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Performance analysis of combining scheduling and space–time block coding under channel estimation error

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Abstract: This study analyses performance-based implications of combining user scheduling and space–time block coding (STBC) (i.e. joint diversity) under channel estimation error. The exact closed-form expression of joint diversity for the achievable rate is derived. Moreover, the approximate closed-form expression of joint diversity for the outage achievable rate is derived through Gaussian approximation. The exact closed-form expression of joint diversity for the outage probability is finally derived, including the quantification of the order of diversity and the signal-to-noise ratio (SNR) gain. Using analytical results, it is demonstrated that both the achievable rate and the outage achievable rate of joint diversity improves as the number of user terminals increases through multiuser diversity. The approximate results of the analysis and simulation of the outage achievable rate for joint diversity are well matched as the number of users increases. The outage probability enhances with the number of user terminals through diversity order improvement, whereas the SNR gain is identical to that in conventional non-scheduling STBC.

1 Introduction

Demand for wireless multimedia services continues to grow [1] as currently available technologies fall short in terms of achievable rate. A multiple-input multiple-output (MIMO) system in [2, 3] seems to meet these demands through enhancement of spectral efficiency. Of the many technologies in MIMO systems, the diversity improvement technique is a promising method to solve the current problem in wireless systems. In particular, spatial diversity through space–time block coding (STBC) has been widely investigated, as in [4, 5].

Under the assumption of perfect channel estimation, Dohler *et al.* [6] studied the outage probability of STBC over Nakagami fading channels. Perez *et al.* [7] investigated the approximate closed-form expression of STBC for the achievable rate and the outage achievable rate in various fading channels, including the Rayleigh and Nakagami fading channels. Under a Gaussian distribution of channel estimation error in [8], Maaref *et al.* [9] conducted an achievable rate analysis for STBC with adaptive transmission over Rayleigh fading channels under channel estimation error. Furthermore, Ahn *et al.* [10] derived the closed-form expressions of the achievable rate and the outage probability for STBC under channel estimation error.

Since multiuser diversity (MUD) through scheduling improves system performance, combining STBC and user scheduling, referred to as a joint diversity, has been widely investigated in [11–18] under perfect channel estimation. Lee *et al.* [11] obtained closed-form expressions of error probability for joint diversity with a quantification of the diversity order and signal-to-noise ratio (SNR) gain over Rayleigh fading channels. Jiang *et al.* [12] studied the achievable rate of joint diversity over various fading channels, such as the Rayleigh and Rician fading channels. Chen *et al.* [13] carried out an achievable rate analysis of joint diversity over arbitrary Nakagami fading channels, whereas Hung *et al.* [14] studied outage probability for integer and real-valued fading parameters.

Torabi *et al.* [15] and Lee *et al.* [16] evaluated the performance of joint diversity over arbitrary Nakagami fading channels for independent and non-identically distributed users. Li *et al.* [17] analysed the use of joint diversity in relay networks, and Yu *et al.* [18] investigated the impact of feedback delay on symbol error rate over Rayleigh fading channels.

Since perfect channel estimation is impossible in practice, an analysis of the effect of the channel estimation error on system performance, such as in terms of achievable rate and outage probability, is important. Past works, however, have paid little attention to achievable rate and outage achievable rate analysis of joint diversity, including outage probability in the presence of channel estimation error. Thus, the main contributions of this paper are as follows:

1.1 Contributions

- This paper derives the exact closed-form expression of the probability density function (PDF) for joint diversity under channel estimation error. Using the PDF, this paper derives the exact closed-form expression of joint diversity for the achievable rate. Moreover, this paper derives the approximate closed-form expression of joint diversity for the outage achievable rate using Gaussian approximation. Through analytical results, this paper shows that even if the spatial diversity by STBC is diminished, user scheduling provides MUD in joint diversity under channel estimation error. This implies that the proposed scheme contributes robustness to system performance in the presence of channel estimation error.
- This paper also derives the exact closed-form expression of the outage probability for joint diversity under channel estimation error. The diversity order and the SNR gain of the outage probability for joint diversity under channel estimation error are quantified through asymptotic analysis. Through analytical results, this paper shows that outage probability enhances with the number of user terminals through diversity order improvement, whereas the SNR gain is identical to that in conventional STBC.

The remainder of this paper is structured as follows: Section 2 presents the system overview, whereas a performance analysis of the system is provided in Section 3. Section 4 discusses the analytical results, and Section 5 summarises the contributions.

2 System overview

We consider data transmission with M_T transmitting antennas and M_{R_k} receiving antennas for K user terminals, where k is the index of the user terminal and $\boldsymbol{H}_k$ is an $(M_{R_k} \times M_T)$-dimensional channel matrix for the kth user terminal, which has independent and identically distributed circular-complex Gaussian elements with zero mean and unit variance denoted by $CN(0, 1)$. This paper focuses on joint diversity (i.e. combining scheduling and STBC), which selects the user who provides the best effective SNR on the receiver's side under imperfect channel estimation for practical environments. This paper considers orthogonal STBC for two, three, and four transmitting antennas. Rates 1, 2/3, and 3/4 STBCs are given in [4, 5], and are denoted by G_2, G_3, G_4, H_3, and H_4, respectively. This study assumes that the number of receiving antennas for all user terminals is identical. It also assumes a Rayleigh fading channel with a very slowly varying channel.

When E_s and N_0 represent the total signal energy and variance of the additive white Gaussian noise, respectively, the effective SNR of joint diversity is given by

$$\gamma_{sch} = \gamma_0 x_{max}, \quad x_{max} := \max_k \|\boldsymbol{H}_k\|_F^2 \tag{1}$$

where the Frobenius norm is denoted by $\|\cdot\|_F$, $\gamma_0 = E_s/R_c M_T N_o$ with code rate R_c, and x is the chi-squared distribution with $2M_T M_R$ degrees of freedom, where its cumulative density function (CDF) and PDF, expressed by $F(x)$ and $f(x)$, respectively, are given in [19].

By assuming the Gaussian distribution of channel estimation error in [8, 9], its PDF is expressed as

$$f(x) = \sum_{m=1}^{M_T M_R} \binom{M_T M_R - 1}{m-1} \frac{(\rho^2)^{m-1}(1-\rho^2)^{M_T M_R - m}}{(m-1)!} x^{m-1} e^{-x} \tag{2}$$

and by employing $A(x) = \sum_{p=0}^{1} (-1)^p (1 - A(x))^p$, its CDF is given by (see (3))

Using the order statistics in [20], the PDF of the effective SNR for joint diversity in the presence of channel estimation error can be obtained as follows (see (4))

where $\sum_M \sum_P \sum_Q$ denotes three $(K-1)$ fold summations and (see (5))

and $a = \sum_{k=1}^{K-1} (m_k - 1)$, $b = \sum_{k=1}^{K-1} (M_T M_R - m_k)$, $c = \sum_{k=1}^{K-1} p_k$, and $d = \sum_{k=1}^{K-1} q_k$. $C_i^n(t) := \binom{n}{i} t^i (1-t)^{n-i}$ are Bernstein polynomials. The channel correlation coefficient ρ between the actual channel h_{ij} and its estimate $\hat{h}_{ij}$ is given by

$$\rho = \frac{\mathcal{E}\{h_{ij}\hat{h}_{ij}^*\} - \mathcal{E}\{h_{ij}\}\mathcal{E}\{\hat{h}_{ij}^*\}}{\sqrt{\mathrm{Var}\{h_{ij}\}\mathrm{Var}\{\hat{h}_{ij}^*\}}}. \tag{6}$$

3 Performance analysis

We first derive the exact closed-form expressions of the achievable rate and the outage achievable rate of joint diversity, including the outage probability under a Gaussian distribution of channel estimation error. Following this, using asymptotic analysis, this paper quantifies the diversity order and the SNR gain of joint diversity for the outage probability in the presence of channel estimation error.

3.1 Achievable rate

Using the PDF of (4), the achievable rate of joint diversity under channel estimation error can be written as follows (see (7))

Using partial integration and the integration function of ([21], Eq. (2.321.2)), the exact achievable rate of joint diversity under channel estimation error is evaluated as (see equation (8) at the bottom of the next page)

By using the integration by ([21], Eq. 3.383.10), the exact

$$F(x) = \sum_{m=1}^{M_T M_R} \binom{M_T M_R - 1}{m-1} \frac{(\rho^2)^{m-1}(1-\rho^2)^{M_T M_R - m}}{(m-1)!} \left(1 - \exp^{-x} \sum_{n=0}^{m-1} \frac{x^n}{n!}\right) = \sum_{m=1}^{M_T M_R} \sum_{p=0}^{1} \sum_{q=0}^{p(m-1)} \binom{M_T M_R - 1}{m-1} \frac{(\rho^2)^{m-1}(1-\rho^2)^{M_T M_R - m}}{(m-1)!} \frac{(-1)^p e^{-px} x^q}{q!}. \tag{3}$$

$$\begin{aligned} f_{sch}(x) &= K f(x) F(x)^{K-1} \\ &= K \sum_{m=1}^{M_T M_R} \sum_M \sum_P \sum_Q \binom{M_T M_R - 1}{m-1} \left[\prod_{k=1}^{K-1} \binom{M_T M_R - 1}{m_k - 1}\right] \frac{(\rho^2)^{a-m-1}(1-\rho^2)^{b-M_T M_R - m}(-1)^c}{\prod_{k=1}^{K-1}(q_k!)(m-1)!} e^{-(c+1)x} x^{d+m-1} \end{aligned} \tag{4}$$

$$\begin{aligned} F(x)^{K-1} &= \left[\sum_{m=1}^{M_T M_R} \sum_{p=0}^{1} \sum_{q=0}^{p(m-1)} \binom{M_T M_R - 1}{m-1} \cdot \frac{(\rho^2)^{m-1}(1-\rho^2)^{M_T M_R - m}}{(m-1)!} \frac{(-1)^p e^{-px} x^q}{q!}\right]^{K-1} \\ &= \sum_{m_1=0}^{M_T M_R} \sum_{m_2=0}^{M_T M_R} \cdots \sum_{m_{K-1}=0}^{M_T M_R} \sum_{p_1=0}^{1} \sum_{p_2=0}^{1} \cdots \sum_{p_{K-1}=0}^{1} \sum_{q_1=0}^{p_1(m_1-1)} \sum_{q_2=0}^{p_2(m_2-1)} \cdots \sum_{q_{K-1}=0}^{p_{K-1}(m_{K-1}-1)} \left[\prod_{k=1}^{K-1} \binom{M_T M_R - 1}{m_k - 1}\right] \frac{(\rho^2)^a (1-\rho^2)^b (-1)^c}{\prod_{k=1}^{K-1}(q_k!)} e^{-cx} x^d \end{aligned} \tag{5}$$

$$\begin{aligned} C_{sch}(\gamma_0) &= R_c \int_0^\infty \log_2(1+\gamma_0 x) f_{sch}(x)\, dx \\ &= \log_2(e) R_c K \sum_{m=1}^{M_T M_R} \sum_M \sum_P \sum_Q \binom{M_T M_R - 1}{m-1} \left[\prod_{k=1}^{K-1} \binom{M_T M_R - 1}{m_k - 1}\right] \frac{(\rho^2)^{a-m-1}(1-\rho^2)^{b-M_T M_R - m}(-1)^c}{\prod_{k=1}^{K-1}(q_k!)(m-1)!} \int_0^\infty \ln(1+\gamma_0 x) e^{-(c+1)x} x^{d+m-1}\, dx. \end{aligned} \tag{7}$$

closed-form expression of the achievable rate for joint diversity under channel estimation error is obtained as (see (9))

3.2 Outage achievable rate

When the distribution of the achievable rate is Gaussian and the q % outage achievable rate is defined as the guaranteed transmission rate for 1–q/100, the q % outage achievable rate $C^q_{\text{sch}}(\gamma_0)$ for joint diversity can be approximated as in [7]

$$C^q_{\text{sch}}(\gamma_0) \simeq C_{\text{sch}} + \sigma_{C_{\text{sch}}}\sqrt{2}\,\text{erfc}^{-1}\left(2 - \frac{q}{50}\right) \tag{10}$$

where erfc(·) is the complementary error function, and the achievable rate of joint diversity under channel estimation error is given in (9).

Using [7], the variance of the achievable rate for joint diversity is approximated as

$$\sigma^2_{C_{\text{sch}}} \simeq (R_c \log_2(e))^2\left[\frac{\sigma^2_{\gamma_{\text{sch}}}}{(1+\mathcal{E}\{\gamma_{\text{sch}}\})^2} - \frac{\sigma^4_{\gamma_{\text{sch}}}}{4(1+\mathcal{E}\{\gamma_{\text{sch}}\})^4}\right] \tag{11}$$

where $\mathcal{E}[\cdot]$ is the statistical expectation. The variance of the effective SNR, $\sigma^2_{\gamma_{\text{sch}}}$, is given as

$$\sigma^2_{\gamma_{\text{sch}}} = \mathcal{E}\{\gamma^2_{\text{sch}}\} - \mathcal{E}^2\{\gamma_{\text{sch}}\}. \tag{12}$$

The first and second moments of γ_{sch} for joint diversity under channel estimation error is calculated as

$$\begin{aligned}\mathcal{E}\{\gamma_{\text{sch}}\} &= \gamma_0\int_0^\infty x f_{\text{sch}}(x)\,\text{d}x\\ &= \gamma_0 K\sum_{m=1}^{M_TM_R}\sum_M\sum_P\sum_Q\binom{M_TM_R-1}{m-1}\left[\prod_{k=1}^{K-1}\binom{M_TM_R-1}{m_k-1}\right]\\ &\quad\times\frac{(\rho^2)^{a-m-1}(1-\rho^2)^{b-M_TM_R-m}(-1)^c}{\prod_{k=1}^{K-1}(q_k!)(m-1)!}\frac{(d+m)!}{(c+1)^{d+m+1}},\end{aligned} \tag{13}$$

and

$$\begin{aligned}\mathcal{E}\{\gamma^2_{\text{sch}}\} &= \gamma_0^2\int_0^\infty x^2 f_{\text{sch}}(x)\,\text{d}x\\ &= \gamma_0^2 K\sum_{m=1}^{M_TM_R}\sum_M\sum_P\sum_Q\binom{M_TM_R-1}{m-1}\left[\prod_{k=1}^{K-1}\binom{M_TM_R-1}{m_k-1}\right]\\ &\quad\times\frac{(\rho^2)^{a-m-1}(1-\rho^2)^{b-M_TM_R-m}(-1)^c}{\prod_{k=1}^{K-1}(q_k!)(m-1)!}\frac{(d+m+1)!}{(c+1)^{d+m+2}}.\end{aligned} \tag{14}$$

3.3 Outage probability

When defining outage probability as the effective SNR falling below a certain threshold value, the outage probability of joint diversity $P_{\text{sch}}(\gamma_0)$ is given as

$$P_{\text{sch}}(x_{\text{th}}) = P\left(x < x_{\text{th}} = \frac{2^{C_0}-1}{\gamma_0}\right) \tag{15}$$

where C_0 denotes the target achievable rate [bps/Hz] and x_{th} is the threshold value.

Thus, the exact closed-form expression of joint diversity for the outage probability under channel estimation error is given as (see (16))

Using power series expansion, the CDF of the effective SNR for STBC under channel estimation error is given as

$$\begin{aligned}F(x) &= \int_0^x f(x)\,\text{d}x\\ &= \sum_{m=1}^{M_TM_R}\frac{C^{M_TM_R-1}_{m-1}(\rho^2)}{(m-1)!}\int_0^{x_{\text{th}}} x^{m-1}\,\text{e}^{-x}\,\text{d}x\\ &= \sum_{m=1}^{M_TM_R}\sum_{n=0}^{\infty}\frac{C^{M_TM_R-1}_{m-1}(\rho^2)}{(m-1)!}\frac{(-1)^n x^{m+n}}{n!(m+n)}.\end{aligned} \tag{17}$$

As γ_0 approaches infinity (i.e. $\gamma_0 \to \infty$), (17) is dominant at $n = 0$ and $m = 1$. Then, the CDF and PDF of the effective SNR for STBC under

$$\begin{aligned}C_{\text{sch}}(\gamma_0) &= \log_2(e)R_cK\sum_{m=1}^{M_TM_R}\sum_M\sum_P\sum_Q\binom{M_TM_R-1}{m-1}\left[\prod_{k=1}^{K-1}\binom{M_TM_R-1}{m-1}\right]\frac{(\rho^2)^{a-m-1}(1-\rho^2)^{b-M_TM_R-m}(-1)^c}{\prod_{k=1}^{K-1}(q_k!)(m-1)!}\\ &\quad\times\left[\sum_{l=0}^{d+m-1}(c+1)^{-(l+1)}\frac{(d+m-1)!\gamma_0}{(d+m-l-1)!}\int_0^\infty\frac{x^{d+m-l-1}}{1+\gamma_0 x}\text{e}^{-(c+1)x}\,\text{d}x\right].\end{aligned} \tag{8}$$

$$\begin{aligned}C_{\text{sch}}(\gamma_0) &= \log_2(e)R_cK\sum_{m=1}^{M_TM_R}\sum_M\sum_P\sum_Q\sum_{l=0}^{d+m-1}\binom{M_TM_R-1}{m-1}\left[\prod_{k=1}^{K-1}\binom{M_TM_R-1}{m_k-1}\right]\\ &\quad\times\frac{(\rho^2)^{a-m-1}(1-\rho^2)^{b-M_TM_R-m}(-1)^c}{\prod_{k=1}^{K-1}(q_k!)(m-1)!}(c+1)^{-(l+1)}\frac{(d+m-1)!}{(m-1)!}\left(\frac{1}{\gamma_0}\right)^{d+m-l-1}\text{e}^{\frac{1+c}{\gamma_0}}\Gamma\left(1-(d+m-l)),\ \frac{1+c}{\gamma_0}\right)^{K-1}.\end{aligned} \tag{9}$$

$$\begin{aligned}P_{\text{sch}}(x_{\text{th}}) &= \int_0^{x_{\text{th}}} f_{\text{sch}}(x)\,\text{d}x\\ &= \sum_{m_1=0}^{M_TM_R}\sum_{m_2=0}^{M_TM_R}\cdots\sum_{m_K=0}^{M_TM_R}\sum_{p_1=0}^{1}\sum_{p_2=0}^{1}\cdots\sum_{p_K=0}^{1}\sum_{q_1=0}^{p_1(m_1-1)}\sum_{q_2=0}^{p_2(m_2-1)}\cdots\sum_{q_K=0}^{p_{K-1}(m_K-1)}\\ &\quad\times\left[\prod_{k=1}^{K}\binom{M_TM_R-1}{m_k-1}\right]\frac{(\rho^2)^a(1-\rho^2)^b(-1)^c}{\prod_{k=1}^{K}(q_k!)}\text{e}^{-cx}x^d_{\text{th}}.\end{aligned} \tag{16}$$

channel estimation error are approximated as follows

$$F(x) \simeq (1-\rho^2)^{M_T M_R - 1} x, \tag{18}$$

and

$$f(x) \simeq (1-\rho^2)^{M_T M_R - 1}. \tag{19}$$

Since the PDF of the effective SNR is approximated as

$$f_{sch}(x) \simeq K(1-\rho^2)^{K(M_T M_R - 1)} x^{K-1}, \tag{20}$$

the outage probability of joint diversity under the channel estimation error is obtained as

$$P_{sch}(x_{th}) \simeq (1-\rho^2)^{K(M_T M_R - 1)} \left(\frac{x_{th}}{2^{C_0-1}}\right)^{-K}. \tag{21}$$

At high values of SNR, diversity order G_t and SNR gain G_s can be observed when the outage probability is approximated in the form $P(\gamma_0) \simeq (G_s \cdot \gamma_0)^{-G_t}$ in [22]. From asymptotic analysis, the diversity order and the SNR gain of joint diversity for the outage probability over Rayleigh fading channels under the channel estimation error is given by

$$G_t = K, \tag{22}$$

and

$$G_s = \frac{1}{2^{C_0-1}}(1-\rho^2)^{1-M_T M_R}. \tag{23}$$

From the above results, the diversity order of joint diversity under channel estimation error is K, which comes from MUD. The SNR gain of joint diversity is not affected by the number of user terminals. The results show that the diversity order gain of joint diversity is K in comparison with that of conventional non-scheduling STBC, whereas its SNR gain is identical. This means that even if the spatial diversity is diminished through STBC, user scheduling provides MUD in joint diversity under channel estimation error. Although perfect channel estimation is desirable, channel estimation methods used in practice inevitably incur estimation error. For this reason, the proposed joint diversity contributes robustness to system performance against channel estimation error.

4 Analytical results and discussion

This section presents analytical results for the achievable rate and the outage achievable rate, including the outage probability of joint diversity under a Gaussian distribution of the channel estimation error, as shown in (9), (10), and (16). To demonstrate the validity of our analytical results, this paper compares the results of analysis with the results of Monte Carlo simulation in MATLAB. This paper generates 10 million transmission data symbols to simulate the achievable rate and the outage probability. We consider the STBC proposed by Tarokh in [4, 5], that is, code rate $R_c = 1$ STBC for $M_T = 2$ denoted by G_2.

Fig. 1 shows the results of an exact analysis of the achievable rate for joint diversity under perfect channel estimation. This plot shows that the achievable rate at an SNR of 15 dB is 5.5 [bps/Hz] for $K=3$ and 4.5 [bps/Hz] for $K=1$. This result shows that the achievable rate increases with the number of user terminals. This is because opportunistic scheduling provides MUD. Fig. 2 shows the results of the exact analysis of the achievable rate for joint diversity under imperfect channel estimation $\rho^2 = 0.5$. This plot shows that the achievable rate at an SNR of 15 dB is 5 [bps/Hz] for $K=3$ while providing 4 [bps/Hz] for $K=1$. This result shows that the achievable rate increases with the number of user terminals under imperfect channel estimation error by MUD. Further, since user scheduling in joint diversity provides MUD under channel estimation error, the enhancement of the achievable rate as a function of the number of users is almost identical for perfect channel estimation $\rho^2 = 1$ and imperfect channel estimation $\rho^2 = 0.5$.

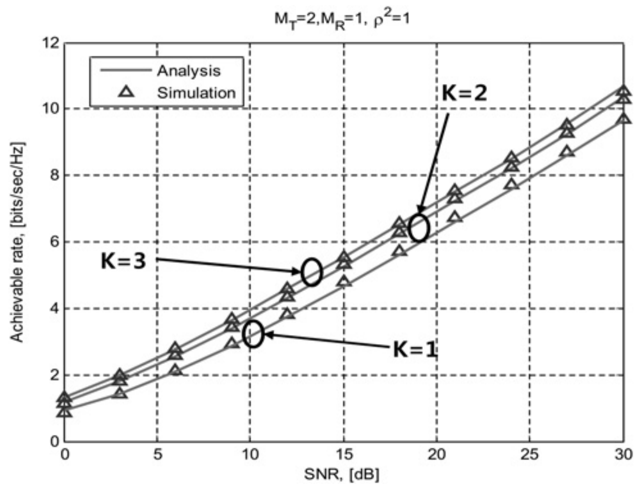

Fig. 1 *Achievable rate of joint diversity under perfect channel estimation (i.e. $\rho^2 = 1$) as a function of the number of users K*

Fig. 3 shows the results of an approximate analysis of the outage achievable rate for joint diversity as a function of outage probability q. Here, this paper considers the number of user terminals with $K=3$. This plot shows that the outage achievable rate at an SNR of 15 dB is 5 [bps/Hz] for $q = 20\%$ while providing 4.5 [bps/Hz] for $q = 5\%$. This result shows that the outage achievable rate increases with q. Fig. 4 shows the results of an approximate analysis of the outage achievable rate for joint diversity as a function of the number of users K. This plot shows that the outage achievable rate increases with the number of user terminals through MUD. Furthermore, analysis and simulation results are well matched as the number of users increases. This is because the distribution of the achievable rate is approximated to Gaussian as the number of user terminals increases.

Fig. 5 shows the results of the exact and asymptotic analyses of the outage probability for joint diversity as a function of the channel estimation error ρ^2. Here, this paper considers the number of user terminals with $K=2$. The analytical results of (22) show that the diversity order of joint diversity for Fig. 5 is 2. This plot shows that the SNR required to satisfy the outage probability of 10^{-2} is 15 dB for $\rho^2 = 0.7$ and 18 dB for $\rho^2 = 0.1$. This result shows that

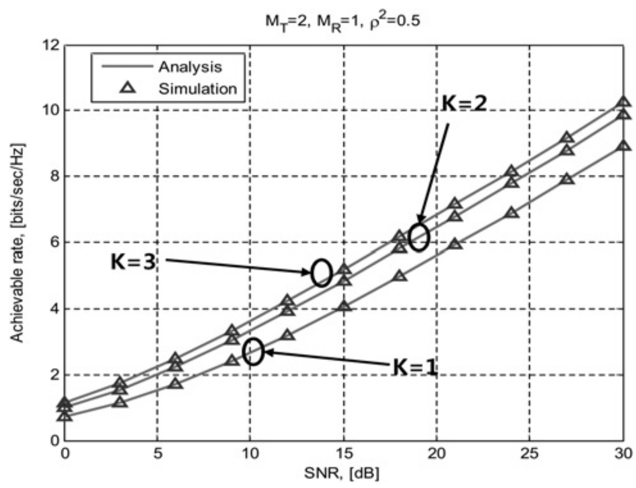

Fig. 2 *Achievable rate of joint diversity under channel estimation error (i.e. $\rho^2 = 0.5$) as a function of the number of users K*

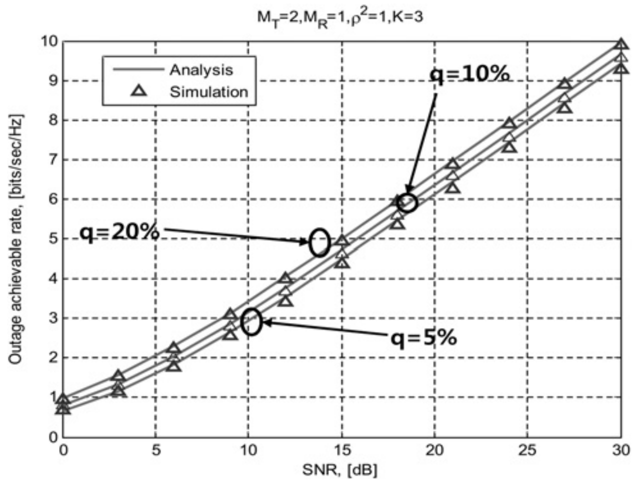

Fig. 3 *Outage achievable rate of joint diversity under perfect channel estimation (i.e. $\rho^2 = 1$) as a function of the outage probability q*

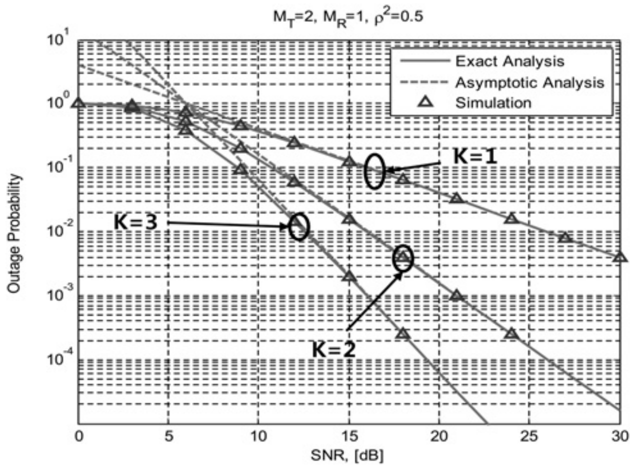

Fig. 6 *Outage probability of joint diversity under channel estimation error (i.e. $\rho^2 = 0.5$) as a function of the number of users K*

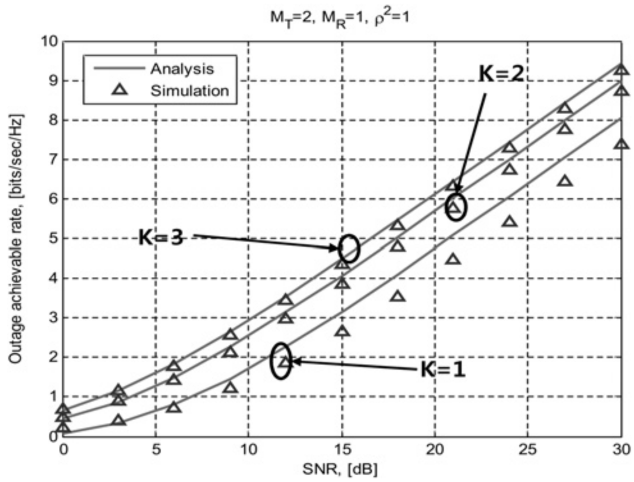

Fig. 4 *Outage achievable rate of joint diversity under perfect channel estimation (i.e. $\rho^2 = 1$) as a function of the number of users K*

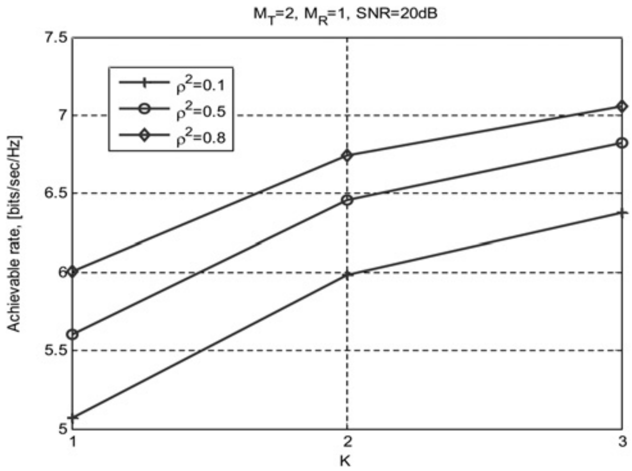

Fig. 7 *Achievable rate of joint diversity under channel estimation error as a function of channel estimation error ρ^2*

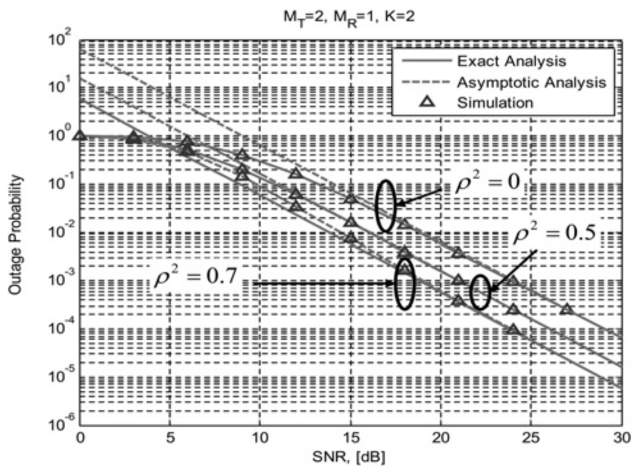

Fig. 5 *Outage probability of joint diversity as a function of the channel estimation error ρ^2*

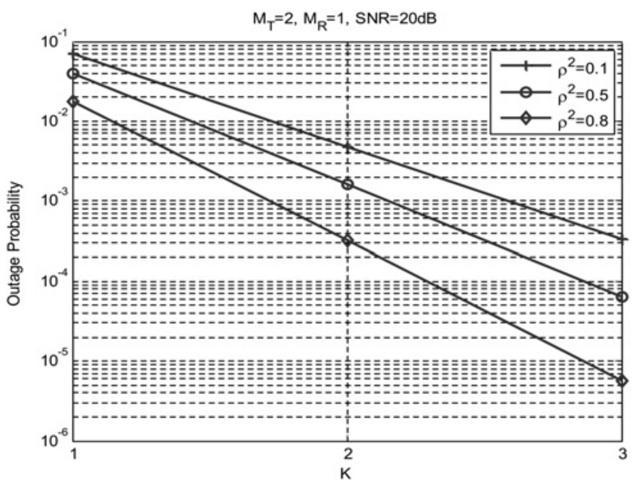

Fig. 8 *Outage probability of joint diversity under channel estimation error as a function of the channel estimation error ρ^2*

the diversity order of joint diversity is independent of the degree of channel estimation error, whereas the SNR gain increases with ρ^2. Fig. 6 shows the results of the exact and asymptotic analyses of the outage probability for joint diversity as a function of the number of users K. The analytical results of (22) show that the diversity order of joint diversity for Fig. 6 is 1 for $K = 1$, 2 for

$K = 2$, and 3 for $K = 3$. This plot shows that the outage probability enhances with the number of user terminals through diversity order improvement, whereas the SNR gain is identical to that in conventional non-scheduling STBC. This is because user scheduling provides MUD in joint diversity, whereas spatial diversity by STBC is diminished in the presence of channel estimation error. Further, exact analysis and simulation results are well matched for the outage probability.

Fig. 7 shows the exact achievable rate results of joint diversity as a function of channel estimation error ρ^2. The exact achievable rate of joint diversity is plotted using the analytical results of (9). As shown in the figure, the achievable rate improved as the number of user terminals increased regardless of channel estimation error. Fig. 8 shows the exact outage probability results of joint diversity with channel estimation error ρ^2. The exact outage probability of joint diversity is plotted using the analytical results of (16). As shown in the figure, the outage probability increased as the number of user terminals increased, regardless of channel estimation error. The performance gain for the achievable rate and the outage probability is due to MUD in a channel estimation environment.

5 Conclusions

This paper investigated the impact of channel estimation error on the achievable rate and the outage achievable rate for joint diversity under a Gaussian distribution of channel estimation error. Using analytical results, this paper showed that both the achievable rate and the outage achievable rate of joint diversity improve as the number of user terminals increases through MUD. Moreover, this paper derived the exact closed-form expression of the outage probability for joint diversity. Through asymptotic analysis, the diversity order and the SNR gain of the outage probability was quantified. From this analysis, it was shown that the diversity order of joint diversity under channel estimation error is K, which is from MUD, while the diversity order of the conventional STBC is one. The SNR gain of joint diversity was unaffected by the number of user terminals, and was identical to that in conventional non-scheduling STBC.

6 Acknowledgments

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7 References

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