Capacity and Diversity Gains of MIMO Systems in Correlated Rician Fading Channels

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Abstract — **This paper investigates the effect of Rician fading and correlation on the capacity and diversity of MIMO channels. The use of antenna arrays at both sides of the wireless communication link (MIMO systems) can result in high channel capacity provided the propagation medium is rich scattering or Rayleigh fading and the antenna arrays at both sides are uncorrelated. However, the presence of line-of-sight (LOS) component and correlation of real world wireless channel may affect the system performance. Block and frequency nonselective Rician fading channel is assumed, and the effect of Rician factor (*K*), and the correlation parameter (*r*) on the capacity and diversity gains of MIMO channels is investigated. We also endorsed the view point that the loss or gain in the capacity or diversity gains can be considered as an equivalent increase or decrease in the signal-to-noise power ratio (SNR).**

Index Terms — **Correlation, fading, multiple-input multiple-output (MIMO), diversity, Rician channel, spatial multiplexing.**

I. Introduction

There continues to be substantial interest in wireless communication systems that employ multiple transmit and receive antennas, due to their promise for dramatically increasing the performance and capacity to 20-40 bit/s/Hz when the system design is optimal [1]. Multiple-input multiple-output (MIMO) system can provide two types of gains: diversity gain and spatial multiplexing gain or capacity gain. With *T* transmit and *R* receives antennas, the system can provide spatial multiplexing gain of $m = min$ (T, R) or diversity gain (*D*) of order *T.R* [2]. However, the correlation of a real-world wireless channel may result in a substantial degradation of the MIMO architecture performance [3]–[6]. Secondly, there is a possibility that the line-of-sight (LOS) component may exist in addition to scattered components. Then, the fading will follow the Rician distribution, degrading the performance of MIMO, compared to Rayleigh fading [7-8]. Recently, Sun and Reed [9] presented diversity analysis for MPSK transmitted over uncorrelated Rician fading channels. In most of the published work, the joint effect of Rician fading, correlated channels and availability of channel information were not discussed.

In this paper, we investigate the effect of Rician factor *K*, and correlation parameter (*r*) on the capacity and diversity gains of MIMO channels. Capacity and diversity gains of block and frequency nonselective fading MIMO systems are obtained using hybrid simulations. The effect of AWGN is calculated analytically, whereas the effects of Rician factor, and correlated fading are obtained using Monte Carlo simulation. Also, the effect of CSI at the transmitter on the capacity gains is studied using Monte Carlo simulation.

II. Overview Of The Paper

The paper is organized as follows. Section III describes the signal and the channel model. The capacity and diversity gains of Rician fading channel are discussed in section IV and section V respectively. Section VI presents the simulation results and discussion followed by conclusions in section VII.

III. MIMO Channel And Signal Model

Consider a single user MIMO system with *T* antennas at the transmitter and *R* antennas at the receiver.

A. MIMO Signal Model

The system is described by the matrix equation [10]–[12].

$$\mathbf{y} = \sqrt{\frac{E_S}{T}}\mathbf{Hs} + \mathbf{n} \tag{1}$$

where E_s is the total energy available at the transmitter, $\mathbf{y}$ is the $R \times 1$ vector of signals received on the *R* antennas, $\mathbf{s}$ is the $T \times 1$ vector of signals transmitted on the *T* transmit antennas, $\mathbf{n}$ is the $R \times 1$ noise vector consisting of independent complex Gaussian distributed elements with zero mean and variance σ^2, and $\mathbf{H}$ is the $R \times T$ channel matrix.

B. Correlated Rician fading Channel Model

In Rician fading the elements of $\mathbf{H}$ are non-zero mean complex Gaussians. Hence we can express $\mathbf{H}$ in matrix notation as [11]–[12]

$$\mathbf{H} = a\mathbf{H}^{sp} + b\mathbf{H}^{sc} \tag{2}$$

where the specular and scattered components of $\mathbf{H}$ are denoted by superscripts, $a > 0$, $b > 0$ and $a^2 + b^2 = 1$. $\mathbf{H}^{sp}$ is a matrix of unit entries denoted as $\mathbf{H}_1$. If there is no correlation at the transmitter or at the receiver side then the entries of $\mathbf{H}^{sc}$ are independent and identically distributed (i.i.d) complex Gaussian random variables with zero mean and unit magnitude variance, usually denoted by $\mathbf{H}_\omega$. If there is correlated fading then the $\mathbf{H}^{sc}$ matrix can be modeled as [3], [4].

$$\mathbf{H}^{sc} = \mathbf{R}_r^{1/2}\mathbf{H}_\omega\mathbf{R}_t^{1/2} \tag{3}$$

where $\mathbf{R}_t$ and $\mathbf{R}_r$ are the correlation matrix at the transmitter and at the receiver side, respectively. The correlation matrix $\mathbf{R}$ is defined as [5]

$$r_{ij} = \begin{cases} r^{j-i}, & i \le j \\ r_{ji}^{*}, & i > j \end{cases} \quad ,|r| \le 1 \tag{4}$$

where "*" denotes the complex conjugate. The Rician factor, K is defined as a^2/b^2. Thus, the above **H** matrix can be written as [11]–[12]

$$\mathbf{H} = \sqrt{\frac{K}{K+1}}\mathbf{H}_1 + \sqrt{\frac{1}{K+1}}\mathbf{R}_{\mathrm{r}}^{1/2}\mathbf{H}_{\omega}\mathbf{R}_{\mathrm{t}}^{1/2} \tag{5}$$

IV. MIMO Capacity

In the following, we assume that the channel is perfectly known to the receiver (channel knowledge at the receiver can be maintained via training and tracking) whereas the channel state information at the transmitter may be available or not. Furthermore, we assume an ergodic block fading channel model where the channel remains constant over a block of consecutive symbols, and changes in an independent fashion across blocks. In fading channels there are essentially two notions of capacity: ergodic capacity and outage capacity [1] which relate to the mean and the tail behavior of capacity, respectively.

Ergodic Capacity: This is the time-averaged capacity of a stochastic channel. It is found by taking the mean of the capacity values obtained from a number of independent channel realizations.

Outage Capacity: The q% outage capacity $C_{out,q}$, is defined as the capacity that is guaranteed for $(100 - q)$% of the channel realizations [1], i.e.,

$$P\left(C \le C_{out,q}\right) = q\% \tag{6}$$

A. Channel Unknown at the Transmitter

Acquiring channel knowledge at the transmitter is in general very difficult in practical systems. When the transmitter has no channel state information, it is optimal to evenly distribute the available power ρ among the transmit antennas. The MIMO channel capacity with $\rho = E_s/\sigma^2$ can be written as [13], [14]

$$C = E_{\mathbf{H}}\left\{\log_2 \det\left(\mathbf{I}_R + \frac{\rho}{T}\mathbf{H}\mathbf{H}^H\right)\right\} \tag{7}$$

where $E_{\mathbf{H}}\{.\}$ denote the expectation over **H** and the operator $\mathbf{H}^H$ indicates the hermitian of the matrix **H**. Using singular value decomposition (SVD), (7) can be decomposed as

$$C = E_{\lambda}\left\{\sum_{i=1}^{k}\log_2\left(1 + \frac{\rho}{T}\lambda_i\right)\right\} \tag{8}$$

where $E_{\lambda}\{.\}$ denote the expectation over λ, k, $(k \le m)$ is the rank of **H**, and λ_i (i = 1, 2, ….., k) denotes the positive eigenvalues of $\mathbf{H}\mathbf{H}^{\mathrm{H}}$.

B. Channel Known at the Transmitter

When the channel parameters are known at the transmitter, i.e., the channel state information (CSI) is available at the transmitter, the capacity given by (7), or (8), can be increased by assigning the transmitted power to various antennas according to the "water-filling" algorithm [14].

$$C = E_{\lambda}\left\{\sum_{i=1}^{k}\log_2\left(1 + \rho_i\lambda_i\right)\right\} \tag{9}$$

Where ρ_i , is the power assigned to the i^{th} transmitter and μ is chosen to satisfy:

$$\rho_i = (\mu - \lambda_i^{-1})^{+} \tag{10}$$

$$\rho = \sum_{i=1}^{k}\rho_i \tag{11}$$

and "+" denotes taking only those terms which are positive.

V. MIMO Diversity

In the following, we assume that the channel is perfectly known to the receiver. Furthermore, we assume an ergodic block fading channel model where the channel remains constant over a block of consecutive symbols, and changes in an independent fashion across blocks. It has been shown that effective channel for MIMO using Orthogonal Space-Time Block codes (OSTBCs) resembles the effective channel obtained for maximum ratio combining (MRC) [11]. Thus, we carried out the MRC analysis of the SIMO equivalent channels of the MIMO system.

Let there be D identical independent fading links exists between transmitter and receiver. Then, the signal model is given as

$$y_i = \sqrt{\frac{E_s}{D}}h_i s + n_i, \quad i = 1,2,\cdots,D \tag{12}$$

where y_i is the received signal on the i^{th} diversity branch, h_i is the channel corresponding to the i^{th} diversity branch, s is the transmitted symbol. E_s/D is the symbol energy available to the transmitter for each of the D branches; n_i is the AWGN with variance σ^2. In vector format, (12) can be written as

$$\mathbf{y} = \sqrt{\frac{E_S}{D}}\mathbf{hs} + \mathbf{n} \tag{13}$$

where **y** is the $D \times 1$ vector of signals received on the R antennas, **s** is the $T \times 1$ vector of signals transmitted on the T transmit antennas, **n** is the $D \times 1$ noise vector consisting of independent complex Gaussian distributed elements with zero mean and variance σ^2, and **h** represents the vector form of **H** matrix.

$$z = \mathbf{h}^H\mathbf{y} = \sqrt{\frac{E_s}{D}}\mathbf{h}^H\mathbf{hs} + \mathbf{h}^H\mathbf{n} \tag{14}$$

Received Signal Power is given by

$$\left[\sqrt{\frac{E_s}{D}}\mathrm{h}^H\mathrm{h}\right]\left[\sqrt{\frac{E_s}{D}}\mathrm{h}^H\mathrm{h}\right]^H = \frac{E_s}{D}\left(\|\mathrm{h}\|^2\right)^2 \tag{15}$$

Noise Power is given by

$$\left[\mathbf{h}^H\mathbf{n}\right]\left[\mathbf{h}^H\mathbf{n}\right]^H = \sigma^2\|\mathbf{h}\|^2 \tag{16}$$

So, the received Signal-to-noise power ratio (SNR) is calculated as

$$\eta = \frac{\frac{E_s}{D}\left(\|\mathbf{h}\|^2\right)^2}{\sigma^2\|\mathbf{h}\|^2} = \frac{1}{D}\|\mathbf{h}\|^2\bar{\gamma}_s \quad (17)$$

Since, **h** is the vector form of the matrix **H**, so

$$\|\mathbf{h}\|^2 = \|\mathbf{H}\|_F^2 \quad (18)$$

Thus, we can represent the received Signal-to-noise ratio (SNR) as

$$\eta = \frac{1}{D}\|\mathbf{H}\|_F^2\bar{\gamma}_s \quad (19)$$

The probability of symbol error or the symbol error rate for MPSK for an AWGN channel is given as follows [15]:

$$P_s(E) = 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) = 2Q\left(\sqrt{2k\gamma_b}\sin\frac{\pi}{M}\right) \quad (20)$$

where M represents M-ary modulation, k is the number of bits per symbol, γ_s is received SNR per symbol, γ_b is the received SNR per bit, and $Q(\,)$represents Gaussian Q-function. Thus, symbol error rate (SER) for MPSK for a fading channel using MRC can be obtained by modifying (20) as follows [16]:

$$P_s(E) = E_{\mathbf{H}}\left\{2Q\left(\sqrt{2\eta}\sin\frac{\pi}{M}\right)\right\} = E_{\mathbf{H}}\left\{2Q\left(\sqrt{\frac{2\|\mathbf{H}\|_F^2\bar{\gamma}_s}{D}}\sin\frac{\pi}{M}\right)\right\} =$$

$$E_{\mathbf{H}}\left\{2Q\left(\sqrt{\frac{2\|\mathbf{H}\|_F^2 k\bar{\gamma}_b}{D}}\sin\frac{\pi}{M}\right)\right\} \quad (21)$$

where $E_{\mathbf{H}}\{.\}$ denote the expectation over **H**.

VI. Simulation Results

The results in this section illustrate the effect of correlated fading and Rician factor on the capacity and diversity gains of MIMO fading channels. In view of the fact that **H** matrix represents the channel, the elements of **H** matrix are random and depend upon the type of fading encountered by the channel. For Rician fading channels, the elements of **H** matrix consist of two parts (2). The first part, $\mathbf{H}^{sp}$ is fixed while the second part consists of $\mathbf{H}^{sc}$, which is random. The elements of $\mathbf{H}_\omega$ are i.i.d. zero mean circularly symmetric complex Gaussian (ZMCSCG) random numbers with unit variance, generated using Matlab software. Here, in all cases we have considered correlation at both ends. We divide this section into two parts. In the first part we present the capacity results while in the second part, we discuss the diversity gains by calculating the probability of symbol error for MIMO Rician fading channels.

A. Capacity Results

Capacity gains of block and frequency nonselective fading MIMO systems are obtained using hybrid simulations. The effect of AWGN is calculated analytically, whereas the effects of Rician factor, correlated fading, and CSI at the transmitter are obtained using Monte Carlo simulation. Then using (5) and the capacity expressions ((7)–(11)), capacity is calculated. The results are then averaged over 10^4 channel realizations. In all the cases discussed here, it is assumed that the CSI is available at the receiver whereas CSI at the transmitter may be available or not.

Effect of the number of antennas on the capacity:

This section presents the effect of K factor and correlated fading parameter (r) on the capacity of $m \times m$ MIMO systems at a given fixed SNR with correlation at both ends. Fig. 1 show the ergodic and 1 % outage capacities as functions of the number of antennas (m) for various values of Rician fading parameter K, with or without correlation (r). From the figure it is clear that:

- For all values of m, as the value of K increases, the ergodic and the 1 % outage capacity decrease. However, the loss is more at higher values of m. This is because the increase in K factor emphasizes the deterministic part of the channel. The deterministic channel is of rank 1 and so the capacity decreases.
- For all values of m, as the value of r increases, the ergodic and the 1 % outage capacity decrease. However, the loss is more at higher values of m. This is because the increase in correlated fading parameter emphasizes that the fades are less independent and thus reduces the rank of the random channel and so the capacity decreases.
- Results for ergodic and 1 % outage capacities show the same trend, but the ergodic capacity is higher. However, the difference between the ergodic capacity and the 1 % outage capacity reduces at high values of K. This is because the link stabilizes at higher values of K.
- At any value of r, as the value of K increases, the loss increases even further. This is because both K and r contributes to the loss of the overall system capacity.

Effect of CSI at the transmitter on the capacity:

In this section, we present the effect of CSI on the capacity of $m \times m$ MIMO systems under different channel conditions. In all the cases discussed here, we have considered correlation at both ends. Fig. 2 presents the relative capacity gain, as defined in [17] (in percentage) due to the availability of CSI at the transmitter as function of the number of antennas (m) for various values of SNR, Rician fading parameter K, and correlation parameter (r). From the figure it is clear that:

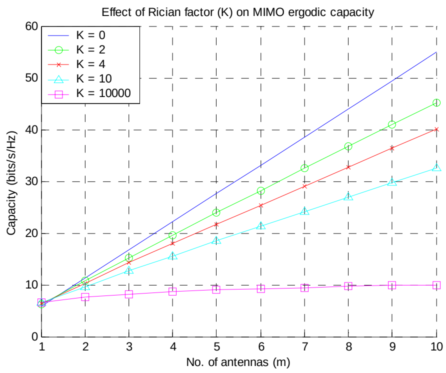
- CSI or Water-filling gains are reduced at high SNR. This is due to the fact that the relative importance of transmit array gain in boosting average SNR decreases in high SNR region and so the benefit of CSI at the transmitter also reduces.
- It is interesting to note that the relative water-filling gains increases with the increase in the K factor and correlation parameter (r). This is due to the fact that K factor and correlation parameter (r) reduces the capacity of the MIMO system; therefore, the availability of CSI at the transmitter becomes relatively more important at higher values of K factor and correlation parameter (r), than when they are small.

Equivalent Capacity gains in SNR:

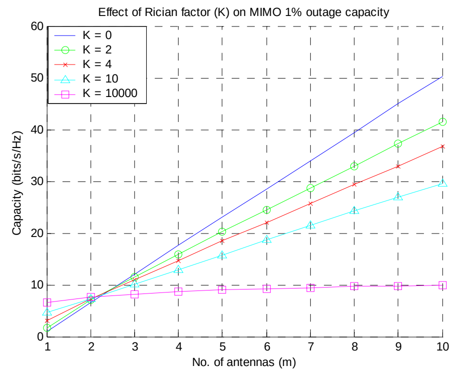
In this section, we present the view point that the effect of K factor and correlated fading parameter (r) on the capacity of m

× *m* MIMO systems can be considered as an equivalent increase or decrease in the SNR. Correlation exists at both ends. For capacity at 10 bits/s/Hz, we calculate the effect of Rician factor (*K*) with or without correlated fading parameter(*r*) in terms of the equivalent loss or gain in the SNR (dB) required achieving this capacity. The gains or losses in the tables 2–4 are calculated with respect to table 1 (i.i.d Rayleigh fading channel, *K* = 0, and *r* = 0). Table 1 represents the SNR required to achieve capacity of 10 bits/s/Hz by *m* × *m* systems. In tables 2–4, plus sign indicates the improvement whereas the negative sign indicates the loss in the performance of the system. From the tables 2–4, we can deduce the following:

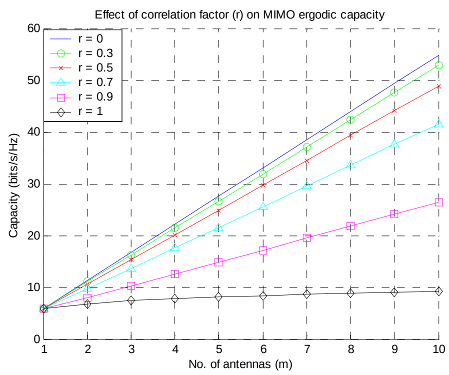
- For all values of *m* (*m* > 1), increase in the *K* factor reduces the capacity of the system. It is also interesting to note that loss due to *K* factor is more for larger values of *m*, and so the relative loss is even more for larger values of *m*.
- Over the practical range of *K* (0–10) and *r* (0–0.95), the combined loss in the SNR due to *K* factor and correlated fading parameter (*r*) at a given fixed capacity and *m* (*m* > 1), can be approximated as the sum of the two individual losses to within 1 dB.



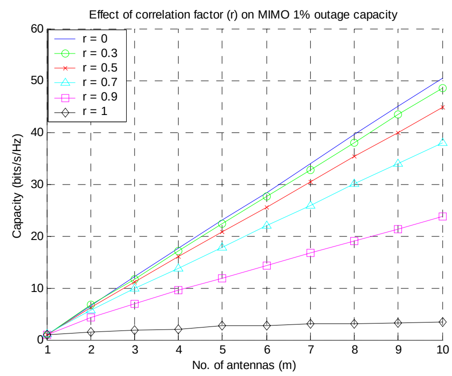
Ergodic Capacity, *r* = 0



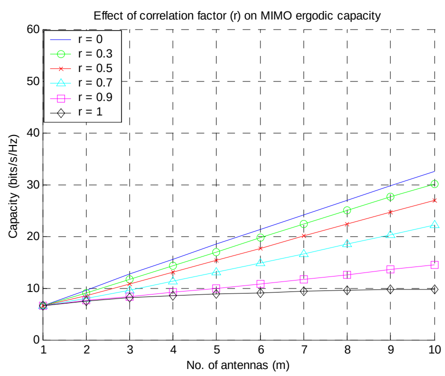
1 % Outage, *r* = 0



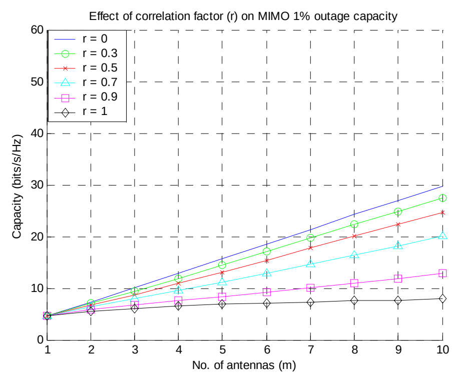
Ergodic Capacity, *K* = 0



1 % Outage, *K* = 0

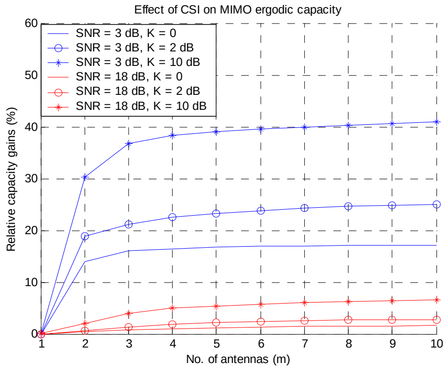


Ergodic Capacity, *K* = 10

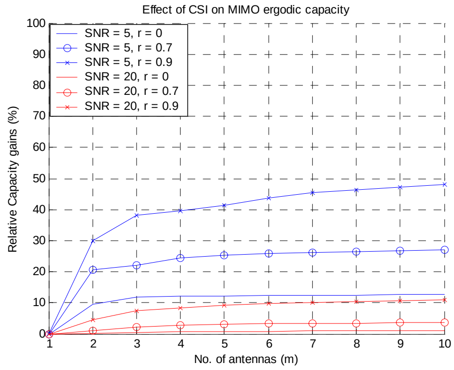


1 % Outage, *K* = 10

Fig. 1: Ergodic and 1 % outage capacities vs. the number of antennas (*m*) at SNR = 20 dB for various values of Rician fading parameter *K* and correlation parameter (*r*).



Relative Capacity gain, $K = 0$



Relative Capacity gain, $K = 10$

Fig. 2: Relative Ergodic Capacity gain due to CSI at the transmitter vs. m, at $K = 10$, for various values of SNR and r.

Table 1: Required SNR (dB) at C = 10 bits/s/Hz,

m	SNR (dB) $K = 0$, $r = 0$
1	32.53
2	17.91
4	9.01
10	1.19

Table 2: Equivalent loss or gain in SNR (dB) at C = 10 bits/s/Hz, $K = 0$

m	$r = 0$	$r = 0.3$	$r = 0.5$	$r = 0.7$	$r = 0.9$	$r = .95$	$r = 1$
1	0	0	0	0	0	0	0
2	0	-0.36	-1.18	-2.69	-6.12	-8.13	-11.65
4	0	-0.43	-1.33	-3.13	-7.61	-10.37	-17.50
10	0	-0.33	-1.02	-2.51	-6.79	-9.85	-21.39

Table 3: Equivalent loss or gain in SNR (dB) at C = 10 bits/s/Hz, $K = 4$

m	$r = 0$	$r = 0.3$	$r = 0.5$	$r = 0.7$	$r = 0.9$	$r = 0.95$	$r = 1$
1	1.49	1.49	1.49	1.49	1.49	1.49	1.49
2	-1.51	-2.75	-3.89	-5.57	-8.36	-9.37	-10.17
4	-2.95	-4.04	-5.33	-7.32	-11.52	-13.62	-16.02
10	-3.92	-4.55	-5.43	-7.13	-11.48	-14.23	-19.82

Table 4: Equivalent loss or gain in SNR (dB) at C = 10 bits/s/Hz, $K = 10$

m	$r = 0$	$r = 0.3$	$r = 0.5$	$r = 0.7$	$r = 0.9$	$r = 0.5$	$r = 1$
1	2.05	2.05	2.05	2.05	2.05	2.05	2.05
2	-2.76	-3.95	-5.07	-6.55	-8.71	-9.28	-9.58
4	-4.87	-5.94	-7.11	-9.07	-12.69	-14.24	-15.48
10	-6.24	-6.85	-7.67	-9.36	-13.29	-15.69	-19.30

B. Diversity Results

In this section, we present the diversity gains of MIMO systems obtained from hybrid simulations. The effect of AWGN is calculated analytically whereas the effect of Rician factor and correlation factor is obtained using Monte Carlo simulation. Using (5), and (21), the symbol error rate (SER) is calculated. The results are then averaged over 10^6 channel realizations. Each simulation run took almost 20 hours on Pentium-IV, 2.99 GHz, and 256 MB of RAM. The simulations are then rerun 10 times and the results are then averaged over those numbers of runs. So, we restrict the number of cases to present our work. We select different values of diversity order (*D*), Rician factor (*K*), and correlation factor (*r*), to present different scenarios of correlated MIMO Rician fading.

We choose diversity orders of 1, 2, 4, and 6, Rician factor having values 0, 4, and 10, and correlation factor having values, 0, 0.7, 0.9, and 1. Rician factor of value 0 represents the Rayleigh fading, Rician factor of values 4 and 10 represents two different cases of Rician fading. Correlation factor of value 0 represents no correlation, correlation factor of values 0.7 and 0.9 represents two different cases of correlated fading, and correlation factor of value 1 represents fully correlated channels. The values of correlation are chosen in accordance with the information available on correlated fading in the literature. Also, we compare our results with the exact results obtained by Sun and Reed [9].

Uncorrelated fading: Comparison of Simulation Results with Exact Results:

For the validation of our model, we compare our simulated results with the results (exact) obtained by Sun and Reed [9]. From fig. 3, we deduce that simulated and exact results comply well with each other.

Effect of Rician factor, and correlation parameter on the diversity gains:

In this section, we present the effect of Rician factor, and correlation parameter on the diversity gains of MIMO system with different orders of diversity (*D*), correlated fading parameter (*r*), and Rician factor (*K*). The results are summarized in tables 5–10. Tables 5–7 presents the SNR required to achieve the SER (Ps) of 10^{-4} for different values of *D*, *r*, and *K*. Tables 8–10 presents the relative correlation losses. From the tables 5–10, we deduce the following:

- For uncorrelated fading channels, increase in *K* factor improves the symbol error rate (SER) and the improvement in SER due to *K* factor reduces at higher diversity order. The correlation reduces the diversity order thereby increasing the SER.
- Fading channels having high values of *K* are more affected by correlated fading. For any diversity order *D*, the relative loss due to correlation (in percentage) increases with *K*, where the relative correlation loss (RCL) is defined as follows:

$$\text{RCL}(\%) = \frac{\text{Loss in SNR(dB) at any value } r}{\text{Loss in SNR(dB) at } r = 1} \times 100$$

- Diversity order of 4 having r = 0.7 gives better performance than diversity order of 6 having r = 0.9, which implies that if there is insufficient space for placing antennas (which is the cause of correlated fading); the decision for choosing the number of antenna should be taken carefully.

Table 5: Required SNR (dB) at Ps = 10^{-4}, $K = 0$

D	$r = 0$	$r = 0.7$	$r = 0.9$	$r = 1$
1	45.15	45.15	45.15	45.15
2	29.09	30.40	32.50	45.21
4	22.14	24.63	27.80	45.29
6	20.16	22.50	25.93	45.17

Table 6: Required SNR (dB) at Ps = 10^{-4}, $K = 4$

D	$r = 0$	$r = 0.7$	$r = 0.9$	$r = 1$
1	34.88	34.88	34.88	34.88
2	21.88	27.01	29.61	34.70
4	18.69	23.96	27.39	34.87
6	17.78	22.59	26.27	34.90

Table 7: Required SNR (dB) at Ps = 10^{-4}, $K = 10$

D	$r = 0$	$r = 0.7$	$r = 0.9$	$r = 1$
1	22.29	22.29	22.29	22.29
2	18.63	20.77	21.67	22.25
4	17.34	19.59	20.94	22.31
6	16.98	19.34	20.91	22.31

Table 8: RCL in (%) at Ps = 10^{-4}, $K = 0$

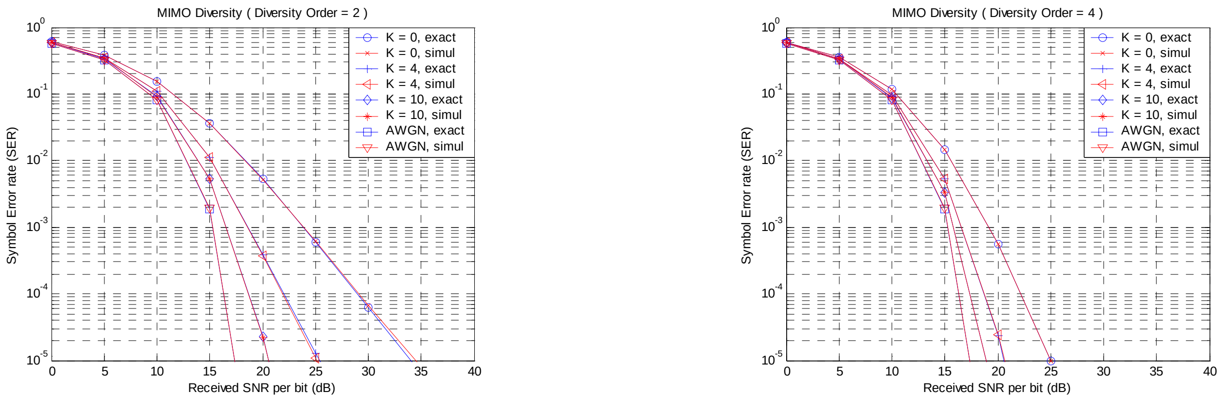
D	$r = 0$	$r = 0.7$	$r = 0.9$	$r = 1$
1	0	0	0	0
2	0	8.13	21.15	100
4	0	10.76	24.44	100
6	0	9.30	23.07	100

Table 9: RCL in (%) at Ps = 10^{-4}, $K = 4$

D	$r = 0$	$r = 0.7$	$r = 0.9$	$r = 1$
1	0	0	0	0
2	0	40.01	60.30	100
4	0	32.57	53.77	100
6	0	28.00	49.59	100

Table 10: RCL in (%) at Ps = 10^{-4}, $K = 10$

D	$r = 0$	$r = 0.7$	$r = 0.9$	$r = 1$
1	0	0	0	0
2	0	59.12	83.98	100
4	0	45.27	72.44	100
6	0	44.27	73.73	100



Diversity order 2 (1×2 or 2×1)   Diversity order 4 (1×4, 4×1, or 2×2)

Fig. 3: SER for 16PSK over Rician fading channels for Diversity orders 2, and 4; Exact vs. Simulation results

VII. Conclusions

For $m \times m$ MIMO systems, we found that for all values of m, as the value of Rician factor K, and correlated fading parameter (r) increases, the ergodic and the 1 % outage capacity decreases. However, the loss in the capacity is more at higher values of m. We note that the relative water-filling capacity gains increases with increasing values of K and r. Also, we found that, over a practical range of K and r, the combined loss in the SNR due to K factor and correlated fading parameter at a given fixed capacity and m, can be approximated as the sum of the two individual losses.

Diversity gains of fading channels having high values of K are more affected by correlated fading as illustrated from the relative correlation losses. If there is insufficient space for placing antennas, the decision for choosing the number of antenna should be taken carefully.

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