IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 5 (May. 2019), ||S (III) || PP 52-58

Survey on channel estimation techniques for mm wave massive MIMO with hybrid precoding

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Abstract: Estimating a channel has become a difficulty for a mm wave system massive MIMO system with hybrid as the number of Radio Frequency (RF) chains are less than the number of antennas. For having a super resolution for the channel estimation the true parameters have been resolved with good precision. Some of the methods used for estimating channels are Auxiliary Beam pair(ABP), Adaptive algorithm based Code book design,2 D Unitary ESPRIT and Iterative Reweight (IR). In ABP amplitude comparison is done against each auxiliary beam pair thus by obtaining the best ratio which gives way to the estimation of angles. Code book design is done by rotating and scaling a code book.2 D Unitary ESPRIT method is the 2D version of the 1 D Estimation of Signal Parameters by Rotational InvarianceTechnique (ESPRIT) is used in a Mm wave Massive MIMO channel. The precoding technique used is hybrid precoding. Hybrid precoding is used in order to reduce power consumption and the power loss. A 2D ESPRIT method is used to estimate the direction or angles of the signals. An iterative reweight (IR) based super resolution channel estimation is used to improve channel estimation accuracy. In this method a gradient descent method is used to find an objective function which can iteratively change direction of the estimated angles of arrivals and departures in order to have a super resolution channel estimation. While optimizing, weighing parameter is used to control balance between sparsity and data fitting error. A singular value decomposition(SVD) is used in order to reduce the computational complexity.

Keywords: Hybrid precoding, Millimetre- wave (mm Wave), Channel estimation, Angle of departure(AoDs), Angle of Arrivals (AoAs), beam forming, codebook design, hybrid precoding, Auxiliary Beam Pair (ABP)

Date of Submission: 21-05-2019 Date of acceptance: 07-06-2019

I. INTRODUCTION

A Milli–meter(mm) wave massive MIMO is a new research field. As the mm wave is having a disadvantage of path loss. In order to overcome that number of antennas placed at both the Base Stations(BS) and Mobile Stations(MS) are increased but the number of Radio Frequency (RF)chains are less compared to that of the number of antennas [1]. A mm wave is used because it is having large number of underutilized bandwidth. Precoding is the technique of using a group of antennas which are placed in an array which are used for transmitting one or more spatially directive signals. Precoding is related to beam forming in which the same spatially directive signals are fed to each antenna and then analog phase shifters are used to control the signals which are emitted by the array of antennas. The advantage of using precoding is that it increases the spectral efficiency. Spectral efficiency or bandwidth efficiency is the rate of information that can be transmitted over a particular band width in a given communication system. Hybrid precoding is used because it reduces cost and power consumption. It is having both the analog and digital section. Both of the section requires Channel State Information (CSI). The number of RF chains are less it becomes difficult for the antennas to access. Therefore, a multiple input multiple output high dimensional channel is difficult to accurate. The massive MIMO is having more advantages than point to point MIMO. As it is using mm wave the data rate is expected to be greater than today's LAN technologies. Mm waves are having large bandwidth.

An adaptive channel estimation algorithm is done by enabling a multi resolution code book in order to construct beam forming vectors which are having different values for their bandwidths. First of all, it is done for single path and then it can be extended to multipath cases. Other than the precoding vectors quantized beam steering vectors are also being considered. In order to estimate angles of signals transmitted or received by the antennas which are represented as Angles of Arrivals (AoAs) and Angles of Departures (AoDs) an auxiliary beam pair based method is used. An amplitude comparison is done by taking each auxiliary beam pair which estimates the angles of the channel. As the selection process is having many disadvantages ESPRIT method can be used in practical cases. A simple ESPRIT method includes the process of taking the covariance matrices of the received channel, Eigen Value Decomposition (EVD) is done with the matrix which separates the signal and noises subspaces, after that another matrix which is the real matrix is determined and again EVD is done and thus the angles or the directions of the signals can be estimated [2].

About the 2D ESPRIT method. First of all, the training signals are designed at both the MS and BS for uplink transmission then a low dimensional channel is obtained with less pilot overhead [3]. The AoAs and AoDs are found out with help of algorithm. The path gains are obtained using Least Square (LS) estimator. At last, a high dimensional channel is reconstructed with angles and path gain. Least square estimator does not require correlation function or matrix inversion. So it is termed as a simple estimation technique. By using the Least square estimator, the channel can be estimated according to the pilot subcarriers.

An Iterative Reweight (IR) method is used to improve the efficiency of channel estimation [4]. In IR method the estimates of the angles, angles of arrivals (AoAs) /departures(AoDs) are iteratively optimized in order to cause a decrease in the weighted summation of sparsity and data fitting error. This is done by optimizing an objective function by using a gradient descent method. In order to avoid the over or the under fitting a weight controlling parameter which is the balance between sparsity and data fitting error can be valued. As the estimated angles are moved from initial angle domain grids to the off grids which are continuously distributed grids then the super resolution channel is estimated. A Singular value decomposition is also done to reduce the complexity. It is done by decreasing number of first receiving values of the angles.

II. SYSTEM MODEL

Amm wave massive MIMO with uplink transmission using hybrid precoding is considered,

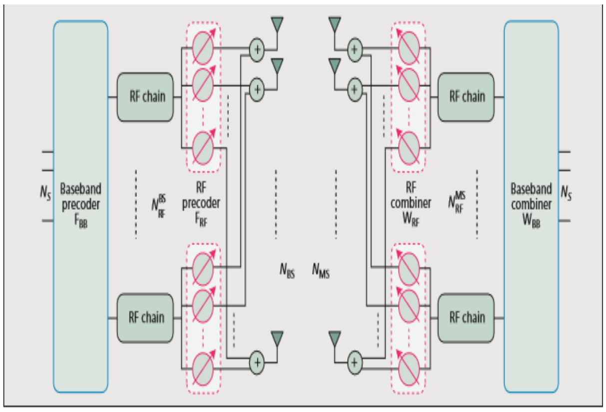


Figure1: *Transceiver for the system.*

Figure 1 illustrates a transmitter receiver where$\mathrm{N_{BS}}$ and$\mathrm{N_{MS}}$ represents number of antennas at the base stations and mobile stations .$N_{RF\ BS}$, $N_{RF\ MS}$ represents the number of radio frequency chains at base stations and mobile stations.$N_S$is the independent data stream at base stations and the mobile stations.

2.1Adaptive algorithm based codebook design

The conditions for the selection of independent stream are $\mathrm{N_S} \leq \mathrm{N_{RF\,MS}} \leq \mathrm{N_{MS}}$ and $\mathrm{N_S} \leq \mathrm{N_{RF\,BS}} \leq \mathrm{N_{BS}}$. Considering the downlink transmission. Let transmitted signal be x= $\mathrm{F_T}$s where $\mathrm{F_T}$ is base station precoding matrix and s is transmitted signal vector. A channel which is a block fading is considered. At the mobile station received signal is observed as :

$$r= \mathrm{HF_T}s + n\ldots(1)$$

'H' is channel matrix ,'n' is the Gaussian noise. When baseband and radio frequency combiners are used in r then it becomes:

$$y= {W_T}^H \mathrm{H} F_T s + {W_T}^H n\ldots(2)$$

Channel matrix 'H'is expressed as :

$$\mathrm{H}=\sqrt{\frac{N_{BS}\ N_{MS}}{\rho}}\sum_{l=1}^{L}\alpha_l\, a_{MS}(\theta_l)\, {a_{BS}}^H(\Phi_l)\ldots(3)$$

where $\propto_l$ is the complex gain of the l^{th} path ,θ_l and $\Phi_l$are azimuthal angles of AoA and AoD of the l^{th}path.

2.2Auxiliary Beam Pair Enabled estimation

A narrow band MIMO system is taken into account. The architecture used at transmitter and receiver is a shared one. After baseband and analog combining received signal is :

$$y= {W_{BB}}^* {W_{RF}}^* \mathrm{H} F_{RF} F_{BB}\, x + {W_{BB}}^* {W_{RF}}^* n \ldots(4)$$

${W_{BB}}^{*}{W_{RF}}^{*}$ and $F_{RF}F_{BB}$ are hybrid combiners and precoders.Uniform Parallel Array and Uniform Linear Array are the stations. ULA share same propagation path so that MIMO channel become co -related at both the ends.Then:

$$H=\sqrt{N_R N_T}\sum_{r=1}^{N_R} g_r a_r(\psi_r)\, a_t^{*}(\theta_r, \Phi_r)\ldots(5)$$

where g_r, θ_r and Φ_r are the complex path gain and azimuthal angles.a_r and a_t are the array response array.

2.3 2D Unitary ESPRIT method

The conditions for the selection of independent stream are $N_S \le N_{RF_{MS}} \le N_{MS}$ and $N_S \le N_{RF_{BS}} \le N_{BS}$. Considering the uplink transmission. Let 'y' be the received signal then:

$$y = W^H \text{HFs} + W^H \text{n}\ldots(6)$$

where W = $W_{RF}W_{BB}$,W is the hybrid combiner .W_{RF} and W_{BB} denotes the analog and digital combiners' = $F_{RF}F_{BB}$F is hybrid precoder. F_{RF} and F_{BB} are the analog and digital precoders. Here Time Division Multiplexing (TDM) is used. In TDM independent signals are transmitted or received over a common path by means of switches which are synchronized at each end of the line. Each signal passes through the path in fraction of seconds in different patterns. A TDM is used when the bitrate exceeds to that of the transmitted signal. Both the F_{RF} and W_{RF} are realized using analog RF phase shifters. Consider a severe path loss for Non –Line –Of –Sight (NLOS) path.It is having controlled scattering dueto L dominated paths having L scatterer's which are different in nature. Then channel matrix is:

$$H=\sqrt{\frac{N_{BS}N_{MS}}{L}}\sum_{l=1}^{L} \propto_l\ a_{BS}\ (\theta_l)\, {a_{MS}}^{H}(\psi_l)\ (7)$$

When a Uniform Linear Array (ULA) is considered at both the BS and MS. Then $a_{BS}\ (\theta_l)$,$a_{MS}(\psi_l)$ be steering vectors at l^{th} path.

2.4Iterative Reweight (IR) method

A mm wave massive MIMO system is being considered. (typical)having uniform linear array (ULA). ULA share same propagation path so that MIMO channel become co -related at both the ends. Let N_T and N_R be number of antennas at the transmitters and receivers . $N_{RF\,T}$ represents the number of radio frequency chains at transmitter and $N_{RF\,R}$ represents the number of RF chains at the receiver. For practical cases the number of RF chains are less than the number of antennas for a MIMO channel. Therefore, the model of system can be designed as:

$$r = Q^H \text{HPs} + n\ldots\ (8)$$

where 'r' is the received signal, 'Q' is the hybrid combining matrix, 's' is the transmitted signal, 'H' is the channel matrix,' P' is the hybrid precoding matrix & 'n' is the received noise. Then model for channel is:

$$H=\sum_{l=1}^{L} z_l\ a_R\ (\text{d}\sin\Phi_{R,l/\lambda})\ {a_T}^{H}(\text{d}\sin\Phi_{T,l/\lambda})\ (9)$$

where 'L 'is the number of propagation path, $'z_l'$ is the complex path gain ,$'\Phi_{R,l}$ '&$'\Phi_{T,l}'$ are the physical angles of l^{th}path , 'd' is antenna spacing.$'\lambda'$ is wavelength and' a_R (d sin$\Phi_{R,l/\lambda}$) ,a_T (d sin$\Phi_{T,l/\lambda}$) 'are the steering vectors at transmitter. As number of radio frequency chains are less than the required dimension of received pilot sequence x_p (1≤ p ≤ N_x) .Consider 'M' time slots in order to getN_Y dimensional received pilot sequencey_p .The channel matrix 'H' can be estimated as the angles and the path gain of the signal. Then the sparsity channel estimation problem is:

$$\min \|\tilde{z}\|_o\ ,\ \le\ \varepsilon\ \ldots\ (10)$$

where, $\|\tilde{z}\|_o$ 'is the number of non -zero elements of $\tilde{z}$, ε is error tolerance parameter and the estimated channel matrix.

III. ADAPTIVE ESTIMATION ALGORITHM

First of all, it is formulated for a single path channel model that is a channel with rank one. This channel is having a single non –zero element. A single channel path is said to be estimated by finding the location of this non –zero element which also helps in determining the angles of arrivals / departures and also the path gain. It is done by multi –resolution beam forming vectors. Initially the base station uses 'K 'precoding vectors which will be the training vectors. This will be from the first stages of the codebook. Then the power of the values will be compared at the mobile station. This process is repeated till log_KN in order to achieve maximum resolution ie $\frac{2\pi}{N}$ for the estimated angles .Each beam forming vectors should have 'K' vectors for measurement and beam forming. So the required number of steps can be decreased to K[$\frac{K}{N_{RF}}$] log_KN. Considering a multipath channel model due to reduced scattering nature of mm wave channel a sparse compressed sensing is used. Here the path gain is estimated for L_d paths. Therefore there will be L_d number of non –zero elements which is having maximum power .A modified code book design is used here. Now number of measurement and beam forming vectors will be KL_d.First level of iteration will be s and the next level will be s+1.It is done up to maximum resolution $\frac{2\pi}{N}$.The required number of steps can be decreased up to K${L_d}^2[\frac{LL_d}{N_{RF}}]$ $log_K(\frac{N}{L_d})$.

IV. AUXILIARY BEAM PAIR ENABLED METHOD

Single path channel is assumed. The minimum value **of** path index is taken into account. A single RF chain having analog beam forming and combining is used. To cover up angular ranges a pair of beams are used. For this a Time Division Multiplexing(TDM) is used. Each analog transmit beams are examined by transmitter at every instance. It will continue till beams are probed. Each pair contains two probed analog beams which are probed. In order to estimate the angles auxiliary beam pair having the highest signal to noise ratio is selected. If a multipath channel is selected then dominant path can be identified by power comparison. In order to estimate multi paths many number of RF chains are used.

V. 2D UNITARY ESPRIT BASED SUPER-RESOLUTION CHANNEL ESTIMATION SCHEME

A 2 Dimensional unitary Estimation of Signal Parameters by Rotational Invariance Technique algorithm is a high resolution algorithm which automatically pairs source azimuthal angle and elevation angle in an efficient way to reconstruct the signal which is affected. They are having many advantages. Some of them are, Except for the final Eigen Value Decomposition (EVD) it is formulated in terms of real valued decomposition, it can be said as an efficient Discrete Fourier Transform (DFT) beam space implementation. It is applicable to array configuration with three identical subarrays which are of centro –symmetric in nature and possess invariance in two distinct directions. It takes sources with only one member of the spatial frequency co –ordinate pair. The scheme is such that a training signal for the uplink transmission is designed to estimate a low dimensional effective channel having same shift –invariance array as the high dimensional with low pilot overhead. The angles of arrival and departures are estimated by means of the 2D ESPRIT algorithm which is based on the channel estimation algorithm and path gains are estimated by means of Least Square (LS) estimation. A high dimensional channel can be reconstructed from the estimated angles and path gain. Signals should be designed for uplink transmission. In order to find out a high dimensional mm wave MIMO channel angles have to be estimated with high accuracy. The uplink transmission consists of analog and digital RF base band part at both the stations. For reconstructing the high dimensional channel, a low dimensional channel having shift invariance of array response same in values are required. Consider an uplink channel i.e, the transmission from mobile station to base station in multiple time slots. In order to improve channel estimation performance two time blocks are considered at the transmitter and receiver jointly as ${N_b}^T$&${N_b}^R$.As the time blocks are taken jointly then the received signal ‘Y’can be taken as the aggregate. From the aggregated values of the hybrid combiner and precoder total number of pilot overheads required for the channel estimation can be calculated as:

$$T = T_{MS}{N_b}^T{N_b}^R \quad \ldots (11)$$

Due to RF phase shift network each observation has different signals as it contains more than one antennas. Conventional ESPRIT algorithm cannot be used because shift -invariance of array response may get destroyed in those valuations. In order to solve this problem aggregated precoder and combiners can be preserved. After forming the matrix, the angles can be estimated for a low dimension channel by means of the ESPRIT algorithm instead of the high dimensional channel. In order to obtain AoAs and AoDs at the receiver a 2D ESPRIT algorithm is used. For the algorithm first of all a Hankel matrix should be constructed after that a process called real processing is done Then a rank reduction process is done to it. At last joint diagonalization and spatial smoothening pre - processing of the matrix are done.

VI. ITERATIVE REWEIGHT (IR) BASED METHOD

An IR method is used to recover the sparse signal. A sparse signal is a signal which is expressed as a linear combination of few small numbers of basis functions. In IR method a surrogate function is decreased iteratively which majorizes original log sum objective function. This method is significant because of two reasons, firstly because if surrounding is a noisy one a regularization parameter can be choosing which controls the balance between both the data fitting error and sparsity of signal where sparsity is number of non-zero elements in signal transform function and the next one is an operation to reduce or remove coefficients which are not required. The frequencies of those are taken into account. While iterative process those frequencies are all removed which increases stability and also reduces computational complexity. Gradient descent method is used for finding optimum function. It is the method used to find minimum of a function. To solve the sparsity channel estimation problem a majorization –minimization process is needed .It is because finding the optimal solution by using $l_0$norm is not computationally efficient. Therefore the l_0 should be replaced with log sum function. The log -sum function can be written as:

$$\min_{\mathbf{z},\boldsymbol{\theta}_\mathrm{R},\boldsymbol{\theta}_\mathrm{T}} F(\mathbf{z}) \triangleq \sum_{l=0}^{L} \log\left(|z_l|^2+\delta\right),\ \text{s.t.} \left\|\mathbf{Y}-\mathbf{W}^H\hat{\mathbf{H}}\mathbf{X}\right\|_\mathrm{F} \le \varepsilon \quad (12)$$

where δ > 0 is the log sum function which is defined. A regularization parameter λ is being added to in order to make it an unconstrained optimization problem which can be represented as :

$$\min_{\mathbf{z},\boldsymbol{\theta}_\mathrm{R},\boldsymbol{\theta}_\mathrm{T}} G(\mathbf{z},\boldsymbol{\theta}_\mathrm{R},\boldsymbol{\theta}_\mathrm{T}) \triangleq \sum_{l=1}^{L} \log\left(|z_l|^2+\delta\right)+\lambda\left\|\mathbf{Y}-\mathbf{W}^H\hat{\mathbf{H}}\mathbf{X}\right\|_\mathrm{F}^2 \quad (13)$$

A function which is an iterative surrogate function can be used other than log sum function as :

$$\min_{\mathbf{z},\boldsymbol{\theta}_\mathrm{R},\boldsymbol{\theta}_\mathrm{T}} S^{(i)}(\mathbf{z},\boldsymbol{\theta}_\mathrm{R},\boldsymbol{\theta}_\mathrm{T}) \triangleq \lambda^{-1}\mathbf{z}^\mathrm{H}\mathbf{D}^{(i)}\mathbf{z}+\left\|\mathbf{Y}-\mathbf{W}^H\hat{\mathbf{H}}\mathbf{X}\right\|_\mathrm{F}^2 \quad (14)$$

where $S^{(i)}(z,\ominus_R,\ominus_T)$ is the surrogate function. The objective function $S^{(i)}(z,\ominus_R,\ominus_T)$ is the weighted sum of z^HDz is the part which is used to control the sparsity of the estimation and $\left\|\mathbf{Y}-\mathbf{W}^H\hat{\mathbf{H}}\mathbf{X}\right\|_\mathrm{F}$ which denotes the residue. The regularization parameter λ which controls balance between sparsity and data fitting error. Choice of λ is important for the channel estimation and speed of the channel. Larger λ implies well-fitting solution whereas smaller λ implies worse fitting solution. In this method the value of the regularization parameter λ is updated as:

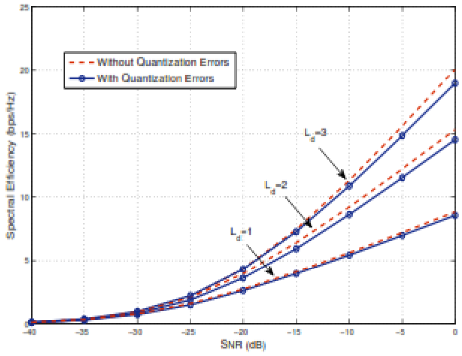
λ=min (d/ r^i,λ_{max}) (15)

where d is the constant scaling factor ,the reason how λ_{max} is selected depends upon whether the problem is well-conditioned and$r^i$is the square of the residue from the last step. Singular Value Decomposition is used to reduce computational complexity of the method used. By using the IR method angle domain grids which are nearer to the real angles can be found out.

VII. SIMULATION RESULTS

Simulation results helps to find out performance of methods used. The values for N_{BS}= N_{MS} = 64 $N_{RF\ BS}$ = $N_{RF\ MS}$= 4 , N_S= 3.

According to adaptive codebook design Fig1, gives out the performance error which is caused due to the quantization of angles [8]. Performance error can be defined as the value formed due to the continuous angle and the value from quantization. It is simulated when the angles are quantized and at different values.In the case of 2D unitary ESPRIT method from Fig 2, normalized mean square error (NMSE) is being compared with the Signal to noise ratio (SNR). From figure itself it's clear that this method gives better value for the NMSE with much less pilot overhead. By using this algorithm rather than the other two there would channel estimation may only be affected by the noise. Fig 3 compares average spectral efficiency(ASE) of different channel estimation schemes with signal to noise ratio [5],[6]. Fig 4 compares NMSE versus Signal to noise ratio of different methods. From the figure it is clear that by using Iterative reweight method high accuracy in performance can be achieved. The adaptive codebook based channel estimation is limited because of the size if the code book [7]. In the case of the auxiliary beam based scheme it suffers great loss due to interference caused due to other paths for finding out the angles [8]. Fig 5 compares ASE of different estimation schemes. The ideal channel state information is chosen as the upper bound for performance criteria. Iterative reweight (IR) method can achieve the upper bound thus by achieving super resolution.



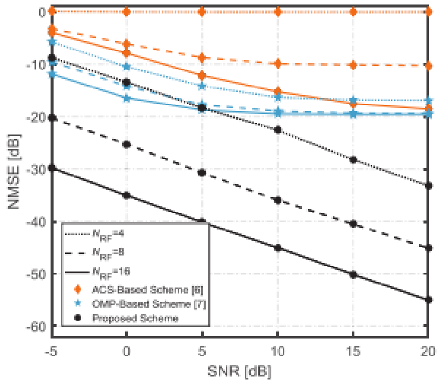
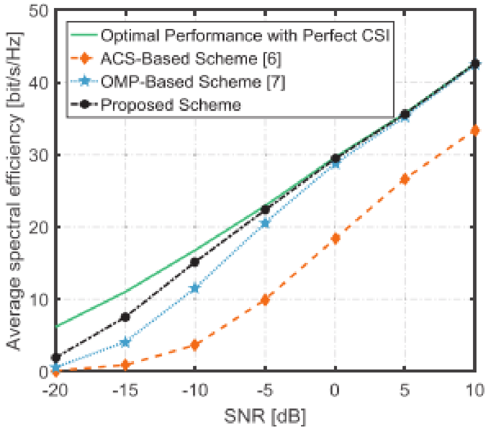


Figure1*Spectral efficiency versus SNR***Figure 2***NMSE versus SNR of different schemes*



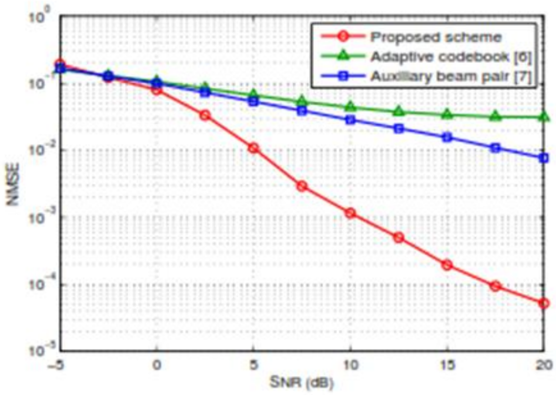


Figure 3*Average spectral efficiency***Figure 4***NMSE versus SNR*

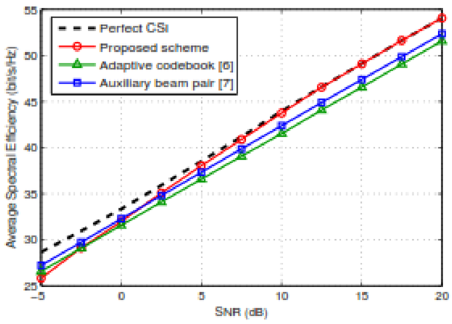


Figure 5*ASE against SNR*

VIII. CONCLUSION

Adaptive channel estimation algorithm is used by formulating a codebook which is having multi resolution.by using a hybrid precoding. Its performance is evaluated by using a single path. This method gives better values for spectral efficiency and path gains as it is having low complexity. Auxiliary Beam Pair (ABP) enabled channel estimation is used to give high resolution of the angles. This can be done by amplitude comparison with respect to auxiliary beam pair. A 2D unitary ESPRIT based super resolution channel estimation is used in order to obtain the super resolution estimates of Angles of Arrivals (AoAs) and Angles of Departures (AoDs). It is done by designing a uplink training signals at both the base stations and mobile stations. Then a low dimensional channel can be constructed such that the shift invariance array response should be similar to that of the high dimensional channel to be reconstructed. After that by using the 2D ESPRIT algorithm the angles of arrivals and departures can be estimated. The path gains can be obtained by using Least Square Estimation (LSE). From the obtained values of the angles and path gain high dimensional channel can be reconstructed.A SVD based preconditioning is used to reduce the computational complexity. By using this method, the surrogate function is iteratively decreased by majorizing an objective function. This overcomes mismatch of grid problems and achieves a super resolution accuracy. It is also used to estimate the off-grid angles with affordable complexity. It shows that the IR based super resolution channel estimation estimates the angles more accurately with high channel accuracy.

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IOSR Journal of Engineering (IOSRJEN) is UGC approved Journal with Sl. No. 3240, Journal no. 48995.

Kalyani .J. "Survey on channel estimation techniques for mm wave massive MIMO with hybrid precoding." IOSR Journal of Engineering (IOSRJEN), vol. 09, no. 05, 2019, pp. 52-58.