth = obw(cx,fs); % Bandwidth of the signal
L=2; % Level of the signal
BitRate = 2*bandwidth*log2(L)
```

Output:
BitRate =

Example: Calculation of SNR

```
close all;
clc;
%Define number of samples to take
fs = 8000; % Sampling frequency
f = 400; %Hz
%Define signal
t = 0:1/fs:1-1/fs;
A = 3.0;
powfund = A^2/2
s = 0.1;
varnoise = s^2;
signal = A*sin(2*pi*f*t);
%noise
noise = s*randn(size(signal));
%noisy signal
noisySignal = signal + noise;

SNR = snr(noisySignal) %Calculation of SNR using snr
function

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

SNR =

defSNR =

Similar task can be done considering a noisy composite signal. Suppose our composite signal is,

signal = 1.5*sin(2*pi*2*t)+0.9*cos(2*pi*10*t)+1.1*sin(2*pi*20*t) + 0.13*randn(size(t));

*****Calculate the SNR value of the signal.**

Total harmonic distortion (THD): The total harmonic distortion (THD) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.
When a signal passes through a non-ideal, non-linear device, additional content is added at the harmonics of the original frequencies. THD is a measurement of the extent of that distortion.

Signal to noise and distortion ratio (SINAD): Signal-to-noise and distortion ratio (SINAD) is a measure of the quality of a signal from a communications device, often defined as

$$\boldsymbol{SINAD} = \frac{P_{signal} + P_{noise} + P_{distortion}}{P_{noise} + P_{distortion}}$$

Create a sinusoidal signal sampled at 48 kHz. The signal has a fundamental of frequency 1 kHz and unit amplitude. It additionally contains a 2 kHz harmonic with half the amplitude and additive noise with variance 0.1^2.

```
fs = 48e3;
t = 0:1/fs:1-1/fs;
A = 1.0;
powfund = A^2/2;
a = 0.4;
powharm = a^2/2;
s = 0.1;
varnoise = s^2;
x = A*cos(2*pi*1000*t) + a*sin(2*pi*2000*t) +
s*randn(size(t));

THD = thd(x); % Total harmonic distortion
defTHD = 10*log10(powharm/powfund);
TH = [THD defTHD]

SINAD = sinad(x); % Signal to noise and distortion
ratio
defSINAD = 10*log10(powfund/(powharm+varnoise));
SI = [SINAD defSINAD]
```

Output:

TH =

SI =

Example of Shannon capacity calculation for a noisy channel:

```
SNR = snr(x);
bandwidth = obw(x,fs); % Bandwidth of the signal

C = bandwidth*log2(1+SNR) % Capacity of the channel
```

C =

Software:

MATLAB2016a

Performance Task for Lab Report: (your ID = AB-CDEFG-H)

**Generate a composite signal using two simple signals as,

x = A_1 sin(2π(C*100)t) + A_2 cos(2π(G*100)t) + s*randn(size(t));

(a) Select the value of the amplitudes as follows: let A_1 = AB, A_2 = AF and s=AH

(b) Calculate the SNR value of the composite signal.

(c) Find the bandwidth of the signal and calculate the maximum capacity of the channel.

(d) What will be the signal level to achieve the data rate?