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Near Optimal Receive Antenna Selection Scheme for MIMO System under Spatially Correlated Channel

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ABSTRACT

Spatial correlation is a critical impairment for practical Multiple Input Multiple Output (MIMO) wireless communication systems. To overcome from this issue, one of the solutions is receive antenna selection. Receive antenna selection is a low-cost, low-complexity and no requirement of feedback bit alternative option to capture many of the advantages of MIMO systems. In this paper, symbol error rate (SER) versus signal to noise ratio (SNR) performance comparasion of proposed receive antenna selection scheme for full rate non-orthogonal Space Time Block Code (STBC) is obtained using simulations in MIMO systems under spatially correlated channel at transmit and receive antenna compare with several existing receive antenna selection schemes. The performance of proposed receive antenna selection scheme is same as conventional scheme and beat all other existing schemes.

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1. INTRODUCTION

Wireless communication in a fading channel is very challenging. Performance of wireless communication systems can be improved by using several diversity techniques using multiple antennas at the transmitter or at the receiver or at both the ends. In general, this is popularly known as multiple input multiple output (MIMO) in standards such as Long Term Evolution (LTE), Wideband Code Division Multiple Access (WCDMA) and Worldwide Interoperability for Microwave Access (WiMAX). In MIMO systems, at the transmitter, space time block coding (STBC) is used to exploit diversity gain. However, adverse effect of STBC is there on the code rate. A special case of Orthogonal STBC, the Alamouti space time code [1], which has been proposed for two transmit antennas, can offer full diversity gain and rate as well i.e. one. For more than two transmit antennas, the code rate is below one [2].

Recently, some non-orthogonal STBC have been proposed with reasonable decoding complexity with a motivation to gain full diversity without loss of code rate [3], [4]. In [4], three and four transmit antennas are used and SER performance was presented using simulations assuming spatially uncorrelated channels.

However, it is hardly possible to assume spatially uncorrelated channels [5], [6]. Therefore, in this paper a real time scenario is considered assuming spatially correlated channels in MIMO system at both the ends with receive antenna selection [7]-[11]. Assuming coherent detection of QPSK modulation with quasi-static rayleigh fading channels, we present SER performance of this system and shows that effect of spatial correlation at the transmit and receive antennas to be nullify and improved with proposed receive antenna selection scheme. The reason behind choosing receive antenna selection are a) No hardware complexity b) No more RF (radio frequency) chain required c) incereses channel capacity d) do not require feedback bit.

The rest of the paper is organized as follows. Section 2 describes the system model, encoding and generation of spatially correlated channels. Section 3 demonstrates Proposed and existing receive antenna selection procedures. Section 4 and Section 5 deal with low complex detection and result discussion respectively.

2. SYSTEM MODEL

We have equipped MIMO system consisting $L_t = 4$ transmit and $L_r=8$ antenna out of which $L_{selected}=4$ receive antennas are selected. The channel fading coefficient $h_{i,j}$ between transmit antenna i $(1 \leq i \leq L_t)$ and receive antenna j $(1 \leq j \leq L_r)$ are $CN \sim (0,1)$ [9]. We assumed channel state information perfectly available at receiver (CSIR).
Then received equation can be expressed as:

$$\mathbf{y = HC+w}, \quad (1)$$

where **C** is code matrix transmitted from the transmitter. For L_t = 4, it can be expressed as [4]:

$$\mathbf{C} = \begin{pmatrix} s_1 & s_2 & s_3 & as_4 \\ -s_2^* & s_1^* & bs_4^* & s_3 \\ s_3^* & cs_4^* & -s_1^* & s_2 \\ ds_4^* & s_3^* & -s_2^* & -s_1 \end{pmatrix} \quad (2)$$

where $a=i,\ b=sin(\pi/6)+icos(\pi/6),\ c=sin(\pi/6)+icos(\pi/6)$ and $d\ =sin(\pi/6)+icos(\pi/6)$. In (1), **w** denotes additive complex gaussian noise with $CN(0,\sigma^2)$. Further, **H** denotes channel matrix of order $L_r \times L_t$ as:

$$\mathbf{H} = \begin{pmatrix} h_{1,1} & h_{1,2} & h_{1,3} & h_{1,4} \\ h_{2,1} & h_{2,2} & h_{2,3} & h_{2,4} \\ h_{3,1} & h_{3,2} & h_{3,3} & h_{3,4} \\ . & . & . & . \\ . & . & . & . \\ h_{Lr,1} & h_{Lr,2} & h_{Lr,3} & h_{Lr,4} \end{pmatrix} \quad (3)$$

where $h_{j,i}$ denotes low pass equivalent channel coefficient between j[th] receive antenna and i[th] transmit antenna. The $h_{j,i}$ is assumed as a complex gaussian variable with mean zero and variance one. We assume that all the channel coefficients in **H** are spatially correlated, which are generated with known correlation using the following steps [8].

a. Stacking all the entries in one column, we can express:

$$\mathrm{vec}(\mathbf{H}) = \begin{pmatrix} h_{1,1} \\ h_{1,2} \\ h_{1,3} \\ h_{1,4} \\ h_{2,1} \\ h_{2,2} \\ h_{2,3} \\ h_{2,4} \\ \ldots \\ h_{Lr,1} \\ h_{Lr,2} \\ h_{Lr,3} \\ h_{Lr,4} \end{pmatrix} \quad (4)$$

b. The correlation matrices at the transmitter and receiver ρ_t and ρ_r respectively, can be expressed as follows:

$$\rho_t = \begin{pmatrix} E[h_{1,1}h_{1,1}^*] & E[h_{1,1}h_{1,2}^*] & E[h_{1,1}h_{1,3}^*] & E[h_{1,1}h_{1,4}^*] \\ E[h_{1,2}h_{1,1}^*] & E[h_{1,2}h_{1,2}^*] & E[h_{1,2}h_{1,3}^*] & E[h_{1,2}h_{1,4}^*] \\ E[h_{1,3}h_{1,1}^*] & E[h_{1,3}h_{1,2}^*] & E[h_{1,3}h_{1,3}^*] & E[h_{1,3}h_{1,4}^*] \\ E[h_{1,4}h_{1,1}^*] & E[h_{1,4}h_{1,2}^*] & E[h_{1,4}h_{1,3}^*] & E[h_{1,4}h_{1,4}^*] \end{pmatrix} \quad (5)$$

$$\rho_t = \begin{pmatrix} 1 & J_0(d_t) & J_0(2d_t) & J_0(3d_t) \\ J_0(d_t) & 1 & J_0(d_t) & J_0(2d_t) \\ J_0(2d_t) & J_0(d_t) & 1 & J_0(d_t) \\ J_0(3d_t) & J_0(2d_t) & J_0(d_t) & 1 \end{pmatrix} \quad (6)$$

$$\rho_r = \begin{pmatrix} E[h_{1,1}h_{1,1}^*] & E[h_{1,1}h_{2,1}^*] & E[h_{1,1}h_{3,1}^*] & E[h_{1,1}h_{4,1}^*] & E[h_{1,1}h_{5,1}^*] & E[h_{1,1}h_{6,1}^*] & E[h_{1,1}h_{7,1}^*] & E[h_{1,1}h_{8,1}^*] \\ E[h_{2,1}h_{1,1}^*] & E[h_{2,1}h_{2,1}^*] & E[h_{2,1}h_{3,1}^*] & E[h_{2,1}h_{4,1}^*] & E[h_{2,1}h_{5,1}^*] & E[h_{2,1}h_{6,1}^*] & E[h_{2,1}h_{7,1}^*] & E[h_{2,1}h_{8,1}^*] \\ E[h_{3,1}h_{1,1}^*] & E[h_{3,1}h_{2,1}^*] & E[h_{3,1}h_{3,1}^*] & E[h_{3,1}h_{4,1}^*] & E[h_{3,1}h_{5,1}^*] & E[h_{3,1}h_{6,1}^*] & E[h_{3,1}h_{7,1}^*] & E[h_{3,1}h_{8,1}^*] \\ E[h_{4,1}h_{1,1}^*] & E[h_{4,1}h_{2,1}^*] & E[h_{4,1}h_{3,1}^*] & E[h_{4,1}h_{4,1}^*] & E[h_{4,1}h_{5,1}^*] & E[h_{4,1}h_{6,1}^*] & E[h_{4,1}h_{7,1}^*] & E[h_{4,1}h_{8,1}^*] \\ E[h_{5,1}h_{1,1}^*] & E[h_{5,1}h_{2,1}^*] & E[h_{5,1}h_{3,1}^*] & E[h_{5,1}h_{4,1}^*] & E[h_{5,1}h_{5,1}^*] & E[h_{5,1}h_{6,1}^*] & E[h_{5,1}h_{7,1}^*] & E[h_{5,1}h_{8,1}^*] \\ E[h_{6,1}h_{1,1}^*] & E[h_{6,1}h_{2,1}^*] & E[h_{6,1}h_{3,1}^*] & E[h_{6,1}h_{4,1}^*] & E[h_{6,1}h_{5,1}^*] & E[h_{6,1}h_{6,1}^*] & E[h_{6,1}h_{7,1}^*] & E[h_{6,1}h_{8,1}^*] \\ E[h_{7,1}h_{1,1}^*] & E[h_{7,1}h_{2,1}^*] & E[h_{7,1}h_{3,1}^*] & E[h_{7,1}h_{4,1}^*] & E[h_{7,1}h_{5,1}^*] & E[h_{7,1}h_{6,1}^*] & E[h_{7,1}h_{7,1}^*] & E[h_{7,1}h_{8,1}^*] \\ E[h_{8,1}h_{1,1}^*] & E[h_{8,1}h_{2,1}^*] & E[h_{8,1}h_{3,1}^*] & E[h_{8,1}h_{4,1}^*] & E[h_{8,1}h_{5,1}^*] & E[h_{8,1}h_{6,1}^*] & E[h_{8,1}h_{7,1}^*] & E[h_{8,1}h_{8,1}^*] \end{pmatrix} \quad (7)$$

$$\rho_r = \begin{pmatrix} 1 & J_0(d_r) & J_0(2d_r) & J_0(3d_r) & J_0(4d_r) & J_0(5d_r) & J_0(6d_r) & J_0(7d_r) \\ J_0(d_r) & 1 & J_0(d_r) & J_0(2d_r) & J_0(3d_r) & J_0(4d_r) & J_0(5d_r) & J_0(6d_r) \\ J_0(2d_r) & J_0(d_r) & 1 & J_0(d_r) & J_0(2d_r) & J_0(3d_r) & J_0(4d_r) & J_0(5d_r) \\ J_0(3d_r) & J_0(2d_r) & J_0(d_r) & 1 & J_0(d_r) & J_0(2d_r) & J_0(3d_r) & J_0(4d_r) \\ J_0(4d_r) & J_0(3d_r) & J_0(2d_r) & J_0(d_r) & 1 & J_0(d_r) & J_0(2d_r) & J_0(3d_r) \\ J_0(5d_r) & J_0(4d_r) & J_0(3d_r) & J_0(2d_r) & J_0(d_r) & 1 & J_0(d_r) & J_0(2d_r) \\ J_0(6d_r) & J_0(5d_r) & J_0(4d_r) & J_0(3d_r) & J_0(2d_r) & J_0(d_r) & 1 & J_0(d_r) \\ J_0(7d_r) & J_0(6d_r) & J_0(5d_r) & J_0(4d_r) & J_0(3d_r) & J_0(2d_r) & J_0(d_r) & 1 \end{pmatrix} \quad (8)$$

Here, d_t and d_r denote distances between two consecutive antennas at the transmitter and receiver respectively, while $J_0(x)$ is the zeroth order Bessel function of first kind. For higher values of d_t or d_r, spatial correlation will reduce and vice a versa.

c. Channel correlation matrix **R** can be expressed as:

$$\mathbf{R} = \rho_t \otimes \rho_r \quad (9)$$

where $\otimes$ denotes kronecker product.

d. Using Eigen Value Decomposition (EVD), we can write:

$$\mathbf{R} = \mathbf{VDV}^* \quad (10)$$

where **V** is a unitary matrix and **D** is diagonal matrix for eigenvalues. The $(\ )^*$ denotes transpose and conjugate.

e. Generate vector **r** of order $L_t \times L_r$, where each entry in **r** is independent and identically distributed as complex gaussian with mean zero and variance one.

f. Now vec (**H**) can be expressed as:

$$\text{vec}(\mathbf{H}) = \mathbf{VD}^{1/2}\mathbf{r} \quad (11)$$

Now, from vec (**H**), we can get **H** as defined in (3) and (4). We assume that channel matrix **H** is perfectly known at the receiver and is quasi static at least for a period of one code symbol.

3. RECEIVE ANTENNAS SELECTION (RAS) SCHEMES

3.1. Scheme-1-conventional receive antenna selection scheme

The receive antenna j^{th} amplitude is given as y_j [5], [9], [11].

Algorithm
for j=1:1: L_r

$$y_r = \|y_j\|^2$$

end for

$$\hat{y} = \arg\max_{r \in L_{selected}} (y_r)$$

In conventional receive antenna selection scheme, the received power gain of all receiver antenna have been measured and as per maximum received power gain of receive antenna, the selection of receive antenna is to be done.This is optimum receive antenna selection scheme which gives better performance compare to all other receive antenna selection scheme.

3.2. Scheme-2-best 2-random 2 receive antenna selection scheme

Algorithm
for j=1:1: L_r

$$y_r = \|y_j\|^2$$

end for

$$y_t = \arg\max_{r \in L_{selected}-2} (y_r)$$

$$y_c = \arg\min_{r \in L_{selected}-2} (y_r)$$

$$\hat{y} = [y_t(1), y_t(2), rand(y_c(1)), rand(y_c(2))]$$

In best 2 –random 2 receive antenna selection scheme [11], there are two receive antenna selected based on maximum received power gain and rest of two receive antenna select randomly from remaining receive antenna.

3.3. Scheme-3-consecutive receive antenna selection scheme

Algorithm
for j=1:1: L_r*-4*

$$y_{r_1} = \sum \|y_j\|^2$$

end for

for j= $L_{selected}$*:1:* L_r

$$y_{r_2} = \sum \|y_j\|^2$$

end for

if $(y_{r1} >= y_{r2})$
 $y=[y_1, y_2, y_3, y_4]$
else
 $y=[y_5, y_6, y_7, y_8]$
end if

In consecutive receive antenna selection scheme [11], there are two group to be divided in sequential number.Then, received power gain of each two group are to be measure in addition of all receive antenna in their group. Finally, highest addition received power gain group will be selected for receive antenna.

3.4. Scheme-4-even odd receive antenna selection scheme

Algorithm
for $j=1:2: L_r$

$$y_{r_1} = \sum \|y_j\|^2$$

end for

for $j=2:2: L_r$

$$y_{r_2} = \sum \|y_j\|^2$$

end for

if $(y_{r1} >= y_{r2})$
$y=[y_1, y_3, y_5, y_7]$
else
$y=[y_2, y_4, y_6, y_8]$
end if

In even odd receive antenna selection scheme [11], even receive antenna and odd receive antenna groups have been created out of which maximum addition of received power gain group is selected as receive antenna.

3.5. Scheme-5-zero forcing (ZF) based receive antenna selection scheme

Algorithm
$y=HC+w$
$yd=(H^H H)^{-1} H^H y$

for $j=1:1: L_r$
$y_r= || yd(:,j)||^2$
end for

$[y_{t1,}in1]=max\ (y_r)$

$y=[\ y(in1(1))\ y(in1(2))\ y(in1(3))\ y(in1(4))]$

In zero forcing (ZF) based receive antenna selection scheme [11], the product of pseudo inverse of channel matrix with matrix of all receive antenna. Then, based on maximum norm of zero forcing equation receive antenna have been selected.

3.6. Scheme-6-gradual elimination receive antenna selection scheme

Algorithm
Initilisation:

$$H = \overline{H}$$

for $t=1:1: L_r$

$$\hat{t} = \overline{H}_t \{I_{N_t} + (E_s / N_0) H^H H\}^{-1} \overline{H}_t^H$$

end for
$[y_{t1,}in_1]=min\ (\hat{t}\ )$

$H=[\ H(in_1(5))\ H(in_1(6))\ H(in_1(7))\ H(in_1(8))]$

In gradual elimination method [11], the fundamental concept behind this method is to remove consecutive exclusion of receive antennas based on which one of the row at each stage have been eliminated. This will be repeated L_r - $L_{selected}$ times in the channel matrix and at each step channel matrix have been updated.

3.7. Scheme-7-proposed receive antenna selection scheme

Algorithm
for j=1:1: L_r

$$ch = \left\| h_j \right\|^2$$

end for
[y_t, in]=argmax (ch)

for in=2:1: $L_{selected}$

for j=1:1: L_r

$$ch_{in} = \arg\max\left(\frac{\left\| h_{\mathrm{j}} \right\|^2}{h_{\mathrm{j}} H_{in}^H} \right)$$

end for

end for

In proposed receive antenna selection scheme, the received power gain of all receiver antenna have been measured and as per received power gain of receive antenna, the selection of first receive antenna is to be done.Then, rest of the antenna are selected from minimization of channel capacity equation at higher SNR.This scheme gives approximately equal performance as conventional or optimum receive antenna selection scheme which gives better performance compare to all other receive antenna selection scheme.

4. LOW COMPLEX DETECTION

We calculate intermediate symbol $I_{j,t}$, where j = 1, 2, 3, 4 and t = 1, 2, 3, 4 using received symbols **Y** and channel $\mathbf{L}_{\mathbf{selected}}$ as shown below [4].

$$I_{j,t} = \mathrm{y}_{\mathrm{j,t}} - \mathrm{h}_{(\mathrm{k,\,j})}\delta_{\mathrm{t,k}}\,(\mathbf{C}) \tag{12}$$

Where $\delta_{\mathrm{t,k}}$ (**C**) signifies the code word element at the t^{th} row and k^{th} column of C, which comprises the transmitted symbol s_4 or s_4^*.
Then, the intermediate symbol $I_{j,t}$ value inserted in to conditional Maximum Likelihood (ML) estimates for s_1, s_2, s_3.The conditional Maximum Likelihood (ML) estimates for s_1, s_2, s_3 can be expressed as:

$$\mathrm{s}_1^{\mathrm{ML}} = \sum_{j=1}^{M} (I_{\mathrm{j,1}}\mathrm{h}_{\mathrm{1,j}}^* + (\mathrm{I}_{\mathrm{j,2}})^*\mathrm{h}_{\mathrm{2,j}} - (\mathrm{I}_{\mathrm{j,3}})^*\mathrm{h}_{\mathrm{3,j}} - \mathrm{I}_{\mathrm{j,4}}\mathrm{h}_{\mathrm{4,j}}^*) \tag{13}$$

$$\mathrm{s}_2^{\mathrm{ML}} = \sum_{j=1}^{M} (I_{\mathrm{j,1}}\mathrm{h}_{\mathrm{2,j}}^* - (\mathrm{I}_{\mathrm{j,2}})^*\mathrm{h}_{\mathrm{1,j}} + I_{\mathrm{j,3}}\mathrm{h}_{\mathrm{4,j}}^* - (\mathrm{I}_{\mathrm{j,4}})^*\mathrm{h}_{\mathrm{3,j}}^*) \tag{14}$$

$$\mathrm{s}_3^{\mathrm{ML}} = \sum_{j=1}^{M} (I_{\mathrm{j,1}}\mathrm{h}_{\mathrm{3,j}}^* + I_{\mathrm{j2}}\mathrm{h}_{\mathrm{4,j}}^* + (I_{\mathrm{j,3}})\mathrm{h}_{\mathrm{1,j}}^* - (\mathrm{I}_{\mathrm{j,4}})^*\mathrm{h}_{\mathrm{2,j}}) \tag{15}$$

Then, receiver minimizes the ML decision metric [8].

$$\sum_{t=1}^{4}\sum_{j=1}^{2}\left\| y_{j,t} - \sum_{i=1}^{N} h_{i,j}\, c_{i,t} \right\|^2 \quad (16)$$

5. RESULTS AND ANALYSIS

In this section, we have presented symbol error rate (SER) versus average signal to noise ratio (SNR) performance of the considered system i.e. correlation coefficient at both the side for QPSK modulations with different receive antenna selection schemes. The avg. SNR is denoted by E_s / N_0 in dB.

Figure 1 present SER versus SNR for spatially correlated antenna at transmitter and receiver (d_t = 0.1λ, d_r = 0.1λ) with various receive antenna selection (4; 8, 4) schemes. It has been observed that the SER vs avg. SNR performance of proposed receive antenna selection scheme beat consuctive receive antenna group selection scheme, even odd receive antenna group selection, gradual elimination receive antenna selection and zero forcing based receive antenna selection scheme in to entire SNR range. The performance of proposed receive antenna selection scheme have same SER with conventional receive antenna selection scheme over entire signal to noise ratio. There is a minimum 0.4dB SNR gap present between proposed scheme and existing schemes through out entire result which shows little complexity increases compare to existing method result improvement in SER.

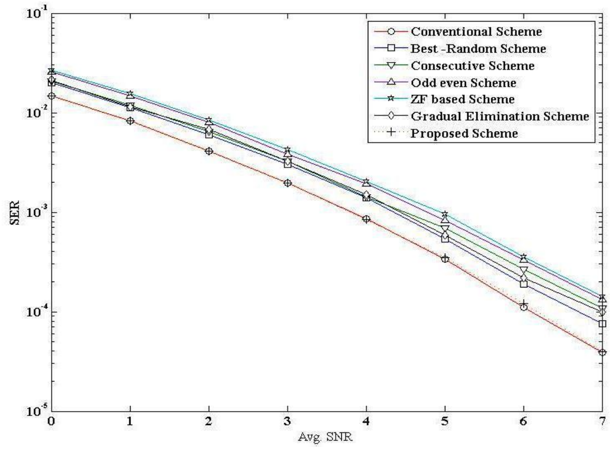

Figure 1. SER Vs. Avg. SNR for spatially correlated antenna at transmitter and receiver (d_t = 0.1λ, d_r = 0.1λ) with various receive antenna selection schemes (4; 8, 4)

6. CONCLUSION

The effect of spatial correlation is to be compensated with proposed receive antenna selection scheme which is as good as conventional method SER performance. It can be observed that proposed receive antenna selection scheme outperforms over all existing schems with little addition of complexity.Receive antenna selection do not increase hardware complexity with RF chain at receiver side. The benefit of the system is not to provide feedback bit for the selection of receive antennas.

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