CWN Lab2:

noted that every unit of SNR and INR is dB not dBm in this report

Report for Task 1:

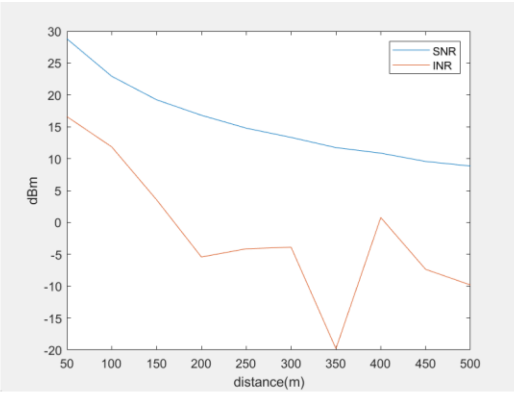
Output your results for d=[50:50:500]m, antenna number 8 and 16:

Antenna number=8, d=[50:50:500]m:

data:

```
Antenna Numbers: 8.000000,Distance: 50.000000 m, average SNR: 28.806219 dBm, average INR: 16.604963 dBm
Antenna Numbers: 8.000000,Distance: 100.000000 m, average SNR: 22.924816 dBm, average INR: 11.851510 dBm
Antenna Numbers: 8.000000,Distance: 150.000000 m, average SNR: 19.237038 dBm, average INR: 3.563733 dBm
Antenna Numbers: 8.000000,Distance: 200.000000 m, average SNR: 16.806349 dBm, average INR: -5.420274 dBm
Antenna Numbers: 8.000000,Distance: 250.000000 m, average SNR: 14.785586 dBm, average INR: -4.137744 dBm
Antenna Numbers: 8.000000,Distance: 300.000000 m, average SNR: 13.334788 dBm, average INR: -3.887841 dBm
Antenna Numbers: 8.000000,Distance: 350.000000 m, average SNR: 11.729967 dBm, average INR: -19.804620 dBm
Antenna Numbers: 8.000000,Distance: 400.000000 m, average SNR: 10.865002 dBm, average INR: 0.765482 dBm
Antenna Numbers: 8.000000,Distance: 450.000000 m, average SNR: 9.566142 dBm, average INR: -7.358002 dBm
Antenna Numbers: 8.000000,Distance: 500.000000 m, average SNR: 8.841174 dBm, average INR: -9.809909 dBm
```

graph:

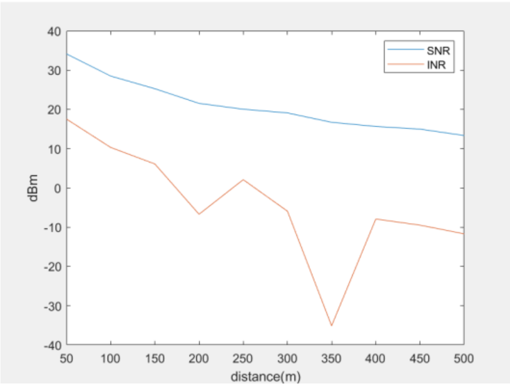


Antenna number=16, d=[50:50:500]m:

data:

```
Antenna Numbers: 16.000000,Distance: 50.000000 m, average SNR: 34.130632 dBm, average INR: 17.536206 dBm
Antenna Numbers: 16.000000,Distance: 100.000000 m, average SNR: 28.487794 dBm, average INR: 10.308327 dBm
Antenna Numbers: 16.000000,Distance: 150.000000 m, average SNR: 25.263140 dBm, average INR: 6.096024 dBm
Antenna Numbers: 16.000000,Distance: 200.000000 m, average SNR: 21.529614 dBm, average INR: -6.704918 dBm
Antenna Numbers: 16.000000,Distance: 250.000000 m, average SNR: 20.037966 dBm, average INR: 2.098481 dBm
Antenna Numbers: 16.000000,Distance: 300.000000 m, average SNR: 19.100822 dBm, average INR: -5.913478 dBm
Antenna Numbers: 16.000000,Distance: 350.000000 m, average SNR: 16.711112 dBm, average INR: -35.113812 dBm
Antenna Numbers: 16.000000,Distance: 400.000000 m, average SNR: 15.650934 dBm, average INR: -7.919673 dBm
Antenna Numbers: 16.000000,Distance: 450.000000 m, average SNR: 14.971758 dBm, average INR: -9.476829 dBm
Antenna Numbers: 16.000000,Distance: 500.000000 m, average SNR: 13.342793 dBm, average INR: -11.696300 dBm
```

graph:



Analysis:

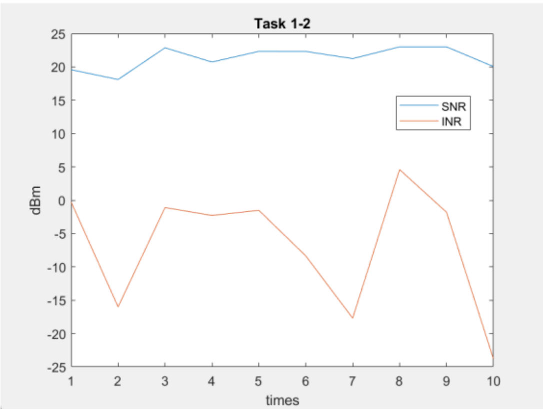
From the figure of average SNR and average INR on different distances, we can clearly see that when distance become larger, the average SNR will become smaller. This is reasonable because from Friis equation we can know that SNR will decrease as distance increase. Average INR of user 2 decrease when distance while distance increase, I think it's because the INR is not only affected by distance but also the location of rx1 and rx2, so each topology with same distance might have extremely different INR. This can explain why some part of average INR increase as distance increase. And we can notice that the SNR of 16 antenna is higher than 8.

Plot the SNR (in dBm) and INR (in dBm) of 10 topologies when d=200m, antenna number=16:

data:

```
Topology: 1, SNR: 19.580700 dBm, INR: -0.279847 dBm
Topology: 2, SNR: 18.115269 dBm, INR: -16.000845 dBm
Topology: 3, SNR: 22.874432 dBm, INR: -1.100718 dBm
Topology: 4, SNR: 20.734565 dBm, INR: -2.281238 dBm
Topology: 5, SNR: 22.334837 dBm, INR: -1.510595 dBm
Topology: 6, SNR: 22.325479 dBm, INR: -8.344283 dBm
Topology: 7, SNR: 21.250067 dBm, INR: -17.692484 dBm
Topology: 8, SNR: 23.015803 dBm, INR: 4.603052 dBm
Topology: 9, SNR: 23.015465 dBm, INR: -1.791799 dBm
Topology: 10, SNR: 20.059056 dBm, INR: -23.790022 dBm
```

graph:



Analysis:

In this part, SNR seems stable under different topologies. I think it's due to the codebook's size. Under different topologies, the SNR will be mainly affected by how large Gtx from analog beamforming is, and different results of Gtx result from the deviation of sector and beam. If codebook's size is larger, SNR will be more stable.

Next, the INR seems more instable than SNR, this can be explained by the random location of rx1 and rx2. As lecture told, the tx can generate a beam close to rx1, and there will be some side lode (power leakage) that will interfere other rxs, in this case, it is rx2. The interference to rx2 can be decided by the location of beam, rx1 and rx2. From the given power graph that produced by given beam, we can know that randomly pick a rx2 will lead to drastically different INR.

Plot the Prx,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:

Codebook [0:10:180]:

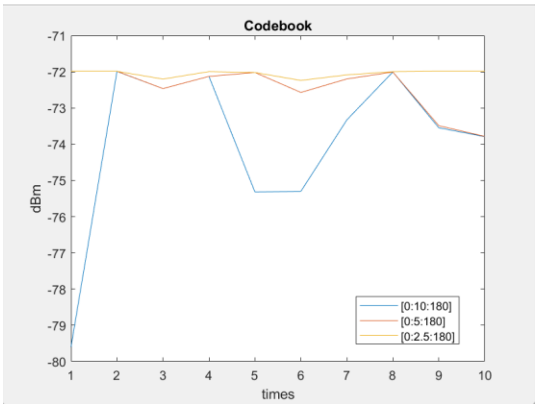
data:

```
Codebook size: [0:10:180], Prx,1: -79.599620 dBm
Codebook size: [0:10:180], Prx,1: -71.989603 dBm
Codebook size: [0:10:180], Prx,1: -72.464757 dBm
Codebook size: [0:10:180], Prx,1: -72.127190 dBm
Codebook size: [0:10:180], Prx,1: -75.316378 dBm
Codebook size: [0:10:180], Prx,1: -75.301802 dBm
Codebook size: [0:10:180], Prx,1: -73.328280 dBm
Codebook size: [0:10:180], Prx,1: -72.005926 dBm
Codebook size: [0:10:180], Prx,1: -73.546705 dBm
Codebook size: [0:10:180], Prx,1: -73.792758 dBm

Codebook size: [0:5:180], Prx,1: -71.984197 dBm
Codebook size: [0:5:180], Prx,1: -71.985905 dBm
Codebook size: [0:5:180], Prx,1: -72.464757 dBm
Codebook size: [0:5:180], Prx,1: -72.127190 dBm
Codebook size: [0:5:180], Prx,1: -72.019210 dBm
Codebook size: [0:5:180], Prx,1: -72.570412 dBm
Codebook size: [0:5:180], Prx,1: -72.198346 dBm
Codebook size: [0:5:180], Prx,1: -72.005926 dBm
Codebook size: [0:5:180], Prx,1: -73.489156 dBm
Codebook size: [0:5:180], Prx,1: -73.785568 dBm

Codebook size: [0:2.5:180], Prx,1: -71.984197 dBm
Codebook size: [0:2.5:180], Prx,1: -71.985905 dBm
Codebook size: [0:2.5:180], Prx,1: -72.201593 dBm
Codebook size: [0:2.5:180], Prx,1: -71.994145 dBm
Codebook size: [0:2.5:180], Prx,1: -72.019210 dBm
Codebook size: [0:2.5:180], Prx,1: -72.239443 dBm
Codebook size: [0:2.5:180], Prx,1: -72.084920 dBm
Codebook size: [0:2.5:180], Prx,1: -71.996194 dBm
Codebook size: [0:2.5:180], Prx,1: -71.984197 dBm
Codebook size: [0:2.5:180], Prx,1: -71.984197 dBm
```

graph:



Analysis:

Compare the highest Prx,1 in each codebook, we can see that these codebooks have nearly same best performance, which is around -82dBm. But, when we turn to smallest Prx,1 in each codebook, we can observe that in [0:10:180], the smallest Prx,1 is approximately -89.6dBm. The smallest Prx,1 in [0:5:180] is nearly -83.5dBm. The smallest Prx,1 in [0:2.5:180] is -82.26dBm.

From the difference of codebook sizes, we can see that larger codebook's size (smaller interval) will lead to a more higher average Prx,1. This can be explained by if you cut the available beam into smaller chunks, you can generate much more accurate beam to the desired rx, which will increase average Prx,1. For example, if rx is at 3 degree. Then the deviation in [0:2.5:180] will only be 0.5 degree; however, in [0:5:180], it will increase to 2 degree, and in [0:10:180], it will increase to 3 degree. So, if you use a larger codebook, you may expect to gain higher average Prx.

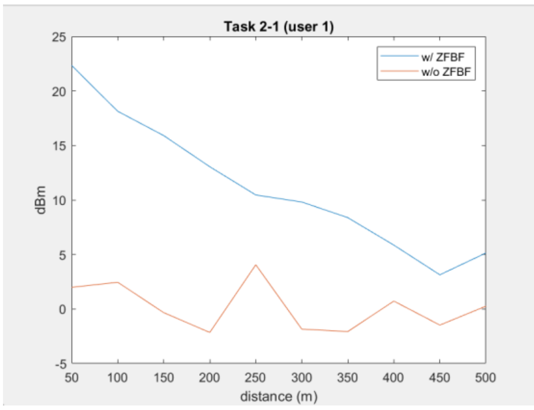
Report for Task 2:

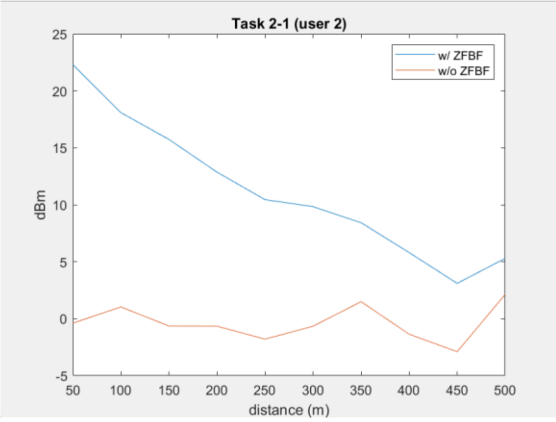
Output your results for d=[50:50:500]m:

data:

```
Distance: 50.000000 m, SNR1 w/: 22.318220 dBm, SNR2 w/: 22.298037 dBm, SNR1 w/o: 1.982966 dBm, SNR2 w/o: -0.392003 dBm
Distance: 100.000000 m, SNR1 w/: 18.130088 dBm, SNR2 w/: 18.088607 dBm, SNR1 w/o: 2.449048 dBm, SNR2 w/o: 1.026330 dBm
Distance: 150.000000 m, SNR1 w/: 15.894868 dBm, SNR2 w/: 15.736218 dBm, SNR1 w/o: -0.340083 dBm, SNR2 w/o: -0.644416 dBm
Distance: 200.000000 m, SNR1 w/: 13.044867 dBm, SNR2 w/: 12.864054 dBm, SNR1 w/o: -2.155277 dBm, SNR2 w/o: -0.662921 dBm
Distance: 250.000000 m, SNR1 w/: 10.453216 dBm, SNR2 w/: 10.448078 dBm, SNR1 w/o: 4.053230 dBm, SNR2 w/o: -1.795689 dBm
Distance: 300.000000 m, SNR1 w/: 9.806292 dBm, SNR2 w/: 9.834753 dBm, SNR1 w/o: -1.849144 dBm, SNR2 w/o: -0.664482 dBm
Distance: 350.000000 m, SNR1 w/: 8.371263 dBm, SNR2 w/: 8.423344 dBm, SNR1 w/o: -2.071881 dBm, SNR2 w/o: 1.490737 dBm
Distance: 400.000000 m, SNR1 w/: 5.855018 dBm, SNR2 w/: 5.803477 dBm, SNR1 w/o: 0.723577 dBm, SNR2 w/o: -1.362911 dBm
Distance: 450.000000 m, SNR1 w/: 3.131158 dBm, SNR2 w/: 3.098073 dBm, SNR1 w/o: -1.481490 dBm, SNR2 w/o: -2.902158 dBm
Distance: 500.000000 m, SNR1 w/: 5.130518 dBm, SNR2 w/: 5.295673 dBm, SNR1 w/o: 0.256554 dBm, SNR2 w/o: 2.126937 dBm
```

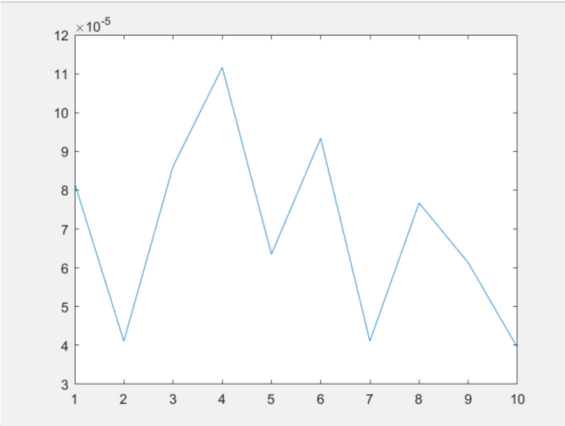
graph:



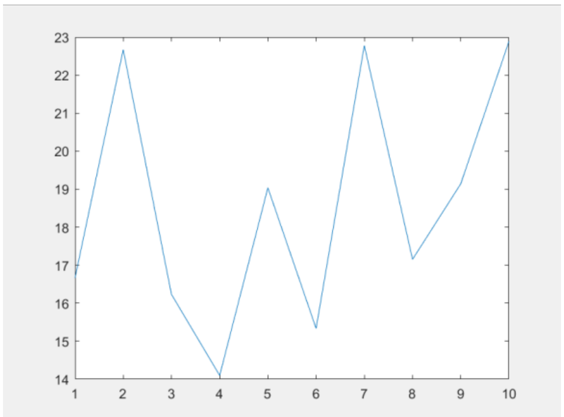


Plot the h_eq, error (in dBm) of R1 with ZFBF when d=200m:

graph of h_eq (x-axis: topology, y-axis: h_eq):



graph of error (x-axis: topology, y-axis: dBm):



Analysis:

The reason that h_eq will be different in different rounds is in this code, channel H is be produced randomly and different H will produce different h_eq. This is also the reason why error varies across different rounds of experiments. If the channel between the row is more independent, then the h_eq will be larger and considering the formula to estimate the x, it is clear that larger h_eq will cause smaller error.

From the graphs above, we can also see that the correlation of h_eq and error is negative correlation. If h_eq increase, error is more likely to decrease, vice versa.

Answer the following questions in short:

What have you learned from this lab?

1. I learned the implementation's detail of how to execute analog beamforming and digital beamforming.
2. I have reviewed the step and the theory of analog beamforming and digital beamforming.
3. I have reviewed the calculation and the definition of SNR and INR.
4. I am more familiar to MATLAB after this lab.

What difficulty have you met in this lab?

Actually, the hardest thing I met in this lab is to understand each meaning of the variable and the size or type of it. The introduction of steering and beam from professor shared in Microsoft Teams have benefitted me a lot of understanding the meaning of the value in the gain table. And the detailed comment let me quickly know what each part's is doing about or calculating of. More, I have searched online for some code that is not so familiar to me. I also go read through the slide of lecture 9 when I was doing this lab. I think these methods help me overcome this difficulty and finish this lab.