# Massive MIMO Laboratory Report

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Consider a single Massive MIMO BS with M antennas and K users and transmission based on Conjugate Beamforming and Zero Forcing.

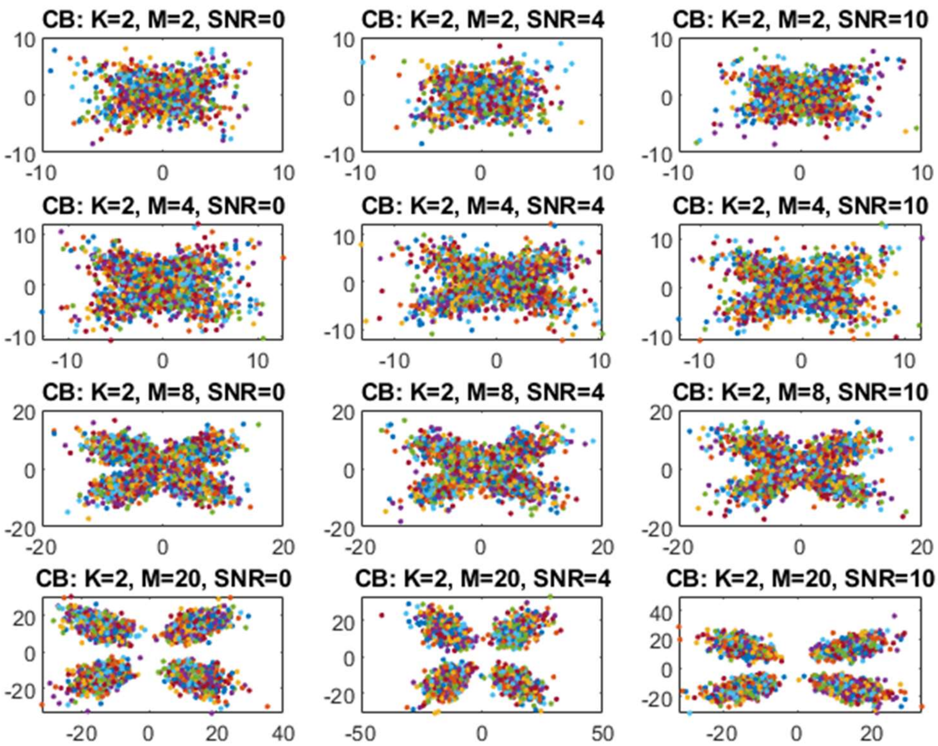
1. Plot the resulting constellation for the transmission of 1000 QPSK symbols for EbN0 = {0, 4,10} dB in the following cases:

1.1. K = 2, M = {2, 4, 8, 20}

1.1.1. <u>Conjugate Beamforming</u>

In conjugate beamforming, the hemitian of the channel is used as precoding, trying to obtain that the product of the channel and the precoding matrix A=H*W is a diagonal matrix.

Its main advantage is its simplicity and efficient power consumption.



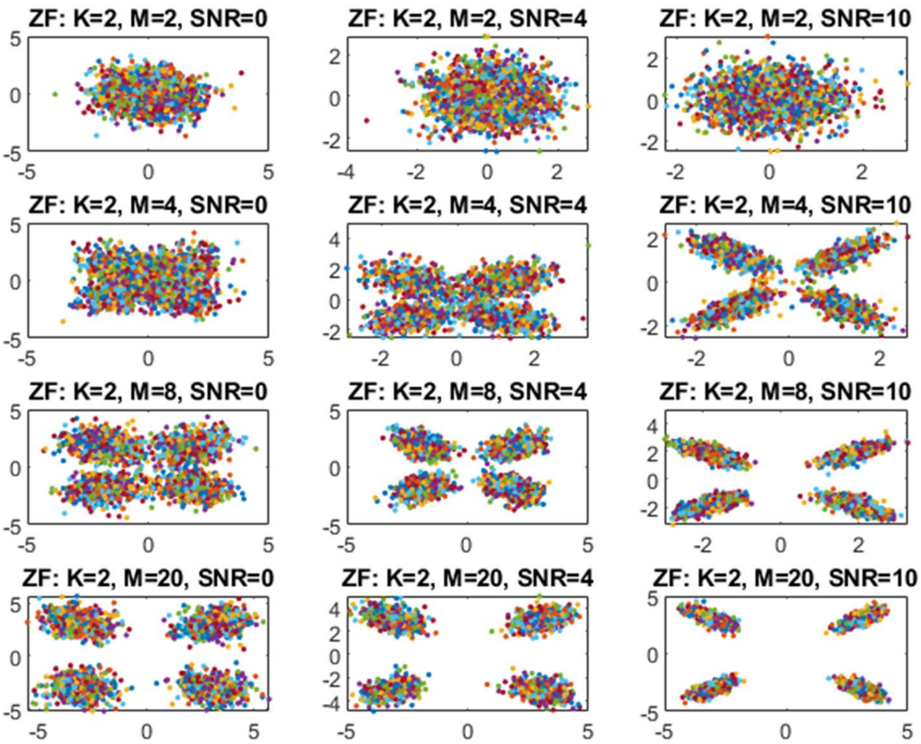

In the figure we can see that, for a low number of transmitting antennas, even if the SNR is good, the received signal will not be able to be demodulated, as the channel is not compensated properly (A is far away from being a diagonal matrix).

As the number of transmitting antennas is increased, we can see that the precoding is better, resulting in a better received signal that can be demodulated. In the figure, this case is only valid for M=20. As expected, the higher the SNR, the better signal is received.

### 1.1.2. Zero Forcing

In Zero Forcing, the precoding matrix is the pseudoinverse matrix of the channel (as inverse matrix computation has a large computational charge). It involves an estimation error, so A will not be an exact diagonal matrix.

It is more complex than conjugate beamforming and it obtains better results, but its computational charge is higher (it can be noticed when running the simulation). Finally, tt is inefficient when channel gains $h_{ij}$ for a user j are close.



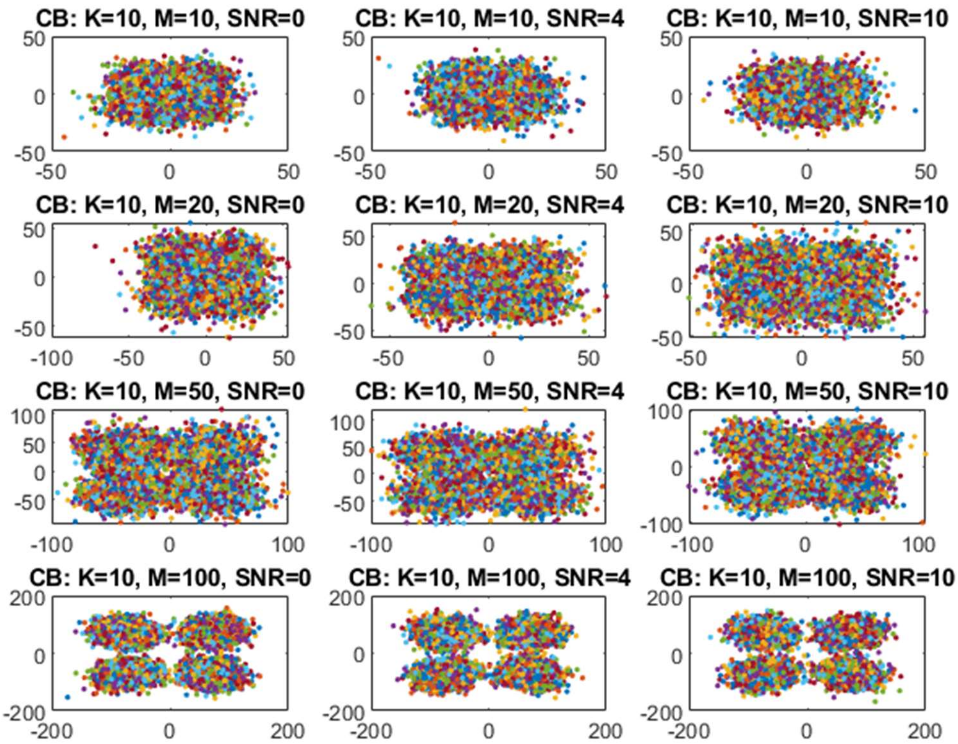

As in the case of conjugate beamforming, for a low number of transmitting antennas, even if the SNR is good, the received signal will not be able to be demodulated, as the channel is not compensated properly. However, the improvement of the received signal is performed for a lower number of M, resulting in that for M=4, if SNR is good enough, signal could be correctly demodulated.

Similarly to conjugate beamforming, as the number of transmitting antennas is higher, the estimation of the precoding matrix is better, so the received signal will have a better quality.

1.2. K = 10, M = {10, 20, 50, 100}

1.2.1. <u>Conjugate Beamforming</u>

As the number of users is increased, the minimum number of transmitting antennas must be increased too (it must be at least equal to the number of users). Due to its simplicity, simulations are expected to behave worse for smaller M.

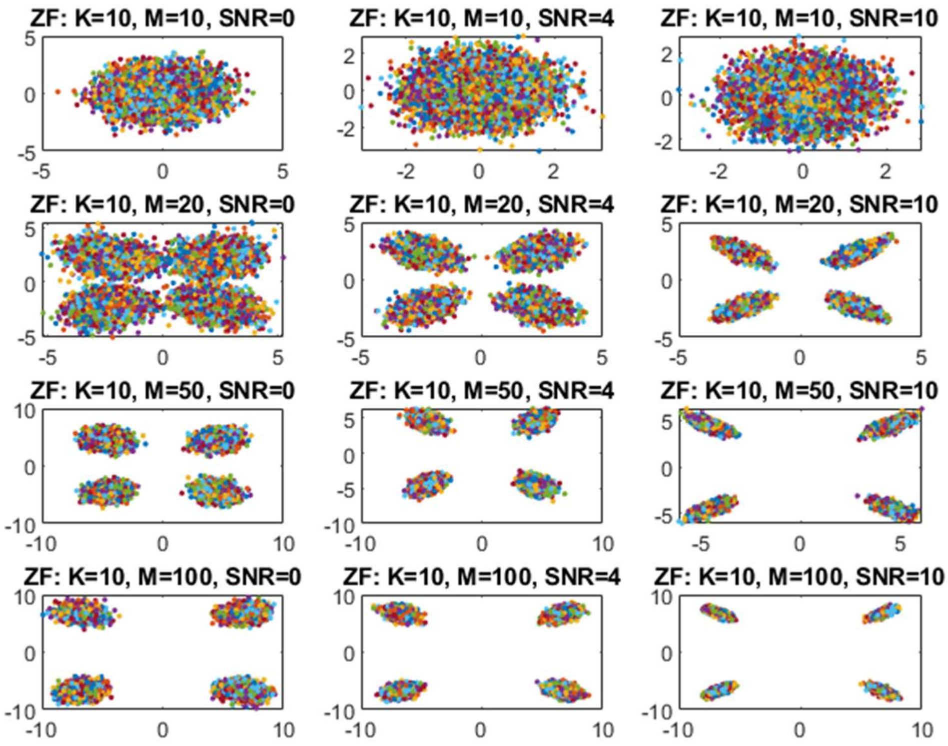



In the figure we can see that the quality of the received signal is much worse than in cases where K was lower. That is because of multi-user interference.

As the number of transmitting antennas is higher, the precoding estimation is better. However, in this figure we can see that for a quite correct received signal's quality, the proportion between K and M is ~10 (higher than for low users, where it was ~4)

### 1.2.2. Zero Forcing

As commented before, as this precoding estimation is more complex, results are expected to be better than for conjugate beamforming.



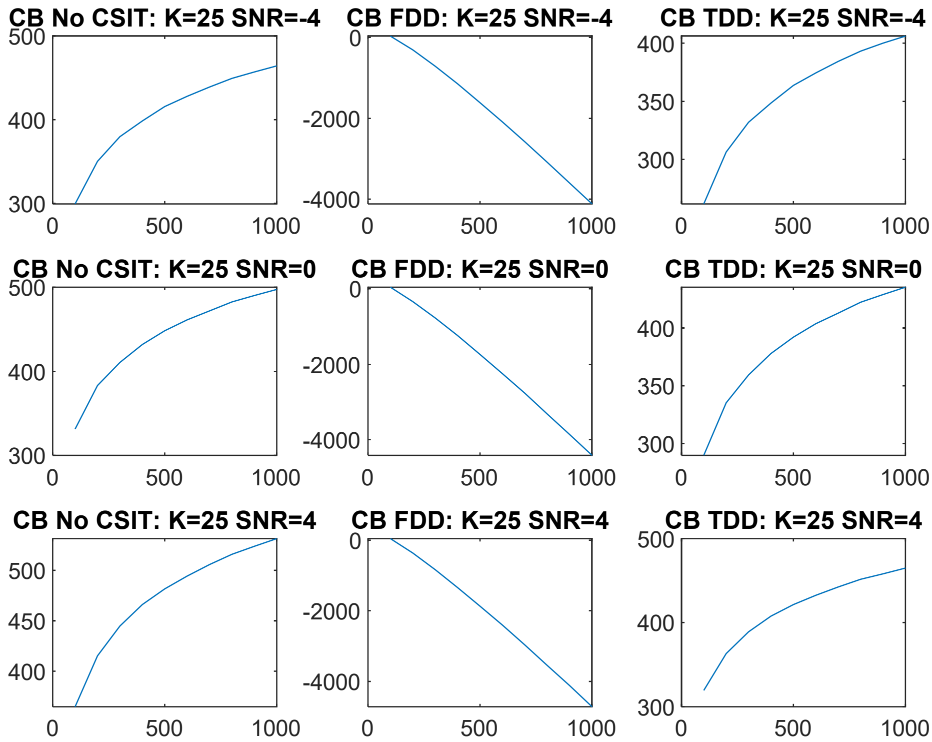

As expected, the estimation of the precoding matrix is not good when the number of transmitting antennas is low. However and contrary to conjugate beamforming estimation, the improvement can be noticed when the ratio of users and transmitting antennas is 2 (even for not so good SNR values).

You can also notice that it is true that this estimation has better performances for a higher number of antennas: if we compare this case with the zero forcing when K=2, in the current scenario the estimation is much better and the signal can be demodulated with a ratio of 2 but in the previous case it was not possible (considering the same SNR).

2. Considering a coherence block of 200 symbol extensions and a SNR [dB] = {-4, 0, 4}, obtain the achievable rate regarding the number of transmit antennas for K = {25, 10, 100} users

2.1. K = 25

2.1.1. <u>Conjugate Beamforming</u>




2.1.1.1. No CSIT

In the first columns of the figure we can see that capacity gets bigger if there are more transmitter antennas (diversity increases). The capacity seems to have an asymptote when a number of M is reached. As expected, the higher the SNR, the better the capacity is.

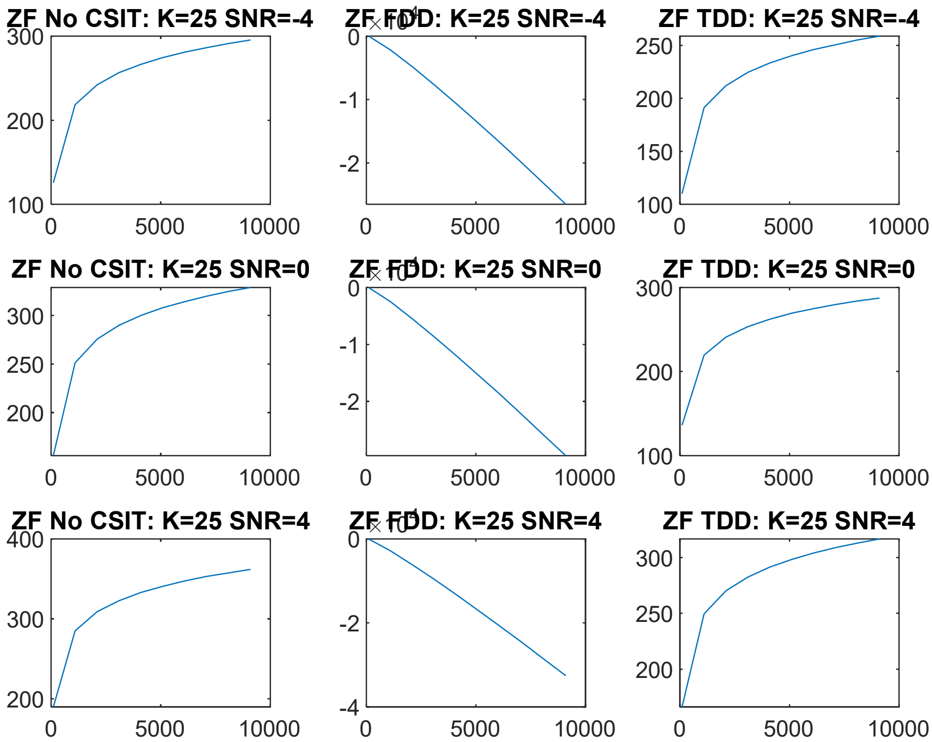
2.1.1.2. FDD

In the second column we can see negative capacity values (no sense in real life) as the number of pilots is larger than the data size.

2.1.1.3. TDD

In the third column we can see a similar graphic than for No CSIT, but with smaller capacity values (pilots reduce effective data). It also seems to have an asymptote and the capacity is higher when SNR is better.

### 2.1.2. Zero Forcing




2.1.2.1. No CSIT

In the first columns of the figure we can see that capacity gets bigger if there are more transmitter antennas (diversity increases). The capacity seems to have an asymptote when a number of M is reached. As expected, the higher the SNR, the better the capacity is.

Compared with Conjugate Beamforming we can see that the capacity is smaller.

2.1.2.2. FDD

In the second column we can see negative capacity values (no sense in real life) as the number of pilots is larger than the data size.

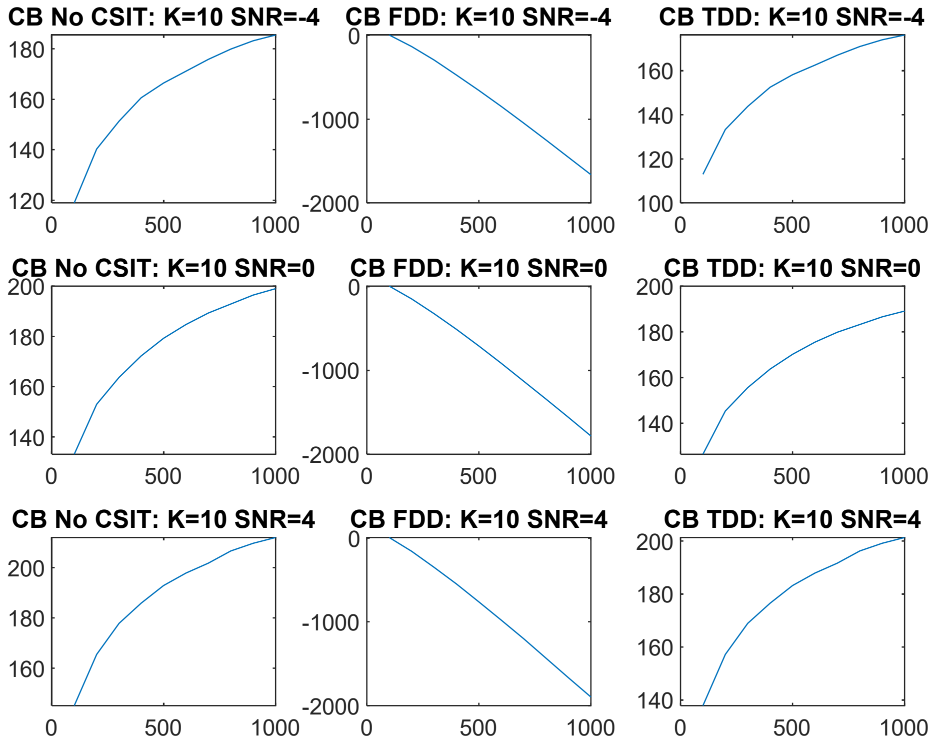
2.1.2.3. TDD

In the third column we can see a similar graphic than for No CSIT, but with smaller capacity values (pilots reduce effective data). It also seems to have an asymptote and the capacity is higher when SNR is better.

As for no CSIT, compared with Conjugate Beamforming we can see that the capacity is smaller.

2.2. K = 10

2.2.1. Conjugate Beamforming




2.2.1.1. No CSIT

In the first columns of the figure we can see that capacity gets bigger if there are more transmitter antennas (diversity increases). The capacity seems to have an asymptote when a number of M is reached. As expected, the higher the SNR, the better the capacity is.
Compared with the first scenario, we can see that the capacity is smaller as the number of transmitting antennas is lower.

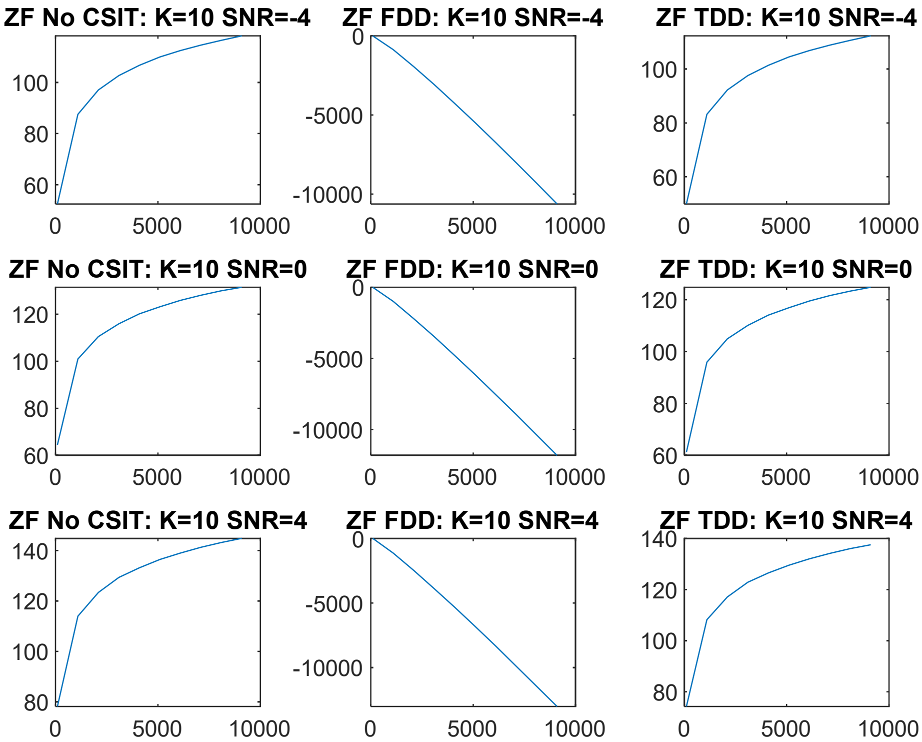
2.2.1.2. FDD

In the second column we can see negative capacity values (no sense in real life) as the number of pilots is larger than the data size. The capacity is higher (less negative) than for greater M antennas as the total information size is smaller.

2.2.1.3. TDD

In the third column we can see a similar graphic than for No CSIT, but with an slightly smaller capacity values (pilots reduce effective data, but as the number of users is lower, the number of pilots also is smaller). It also seems to have an asymptote and the capacity is higher when SNR is better.
Similarly than in No CSIT scenario, we can see that the capacity is smaller if M is smaller, as the number of transmitting antennas is lower.

### 2.2.2. Zero Forcing




#### 2.2.2.1. No CSIT

In the first columns of the figure we can see that capacity gets bigger if there are more transmitter antennas (diversity increases). The capacity seems to have an asymptote when a number of M is reached. As expected, the higher the SNR, the better the capacity is.
Compared with Conjugate Beamforming we can see that the capacity is smaller, as it also is smaller for Zero Forcing with more transmitting antennas.

#### 2.2.2.2. FDD

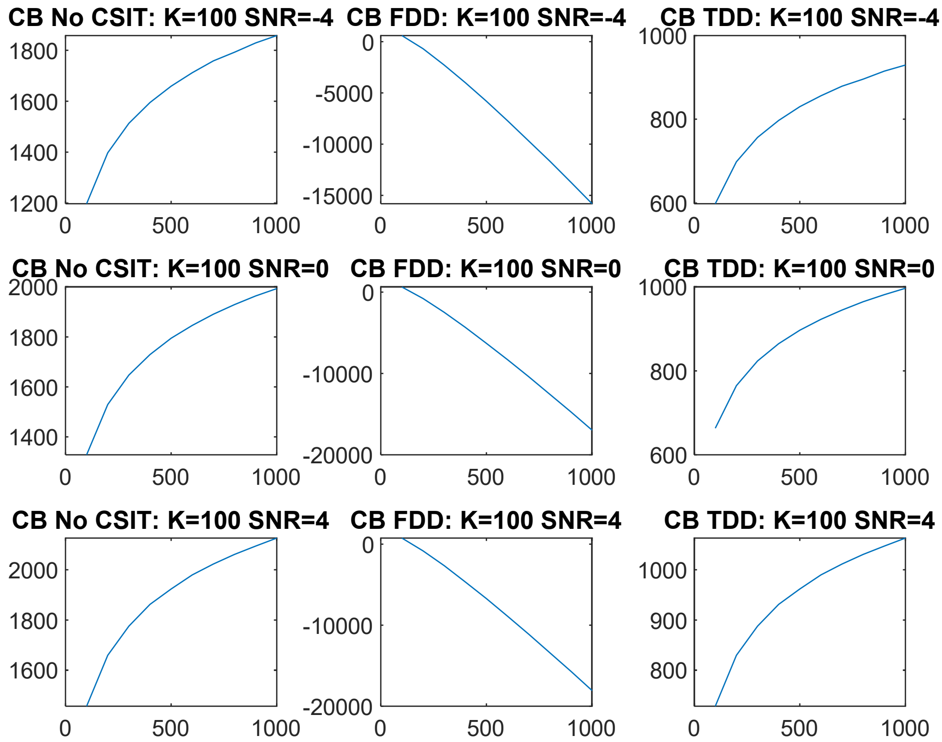
In the second column we can see negative capacity values (no sense in real life) as the number of pilots is larger than the data size.

#### 2.2.2.3. TDD

In the third column we can see a similar graphic than for No CSIT, with almost the same values (the number of needed pilots is lower). It also seems to have an asymptote and the capacity is higher when SNR is better.
As for no CSIT, compared with Conjugate Beamforming we can see that the capacity is smaller, as it also is smaller for Zero Forcing with more transmitting antennas.

2.3. K = 100

2.3.1. Conjugate Beamforming




2.3.1.1. No CSIT

In the first columns of the figure we can see that capacity gets bigger if there are more transmitter antennas (diversity increases). The capacity seems to have an asymptote when a number of M is reached. As expected, the higher the SNR, the better the capacity is.
Compared with the first scenario, we can see that the capacity is bigger as the number of transmitting antennas is greater.

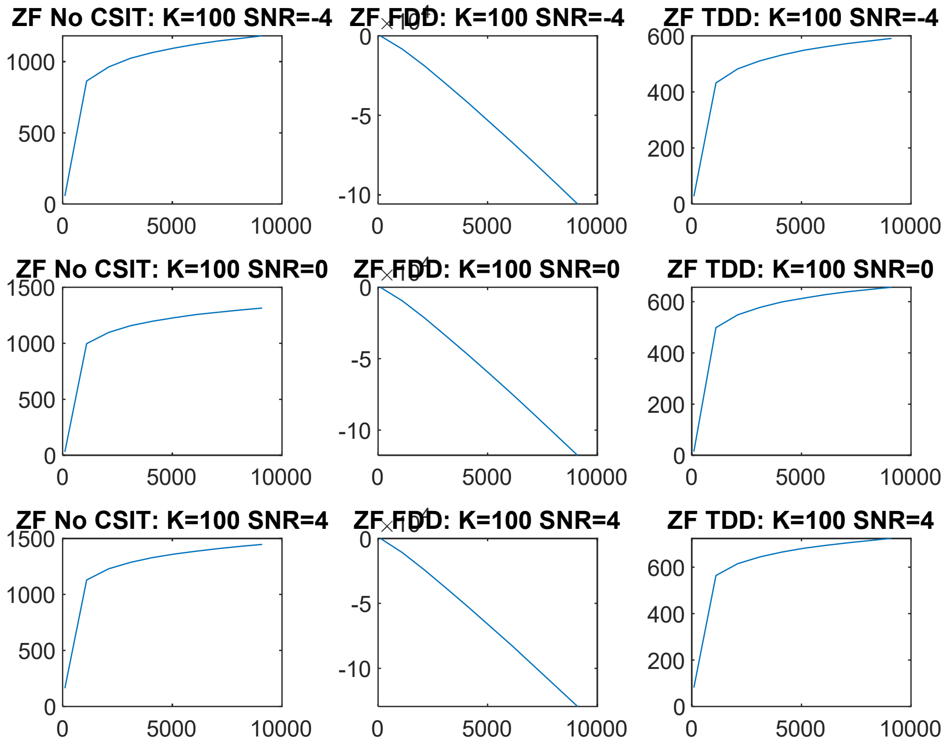
2.3.1.2. FDD

In the second column we can see negative capacity values (no sense in real life) as the number of pilots is larger than the data size. The capacity is higher (less negative) than for greater M antennas as the total information size is smaller.

2.3.1.3. TDD

In the third column we can see a similar graphic than for No CSIT, but with smaller capacity values (pilots reduce effective data). The difference is greater than for less users, as more pilots are needed. It also seems to have an asymptote and the capacity is higher when SNR is better.
Similarly than in No CSIT scenario, we can see that the capacity is smaller if M is smaller, as the number of transmitting antennas is lower.

2.3.2. <u>Zero Forcing</u>




2.3.2.1. No CSIT

In the first columns of the figure we can see that capacity gets bigger if there are more transmitter antennas (diversity increases). The capacity seems to have an asymptote when a number of M is reached. As expected, the higher the SNR, the better the capacity is.

Compared with Conjugate Beamforming we can see that the capacity is greater, as it also is higher than for Zero Forcing with less transmitting antennas.

2.3.2.2. FDD

In the second column we can see negative capacity values (no sense in real life) as the number of pilots is larger than the data size.

2.3.2.3. TDD

In the third column we can see a similar graphic than for No CSIT, with a bigger difference as for more users, more pilots are needed. It also seems to have an asymptote and the capacity is higher when SNR is better.

As for no CSIT, compared with Conjugate Beamforming we can see that the capacity is smaller, and it is greater than for Zero Forcing with less transmitting antennas.