Communications and Wireless Networks @CS.NYCU

Lab. 2: Analog and Digital Beamforming

Instructor: Kate Ching-Ju Lin (林靖茹)

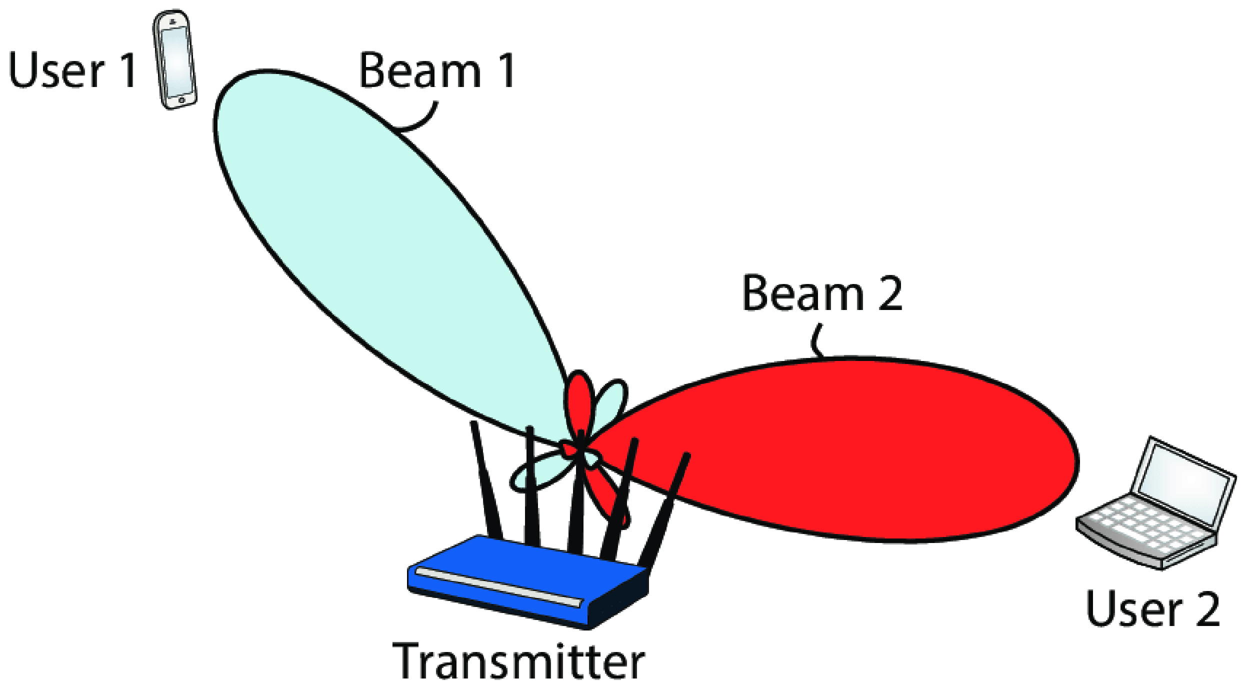
Deadline: 2024.06.19 23:59

Agenda

- Overview
- Topology & Parameters
- Tasks
- Report
- Submission
- Grading Policy

Overview

In this lab, we are going to write a Matlab program that simulates analog beamforming and digital beamforming



Topology and Parameters

- Tx/Rx locations
  - 1 Tx: [0, 0]
  - 2 Rx: random [x_1, y_1] [x_2, y_2]
- Power: P_{tx}= 10 dBm, N0 = -95 dBm
- Analog beamforming
  - Frequency: 24GHz
  - 16-antenna Tx with linear phased array / 1-antenna Rx
  - Default codebook: [0:10:180]
- Digital beamforming
  - Frequency: 2.4GHz
  - 2-antenna Tx / 1-antenna Rx
  - Random channel of each link: a+bi
    - Gaussian normal: a,b~N(0,1)

Task 1: Analog Beamforming

a) Identify the optimal beam by linear beam scanning
b) Calculate receiving power & SNR of the primal user (user 1)
c) Calculate interfering power & INR of the secondary user (user 2)

- Derive SNR only
- No need to transmit actual symbols

- Follow the TODO & Hints in Matlab code
- You can add code to show results, but make sure lab2_studentID can run

Task 2: Digital Beamforming

a) Decode (equalize) the non-precoded signals (without ZFBF)
   - Find the equalizer h_{eq} for two users
   - Calculate decoding errors & SNR of two users without ZF beamforming

b) Generate precoding weight **W**

c) Decode (equalize) the precoded signals (with ZFBF)
   - Find the equalizer h_{eq} for two users
   - Calculate decoding errors & SNR of two users with ZF beamforming

> - Simulate the transmission of signal x~N(0,1)
> - Calculate the decoding errors and SNR

Task 1a: Analog Beam Scanning

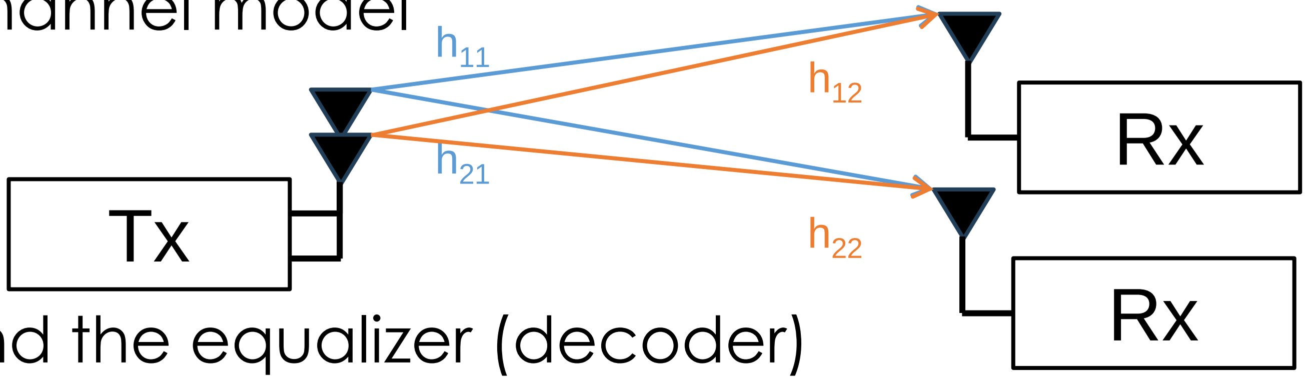
- Find the actual sector angle θ_1 and θ_2 of user 1 and user 2
- Given the feasible beams [0:10:180] degrees, scan all the beams and identify the optimal beam θ^* for user 1
  - i.e., the direction that maximizes the gain for user 1
- Plot the beam pattern of the optimal beam θ^*

Task 1b-c: SNR with Analog BF

- Identify the Tx gains of users 1 and 2 based on θ_1 and θ_2 from the optimal beam θ^* found in task 1a
- Calculate receiving power and SNR for user 1
  - Pathloss: Use Friis' Free space model with the identified Tx gain
  - Convert power and SNR to dBm
- Calculate interfering power and INR for user 2
  - Pathloss: Use Friis' Free space model with the identified Tx gain
  - Convert power and INR to dBm

Task 2a: Original SNR w/o ZFBF

- Channel model



- Find the equalizer (decoder)
  - $h_{eq,1} = h_{11} + h_{12}$
  - $h_{eq,2} = h_{21} + h_{22}$
- Equalize (decode) the signal by
  - $\hat{x}_1 = y_1 / h_{eq,1}$
  - $\hat{x}_2 = y_2 / h_{eq,2}$
- Calculate the mean decoding errors
  - $|\hat{x}_1 - x_1|^2$ and $|\hat{x}_2 - x_2|^2$
- Calculate the SNR (in dBm) of user 1 and user 2

Task 2b: ZFBF Precoding

- Channel model:
  - $\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \mathbf{H} * \mathbf{W} * \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \mathbf{n};$
- Find the precoding weight matrix **W**
  - **W** = pseudo inverse of **H**
  - Scale **W** into unit power ($|\mathbf{W}|^2=1$)

Task 2c: Equalization with ZFBF

- Find the equalizer (decoder)
  - $\mathbf{h}_{eq}$ = H * W (deem $\mathbf{h}_{eq}$ as the new channel)
- Calculate the mean decoding errors
  - $|\hat{x}_1 - x_1|^2$ and $|\hat{x}_2 - x_2|^2$
- Calculate the SNR (in dBm) for user 1 and user 2

Report for Task 1

A report in PDF format, contains:

- Output your results for d=[50:50:500]m, antenna number 8 and 16
  - For each distance, repeat your code 10 times to generate 10 random topology
  - Plot the average SNR_{dBm} of user 1 and INR_{dBm} of user 2 (x-axis: distances)
- Plot the SNR_{dBm} and INR_{dBm} of 10 topologies when d=200m, antenna number = 16
  - Explain your observation about the size lobe interference
- Plot the $P_{rx,1}$ (in dBm) of 10 topologies for various codebook sizes (19, 37, 73, i.e., [0:10:180], [0:5:180], [0:2.5:180]) when d=200m, antenna number = 16
  - Explain your observation about the impact of codebook sizes

Report for Task 2

A report in PDF format, contains:

- Output your results for d=[50:50:500]m
  - For each distance, repeat your code 10 times to generate 10 random topology
  - Plot the average SNR_{dBm} of two users w/ and w/o ZFBF (x-axis: distances)
- Plot the $\mathbf{h}_{eq}$, error(in dBm) of R_1 with ZFBF when d=200m
  - Repeat your code 10 times to generate 10 random channel H
  - Explain why error varies across different rounds of experiments
  - Discuss why $\mathbf{h}_{eq}$ would be different in different rounds of experiments
  - Explain your observation about the correlation between $\mathbf{h}_{eq}$ and error

Report for additional questions

A report in PDF format, contains:

- Answer the following question in short:
  - What have you learned from this lab?
  - What difficulty have you met in this lab?

Notice: You should write your report in English

Submission

- Replace [studentID] in filenames with your studentID
- Zip your matlab code and report(studentID.pdf) to StudentID.zip
- File structure:

```
lab2
 │   lab2_studentID.m
 │   studentID.pdf
 │
 ├─ewa_function
 │       bwidth.m
 │       dtft.m
 │       friis_equation.m
 │       scan.m
 │       steer.m
 │       uniform.m
 │
 └─tasks
          analog_beamforming.m
          digital_beamforming.m
```

Submission

- Submit your zip files to the assignment in Teams 112-2 CWN
- Deadline: 2024.06.19 23:59

Notice: Remember to press the submit button after you upload your files

Notice: You will get penalty with wrong file structure and naming

Grading Policy

- Grade
  - Code correctness - 40%
  - Report - 60%
- Late Policy
  - (Your score) * 0.8^D, where D is the number of days over due
- Cheating Policy
  - Academic integrity: Homework must be your own – cheaters share the score
  - Both the cheaters and the students who aided the cheater equally share the score