PMI Selection Algorithm for 5G codebook

A Project Report

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THESIS CERTIFICATE

This is to certify that the thesis titled PMI Selection Algorithm for 5G codebook, submitted by **Anit Tomy**, to the Indian Institute of Technology, Madras, for the award of the degree of **Dual Degree**, is a bonafide record of the research work done by her under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: LTE, MIMO, FD-MIMO, CSI, PMI, precoding, beamforming, DFT, PMI, Multiantenna transmission,OMP

In this project, I am finding a new algorithm for PMI selection for type 2 codebook and comparing it with existing PMI selection methods for type 1 codebook. There are conventional methods based on explicit codebook search based on mutual information. And SVD method which finds the best matrix based on SVD of the channel. The best method is search free algorithm, which directly estimates the best PMI from singular vectors of channel matrix. The search free algorithm exploits the DFT structure of the codebook by estimating the linear phase ramping of the sequence. In this method the complexity does not scale with the size of the codebook. The proposed method for PMI selection for codebook type 2 uses OMP(Orthogonal matching pursuit) in wideband and MI based exhaustive search in subband.

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ABBREVIATIONS

NR	New Radio
CSI	Channel State Information
PMI	Precoding Matrix Indicator
RI	Rank Indicator
CQI	Channel Quality Indicator
MI	Mutual Information
SVD	Singular Value Decompostion
SNR	Signal to Noise Ratio
MMSE	Minimum Mean Square Error
DFT	Discrete Fourier Transform
MIMO	Multiple Input Multiple Output
SINR	Signal to Interference and Noise Ratio
OMP	Orthogonal Matching Pursuit
uE	user Equipment
gNB	gNodeB

CHAPTER 1

INTRODUCTION

1.1 Multi-antenna transmission

In 5G, multiple antennas are used for transmission and reception. Multiple antennas provide diversity, spatial multiplexing by exploiting correlation between antennas. Correlation between antennas depends on inter-antenna distance and polarization between antennas. By adjusting the phase,amplitude of each antenna element, multiple antennas are used for beamforming. The overall transmitted power is focused to certain direction or location in space. As a result of beamforming, datarates and range available to each user can be increased. Beamforming also reduces inference between users. It improves overall spectral efficiency. As mulltiple transmission antennas provide beamforming at transmission, multiple receiver antennas provide beamforming at receiver. Receiver side beamforming suppresses the interference from other directions

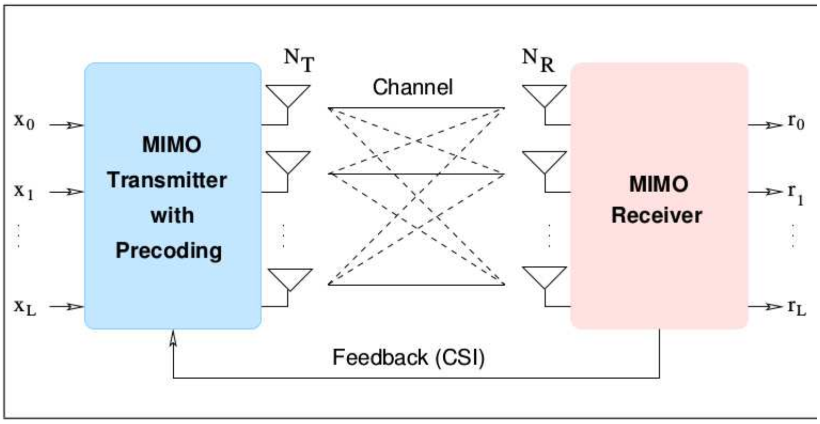

Figure 1.1: Multiantenna transmission

Mutiantenna transmission and reception makes diversity, beamforming and spatial multiplexing possible and as a result high data rates and system efficiency. Spatial multiplexing is the transmission of multiple layers in parallel using same time or frequency resources. Multiple antennas are used in 5G NR as 5G deploys higher frequencies compared to LTE. At higher frequencies, propagation loss is higher due to higher atmospheric attenuation and less diffraction leading to degraded non LOS propagation. The gain from beamforming at transmitter and receiver and LOS links allows long range communication despite the losses due to high frequencies.

As uEs are located at different locations with respect to base station, an highly directional antenna is not so useful, instead an antenna panel consisting of many small elements having similar effect is suggested. The dimension of and distance between antenna elements is proportional to the wavelength. As frequency increases, mutual distance is reduced. Benefit of multiple small antennas instead of a single large antenna is that the direction of the transmitter beam can be adjusted by separately adjusting the amplitude and phase of the signals received at each antenna element. This method is also applicable on receiver side.

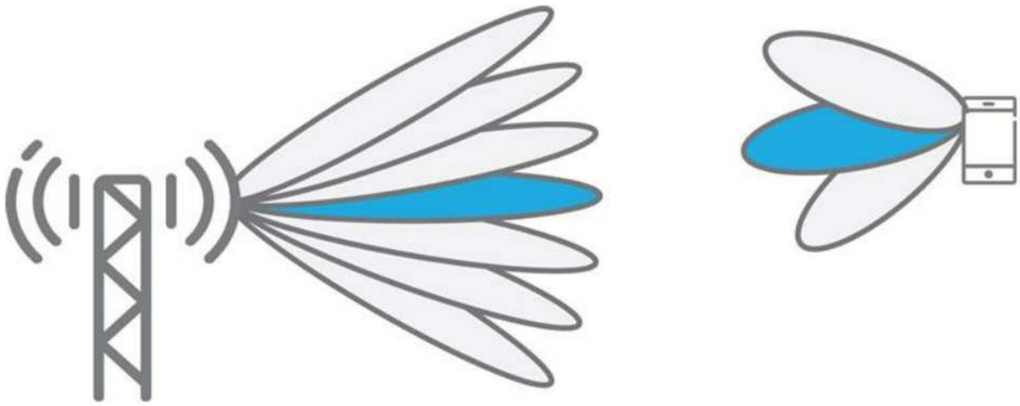

Figure 1.2: Beamforming

When unequal number of antennas are present at transmitter and receiver of a MIMO system, spatial multiplexing and diversity can be combined for better performance. The performance of MIMO system depends on SINR , polarization and number of antennas at both ends and correlation between individual wireless channels. Low antenna spacing results in higher antenna correlation and lower channel rank and less capacity. The transmitter should know the rank of the channel for adopting the best transmission mode. Spatial multiplexing works better for a high rank system and beam forming for a rank deficient system for better performance. These operations are effectively done by precoding the signal to be transmitted using multiple antennas.

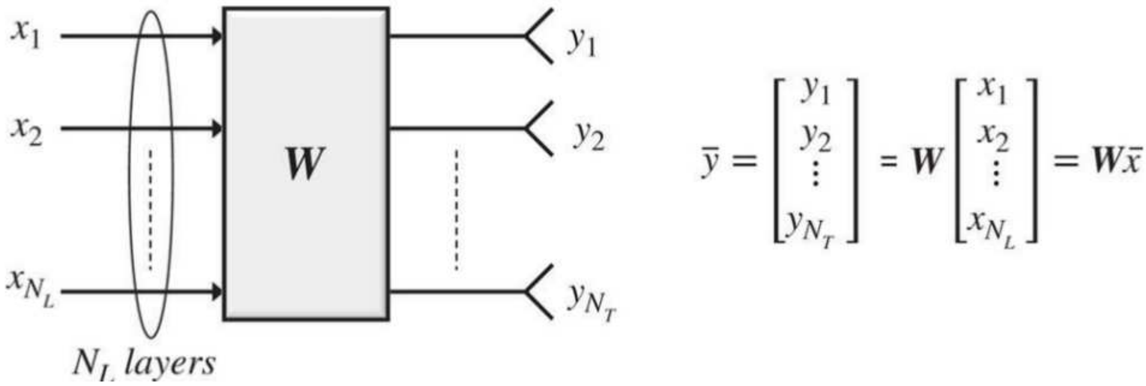

Figure 1.3: Precoding and codebook

1.2 Precoding and codebook

Precoding is the superposition of multiple beams for spatial multiplexing of several data streams. It exploits the direction of strongest eigen vector. Precoding is similar to equalization and makes equalization at receiver easier. Precoding and equalization improves SINR and channel capacity. Ideal precoding is based on SVD. In practice, ideal precoding is not possible due to the high feedback overhead. To save the feeback overhead, codebook based precoding is used. In this method a codebook is constructed and available at both transmitter and receiver. The receiver selects the best precoding matrix from the codebook based on channel and sends the index to the transmitter as feedback. The size of codebook determines the quality of precoder. The size is limited by the number of feedback bits. Precoding results in low complexity in symbol decoding.

The receiver reports CSI to the transmitter and the CSI report consists of following:

1. **Rank Indicator (RI)**, indicates a suitable transmission rank, that is, a suitable number of transmission layers or streams for the downlink transmission that can be supported in MIMO.
2. **Precoder-Matrix Indicator (PMI)**, indicates the index of the codebook for precoding, given the selected rank.
3. **Channel-Quality Indicator (CQI)**, indicates the best modulation and coding scheme that can be operated for the subsequent transmission, given the selected precoder matrix.

The process of codebook based precoding is as follows:

1. gnB(Base station) sends CSI-RS (Channel State Information Reference signal) to UE.

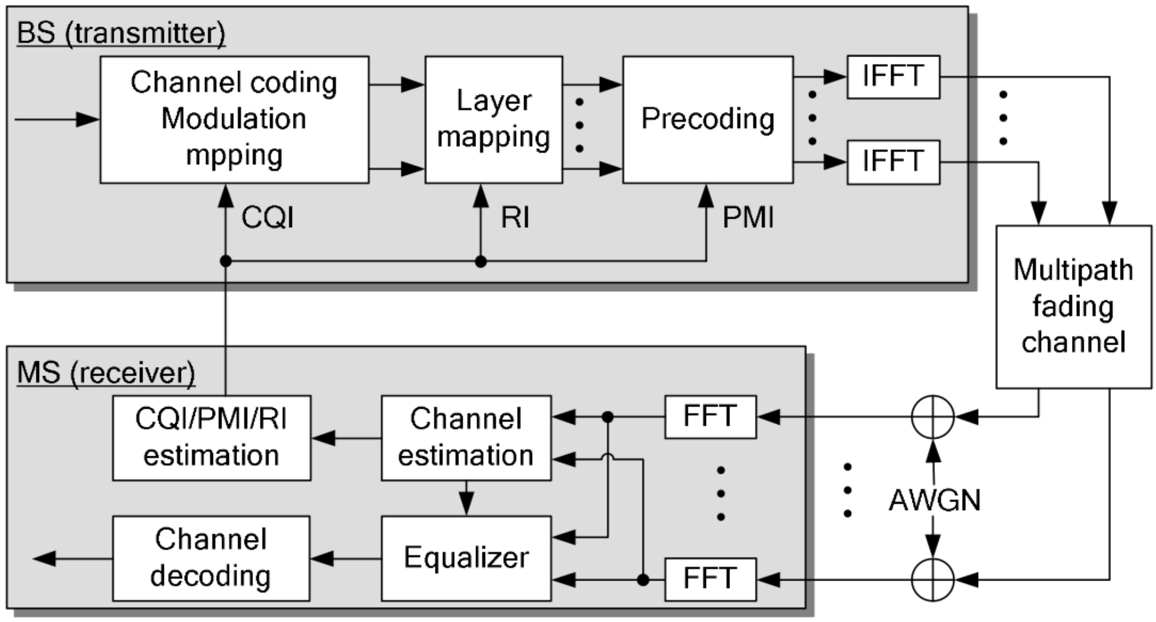

Figure 1.4: CSI Reporting

2. UE gets CSI(Channel State Information) from CSI-RS(by estimating channel).
3. UE chooses precoding matrix from codebook based on CSI.
4. UE feedsback a PMI (Precoding Matrix Indicator).
5. gnB chooses precoding matrix from codebook based on PMI(Need not be same precoder).
6. gnB applies the spatial domain precoding on the data and send the verifying information of the precoding matrix.
7. uE obtain the PMI and choose the precoding matrix from the codebook based on PMI.
8. gnB sends the precoded data.
9. uE demodulate the data using the precoding matrix.

The uE reports the PMI from codebook which it believes is the best for it in downlink. But the base station need not neccesarily use the precoder indicated by the uE. Base station can select any precoding matrix, it need not even be in the predefined codebook. This happens in MU-MIMO when network also need to taken into consideration to reduce the interference between users. It takes into account the PMI reported by all the devices.

MU-MIMO scenario requires more detailed knowledge of the channel experienced by each device, compared to precoding in the case of transmission to a single device.

For this reason, NR defines two types of CSI that differ in the structure and size of the precoder codebooks, Type I CSI and Type II CSI.

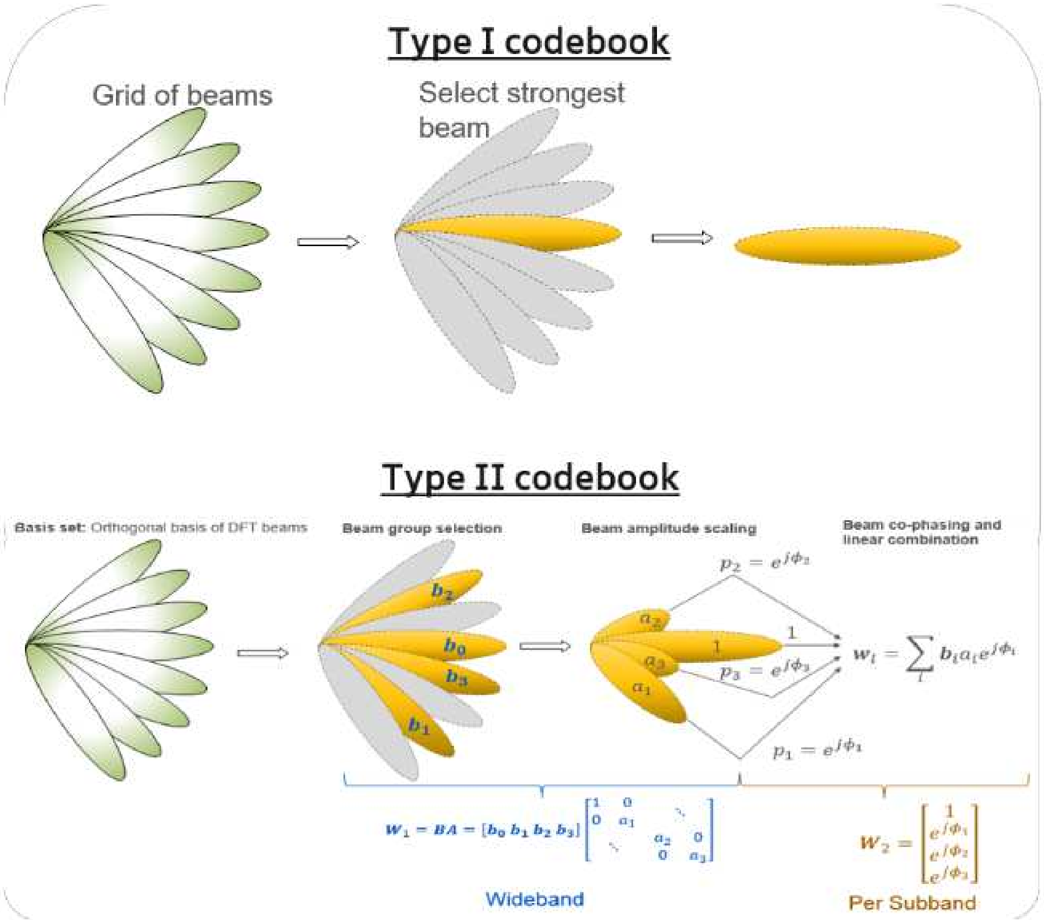

Figure 1.5: Type 1 and Type 2 codebook

1.2.1 Type I CSI

Type I CSI is simple and aim at focusing the transmitted energy to a single user. MU-MIMO is not taken into consideration. It is focused on higher order spatial multiplexing. It doesnot take into consideration the interference between the layers. PMI report consists of atmost few tens of bits.

Codebooks are designed assuming crosspolarized antennas. The precoder matrices W in the codebook can be expressed as product of two matrices W1 and W2. W1 matrix is reported in wideband basis and captures long term frequency independent characterstics of the channel. W2 is reported in subband basis and captures short term frequency dependent characterstics. Wideband is the entire reporting bandwidth and subband is the fraction of overall reporting bandwidth.

$$W = W1 * W2$$
$$W1 = \begin{bmatrix} B & 0 \\ 0 & B \end{bmatrix}$$

The matrix W1 defines a beam or a set of beams from codebook. W1 can be written in terms of B, where each columnn of B defines a beam or 4 beams and block structure is due to cross polarization. When B is only a single beam W2 only applies cophasing. When B have 4 beams, W2 selects the exact beam to be used and provides cophasing between the two polarizations.The Type I codebooks are supported up to rank-8.

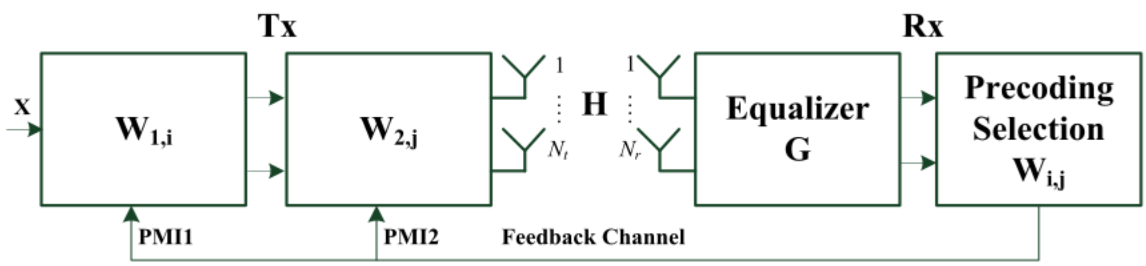

Figure 1.6: PMI Selection

Precoders in codebook have the following structure: each column of the precoding matrix (one for each layer) is a Kronecker product of three DFT vectors of length N_1 , N_2 , P , and with oversampling factors O_1 , O_2 , 2, respectively:

$b_1(l) = [1 \quad e^{j\frac{2\pi l}{O_1 N_1}} \quad ... \quad e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}}]^T$, which determines beam direction in horizontal direction

$b_2(m) = [1 \quad e^{j\frac{2\pi m}{O_2 N_2}} \quad ... \quad e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}]^T$, which determines the beam direction in vertical direction

$b_0(n) = [1 \quad \phi(n)\ ]^T$, where $\phi(n) = e^{j\pi n/2}$, which determines cophasing.

where $l \in 0, ..., O_1 N_1$, $m \in 0, ..., O_2 N_2$ and $n \in 0, .., 4$

The precoders w in codebook are defined as

$$w(l, m, n) = \frac{1}{\sqrt{Q}} b_0(n) \circledast (b_1(l) \circledast b_2(m))$$

where $\circledast$ is the Kronecker product. In the standard, the PMI reporting is done to three indices (i_{11},i_{12},i_2) which are mapped to l,m,n through predefined configurations.

1.2.2 Type II CSI

Type II CSI targets MU-MIMO scenario. Type II CSI is more extensive and aims at focusing the transmitted energy into multiple users simultaneously with limited number of layers (maximum of two layers) per device. Type II CSI provides channel with higher spatial granularity than type I. It takes into consideration the interference between the layers. PMI report consists of several hundreds of bits and has high signalling overhead. Applicable for low mobility scenario where the feedback periodcity is low. While Type I CSI selects one beam with cophasing, Type II CSI reports upto 4 beams. For each selected beam and polarization, the reported PMI provides an amplitude value (partly wideband and partly subband) and a phase value (subband). Base station selects which transmission to be done and what precoder to be used for each transmission from the PMI reported from multiple devices.

Type II employs a dual-stage W = W1W2 codebook where W1 is wideband and W2 is subband. Here different precoders can be of different amplitudes. W1 matrix selects L beams (L $\in$ $\{2, 3, 4\}$) which becomes the basis set for linear combination performed by W2. The same L beams are used for both polarization. The amplitude components of LC coefficients is composed of wideband and subband components. The phase component is subband and can be QPSK or 8-PSK. For L=4,

$$W1 = BA = [b_0 \;\; b_1 \;\; b_2 \;\; b_3] \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & a_1 & 0 & 0 \\ 0 & 0 & a_2 & 0 \\ 0 & 0 & 0 & a_3 \end{bmatrix}, \; W2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c_1 & 0 & 0 \\ 0 & 0 & c_2 & 0 \\ 0 & 0 & 0 & c_3 \end{bmatrix} \begin{bmatrix} 1 \\ e^{j\phi_1} \\ e^{j\phi_2} \\ e^{j\phi_3} \end{bmatrix}$$

where b_i's are beams, a_i's are wideband amplitudes, and c_i's are subband amplitudes $a_i \in \{1, \sqrt{.5}, \sqrt{.25}, \sqrt{.125}, \sqrt{.0625}, \sqrt{.0313}, \sqrt{0.0156}, 0\}$ and $c_i \in \{1, \sqrt{.5}, 0\}$. W1 does the selection of beams and wideband amplitude. W2 does subband amplitude and cophasing.

CHAPTER 2

Problem statement

2.1 Problem Formulation

There are several existing algorithms for codebook type 1 as exhaustive MI based search method, SVD based method, Search free algorithm. Our aim is to implement an algorithm for codebook type 2. Since Type 2 codebook is extensive, search methods are not possible due to time complexity. We have to implement an algorithm which returns PMI based on the channel conditions for codebook type 2.

2.2 Channel model

The extended vehicular A (EVA) channel model as specified in the 3rd generation partnership project (3GPP) is considered for the simulation. System model assumes independent channel realizations and hence no doppler frequency is used. The Kronecker model has been used for this MIMO channel. The matrix H_t which represents the channel tap is generated in the time domain with the correlation matrices as follows,

$$H_t = \frac{1}{\sqrt{tr(R_{UE})}} R_{UE}^{1/2} G (R_{eNB}^{1/2})^T$$

where, G is the channel matrix containing independent complex Gaussian entries with size $N_R \times N_T$. The eNB and UE correlation matrices are R_{eNB} and R_{UE} , respectively. Three different correlation levels are also defined and used in the simulations: (i) low (ii) medium and (iii) high correlation. R_{eNB} is based on the distance between the adjacent transmit antennas and it is specified using a parameter α. R_{UE} is based on the distance between the adjacent receive antennas and it is specified using a parameter β. The parameters α and β are defined for each level of correlation: $\alpha = 0$ and $\beta = 0$ for low correlation, $\alpha = 0.3$ and $\beta = 0.9$ for medium correlation, $\alpha = 0.9$ and $\beta = 0.9$ for

high correlation.
Finally, the channel matrix H_k for kth subcarrier in the frequency domain is obtained by taking the Fast Fourier transform (FFT) of the time domain matrix H_t. For channel, an in built function based on [3] is used. The function returns channel based on correlation for 20MHz channel and for 1200 subcarriers. 1200 subcarriers is taken as wideband and 60 subcarriers are taken as subband.

2.3 System Model

We consider a multi antenna system with N_1 horizontal antennas and N_2 vertical antennas and diversity factor $P = 2$, which indicates cross polarization at transmitter. Total number of tx antennas is $2N_1N_2$.

The recieved symbol vector **y** is given by

$$\mathbf{y} = \mathbf{HWx} + \mathbf{n}$$

where **x** is the symbols transmitted by the base station, **W** is the precoder, **H** is the channel matrix in the frequency domain and n is the complex guassian noise. The received symbol vector **y** is filtered by a linear MMSE equalizer **F**.The output of this filter is the post equalization symbol vector **r** is given by,

$$\mathbf{r} = \mathbf{Fy} = \mathbf{FHWx} + \mathbf{Fn}$$

$$\mathbf{F} = (\mathbf{\tilde{H}\tilde{H}^H} + \sigma_\mathbf{n}^\mathbf{2}\mathbf{I})^{-\mathbf{1}}\mathbf{\tilde{H}^H}$$

The effective channel $\tilde{H}$ is given by

$$\mathbf{\tilde{H}} = \mathbf{HW}$$

2.4 Existing Methods for PMI selection

The selection of PMI is dependent on RI. The selection of RI is the first step for CSI. RI is selected in wideband ie. for entire band of sub carriers. PMI is selected partly in wideband and subband. There are different papers on methods for RI selection and PMI selection for LTE. Only PMI selection methods are discussed here. In LTE, only codebook type 1 existed. Here we are discussing different methods for PMI selection for LTE. Each function takes channel and other parameters as inputs and returns the wideband PMI and subband PMI for the optimal precoder to be used.

2.4.1 Ideal precoding

Theoretically, the ideal precoding is based on the singular value decomposition (SVD), which creates a diagonal channel matrix and ensures no interference between the parallel streams. However in practice, ideal precoding is not possible due to the high overhead involved in the feedback of the complete CSI. SVD decomposition of the channel is done as $\mathbf{UDV^H} = \mathbf{H}$, where U and V are unitary matrices. $\mathbf{V}$ is the ideal precoder. When we use $\mathbf{V}$ as the precoder, channel achieves the maximum capacity. But this is not practical since infinite information is not possible to give as feedback. V cannot be used since giving V as feedback to transmitter includes a lot of overhead. So quantization is done and codebook is constructed at both sides. All other methods are compared with this method.

2.4.2 SVD based method

In this method, rank is selected based on SVD decomposition. RI can be selected upto layer 4. For selecting PMI, perform SVD on each subcarrier channel matrix.

$$\mathbf{H} = \mathbf{UDV^H}$$

The matrix P after equalizing the effective channel is given by

$$\mathbf{P} = \mathbf{U^H HW} = \mathbf{DV^H W}$$

Then the PMI is selected by maximizing the average sum of diagonal elements of the effective channel over wideband for wideband PMI and over sub-band for subband PMI.

$$\mathbf{W_i} = \mathbf{arg}(\mathbf{max}_{\mathbf{W} \in \mathbf{Codebook}}(\sum \mathbf{P}(\mathbf{j}, \mathbf{j})))$$

Complexity scales up with the size of codebook since search is involved.

2.4.3 MI based Exhaustive search

This method is the conventional method and gives the best performance using codebook type 1. In this method, we search through the all possible ranks, precoders in the codebook and finds the precoding matrix which maximizes the channel capacity.

First the rank and first PMI is selected. By using selected rank and the first PMI, the second PMI is selected based on which maximizes the subband capacity.

MMSE equalizer is assumed to be used. The post-equalization SINR for layer l is calculated as follows:

$$SINR = \frac{|K(l,l)|^2}{\Sigma_{j \neq l}|K(l,j)|^2 + \sigma_n^2 \Sigma_j |F(l,j)|^2}$$

where $K = F\tilde{H}$. The first term inter-stream interference and the seond term noise are taken into consideration in denominator while calculating SINR. The mutual information for each subcarrier and each layer and for all precoding matrices is given as:

$$I_i = log_2(1 + SINR_i)$$

This layer specific mutual information for each layer will be used to find out the RI and PMI. The mutual information can be averaged over the entire band of subcarriers and added over layers. Adding this mutual information over the layers is the capacity of a whole system.

$$\mathbf{Capacity_i} = \sum_{\mathbf{layers}} \mathbf{I_i}$$

The RI and wideband PMI are selected by maximizing the capacity. The mutual information is averaged over sub-band and added over layers. Adding this mutual information over the layers gives the capacity of a sub-band.Then the sub-band PMI is selected by maximizing the subband capacity.

$$\mathbf{W_i} = \mathbf{arg}(\mathbf{max}_{\mathbf{W} \in \mathbf{Codebook}}(\mathbf{Capacity_i}))$$

Complexity scales up with the size of codebook since search is involved. MS estimates the optimum precoding matrix from all possible precoding matrices which are predefined as the codebook. When such an exhaustive search algorithm is utilized, the MS needs huge computation power because the number of rank and precoding matrix patterns is large.

2.4.4 Search free algorithm

This algorithm selects the PMI without explicit codebook search. It exploits the DFT structure of the codebook and finds PMI using method for estimating the linear phase ramping of a sequence and directly estimates PMI from singular vectors of the channel matrix. Complexity does not depend on the size of codebook without affecting the performance much.

The ideal precoder which maximizes capacity for channel H is V where $H = U \Sigma V^H$. In this method we express V as the sum of closest precoder in codebook and an error term.

$$v = e^{-j\phi} w(l, m, n) + e$$

where v is the first column of V , w is the closest precoder and e is the error term. We estimate l,m and n where $\theta_l = \frac{2\pi}{O_1 N_1} l$, $\theta_m = \frac{2\pi}{O_1 N_1} m$, $\theta_n = \frac{\pi}{2} n$ and find PMI feedback from l, m, n to be given to transmitter.

To find m, we consider v like this:

$$v = \begin{bmatrix} v_{2,0} \\ . \\ . \\ . \\ v_{2,N_1 P-1} \end{bmatrix} = \begin{bmatrix} b_2(m) b_{1,0}(l) \\ . \\ b_2(m) b_{1,N_1-1}(l) \\ b_2(m) b_{1,0}(l) \phi(n) \\ . \\ b_2(m) b_{1,N_1-1}(l) \phi(n) \end{bmatrix}$$

We estimate $\hat{\theta_m}$ by applying linear phase estimation to each vector as

$$\hat{\theta_m} = \angle \left(\sum_{i=0}^{N_1 P-1} \sum_{k=0}^{N_2-2} v_{2,i,k}^{*} v_{2,i,k+1} \right)$$

Similarly we estimate l and n and find the precoding matrix from codebook. Because of the Kronecker structure, we have three different tones. We use linear phase estimation to find out PMI. To get wideband PMI the SVD of channel averaged over the wideband is used and over subband to get subband PMI.

CHAPTER 3

Our approach

3.1 New method

In this method, we are considering a new method for PMI selection algorithm for codebook type 2. We are using orthogonal matching pursuit for finding the beams and amplitude in wideband and MI based exhaustive search method for finding subband amplitude and co-phasing. Using the orthogonal matching pursuit algorithm, we find the beams and coefficients required to represent v in wideband.

3.1.1 Orthogonal matching pursuit

This algorithm finds $\vec{x}$ such that min $||\vec{x}||_0$ subject to $\vec{y} = \phi\vec{x}$ where $\phi = [\tilde{\phi}_1\ \tilde{\phi}_2\ ..\ \tilde{\phi}_N]$ and $\vec{x} = [x_1\ \ x_2\ \ ..\ x_N]^T$

We find the projection of $\vec{y}$ in each of columns of ϕ and thus find $\vec{y}$ as the linear combination of columns of ϕ.

Find the column $i(1)$ of ϕ that has largest correlation of projection with $\vec{y}$.

$$i(1) = argmax_j|\tilde{\phi}_j^{\,T}\vec{y}|$$

Choose the column that has maximum projection $A_{(1)} = [\tilde{\phi}_{i(1)}]$ .This is the first iteration and using the basis matrix $A_{(1)}$ we find the estimate of $\vec{x}$ as

$$\hat{x}^{(1)} = (A_{(1)}^T A_{(1)})^{-1} A_{(1)}^T \vec{y}$$

We continue the next iteration by minimizing $||\vec{y} - A_{(1)}\vec{x}||$.

By repeating the iteration n times, we can find n columns of ϕ which are basis for $\vec{y}$ and the coefficients $\vec{x}$.

We do orthogonal matching to find the beams and wideband amplitudes. Here y is the strongest eigen vector of V. V is obtained by the SVD of the channel H. $H = UDV^H$. ϕ is the set of all beams and L beams for wideband are selected by orthogonal matching. The indices of nonzero elements in x give the indices of beams in ϕ for wideband. L number of iterations are performed to get L non zero indices to get L beams. The values in wideband amplitudes which are closest to the elements in x are chosen for wideband amplitudes.

3.2 Difference from other methods

We have seen the existing methods for PMI selection in LTE. In LTE, only codebook type 1 existed. In NR, codebook type 2 was incorporated. We cannot do the MI based or SVD based exhaustive search method since the codebook type 2 is complex and extensive. Search complexity is much higher and takes more time if implemented for type 2. Search free algorithm, which exploits the DFT structure of type 1 codebook is not possible since precoders in codebook type 2 does not have DFT structure. We are considering only rank 1 for simulation. Since the type 2 precoding vector is a combination of L beams, we are using orthogonal matching and performed L iterations to find the L beams and corresponding amplitudes in wideband. To find the subband amplitudes and cophasing, we use MI based exhaustive search and found out the best subband amplitudes and cophasing which maximizes capacity. When compared to other methods, it has less search complexity than exhaustive search methods, but more search complexity than search free algorithm since search is involved in subband and not in wideband. The feedback overhead is more for OMP based method since it is for codebook type 2.

3.3 Implementation

Codebook type 1 and 2 was implemented in MATLAB. Different functions for each method was implemented. Each function takes the channel H and multi-antenna information such as N1, N2, mode etc. and returns the wideband and subband PMI based on the inputs. The capacity that can be achieved when using the returned PMI is calculated. The performance of the new method was compared with the existing methods for codebook type 1. The metric for the performance of a method is the total capacity. Capacity was calculated based on mutual information. Capacity v/s SNR plots are plotted for each method and compared. In the simulation we fixed N1=2,N2=1,P=2. 4×4 channel is taken into consideration ie. 4 transmit antennas and 4 receive antennas. For each method, simulation is performed over 10 iterations before plotting. An function based on [3] is used for channel model. The function returns the channel based on number of transmit antennas, receive antennas and correlation. 1200 subcarriers is considered as wideband and 60 sub-carriers as subband. Only one base station and one user is taken into consideration. Ideal precoding returns the precoder which can achieve the maximum capacity. No method can achieve a capacity greater than this. All other methods are compared with this method.

3.4 Assumptions

We are assuming that the channel estimation is accurate. In practice, the channel is estimated by the CSI-RS signal transmitted from base-station to user. Channel estimation error is not taken into consideration. The channel is used directly for channel capacity calculations. We have considered channel capacity as the metric for performance comparison. The minimum mean squared error (MMSE) based receiver is considered for the simulation, the performance can be affected by quantization error due to unitary precoding, channel estimation error, feedback delay, and processing delay for scheduling users at the gNB. Precoding is performed based on the current CSI i.e., we are assuming no feedback delay in the CSIT. All the simulations are done by fixing the rank as 1.

CHAPTER 4

Results

4.1 Performance Simulations

We simulated the existing methods and the new method based on OMP and compared the performance ie. we plotted the total capacity v/s SNR for each method for different channel correlations.

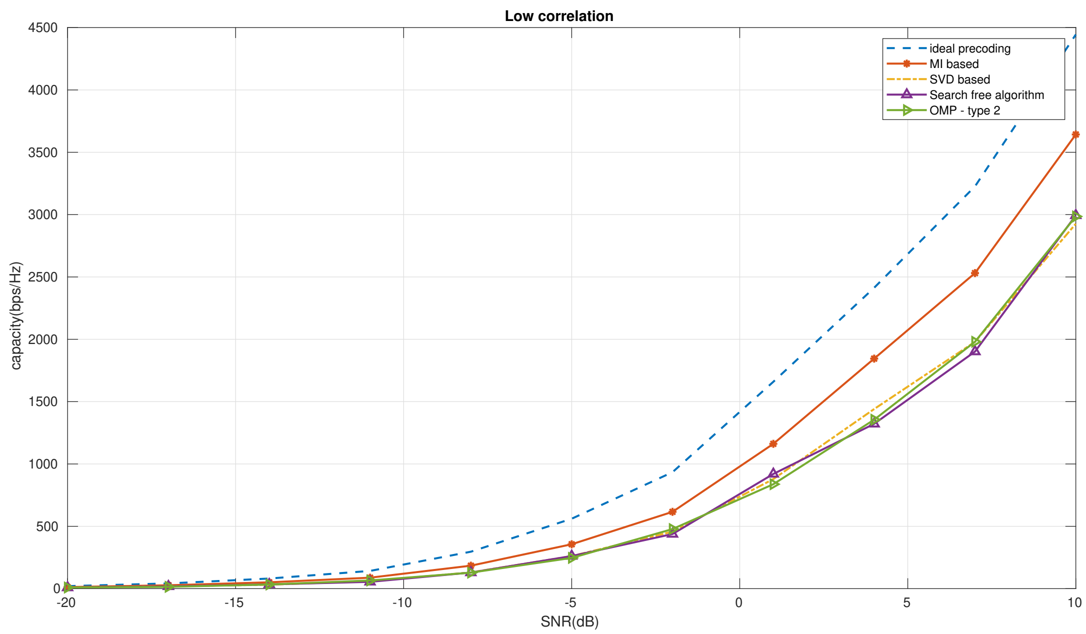

Figure 4.1: Capacity v/s SNR for low correlation channel

The Figure 4.1 shows the plot of total capacity v/s SNR for low correlation channel. Ideal precoding achieves the maximum performance and it cannot be achieved by codebook based method. MI based exhaustive search method achieves the performance less than ideal precoding but achieves the maximum performance that can be achieved using codebook. SVD based method, Search free algorithm and OMP based method for type 2 achieves similar performance but less than MI based method.

The Figure 4.2 shows the plot of total capacity v/s SNR for medium correlation channel. Ideal precoding achieves the maximum performance like last one and it cannot

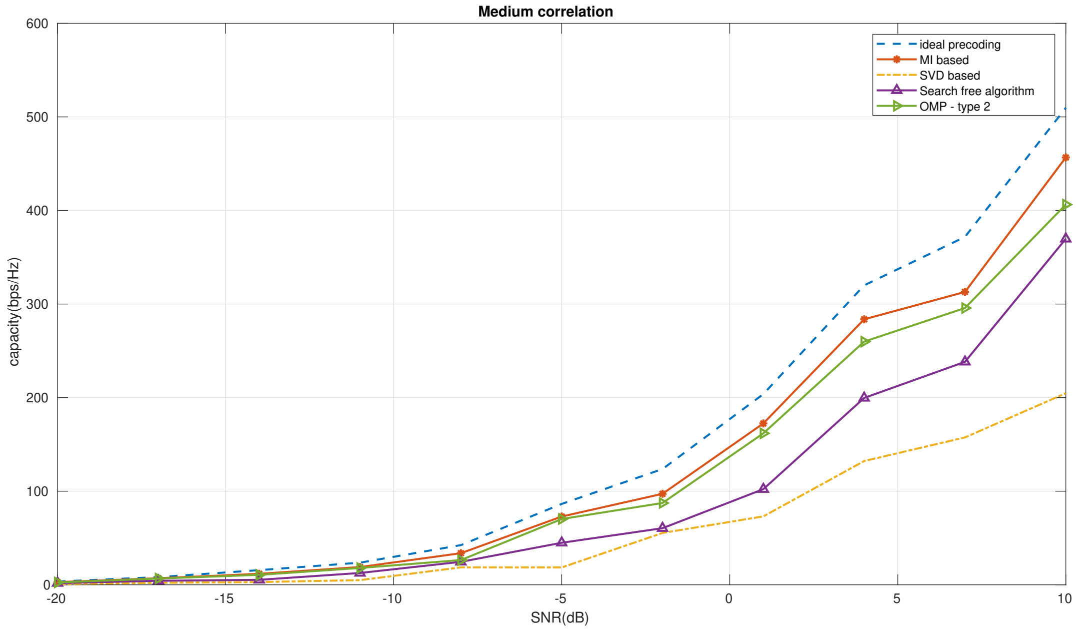

Figure 4.2: Capacity v/s SNR for medium correlation channel.

be achieved by codebook based method. MI based exhaustive search method achieves the performance less than ideal precoding but achieves the maximum performance that can be achieved using codebook type 1. When comparing the other methods, OMP based method achieves better performance and closer to MI based method. And then comes the search free algorithm. The SVD based method performs very poorly for medium correlation channel. When comparing low correlation and medium correlation for all methods, all the methods gives better performance when the channel correlation is low.

The Figure 4.3 shows the plot of total capacity v/s SNR for highly correlation channel. Ideal precoding achieves the maximum performance as always. MI based exhaustive search method and OMP based method achieves similar performance. When comparing the other methods, search free algorithm performs better than SVD based method. When comparing the performance of the methods at different correlation, performance reduces as correlation increases.

The figure 4.4 shows the comparison of time taken by different PMI selection algorithms. MI based and SVD based exhaustive search methods takes a lot of time since search is involved and the search complexity increases exponentially as number of antenna ports increases. Search free algorithm has least search complexity. OMP

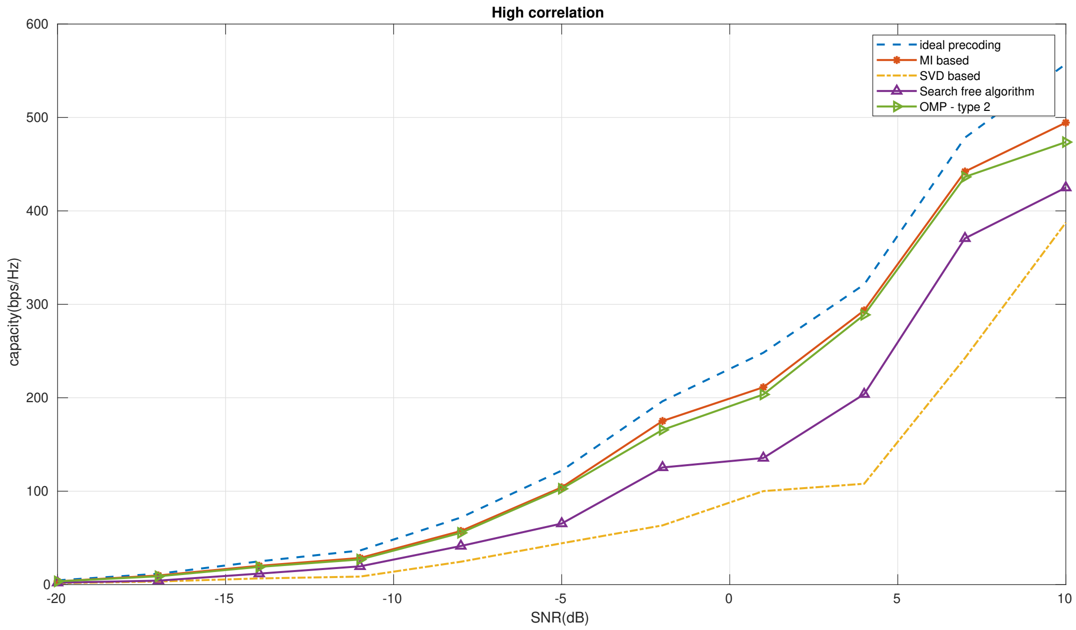

Figure 4.3: Capacity v/s SNR for high correlation channel.

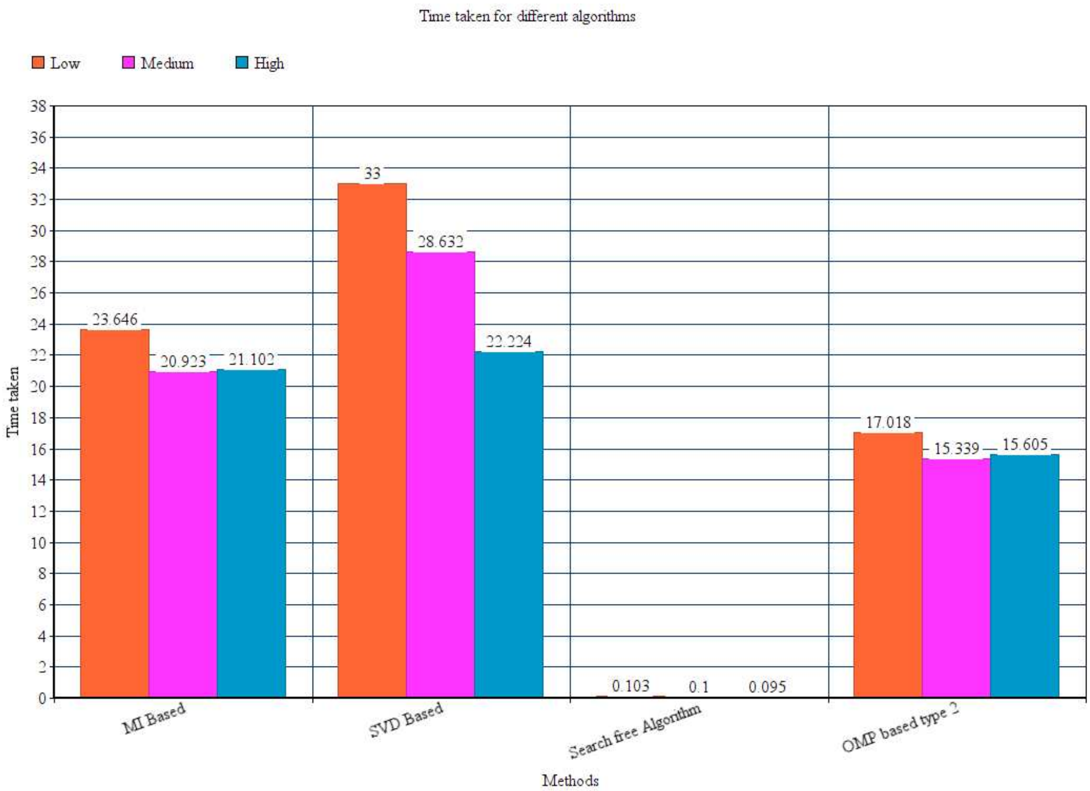

Figure 4.4: Time taken for different methods

based method also takes time since exhaustive search is used in subband. Time taken by OMP based method is less than exhaustive search methods, but more than search free algorithm. But the time taken does not increase with increase in antenna ports since selection of L beams uses orthogonal matching and it doesnot include exhaustive search.

4.2 Comparison of performance

The performance of the MIMO system depends on signal-to-interference-plus-noise ratio (SINR), polarization and number of antennas at both ends and correlation between the individual wireless channels low antenna spacing results in higher correlation between the antennas leading to lower rank of the channel matrix and hence, less channel capacity.

Ideal precoding gives the maximum performance, maximum capacity. MI based exhaustive search method gives the maximum performance that can be achieved using codebook type 1, but higher time complexity. SVD based method is more complex and has less performance than MI based method. Search free algorithm takes least time and performance reduces with increase in correlation. OMP based method is implemented for type 2 codebook, has less time complexity than MI based and SVD based methods, but higher feedback overhead. OMP based method achieves the performance as MI based at high correlation.

CHAPTER 5

Future work and conclusion

5.1 Contributions of thesis

This thesis has contributed a method for PMI selection for codebook type 2 which did not existed. Even though there are lot of papers on different methods for PMI selection codebook type 1, there were none dealing with PMI selection for codebook type 2. Also it has achieved performance similar to MI based type 1 at higher correlation, with comparatively less time complexity, but with more feedback overhead. If an exhaustive search method was used for type 2, it would have achieved performance much better than that of type 1, but has high search complexity. So it cannot be implemented. New OMP based method contributes to a new PMI selection algorithm for codebook type 2.

5.2 Potential extensions

There are different existing methods for PMI selection in codebook type 1. The new method implemented achieves performance as MI based for high correlation. We can find methods to improve performance in low correlation. Also we can extend other algorithms and implement for codebook type 2. All the methods was implemented for layer 1. We can extend the search free algorithm for type 1 to layer 2. Also new methods have to be find out for codebook type 2 for layer 2. We can try to extend OMP based method for layer 2.

Another aim is be to reduce the feedback complexity. We have not considered the amount of feedback overhead in these methods. We have focused only on reducing the time complexity and improving the performance. Different methods can be implemented for reducing feedback overhead.

5.3 Conclusions

In this project, an overview of precoding techniques and the performance of various precoding schemes is studied using simulations. Existing PMI selection methods are compared with the new method and the results indicate that the mutual information based method achieves better results. The new method achieves the performance like mutual information based exhaustive search method at high correlation.

APPENDIX A

APPENDIX

A.1 Pseudo code

A.1.1 MI based exhaustive search

```
for all i11,i12
    w=codebook with index i11,i12
    find capacity for the precoder w
    for the channel averaged over the entire wideband

find the precoder and indexes i11,i12 with maximum capacity

for every suband
    for  all i2
        w=codebook with index i11,i12,i2
        find capacity for the precoder w
        for the channel averaged over the subband

    find the precoder and indexes i2 with maximum capacity
    for each subband
```

A.1.2 SVD based

```
for  all i11,i12
    w=codebook with index i11,i12
    [~,D,Vh]=svd(averaged wideband channel)
```

```
    P=D*Vh*w

    find average sum of diagonal elements of the effective
    channel P over wideband for the precoder w

find the precoder and indexes i11,i12 with maximum sum

for every subband
    for  all i2
        w=codebook with index i11,i12,i2
        [~,D,Vh]=svd(averaged subband channel)
        P=D*Vh*w

        find average sum of diagonal elements of the
        effective channel P over wideband for precoder w

    find the precoder and indexes i2 with maximum sum
    for each subband
```

A.1.3 Search free algorithm

```
%wideband PMI

[~,~,Vh]=svd(averaged wideband channel)
v=first column of Vh

thetal=(angle(v(1)*v(2)'+v(3)*v(4)'));
thetam=0;

find l and m from thetam
find i11,i12 from l and m
```

```
for every subband
    [~,~,Vh]=svd(averaged subband channel);
    v=first column of Vh normalized

    thetan=(angle(v(1)*v(3)'+v(2)*v(4)'))
    find n from thetan
    find i2 from n
```

A.1.4 OMP based type 2

```
beams = set of all beams;
widebandamplitudes=[1 sqrt(.5) sqrt(.25) sqrt(.125)
sqrt(.0625) sqrt(.0313) sqrt(0.0156) 0]

[~,~,Vh]=svd(averaged wideband channel)
v=first column of Vh

Do orthogonal matching pursuit algorithm and
find the beams and their corresponding coefficients.

find the closest values in widebandamplitudes for
coefficients

subbandamplitudes=[1 sqrt(.5) 0 ]
for every subband
    for possible subbandamplitudes and phases
        find capacity for each w

    find w which has maximum capacity for each subband
```

OMP

```
function [x] = OMP (K,y,A)

Res = y.' ;
[m,n] = size (A) ;

Q = zeros (m,K) ;
R = zeros (K,K) ;
Rinv = zeros (K,K) ;
w = zeros (m,K) ;
x = zeros (1,n) ;

for J = 1 : K

    %Index Search
    [V ,kkk] = max(abs(A'*Res)) ;
    kk (J) = kkk ;

    %Residual Update
    w (:,J) = A (:,kk (J)) ;
    for I = 1 : J-1
        if (J-1 ~= 0)
            R (I,J) = Q (:,I)' * w (:,J) ;
            w (:,J) = w (:,J) - R (I,J) * Q (:,I) ;
        end
    end
    R (J,J) = norm (w (:,J)) ;
    Q (:,J) = w (:,J) / R (J,J) ;
    Res = Res - (Q (:,J) * Q (:,J)' * Res) ;

end

%Least Squares
```

```
for J = 1 : K
    Rinv (J,J) = 1 / R (J,J) ;
    if (J-1 ~= 0)
        for I = 1 : J-1
            Rinv (I,J) = -Rinv (J,J) * ...
            Rinv(I,1:J-1) * R (1:J-1,J)) ;
        end
    end
end

xx = Rinv * Q' * y.' ;

for I = 1 : K
    x (kk (I)) = xx (I) ;
end
```

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