Reduced Complexity in Antenna Selection for Polarized MIMO System with SVD for the Practical MIMO Communication Channel Environment

Maung Sann Maw[1], **Iwao Sasase**[1]
Contact: sannmaw@sasase.ics.keio.ac.jp

[1]SASASE Laboratory
Information and Computer Science
Graduate School of Science and Technology
KEIO University, Japan.

Abstract

In the conventional multi-input multi-output (MIMO) communication systems, most of the antenna selection methods considered only for spatially separated uni-polarized system under Rayleigh fading channel in non-line of sight (NLOS) condition. There have a few antenna selection schemes for the cross-polarized system in LOS condition and Ricean fading channel, and no antenna selection scheme for the MIMO channel environment effected by both LOS and NLOS conditions. In the practical MIMO channel case, influence of LOS and NLOS conditions in the channel can vary from time to time according to the channel parameters and user movement in the system. Based on these influences and channel condition, uni-polarized system may outperform than cross-polarized system and vice versa. Thus, we should consider this kind of practical MIMO channel environment when developing the antenna selection scheme. Moreover, no research work has been done on the reduction of complexity in the antenna selection for this kind of practical MIMO channel environment. In this paper, reduced complexity in antenna selection is proposed to give the higher throughput in the practical MIMO channel environment. In the proposed scheme, suitable polarized antennas are selected based on the calculation of singular value decomposition (SVD) of channel matrix and then adaptive bit loading is applied. Simulation results show that throughput of the system can be improved under the constraint of target BER and total transmit power of the MIMO system.

I. INTRODUCTION

Spatial multiplexing offers high channel capacity and transmission rate for the same bandwidth without additional power requirement by employing multiple antennas at the transmitter and receiver. Adaptive modulation scheme can be applied in the multi-input multi-output (MIMO) system to further improve the system capacity. Adaptive modulation method to enhance the spectral efficiency while keeping the bit error rate (BER) under predefined level is proposed in [1]. When adaptive modulation is applied in quality of service (QoS) based MIMO system with VBLAST-zero forcing (ZF) receiver, the worst SNR link in the MIMO system will decide the overall modulation mode for that system to give the predefined target BER level in the system. In that case, system's efficiency might be decreased if the SNR gap between the worst link and other links is large. Because all MIMO links have to transmit the same number of bits from each transmit antenna to spatially separate the transmitted symbols in the ZF receiver. The modulation mode will be decided based only on the worst case SNR link although higher SNR links can load the higher modulation mode for the transmission. If we can increase the lowest SNR level without increasing the transmit power to match with higher modulation mode, then overall system efficiency will be improved.

SNR levels of MIMO links can vary depending on the polarization in the system. A lot of papers have been published for the research of uni-polarized spatial MIMO communication systems, where the antennas elements are physically separated in space [2]. However, spatial correlation might occur in line-of-sight (LOS) condition. In order to reduce the spatial correlation small enough to be ignored, there will be a strict limit on the spacing distance between the antenna elements especially for mobile station (MS).

In this regard, dual-polarized antennas are inclined to be introduced into the MIMO system since they can reduce the requirement of the spacing between the antennas [3]. With dual-polarized antennas, we can place more antenna elements with the same space limit, or obtain better channel performance under poor channel conditions such as highly correlated LOS channel conditions. However, high cross polarization discrimination (XPD) reduces the mean power of the cross coupled component, and thus, the available diversity benefit due to uncorrelated cross coupling decreases [4]. On the other hand, MIMO systems with uni-polarized antennas have better array gain than cross-polarized MIMO systems and thus offer more system throughput in the independent and identically distributed (i.i.d) rayleigh fading channel for NLOS condition [5]. Measurement results show that in the environment with rich scattering, there is no benefit to use cross-polarized combination to increase channel capacity. While in the environment without rich scattering, like in space of hall-way, the cross-polarized combination is an efficient way for enhancing channel capacity [6]. However in the practical communication system environment, considering the channel condition with only LOS condition or NLOS condition is far from the reality. And it is better to depict the practical channel as the sum of fixed (possibly LOS) component and a variable or scattered (NLOS) component. This real-world channel condition is effected by the average subchannel imbalances, Ricean K-factor and correlation properties [7].

Therefore, it is not a good idea to use the constant polarized antennas without adapting to match with the requirement of the practical channel condition. If a particular MIMO system is employed both uni-polarized and dual-polarized antennas, then we can use both uni-polarized and cross-polarized antennas based on the average subchannel power imbalances, Ricean K-factor and correlation properties to achieve the better MIMO system performances. But this will increase the hardware and signal processing complexity, power consumption, and component size in the transmitter and the receiver [8]. One of the main culprits behind this increase in complexity is that each antenna element requires a dedicated radio frequency (RF) chain. Moreover, processing the signals received in spatial multiplexing schemes calls for sophisticated receivers whose complexity increases, sometimes exponentially, with the number of transmit and receive antenna elements. Antenna selection is a solution which can reduce the hardware complexity of transmitters and receivers by using fewer RF chains, while exploiting the diversity benefits offered by the MIMO architecture. In antenna selection, a subset of the available antenna element is adaptively chosen by a switch, and only signals from the chosen subset are processed further by the available RF chains. This technique has been extensively studied in the context of spatial channels [9]. Antenna selection for MIMO systems was first presented in [10] based on an argument of capacity increase. The selection criterion proposed therein is based on Shannon capacity and does not readily apply to spatial multiplexing with linear receivers. Therefore, some researcher considered the antenna selection for spatial multiplexing systems with linear receivers [11] to reduce the complexity in MIMO system. The selection scheme uses the post-processing SNRs (signal to noise ratios) of the multiplexed streams and the antenna subset that induces the largest minimum SNR is chosen. However, it is necessary to use the SVD for every subchannel matrixes and it takes more time compared with Frobenius norm base selection. Moreover, there has no consideration about effect of adaptive modulation and total transmit power constraint on the selection method.

In [8], the reduced complexity with Frobenius norm base antenna selection is expressed for joint transmit/receive selection strategies. This strategies choose a subset of the rows and columns of H to maximize the sum of the squared magnitudes of transmit-receive channel gains. But there has no consideration about transmit and receive antenna correlation and K-factor effect in the system and it can not work very well in the ill-condition channel matrix of MIMO system. Therefore, efficient (optimal or suboptimal) joint selection of transmit and receive antennas remains an interesting open problem.

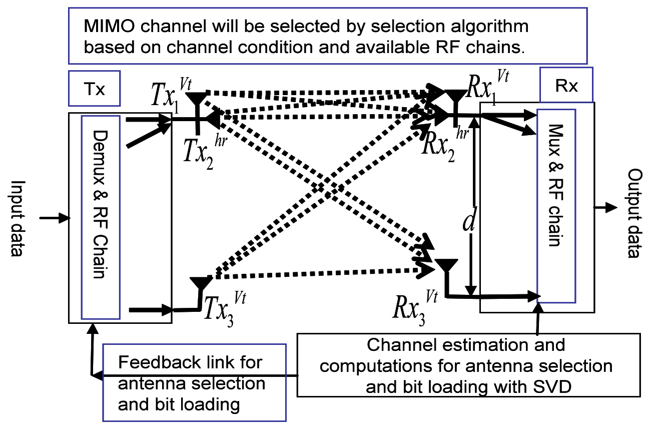

Fig. 1: MIMO System Model.

In this paper, we propose the SVD based reduced complexity antenna selection method for the practical MIMO communication system with linear receivers. The proposed system and selection method not only consider reducing the complexity but also considering the effect of adaptive modulation and total transmit power constraint under the target BER rate in the MIMO system to fulfill the requirements in [8] and [11]. At first step, the selection algorithm will choose the best subchannel matrix with reduced complexity, based on the second largest minimum singular value and minimum singular values from main MIMO channel matrix and subchannel matrixes, respectively. After that, adaptive bit loading is applied to the selected subchannel under the constraint of total transmit power and target BER rate and available RF chains in the system. In the first step, there has no consideration about constraint of total transmit power and adaptive bit loading in the transmit side. Therefore, there might be error in the first step channel matrix selection and it might be necessary to recheck the capacity of main MIMO channel matrix and selected subchannel matrix according to the available of RF chains in the system.

This paper is organized as follows. Section 2 introduces our MIMO system model with uni-polarized and cross-polarized antenna for the practical MIMO communication channel environment. Section 3 describes the reduced complexity in antenna selection algorithm which is jointly combined with adaptive bit loading and transmits power distribution. Section 4 shows simulation results and conclusion is shown in section 5.

II. SYSTEM MODEL

System model is shown in Fig. 1. We consider a MIMO system with two vertical polarized antennas and one horizontal polarized antenna. In the hardware design, one vertical polarized antenna is separated by half of the transmitted wavelength distance (d) from the cross-polarized antenna as shown in Fig. 1. Based on the available RF chains, we can use 3X3 MIMO system, 3X2 MIMO system or 2X2 MIMO system by choosing the suitable antenna pairs in transmitter and receiver side, receptively. Practical MIMO channel matrix $\mathbf{H}$ can be modelled as follows [12]:

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} = \sqrt{\frac{K}{1+K}}\mathbf{H}_{LOS} + \sqrt{\frac{1}{1+K}}\mathbf{H}_{NLOS}, \qquad (1)$$

$$\mathbf{H}_{LOS} = \begin{bmatrix} 1 & \sqrt{\beta} & 1 \\ \sqrt{\beta} & 1 & \sqrt{\beta} \\ 1 & \sqrt{\beta} & 1 \end{bmatrix}, \qquad (2)$$

$$\mathbf{H}_{NLOS} = \left(R_{RX}\right)^{1/2} \mathbf{H}_{iid} \left(R_{TX}\right)^{1/2}, \qquad (3)$$

$$\mathbf{H}_{iid} = \begin{bmatrix} h^{iid}{}_{11} & \sqrt{\alpha} h^{iid}{}_{12} & h^{iid}{}_{13} \\ \sqrt{\alpha} h^{iid}{}_{21} & h^{iid}{}_{22} & \sqrt{\alpha} h^{iid}{}_{23} \\ h^{iid}{}_{31} & \sqrt{\alpha} h^{iid}{}_{32} & h^{iid}{}_{33} \end{bmatrix}, \qquad (4)$$

where $\sqrt{K/(1+K)}\mathbf{H}_{LOS}$ is the fixed component of the channel and $\sqrt{1/(1+K)}\mathbf{H}_{NLOS}$ is the fading component of the channel. K is the Ricean K-factor of the channel and is the ratio of the total power in the fixed component of the channel to the power in the fading component. α and β are the attenuated cross coupling coefficients for the polarization case. $\mathbf{H}_{idd}$ is the flat-fading Rayleigh component of the MIMO channel. The elements of $\mathbf{H}_{idd}$ are complex Gaussian random variables with zero mean and unit variance. $\mathbf{R}_{RX}$ and $\mathbf{R}_{TX}$ are the receive and transmitter side correlation matrices, respectively, and are given by

$$\mathbf{R_{RX}} = \begin{bmatrix} 1 & r_{1,2} & r_{1,3} \\ r_{2,1} & 1 & r_{2,3} \\ r_{3,1} & r_{3,2} & 1 \end{bmatrix}, \qquad (5)$$

$$\mathbf{R_{TX}} = \begin{bmatrix} 1 & t_{1,2} & t_{1,3} \\ t_{2,1} & 1 & t_{2,3} \\ t_{3,1} & t_{3,2} & 1 \end{bmatrix}, \qquad (6)$$

$$r_{i,j} = \rho^{spl}{}_{i,j} \times \rho^{pol}{}_{i,j},$$

$$t_{i,j} = \rho^{spl}{}_{i,j} \times \rho^{pol}{}_{i,j},$$

where $r_{i,j}$ and $t_{i,j}$ are the correlation coefficient between the i^{th} antenna and j^{th} antenna at transmitter and receiver side, respectively. $\rho^{spl}{}_{i,j}$ and $\rho^{pol}{}_{i,j}$ denote the real correlation coefficient due to the spacing and polarization between antennas i and j, respectively. In order to simplify the MIMO system simulation, we assume that the correlation coefficients between the cross-polarized antennas are equal to zero in the transmitter and receiver side. It is also noted that if selected antennas are of the same polarization, then α, β and $\rho^{pol}{}_{i,j}$ are equal to one. By substituting this assumption into (5) and (6), we can get the simplified receive and transmitter side correlation matrices as follows:

$$\mathbf{R_{RX}} = \begin{bmatrix} 1 & 0 & \rho^{spl}{}_{1,3} \\ 0 & 1 & 0 \\ \rho^{spl}{}_{3,1} & 0 & 1 \end{bmatrix}, \qquad (7)$$

$$\mathbf{R_{TX}} = \begin{bmatrix} 1 & 0 & \rho^{spl}{}_{1,3} \\ 0 & 1 & 0 \\ \rho^{spl}{}_{3,1} & 0 & 1 \end{bmatrix}. \qquad (8).$$

III. Reduced Complexity in Antenna Selection Methods Based on the SVD and Adaptive Bit Loading

3.1 Minimum Singular Value and its Effect on the Linear Receivers

We use the V-BLAST implementation with ZF receiver to reduce the complexity in our system model. V-BLAST MIMO system improves the system performance based on ZF detection combined with symbol cancellation while maintaining low implemental complexity [13]. When symbol cancellation is used, the order in which the sub-streams are detected becomes important for the overall performance of the system. Performance of spatial multiplexing with linear receivers depends on the minimum *SNR* induced by the particular subset of transmit antennas. The transmitted symbol with the smallest post-detection *SNR* dominates the error performance of the system [11]. That's why we use the minimum SNR as a key factor to choose the best modulation mode and channel matrix for the system. The dispread signal $\boldsymbol{Z}$ can be obtained by correlating the received signal $\boldsymbol{Y}$ with pseudo-inverse $\boldsymbol{U}$ of the selected channel matrix $\mathbf{H}$.

$$\mathbf{Z} = \mathbf{U}\ \mathbf{Y} = \sqrt{E_s}\ \mathbf{U}\ \mathbf{H}\ \mathbf{S} + \mathbf{U}\ \mathbf{N}. \qquad (9)$$

For the ZF receiver, the post-processing *SNR* of the worst sub-stream is expressed in [14]

$$\Psi^{ZF}{}_{\min} \geq \lambda^2{}_{\min}(\mathbf{H})\frac{E_s}{TN_0}, \qquad (10)$$

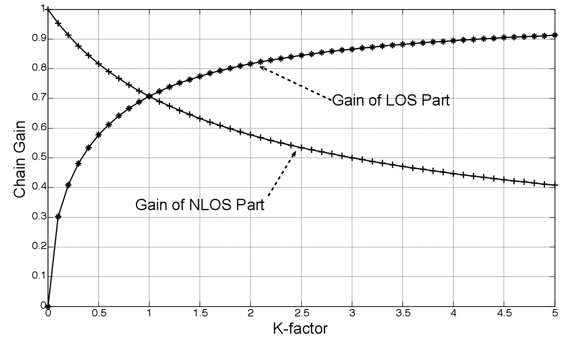

Fig. 2: Relationship between gains of LOS, NLOS Parts and K-factor

3.2 Relationship between Minimum Singular Value and Parameters of MIMO Channel Matrix

The value of $\lambda_{\min}(\mathrm{H})$ can be obtained by using SVD method. SVD method decomposes the channel matrix $\mathbf{H}$ into a diagonal matrix $\boldsymbol{S}$ of the same dimension with non-negative diagonal elements $\lambda(\mathrm{H})$ in decreasing order and unitary matrices $\boldsymbol{U}$ and $\boldsymbol{V}$ so that

$$\mathrm{H}=\mathrm{U\ S\ V}^{\mathrm{H}} = \sum_{i=1}^{\mathrm{rank(H)}} \mathrm{u}_i s_i \mathrm{v}_i^{H} \ . \qquad (11)$$

In the above equation, $\mathbf{u_i}$ and $\mathbf{v_i}$ are the left and right singular vectors with $\boldsymbol{s}_\mathbf{i}$ denoting the singular values that are arranged in descending order. Among these singular values, the value of $\lambda_{\min}(\mathrm{H})$ is heavily effected by two factors [15]. One factor is fading correlation of channel matrix $\mathbf{H}$. Low correlated channel matrix has higher $\lambda_{\min}(\mathrm{H})$ value than highly correlated channel matrix [15]. The second factor, which influences on the value of $\lambda_{\min}(\mathrm{H})$ is average channel gain of the channel matrix $\mathbf{H}$. Channel matrix with higher average gain has higher singular value than channel matrix with lower channel gain under the same fading correlation condition [15]. In the MIMO system, good channel condition has low correlated fading channel matrix and higher channel gains. We can know the best channel condition based on these two factors. However, sometimes one channel instant may have good channel gain with highly correlated channel matrix and the other time instant may have low channel gain with low correlated channel matrix. In this condition, it is very difficult to consider the best channel condition. Fortunately, these average channel gain and fading correlation are directly related to $\lambda_{\min}(\mathrm{H})$ and we can know the better channel condition by comparing these $\lambda_{\min}(\mathrm{H})$ values. Therefore, $\lambda_{\min}(\mathrm{H})$ can be used as an appropriate performance indicator to choose the best channel matrix for the system.

In the MIMO channel matrix in (1), it is a combination of LOS and NLOS and their values are controlled by using K-factor. If K is equal to zero, then MIMO channel is totally influenced by the NLOS part and changed to pure Rayleigh MIMO channel. In this case, the use of cross-polarized antennas will always result in a performance loss and we should use uni-polarized antennas to improve the capacity or diversity in the system [3]. On the other hand, if K is equal to infinity, then MIMO channel is totally influenced by the LOS part and the NLOS effect will be removed from the system and approaches to non-fading link. In this case, the use of uni-polarized antennas results in high antenna correlation and it is always better to use cross-polarized antenna. If the antenna correlation is very high, it shown in [3] that the use of spatial multiplexing is no longer possible (due to the high error rates), whereas replacing the two antennas by a cross-polarized yields error rates that are acceptable. Therefore, we take these K-factor parts from LOS and NLOS in (1) to show the simplified relationship between K-factor and channel gain for MIMO channel matrix. Fig. 2 shows the relationship between the channel gains and K-factor values for LOS and NLOS parts in (1). According to this figure, we can know that NLOS part is mainly influenced in the lower K-factor region and we should use uni-polarized MIMO system as explained in above. When LOS part is mainly influenced in the higher K-factor region, we should use cross-polarized MIMO system. On the other hand, around the crossing point of LOS and NLOS curves, both LOS part and NLOS part can influence in the MIMO channel matrix and we should use all MIMO antennas for better system performance if there are available RF chains to support 3X3 MIMO system. However, in the practical channel matrix case, channel can not be simplified as stated in the above condition and there will be shift in crossing point between the gain of LOS and NLOS curves in this figure because of the various channel parameters in the MIMO system such as transmit and receive antennas correlations, channel gain, multipath fading, line of sight condition and SNR condition etc… Note that, all these factors have the relationship with $\lambda_{\min}(\mathrm{H})$ value as explained in previously. Therefore, we have to compare all available $\lambda_{\min}(\mathrm{H})$ values which can be obtained from the available subchannel matrixes.

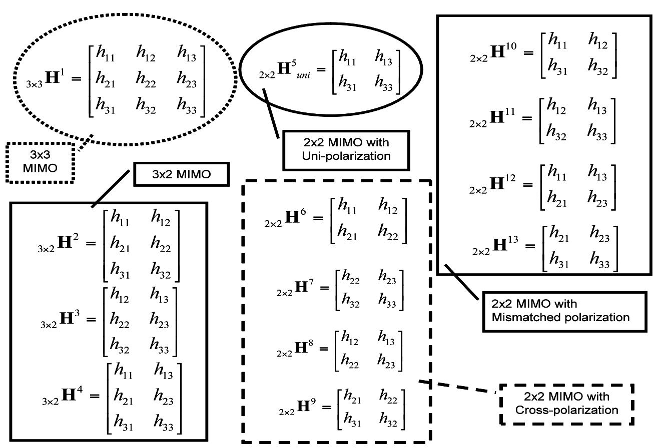

Fig. 3: Possible subchannel matrixes in the proposed MIMO system.

3.3 Reduction of Complexity in the Antenna Selection Method

3.3.1 First Step: Removal of Unnecessary Subchannel Matrixes

Table 1: Random Values of K-factor, Correlation and Average SNR for each channel instant which are used in the development of Fig 4, 5 and 6.

Time Instant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
K-factor	0.6	9	0.1	0.75	0.3	9	18	0.3	0.7	0.95	0.25	0.35	0.15	0.5	0.6	0.65
Correlation	0.55	0.16	0.11	0.7	0.27	0.99	0.63	0.46	0.14	0.34	0.8	0.67	0.96	0.03	0.3	0.7
SNR(dB)	30	2	8	26	27	4	7	27	10	34	16	6	11	28	4	17

Based on the available RF chains in MIMO system, there have 9 possibilities for 2X2 MIMO combinations, three possibilities for 3X2 MIMO combinations and one 3X3 MIMO system can be used in the system and these available channel matrixes are shown in Fig. 3. Therefore, 13 singular values can be obtained from the SVD of 13 subchannel MIMO matrixes. Fig. 4 shows the singular values of these available subchannel matrixes. In Fig. 4, 3X3 MIMO channels $\mathbf{H}_{idd}$ are randomly generated by using Matlab simulator for each time instant. For each time instant, each $\mathbf{H}_{idd}$ is substituted into (1) by using random parameters for K-factors and antenna correlations and average SNR to get each $\mathbf{H}$. The random values which have been used for each time instant are also shown in Table. 1. In this simulation, we show the relationship among the singular values of available subchannel matrixes which are obtained from each time instant of $\mathbf{H}$. For the clear presentation, we will not show the maximum singular values for these channel matrixes because we only need minimum singular values to find the best channel matrix for our antenna selection method as already explained in section 3.2. In Fig. 4, we can see that minimum singular values of mismatched polarized subchannel matrixes (${}_{2\times2}\mathrm{H}^{10}$ to ${}_{2\times2}\mathrm{H}^{13}$) are very low compared with minimum singular values of other subchannel matrixes. That is because of the polarization mismatch in these (${}_{2\times2}\mathrm{H}^{10}$ to ${}_{2\times2}\mathrm{H}^{13}$) subchannel matrixes. Polarization mismatch occurs when transmitter side used in cross-polarization and receiver side used in uni-polarization or vice versa. Because of their polarization mismatch, their channel matrixes have very low rank and it will cause to get very low minimum singular values. Therefore, it is not necessary to consider these subchannel matrixes to use in the proposed antenna selection scheme. That's why, 13 possible subchannel matrixes can be reduced into 9 possible combinations to be considered. That is the first step to reduce the complexity the proposed antenna selection scheme. Therefore, in the following figures, we do not show the values of mismatch polarized subchannel matrixes for the clear explanation and presentation of our proposed method.

Table 2: SNR Threshold and Modulation Modes

SNR Threshold	Γ_2	Γ_4	Γ_{16}	Γ_{64}
Bit Loading	1	2	4	6

3.3.2 Second Step: By Using Upper Bond of Second Largest Minimum Singular Value from Main MIMO Channel Matrix

By applying SVD to the original 3X3 MIMO channel matrix $\mathbf{H}$, we can get three singular values with descending order such as $\lambda_{\max}, \lambda_2, \lambda_{\min}$. And we call λ_2 as a second largest minimum singular value. In this Fig. 4, we also show the λ_2 values and we can see that it is upper bond for all other minimum singular values of subchannel matrixes. This condition occurs because all other subchannel matrixes are taken out from main 3X3 MIMO channel matrixes $\mathbf{H}$. Therefore, we do not need to find all of the available subchannel matrixes at the same time. At first, we have to find the singular values for 3X3 MIMO channel matrix $\mathbf{H}$ and after that we have to find the minimum singular value for other subchannel matrixes and compare with the second largest minimum singular value of 3X3 MIMO matrix $\mathbf{H}$ (λ_2). As soon as they are equal, we can cut off the finding process for the remaining subchannel matrixes. That is the second step for the reduction of complexity in the proposed method. In the conventional antenna selection methods in [8,11], they have to compare all singular values or channel gains which are obtained from all possible subchannel matrixes and select the maximum one after comparing all these possible values.

3.4. Adaptive Bit Loading and Problem Formulation for the MIMO System Model

In our system, we are also applying the adaptive bit loading which dynamically determines the constellation size based on the current channel condition and predefined BER, to improve

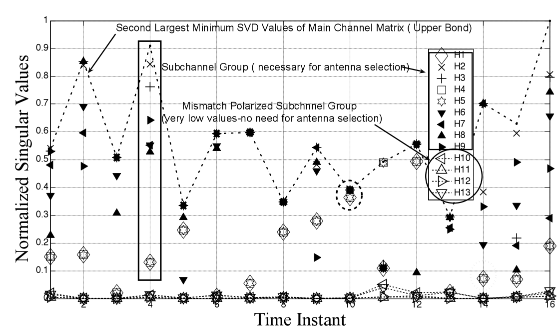

Fig. 4: Comparison of Singular Values for subchannel matrixes from original 3by3 MIMO system for each channel instant.

the capacity under the constraint of QoS requirement. In the context of multiple antenna systems, the constellation size M_i assigned to the i^{th} transmit antenna is varying depending on the subchannel SNR (γ_i). The available modulation orders in our work are constrained to $M_i = \{0, 2, 4, 16, 64\}$, where $M_i = \{0\}$ means no data are transmitted, $M_i = \{2\}$ is BPSK and $M_i = \{4, 16, 64\}$ are M-QAM. The relationship of SNR (γ_i), BER (Pb) for coherent detection of constellation size (M_i) with Gray bit mapping is approximated in [1].

$$P_b \approx 0.2 \exp\left(-1.5 \frac{\gamma_i}{M_i - 1}\right). \tag{12}$$

With a predefined target BER (P_b), the SNR threshold point Γ_{M_i} for a specified bit loading, can be easily found for given constellation size as in (12) and shown in Table.2.

$$\Gamma_{M_i} = \frac{M_i - 1}{1.5} \ln\left(\frac{1}{5P_b}\right). \tag{13}$$

By using (12) and (13), we can calculate the modulation mode (M_i) and Γ_{M_i} based on target BER and instantaneous SNR for the worst MIMO link. Bits, power and antennas should be allocated jointly to achieve the optimal solution. However this causes the high computational complexity at the base station in order to reach the optimal allocation. Hence, we use the equal power distribution and equal number of bit will be loaded on all of the selected transmitted antennas for the simple decoding at the receiver side to reduce the complexity in the system. The proposed method can be started from the following nonlinear constrained optimization problem. Our aim is to maximize the total data throughput under the constraints of total transmit power, available RF chains and predetermined target BER in the system. The allocation problem is formulated as:

$$\max(C_{total}) = \max\left(\sum_{i=1}^{T_{sel}} \log_2(M_i)\right), \tag{14}$$

subject to:

$$\mathrm{T}_{sel} \le \mathrm{R}_{sel} \le \text{Avaliable RF chains} \tag{15}$$

$$e_i\left(\log_2\left(M_i\right)\right) = (P_{total}/T_{sel}). \tag{16}$$

$$BER_i \le P_b, \tag{17}$$

$$\log_2\left(M_i\right) \ge 0, \quad e_i \ge 0, \quad i = 1, 2, \ldots T \tag{18}$$

$$\log_2\left(M_i\right) = \log_2\left(M_k\right), \quad i \ne k \tag{19}$$

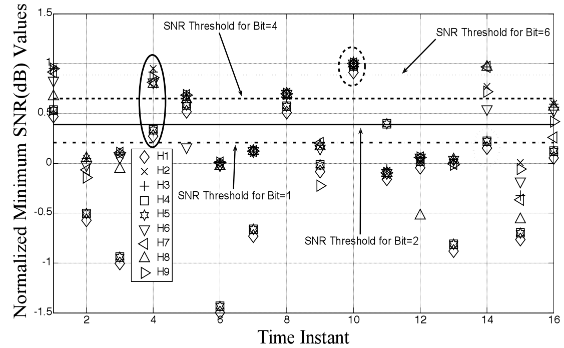

Fig. 5: Comparison of SNR Values for original 3x3 MIMO channel matrix and its subchannel matrixes for 3X2 and 2X2 MIMO systems.

where C_{total} and P_{total} are total data rate and total available transmit power in the system, respectively. T_{sel} and R_{sel} are the selected number of transmit and receive antennas in the system. The convex function $e_i\left(\log_2\left(M_i\right)\right)$ represents the amount of energy necessary to transmit $\left(\log_2\left(M_i\right)\right)$ bits from the i^{th} transmit antenna in the system.

3.5 Joint Antenna Selection Method with Adaptive Bit Loading under the Constraint of Total Transmit Power, Target BER and RF Chins in the System

The simulation results for the SNR values of the 3X3 MIMO links and its subchannel matrixes from time instant 1 to 16 are shown in Fig. 5. When SNR gap between the worst link and other link is very large, then efficiency might be reduced for the usage of resources in the system. According to (19), the worst MIMO link will limit the lower modulation mode for the whole system although other MIMO link can load higher modulation mode. In the case for time instant 4, we should use only H2 channel matrix to give the higher throughput because they have the largest minimum singular values. However, we should not always choose the best channel like that. According

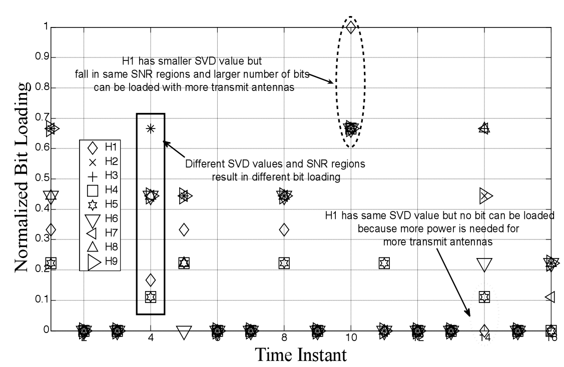

Fig. 6: Comparison of bit loading for original 3x3 MIMO channel matrix and its subchannel matrixes for 3X2 and 2X2 MIMO systems.

to (15) and (16), there are other limitations (which are also degrees of freedom in some conditions) to choose the best channel. In the case for time instant 10, we should use H1 if limitation of RF chains in (15) is allowed to use 3RF chain in both sides. Even the minimum singular values of H1 is a little smaller than other channel matrixes as shown in Fig. 4, its SNR region is the same as other subchannel matrixes as shown in Fig. 5. That means 3RF can transmit higher number of total bit than 2RF chains in the system. When we see at time instant 14 for H1, H4 and H5, we can notice that their minimum singular values are equal, but their SNR regions are different and will give the different level of bit loading. That is because of the limitation of (16) and (19). According to (16), total transmit power is equally distributed to all selected transmit antennas. Therefore, SNR level of 3RF system is less than SNR level of 2RF system and it will cause the lower modulation modes for 3RF system than 2RF system as shown in Fig. 6. That is the weak-points of the selection algorithm in [8] and [11] and we improve this weak-point in our proposed method. In their papers, they did not consider the effect of (15) and (16). They just choose the largest minimum singular values or channel gains for their selection algorithm under the predefined RF chains and this might cause the erroneous choosing in sometime as explain in above. That's why we propose the antenna selection method which jointly considers minimum singular values as well as adaptive modulation and available RF chains for efficient usage of system resources.

According to (15), there is a limitation in the selection of transmit and receive antenna based on the available RF chains in the system. Therefore, we consider our MIMO system based on the available RF chains. In case 1, we assume that there are 3 RF chains in both side and thus we can use all available channel matrixes. In case 2, we assume that there are 2 RF chains in transmitter side and 3 RF chains in receiver side. Therefore, we can use all subchannel matrixes except 3X3 MIMO channel matrixes $\mathbf{H}$. In case 3, we assume that there are 2 RF chains available in both sides and hence we have to exclude one 3X3 and three 3X2 subchannel matrixes in the antenna selection method. These antenna selection algorithms will use adaptive bit loading and antenna selection for the efficient usage of system resources to improve the system throughput under the constraint of total transmit power and predetermined target BER.

3.5.1 Case 1: Three RF Chains are Available in Both Sides

In this case, we can use all available subchannel matrixes. But, we can see in Fig 6 that at least one of the minimum singular values of 3X2 subchannel matrixes is always greater than or equal to other minimum singular values which are obtained from 2X2 subchannel matrixes. That means we do not need to check the minimum singular values of 2X2 subchannel matrixes if there has available RF chains which can support to use 3X2 MIMO system. In that case, we can reduce the complexity in case 1 for the antenna selection methods by removing all subchannel matrixes with 2X2 systems. Therefore, we will compare the second largest minimum singular value from main 3X3 channel matrix with minimum singular values from 3X2 matrixes one by one. As soon as we find it, we can stop the comparison process. However, we still need to compare the capacities of 3X3 MIMO system and the selected 3X2 MIMO system to solve the limitations in (15), (16) and (19).

<u>Step 1:</u> Initialization

a) Calculate Γ_{M_i} for each M_i –QAM modulation with predefined target BER by using (11).

<u>Step 2:</u>

a) *Set,* $H = \left\{H_1^{3\times3}, H_2^{3\times2}, H_3^{3\times2}, H_4^{3\times2}\right\}$.

b) Get the second minimum and minimum singular values by decomposing the 3X3 MIMO channel matrix with SVD.

Get $\lambda^{3\times3}{}_{2^{nd}\min}$ and $\lambda^{3\times3}{}_{\min}$.

c) After getting these values, compare $\lambda^{3\times3}{}_{2^{nd}\min}$ with $\lambda_h^{3\times2}{}_{\min}$ as shown in following.

$\lambda^{3\times2}{}_{sel} = 0;$

For Loop: h=2 to 4

Get $\lambda_h^{3\times2}{}_{\min}$*;*

If $\lambda^{3\times3}{}_{2^{nd}\min} \equiv \lambda_h^{3\times2}{}_{\min}$ *, then* $\lambda^{3\times2}{}_{sel} = \lambda_h^{3\times2}{}_{\min}$ *break;*

Else if $\lambda_h^{3\times2}{}_{\min} > \lambda^{3\times2}{}_{sel}$ *then* $\lambda^{3\times2}{}_{sel} = \lambda_h^{3\times2}{}_{\min}$*;*

End of For Loop.

<u>Step 3:</u> After getting the selected $\lambda^{3\times2}{}_{sel}$. Calculate effective throughput for 3X3 and selected 3X2 MIMO system as shown in following.

$$\gamma^{T_{sel}\times R_{sel}}{}_{\min} = \frac{P_t.\lambda^{T_{sel}\times R_{sel}}{}_{\min}}{N_0.T_{sel}} ,$$

If, $\gamma^{T_{sel}\times R_{sel}}{}_{\min} \geq \Gamma_{64}$ then $c^{T_{sel}\times R_{sel}} = 6;$

Else if, $\gamma^{T_{sel}\times R_{sel}}{}_{\min} \geq \Gamma_{16}$ then $c^{T_{sel}\times R_{sel}} = 4;$

Else if, $\gamma^{T_{sel}\times R_{sel}}{}_{\min} \geq \Gamma_{4}$ then $c^{T_{sel}\times R_{sel}} = 2;$

Else if, $\gamma^{T_{sel}\times R_{sel}}{}_{\min} \geq \Gamma_{2}$ then $c^{T_{sel}\times R_{sel}} = 1;$

Else, $c^{T_{sel}\times R_{sel}} = 0;$

$$c^{T_{sel}\times R_{sel}}{}_{total} = \sum_{i=1}^{T_{sel}} c^{T_{sel}\times R_{sel}}{}_i$$

<u>Step 4:</u> Compare $\mathrm{C}^{3\times3}{}_{total}$ and $\mathrm{C}^{3\times2}{}_{total}$ and choose the MIMO system which is related to the larger one.

<u>Step 5:</u> Step 2 to 4 is repeated for next channel realization.

3.5.2 Case 2: Two RF Chains in Transmit Side and Three RF Chains in Receive Side.

This case is similar to case 1 except that we do not need to compare with 3X3 MIMO system because this system can not be used by limited RF chains in transmitter side. And the antenna selection algorithm is expressed in following for case

2.

Step 1: Same as step 1 incase 1.

Step 2:

a) *Set,* $H = \left\{H_2^{3\times2}, H_3^{3\times2}, H_4^{3\times2}\right\}$.

b) Get the second minimum and minimum singular values by decomposing the 3X3 MIMO channel matrix with SVD.

Get $\lambda^{3\times3}_{2^{nd}\min}$ and $\lambda^{3\times3}_{\min}$.

c) After getting these values, compare $\lambda^{3\times3}_{2^{nd}\min}$ with $\lambda_h{}^{3\times2}_{\min}$ as shown in following.

$\lambda^{3\times2}_{sel} = 0;$

For Loop h=2 to 4

Get $\lambda_h{}^{3\times2}_{\min}$;

If $\lambda^{3\times3}_{2^{nd}\min} \equiv \lambda_h{}^{3\times2}_{\min}$ *, then* $\lambda^{3\times2}_{sel} = \lambda_h{}^{3\times2}_{\min}$ *break;*

Else if $\lambda_h{}^{3\times2}_{\min} > \lambda^{3\times2}_{sel}$ *then* $\lambda^{3\times2}_{sel} = \lambda_h{}^{3\times2}_{\min}$;

End of *For loop*.

Step 3: Step 2 is repeated for next channel realization.

3.5.3 Case 3: Two RF Chains are Available in Both Sides

In this case, we don't need consider mismatch polarized MIMO channel because of very lower minimum singular values in these subchannel matrixes. And the antenna selection algorithm is expressed in following for case 3.

Step 1: Same as step 1 incase 1.

Step 2:

a*) Set,* $H = \left\{H_5^{2\times2}, H_6^{2\times2}, H_7^{2\times2}, H_8^{2\times2}, H_9^{2\times2}\right\}$.

b) Get the second minimum singular values by decomposing the 3X3 MIMO channel matrix with SVD.

Get $\lambda^{3\times3}_{2^{nd}\min}$.

c) After getting this value, compare $\lambda^{3\times3}_{2^{nd}\min}$ with $\lambda_h{}^{2\times2}_{\min}$ as shown in following.

$\lambda^{2\times2}_{sel} = 0;$

For Loop h=5 to 9

Get $\lambda_h{}^{2\times2}_{\min}$;

If $\lambda^{3\times3}_{2^{nd}\min} \equiv \lambda_h{}^{2\times2}_{\min}$ *, then* $\lambda^{2\times2}_{sel} = \lambda_h{}^{2\times2}_{\min}$ *break;*

Else if $\lambda_h{}^{2\times2}_{\min} > \lambda^{2\times2}_{sel}$ *then* $\lambda^{2\times2}_{sel} = \lambda_h{}^{2\times2}_{\min}$;

End of For loop.

Step 3: Step 2 is repeated for next channel realization.

IV. SIMULATION RESULTS

We consider the situation of adaptive modulation with $M_i = \{2, 4, 16, 64\}$ to maximize the transmission rate with the target BER of 10^{-3}. The SNR thresholds Γ_{M_i} can be calculated from (13). We present the simulation results for capacity and processing time for our propose method, methods in [8] and [11] for antenna selection in three cases. We also present the results of fixed MIMO system and fixed 2X2 MIMO system for the references in each case. K-factor and antenna correlation and $\mathbf{H}_{idd}$ is randomly generated to develop the 3X3 channel matrix and we use 250000 simulation times for each methods in the system.

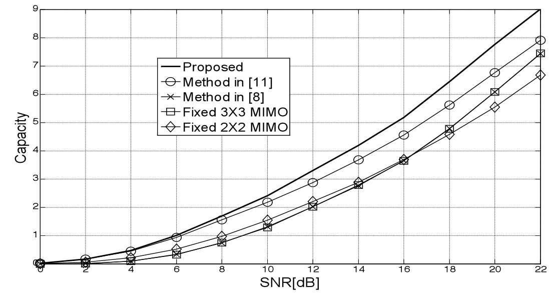

Fig. 7: Capacity comparison for case 1

In Fig.7, we show the capacity comparison for case 1. In Fig.7, we can see that the capacity of proposed method is always better than conventional antenna selection method and fixed MIMO system. That is because of the consideration for the effect of (15), (16) and (19) in the selection method. The capacity of method [8] is always lower than in method [11]. Moreover, capacity of method [8] is overlapped with that of fixed 3X3 MIMO system and their performances are even lower than fixed 2X2 MIMO system in lower SNR range. Method [8] is Frobenius norm based antenna selection method and when they calculate the Frobenius norm for 3X3 MIMO system, its channel gain is always larger than other 3X2 or 2X2 matrixes. That's why it will always choose 3X3 channel matrixes and its performance will be overlapped with fixed 3X3 MIMO system. Because of the equal power distribution in more transmit antennas and limitation in (16) and (19) 3X3 MIMO transmit antennas can not use higher modulation modes in the low SNR range and reduce the capacity. But, when their SNR range is large enough, they can use higher modulation modes with more transmit antennas and will get the higher capacity than 2X2 MIMO system.

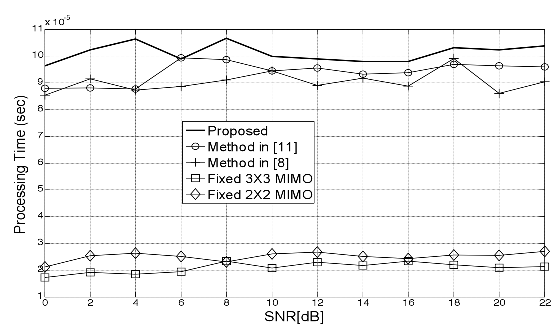

Fig. 8: Processing time comparison for case 1

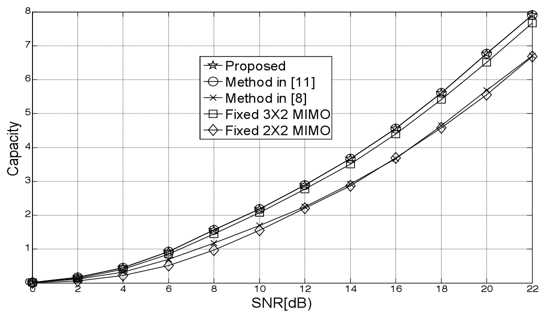

Fig. 9: Capacity comparison for case 2

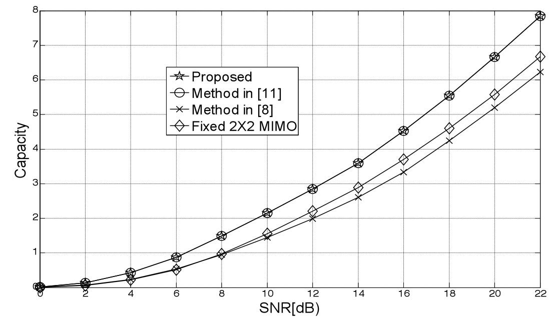

Fig. 11: Capacity comparison for case 3

We also show the simulation result of case 1 for the processing time for each method in Fig. 8. In this figure, we can see that fixed MIMO systems are the fastest ones in the system and conventional antenna selection methods in [8] and [11] are faster than our proposed method. In their methods, they just choose the channel matrix with the largest minimum singular value in [11] and highest gain in [8]. And there has no more calculation is required to consider the limitation in (15), (16) and (19). On the other hand, the propose method will choose the channel matrix with the largest minimum singular value and after that it is still necessary to compare the total capacity of selected channel matrix with 3X3 MIMO channel matrix to consider the effect of (15), (16) and (19). That's why processing time for propose method is a little longer than methods in [8] and [11].

In Fig.9, we show the capacity comparison for case 2. In this Fig. 9, we can see that the capacity of proposed method is overlapped with method in [11] although they are better than method in [8] and fixed MIMO systems. In this case 2, there are only 3X2 MIMO systems available and we do not need to consider the effect of 3X3 MIMO system. That's why our proposed method will choose only the best 3X2 MIMO channel matrix and its performance will be identical to the method in [11]. In this figure, we can see that the capacity of method in [8] is even lower than fixed 3X2 MIMO system. That is because method in [8] will simply choose the highest Frobenius norm from the available channel matrixes and they don't consider the effect of channel correlation effect in the system. When channel is heavily correlated, its minimum singular value will be very low although its effective channel gain might be the largest one in the system. And the highest channel matrix will be chosen even though its lowest SNR link can not carry the higher modulation modes. Therefore, capacity of method in [8] is not as good as fixed 3X2 MIMO system.

Their processing time is also shown in Fig. 10, in this figure, we can see that fixed MIMO system has the fastest processing time and method in [8] has lower processing time than the proposed method and method in [11]. That is because of singular value decomposition process in these two methods. SVD processing time is normally longer than Frobenius norm method for the MIMO channel matrix.

In Fig. 11, we show the capacity comparison for case 3. In Fig. 11, we can see that the capacity of the proposed method is overlapped with method in [11] although they are better than method in [8] and fixed MIMO systems. In this case 3, there are only 2X2 MIMO systems available and we do not need to consider the effect of (15) and (16). That's why our proposed method chooses only the best 2X2 MIMO channel matrix and its performance is identical to the method in [11]. In this figure, we can see that the capacity of method in [8] is also lower than fixed 2X2 MIMO system. That is because of the same reason which is already explained in Fig. 9.

In Fig. 12, we can see that fixed MIMO system has the fastest processing time and the proposed method has lower processing time than conventional methods in [8] and [11]. That is because of the effect of reduced complexity in our proposed methods as explained in section 3.

V. CONCLUSION

We have proposed the reduced complexity antenna

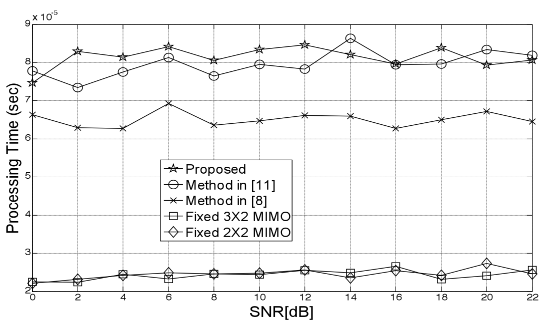

Fig. 10: Processing time comparison for case 2

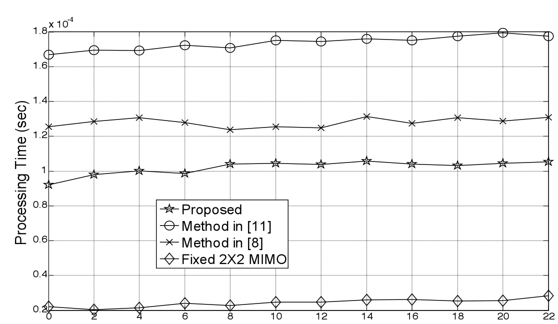

Fig. 12: Processing time comparison for case 3

selection method with adaptive bit loading and polarized antennas based on the SVD to improve the throughput performance under the constraint of total transmit power and predetermined target BER and available RF chains in the system. The complexity is reduced by removing unnecessary subchannel matrixes which have always very low minimum singular values and by comparing the second largest minimum singular value obtained from original main MIMO matrix. Computer simulated results show that the proposed scheme achieves not only higher throughput but also less processing time than conventional schemes in [8] and [11].

REFERENCES

[1] A. J. Goldsmith and S. G. Chua, "Variable-rate Variable-power MQAM for Fading Channels", IEEE Trans. Commu., vol.45, no.10, pp.1218-1230, Oct. 1997.

[2] Alis S. Darkdouki , and Moti Tabulo, "On the Engenvalue Distribution of Smart-Antenna Arrays in Wireless Communication Systems, 'Wireless Corner IEEE Antennas and Propagation Magazine, Vol.46, No.4, August 2004.

[3] Rohit U. Nabar, Helmut Bolcskei, David Gesbert and Arogyaswami J.Paulraj, |Performance of Multi-antenna Signaling Techniques in the Presence of Polarization Diversity, IEEE Transaction on signal processing, Vol. 50. No. 10, October 2002.

[4] C.Degen and W.Keusgen, "Performance Evaluation of MIMO systems Using Dual-polarized Antennas**,"** IEEE 10th International Conference on Telecommunications Vol.2, pp. 1520-1525.

[5] Mikael Coldrey, " Modeling and Capacity of polarized MIMO channels," Vehicular Technology Conference. VTC Spring May 2008. IEEE, Vol.11-14, pp.440 – 444.

[6] Hsuch Jyh Li and Chia Hao Yu,"Correlation Propoerties and Capacity of Antenna Polarization Combinations for MIMO Radio Channel", Antennas and Propagation Society International Symposium, IEEE June-2003 Vol.2, pp.503- 506.

[7] V.R. Anreddy and M.A Ingram, "Capacity of measured Ricean and Rayleigh indoor MIMO channels at 2.4GHz with polarization and spatial diversity," IEEE Wireless Communications and Networking Conference, 2006.

[8] Shahab Sanayei and Aria Nosratinaia," Antenna Selection in MIMO Systems**,"** IEICE Communications Magazine October 2004. pp.68-73.

[9] A.F Molisch and M.Z Win, "MIMO Systems with Antenna Selection," IEEE Microwave Magazine, vol.5, no. 1, pp. 46-56, March 2004.

[10] Nabar R, Gore D, Paulraj A," Optimal Selection and Use of Transmit Antennas in Wireless Systems in Wireless Systems," Proceeding International Conference Telecommunication (ICT) Acapulco, Mexico, May 2000.

[11] R.W.Heath,S.Sandhu and A.Paulraj, "Antenna selection for spatial multiplexing systems with linear receivers," IEEE communi. Letters, vol.5, No.4, pp.142-144 April 2001.

[12] Bedri A. Cetiner and Enis Akay, " A MIMO system with multifunctional reconfigurable antennas', IEEE Antennas and Wireless Propagation Letters, Vol. 5, 2006.

[13] P.W Wolniansky, G.J. Foschini, G.D. Golden, R.A. Valenzuela, "V-BLAST: An architecture for realizing very high data rates over the rich-scattering wireless channel," invited. paper, IEEE ISSSE-98 pp.295-300. Pisa, Italy 1998.

[14] Arogyaswami Paulraj,Rohit Nabar, and Dhananjay Gore," Introduction to space-time wireless communications " , Cambridge University Press , 2003.