Performance of MISO systems with Alamaouti transmit diversity and antenna selection in TDD and FDD

Dehit H. Trivedi, Neel N. Joshi, and Y. N. Trivedi

Department of Electronic and Communication Engineering, Institute of Technology, Nirma University, Ahmedabad-382481, India
dehit.trivedi@gmail.com, neeljoshi3110@gmail.com, yogesh.trivedi@nirmauni.ac.in,

Abstract. In this paper, the focus is to obtain performance of a Multiple Input and Single Output(MISO) wireless communication system in a real time scenarios of Time Division Duplex (TDD) and Frequency Division Duplex (FDD). We consider a MISO system equipped with $2N$ transmit antennas. In the total N pairs of antenna, there is a spatial correlation in each pair (two antennas) only. We assume quasi-static Rayleigh fading channels. We select one pair of antennas with the highest channel power gain. In case of FDD, we assume antenna selection and detection, both based on imperfect Channel State Information (CSI), whereas in case of TDD, detection is based on imperfect CSI, but antenna selection is to be done using perfect CSI. Finally, we use Alamouti transmit diversity. For this system, we present the performance in terms of Bit Error Rate (BER) versus Avg. Signal to Noise Ratio (SNR) and outage probability versus Avg. SNR using Monte Carlo simulations. We have seen the adverse effect of spatial correlation and imperfect CSI on the performance. We conclude that TDD outperforms the FDD due to higher antenna selection gain.

Keywords: Alamouti transmit diversity, Transmit Antenna Selection (TAS), Spatial channel correlation, Imperfect Channel State Information (CSI)

1 Introduction

The next generation mobile communication is demanding for high data rate, which can be accomplished by using techniques such as higher order adaptive modulation and adaptive channel coding, multi carrier modulation, multiple antenna systems etc. [1]. In which multi antenna systems, popularly known as multiple input multiple output (MIMO), is adopted in standards such as LTE and WiMAX due to high spectral efficiency [2], measured in bits per hertz . However, this can be fulfilled by adding complexity such as radio frequency chains (RFC) corresponding to each transmit or receive antenna. The power consumption and space requirements increase with number of RFC. Therefore, antenna selection is used, in which full diversity can be exploited with reduced number of RFC [3]. However, to exploit the benefits of MIMO systems with antenna selection, channel state information (CSI) is to be estimated perfectly. Unfortunately, in the real time scenario, it is not possible always to have perfect CSI. Therefore, detection with imperfect CSI results in error floor in the BER versus SNR performance [4]. Furthermore, antenna selection with imperfect CSI results in loss of diversity gain. The second issue in real time scenario is spatial correlation [5] between adjacent antennas due to limited spacing between antennas. The spatial correlation reduces the diversity gain [6].

In the next generation wireless communication, the variance of data rate is very high. Some applications are based on fast broadband communication such as real time gaming, where target is high spectral efficiency. On the other hand some applications may require low data rate communication with tolerable delay such as Internet of Things (IoT) or communication in low power sensor network, where the target is higher energy efficiency. In both the cases, base station uses either time division duplex (TDD) or frequency division duplex (FDD). Both the duplex schemes have pros and cons over other [7]. For example, FDD supports high data rate communication with double the spectrum compared to TDD. In case of FDD, two separate channels are required for Uplink and Downlink, where as in TDD the same channel is used for Uplink as well as for down link in different time slots, which restricts the data rate due to limited time slot in TDD.

In case of MIMO, where CSI is also required at the transmitter, the TDD has a benefit over FDD. During the first time slot, BS estimates the channel and then use the same channel for transmit beamforming or transmit antenna selection. In this case, the chances of perfect antenna selection is high as the BS can estimate the channel well due to high onboard resources. If we consider a case of FDD, then Uplink and Downlink channels are separate. Hence, the user will estimate the Downlink channel and then feed it back to the transmitter for antenna selection at the BS. In this case, channel estimation quality may be low at the user because of the limited resources and erroneous feedback channel. There, in FDD antenna selection may not be perfect compared to antenna selection in TDD.

In this paper, we have considered a MISO system with a real time practical scenario with FDD or TDD. We have assumed $2N \times 1$ MISO system, where imperfect CSI is available at the receiver (user side). In case of FDD, we assume antenna selection based on imperfect CSI and in case of TDD, we assume antenna selection based on perfect CSI. The correlation between actual CSI and the imperfect CSI is denoted by ρ. At the BS, we assume N pairs of antennas, where in each pair there are two antennas. There is a spatial correlation η in each pair of antennas, however there is no correlation between two pairs of antennas. Based on the perfect (in case of TDD) or imperfect (in case of FDD) CSI, one pair of antennas is selected among all the pairs. Then, we use full Alamouti transmit diversity for the equivalent 2×1 system [8]. The detection at the receiver is assumed using imperfect CSI. We present the performance of the system in terms of BER versus SNR and outage probability versus SNR using simulations. We have presented the performance for different values of ρ and η for both FDD and TDD. We have seen that the performance of TDD is better than the performance of FDD as expected.

The rest of the paper is organized as followed. Section 2 describes the system model. Section 3 presents the BER and outage probability performance of the considered system for different values of ρ and η. Finally, Section 4 concludes the paper.

2 System Model

We consider a MISO system with $2N \times 1$ antennas or at the transmitter total N pairs of antennas are there and each pair has two antennas. The underlying fading channels are assumed to be complex Gaussian with mean zero and variance one.

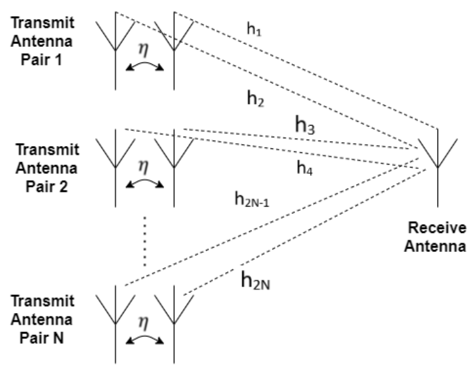

Fig. 1. Considered MISO system

As shown in Fig. 1 the channel coefficients from first pair to the receiver are h_1 and h_2. Similarly, the channel coefficients between the last N^{th} pair and the receiver are h_{2N-1} and h_{2N}. Thus, channel coefficients between k^{th} pair and receive antenna are h_{2k-1} and h_{2k}. In each pair, the spatial correlation is η. Thus

$$E[h^*_{2k-1}h_{2k}] = \eta, \quad 1 \le k \le N, \;\; 0 \le \eta \le 1$$

Thus, h_{2k} is generated from h_{2k-1} using first order Gauss Markov model as follows.

$$h_{2k} = \eta h_{2k-1} + \sqrt{1-\eta^2}\mu_{2k-1}, \quad 1 \le k \le N$$

where h_{2k-1} and μ_{2k-1} are independent and identically distributed complex Gaussian random variables with mean zero and variance one. There is no correlation in between two pairs. At the receiver, imperfect CSI g_k is available instead of h_k, which is generated using first order Gauss Markov model as follows

$$g_k = \rho h_k + \sqrt{1-\rho^2}\delta_k, \quad 1 \le k \le 2N, \;\; 0 \le \rho \le 1$$

where δ_k is complex Gaussian random variable with mean zero and variance one. Further δ_k is independent of h_k.

Subsequently, we select the m^{th} pair of antennas, which has the highest summation of the two channel power gain as shown below. For FDD, the m^{th} pair is selected based on imprefect CSI, hence

$$m = \arg \max_{1 \le k \le N} \{|g_{2k-1}|^2 + |g_{2k}|^2\} \tag{1}$$

In case of TDD, the m^{th} pair is elected based on the perfect CSI, hence

$$m = \arg \max_{1 \le k \le N} \{|h_{2k-1}|^2 + |h_{2k}|^2\} \tag{2}$$

We use g_k for detection in both the FDD and TDD. After selecting the two transmit antennas, we use Alamouti transmit diversity scheme. Hence the received symbols y_1 and y_2 for two consecutive instants can be expressed as

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_{2m-1} & h_{2m} \\ h_{2m}^* & -h_{2m-1}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2* \end{bmatrix}$$

Here, x_1 and x_2 are assumed to be BPSK symbols with average power E_s, whereas n_1 and n_2 are i.i.d. complex Gaussian with mean zero and variance N_0. Thus average SNR per symbol, denoted by $\gamma_c = E_s/N_0$.

Now, for both FDD and TDD, the detection variables $\hat{x}_1$ and $\hat{x}_2$ corresponding to x_1 and x_2 respectively, can be expressed

$$\hat{x}_1 = \begin{bmatrix} g_{2m-1}^* \; g_{2m} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}$$

$$\hat{x}_2 = \begin{bmatrix} g_{2m}^* \; -g_{2m-1} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}$$

As x_1 and x_2 are equi-probable binary symbols, the BER can be expressed as

$$P_e = Prob\{\hat{x}_1 \neq x_1\} \tag{3}$$

The outage probability P_o can be expressed as

$$P_o = Prob\{\gamma \le \gamma_{th}\}$$

Here, γ can be expressed as

$$\gamma = \frac{|g_{2m-1}^* h_{2m-1} + g_{2m} h_{2m}^*|^2 \gamma_c}{|g_{2m-1}^* h_{2m} - g_{2m} h_{2m-1}^*|^2 \gamma_c + 2(|g_{2m-1}|^2 + |g_{2m}|^2)} \tag{4}$$

It can be seen that for perfect CSI i.e. $g_{2m-1} = h_{2m-1}$ and $g_{2m} = h_{2m}$, (4) is reduced to $\gamma = (|h_{2m-1}|^2 + |h_{2m}|^2)\gamma_c/2$. In case of imperfect CSI, the presence of γ_c in the denominator of (4) results in error floor.

3 Results

In this section, we present the performance of the considered system in terms of BER versus Avg. SNR and probability of outage versus Avg. SNR for different values of spatial correlation ρ and imperfect CSI in term of ρ. We have referred the case of imperfect antenna selection and perfect antenna selection as FDD and TDD respectively. We have assumed BPSK constellation and number of pair of antennas $N = 2$ or 3 for simulations.

Fig. 2 presents BER versus Avg. SNR for TDD taking $\eta = 0.5$ for different values of ρ such as 0.9 and 0.6. As expected, by increasing N, the performance improves due to better antenna selection gain and performance degrades when ρ reduces from 0.9 to 0.6. For $\rho = 0.9$, the error floor is also visible. Fig. 3 presents BER versus Avg. SNR for FDD taking $\eta = 0.5$ for different values of ρ such as 0.9 and 0.6. The same trend is visible for FDD also. In the outage probability, also the same trend is visible for both FDD and TDD.

Fig. 4 presents BER versus Avg. SNR for TDD taking $\rho = 0.9$ for different values of η such as 0.3 and 0.9. As expected, by increasing N, the performance improves due to better antenna selection gain and performance degrades when η increases from 0.3 to 0.9. The reason of the error floor is due to $\rho = 0.9$ (not having perfect CSI for detection or $\rho \neq 1$). Fig. 5 presents BER versus Avg. SNR for FDD taking $\rho = 0.9$ for different values of η such as 0.3 and 0.9. The same trend is visible for FDD also. In the outage probability, also the same trend is visible for both FDD and TDD.

Fig. 6 presents BER versus Avg. SNR for both FDD and TDD taking $\rho = 0.6$, $\eta = 0.5$. It can be seen that the TDD outperforms the FDD, as expected due to better antenna selection gain. It shows that in real time scenario, if the BER degrades due to η and/or ρ, the mode can be changed from FDD to TDD.

In Fig. 7, we have shown the outage probability versus Avg. SNR taking $\rho = 0.6$, $\eta = 0.5$, $N = 3$ and $\gamma_{th} = 3\ dB$ for FDD and TDD. The similar trend of BER can be seen in case of outage probability also. It is to be noted that the coverage probability of BS, $P_c = 1 - P_o$. Thus, P_c is more in case of TDD. For example at the SNR of 11 dB, the $P_c = 0.66$ and 0.619 for TDD and FDD respectively. Hence, the mobile can be switched from FDD to TDD to stay in coverage or to prevent it to go to the state of outage.

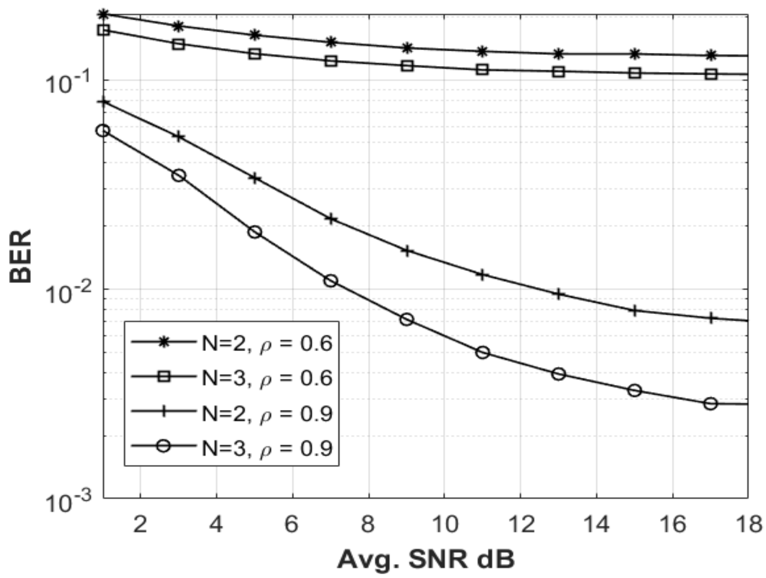

Fig. 2. BER Vs Avg. SNR, TDD, $\eta = 0.5$

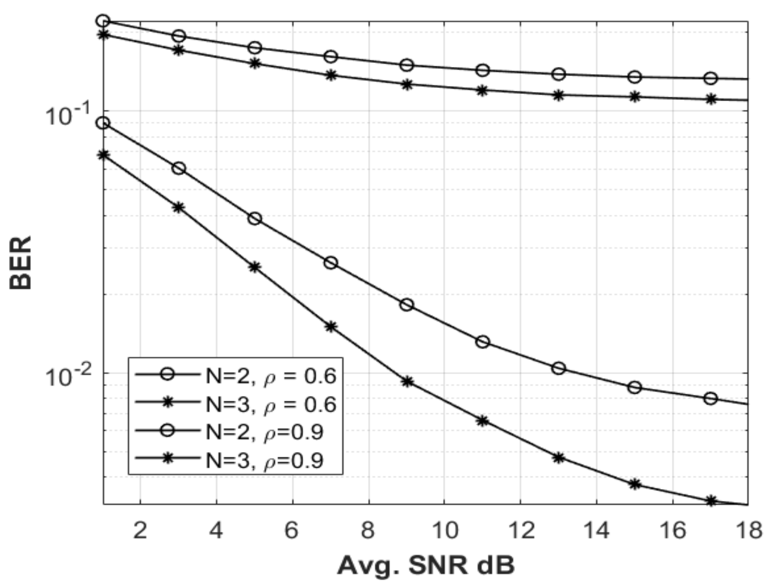

Fig. 3. BER Vs Avg. SNR, FDD, $\eta = 0.5$

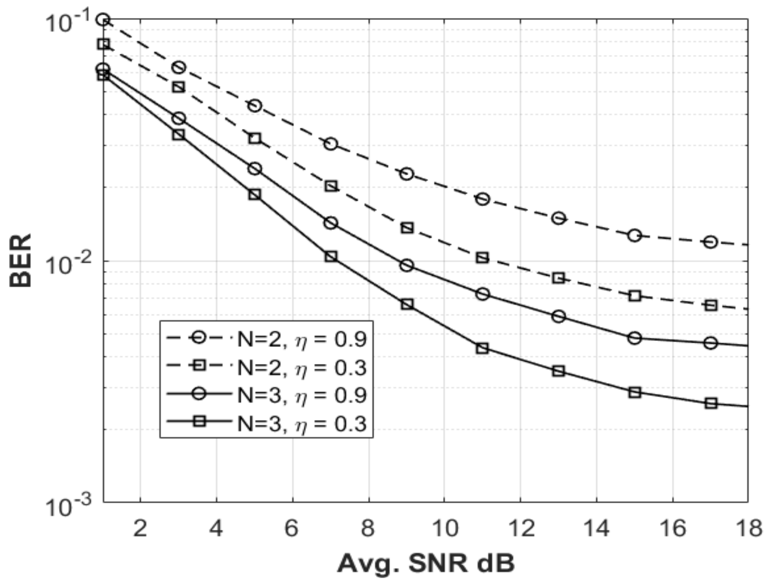

Fig. 4. BER Vs Avg. SNR, TDD, $\rho = 0.9$

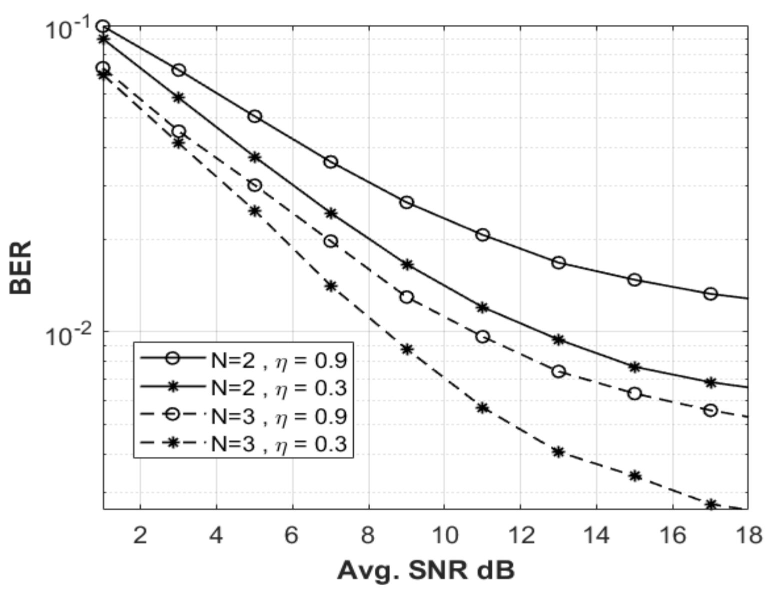

Fig. 5. BER Vs Avg. SNR, FDD, $\rho = 0.9$

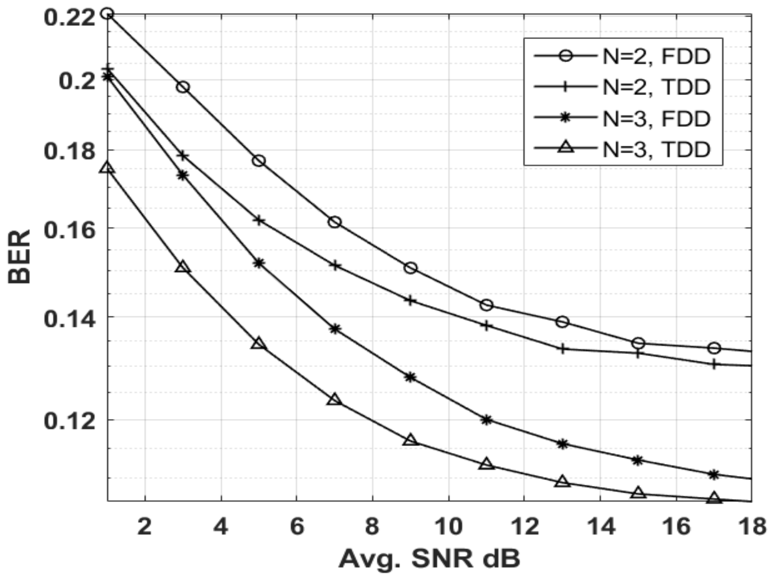

Fig. 6. BER vs Avg. SNR, FDD and TDD comparison, $\eta = 0.5$, $\rho = 0.6$

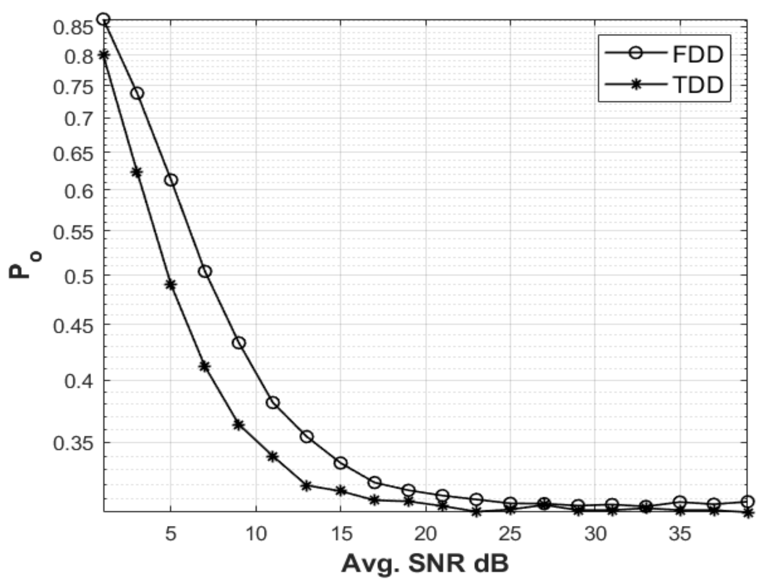

Fig. 7. P_o vs Avg. SNR, FDD and TDD comparison for $\gamma_{th} = 3dB$

4 Conclusion

In this paper, we considered a MISO system with N pairs of antennas and in each pair two antennas are there. We assume spatially uncorrelated, however correlated in each pair with coefficient η, Rayleigh fading channels. We performed selection of the pair of antennas with highest channel power gain using imperfect CSI (referred as FDD) or using perfect CSI (referred as TDD). Finally, we used Alamouti transmit diversity and detection with the imperfect CSI. The imperfection in the CSI is referred by ρ for antenna selection (for FDD) and detection (for FDD and TDD). For the considered system, we presented BER versus Avg. SNR and outage probability versus Avg. SNR using simulations for $N = 2$ and 3. We conclude that the performance degrades, when ρ is reducing from 1 to 0 or/and η is increasing from 0 to 1, and N is decreasing from 3 to 2. The TDD outperforms FDD due to perfect antenna selection. Hence, the operating mode can be switched from FDD to TDD, when the received SNR may drop, so that user may not suffer outage.

References

1. D. Tse and P. Viswanath, "Fundamentals of Wireless communication," Cambridge University Press 2005.
2. C. Gheorghe, R. Dragomir and D. Alexandru Stoichescu, "Massive MIMO technology for 5G adaptive networks", published in 2019 11th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)
3. Z. Chen, I. B. Collings, Z. Zhou and B. Vucetic, "Transmit antenna selection schemes with reduced feedback rate," in IEEE Transactions on Wireless Communications, vol. 8, no. 2, pp. 1006-1016, Feb. 2009, doi: 10.1109/TWC.2009.080296.
4. F. A. Dietrich and W. Utschick, "Impact of imperfect channel knowledge on transmit processing concepts," IEEE International Conference on Communications, 2005. ICC 2005, pp. 1916-1921 Vol. 3, doi: 10.1109/ICC.2005.1494673.
5. L. Sanguinetti, E. Björnson, and J. Hoydis, "Toward Massive MIMO 2.0: Understanding Spatial Correlation, Interference Suppression, and Pilot Contamination", Published in IEEE Transactions on Communications (Volume: 68, Issue: 1, Jan. 2020).
6. J. M. Chakravarti and Y. N. Trivedi, "Performance analysis of MISO systems with antenna selection over correlated channels," 2015 Twenty First National Conference on Communications (NCC), 2015, pp. 1-5, doi: 10.1109/NCC.2015.7084837.
7. J. G. Proakis, "Digital communication 4 ed," MH, 2001.
8. S. M. Alamouti, "A simple transmit diversity technique for wireless communications," in IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, pp. 1451-1458, Oct. 1998, doi: 10.1109/49.730453.