Performance Analysis of Single user Spatial Multiplexing Open-loop MIMO Systems with different Receiver Structures and Modulation Schemes

*Joyatri Bora
Electronics and Comm. Engg. Dept.
North Eastern Regional Institute of Science and Technology
Nirjuli, Itanagar, India

Md. Anwar Hussain
Electronics and Comm. Engg. Dept.
North Eastern Regional Institute of Science and Technology
Nirjuli, Itanagar, India

Abstract— **In wireless communication, MIMO has gained much attention due to large capacity and diversity gain provided by it. Capacity increases linearly as the number of antenna increases. At the same time complexity of detection of signal also increases exponentially with the number of transmit antenna. We study in this chapter the trade-off between MIMO antenna configuration, data rate, modulation order and type of receivers. For specific values of spectral efficiency, we considered different uncoded modulation formats and different MIMO antenna configurations and analysed bit error rate (BER) performance of three receivers for a range of E_b/N_0 values. The rich scattered Rayleigh channel is considered between transmitter and receiver of the MIMO system.**

Keywords—MIMO; diversity gain; detection; spectral efficiency; modulation.

I. INTRODUCTION

The spatial multiplexing (SM) gain or the spectral efficiency can be increased in a wireless communication system by adding multiple antennas both at the transmitter and receiver known as MIMO technology. MIMO increases the multiplexing gain by splitting a high rate signal into many low rate signals and transmitting through different antenna with independent fading path. Reliability in transmission is increased in MIMO by exploiting the diversity gain where several replicas of a signal are transmitted through different fading channel. A well known scheme of exploiting spatial multiplexing (SM) gain is the vertical Bell Labs Layered Space-time (VBLAST) [1], [2] architecture where multiple independent coded streams (layers) are transmitted simultaneously without channel state information (CSI) at the transmitter. Employing spatial multiplexing in MIMO, capacity is increased by *min* (N_T, N_R) [3], [4] where N_T is the number of transmit antenna and N_R is the number of receive antenna in a rich scattering environment. Although gain grows with increased antenna number, detection of signal becomes complex which increases with the number of transmit antenna. The essential part of MIMO system is the detector which separates the spatially multiplexed signals. In open loop MIMO, where only the receiver has information of the channel condition, decoding of signal is done by estimating the received signals using linear and non linear detectors. Maximum likelihood (ML) detector is an optimum non linear detector that decodes the signals through exhaustive search of the most likely transmitted signal. So, error probability is minimized but its complexity increases with MIMO antenna configuration and modulation order [5]. Minimum Mean Square Error (MMSE) and Zero-forcing (ZF) are two linear suboptimal detectors with less complex receiver architecture [6]. However ZF suffers from sudden enhancement of noise. MMSE detector maximizes the SINR output minimizing the mean square error in estimating the transmitted signals for all range of SNR.

We consider an open loop MIMO with no feedback to the transmitter. For spectral efficiency values of 1, 2, and 4 bps/Hz, modulation formats of BPSK, QPSK, and 16 QAM, we considered appropriate transmit and receive antenna orders of the MIMO system and studied BER versus E_b/N_0 (E_b is the bit energy and N_0 is the noise spectral density) performance of ZF-SIC, MMSE-SIC and ML receivers. For example, for the target spectral efficiency of 4 bps/Hz, signal constellation mapping may be (i) BPSK with transmit antenna, M_T = 8 and receive antenna, M_R = 8, or (ii) QPSK with transmit antenna, M_T = 4 and receive antenna, M_R = 4, or (iii) 16 QAM with transmit antenna, M_T = 2 and receive antenna, M_R = 2. We also consider a Single input single output (SISO) system with transmit antenna, M_T = 1 and receive antenna, M_R = 1 for the above said spectral efficiencies of 1, and 2 bps/Hz with appropriate modulation formats and different receiver structures for comparison. For the same SM gain we also compare the performances of different MIMO systems.

II. SYSTEM MODEL

We consider a MIMO system with transmitter having M_T number of antennas and receiver equipped with M_R antennas where M_T=M_R=M for spatial data multiplexing. The channel between transmitter and receiver is assumed to be rich scattered Rayleigh block fading channel. We assume perfect channel knowledge at the receiver end with no feedback to the transmitter i.e. MIMO system is an open loop SU-MIMO.

The channel can be written as

$$y = Hx + n \tag{1}$$

Where transmitted signal vector is, $x \epsilon X^{M_T x1}$, received signal vector is, $y \epsilon X^{M_R x1}$ and $n \epsilon X^{M_R x1}$ is vector of AWGN with zero mean and each element having σ^2 variance. The channel matrix, $H \epsilon X^{M_R x M_T}$ is assumed to be constant within a block and is assumed to be known to the receiver. The channel coefficients h_{ij} are the complex path gain from transmit antenna j to receive antenna i.

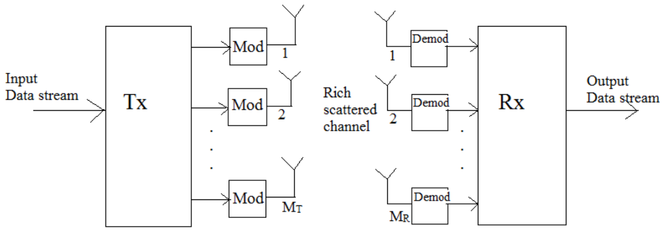

Fig. 1. Block diagram of MIMO system model.

III. Detection for SM

At the receiving end of the system, three detection schemes are applied – ZF-SIC, MMSE-SIC and ML.

A. *ZF-SIC receiver*

The Zero Forcing detection scheme is linear in nature but noise enhancement takes place. At some high value of SNR, it gives optimum result. The estimated result is given by

$$\hat{\boldsymbol{x}} = W_{ZF}\, y \tag{2}$$

Where $W_{ZF} = (H^H H)^{-1} H^H$ and H^H is Hermitian of H. With ZF receiver, the interference can be suppressed but because background noise is multiplied with equalization matrix W_{ZF}, so strong noise amplification is occurred leading to low SNRs. Here, again SIC is done by nulling the effect of k^{th} symbol before estimating the $(k+1)^{th}$ symbol.

B. *MMSE-SIC receiver*

To overcome the drawback of sudden noise enhancement of ZF, the concept of MMSE is introduced for detection. MMSE receiver minimizes the mean square error between the output of the receiver and the true data vector minimizing the average squared Euclidean distance between the estimate of the data vector and the true data vector. MMSE receiver is described by a weighting matrix W_{MMSE} given as

$$W_{MMSE} = \left(H^H H + \frac{N_0}{E_S} I_M\right)^{-1} . H^H \tag{3}$$

So, estimated output of the receiver is

$$\hat{\boldsymbol{x}} = W_{MMSE} \cdot \boldsymbol{y} \tag{4}$$

For better performance, successive interference cancellation is done. The effect of k^{th} symbol is subtracted before the estimation of $(k+1)^{th}$ symbol.

C. *ML receiver*

Maximum likelihood detection calculates the Euclidean distance between received signal vector and the product of all possible transmitted signal vectors with the given channel H, and finds the one with minimum distance. ML receiver tries to detect the transmitted vector x for system model of Equation (1) as

$$\hat{x}_{ML} = argmin\|y - Hx\|^2 \tag{5}$$

IV. Results and Discussions

SM gain of 1 bps/Hz, the basic 2x2 MIMO Rayleigh channel system employing two transmit (M_T=2) and two receive antennas (M_R=2) is simulated in MATLAB environment. For an uncoded BPSK modulated system it employs flat Rayleigh fading over independent transmit-receive links. At the receiver end, we assume perfect channel knowledge with no feedback to the transmitter, i.e. an open-loop spatial multiplexing system. A block of BPSK modulated 10,000 random binary bits are transmitted after subdivided into two independent sub-streams from the two transmit antennas, thus providing SM gain of 1 bps/Hz spectral efficiency by the MIMO system. The BER performance of ZF-SIC, MMSE-SIC and ML receivers are shown in Fig. 2 for a range of E_b/N_0 values. Similar plot has been drawn in Fig. 3 considering QPSK and employing a SISO system with M_T=M_R=1 for the same 1 bps/Hz spectral efficiency. From the Fig. 2 and 3, it is observed that 2x2 MIMO system provides better performance with ZF-SIC, MMSE-SIC and ML receivers compared to the SISO system with QPSK modulation and the same receivers, random binary data blocks, and E_b/N_0 values.

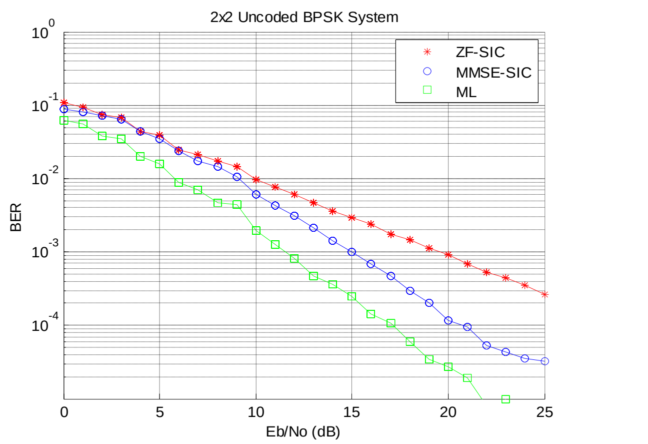

Fig. 2. BER performance of ZF-SIC, MMSE-SIC and ML receiver with BPSK modulation and M_T=M_R=2 for spectral efficiency of 1 bps/Hz.

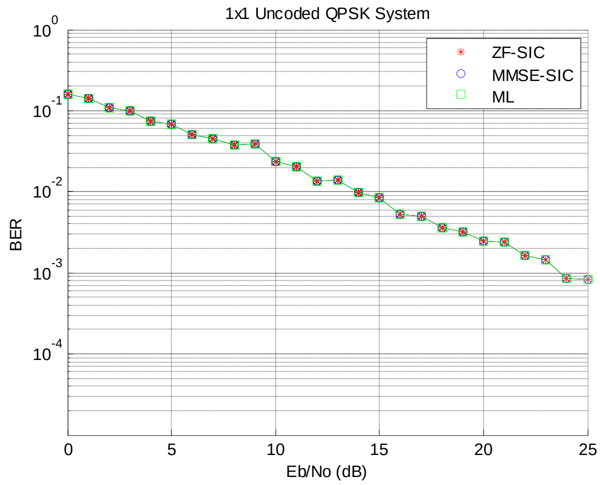

Fig. 3. BER performance of ZF-SIC, MMSE-SIC and ML receiver with QPSK modulation and M_T=M_R=1 for spectral efficiency of 1 bps/Hz.

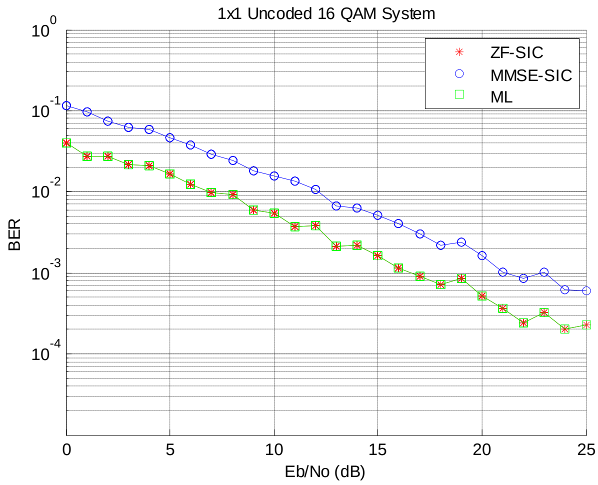

Fig. 6. BER performance of ZF-SIC, MMSE-SIC and ML receiver with 16QAM modulation and M_T=M_R=1 for spectral efficiency of 2 bps/Hz.

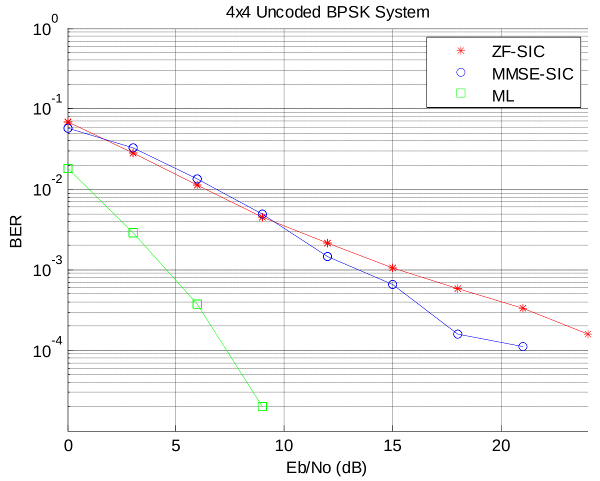

Fig. 4. BER performance of ZF-SIC, MMSE-SIC and ML receiver with BPSK modulation and M_T=M_R=4 for spectral efficiency of 2 bps/Hz.

Hence, a 2x2 MIMO with BPSK modulation is the choice for SM gain of 1 bps/Hz. Also in the SISO system all the receivers have the same performance for obvious reason. Fig.4, 5 and 6 show the results for spectral efficiency of 2 bps/Hz with BPSK, QPSK and 16 QAM modulation of random binary data block, and 4x4 MIMO, 2x2 MIMO, and 1x1 SISO systems, respectively. We notice that BER performance of the three receivers degrades with order of ZF-SIC >MMSE-SIC > ML. In all the three cases of BPSK, QPSK and 16 QAM modulations, the ML receiver shows better performance. It is observed that, at BER=9×10^{-4} the ML receiver of 4x4 MIMO with BPSK signaling, gives about 11 dB gain in E_b/N_0 over the 2x2 MIMO ML receiver with QPSK signaling. As is observed from Fig. 4, 5, and 6 the SISO system with 16 QAM, shows almost equal performance as 2x2 MIMO with QPSK, and 4x4 MIMO with BPSK, at 25 dB E_b/N_0. Also 4x4 MIMO shows better performance than 2x2 MIMO for the entire range of E_b/N_0 values.

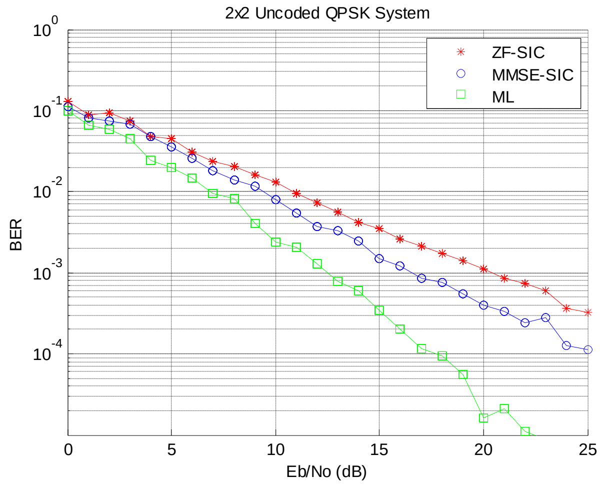

Fig. 5. BER performance of ZF-SIC, MMSE-SIC and ML receiver with QPSK modulation and M_T=M_R=2 for spectral efficiency of 2 bps/Hz.

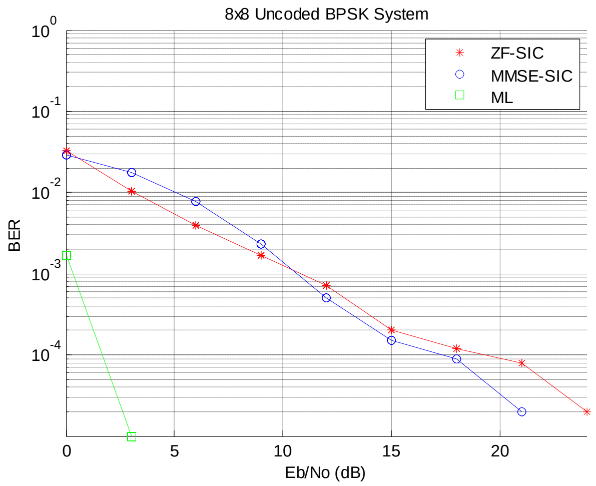

Fig. 7. BER performance of ZF-SIC, MMSE-SIC and ML receiver with BPSK modulation and M_T=M_R=2 for spectral efficiency of 4 bps/Hz.

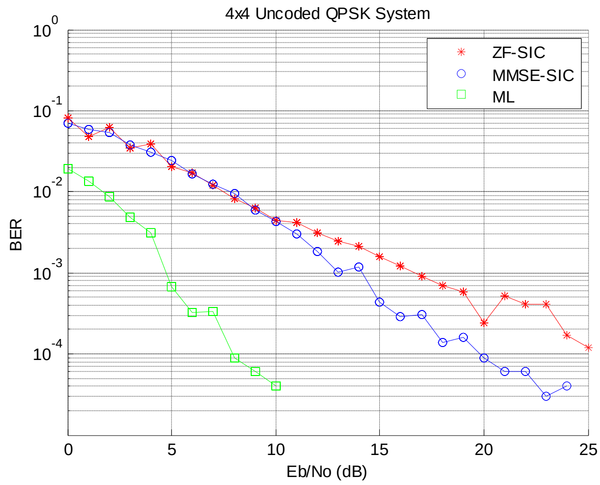

Fig. 8. BER performance of ZF-SIC, MMSE-SIC and ML receiver with QPSK modulation and M_T=M_R=4 for spectral efficiency of 4 bps/Hz.

In Fig. 7, 8 and 9, we show the bit error rate performance for case of 4 bps/Hz with BPSK and 8x8 MIMO, QPSK and 4x4 MIMO, and 16QAM 1x1 SISO systems, respectively. Here also ML receiver shows better performance compared to ZF-SIC and MMSE-SIC, in BPSK and 8x8 MIMO, QPSK and 4x4 MIMO, and 16QAM SISO system. At bit error rate of 10^{-4} , ML receiver with BPSK has E_b/N_0 gain about 6 dB over QPSK and 13 dB over 16QAM. For MMSE-SIC the E_b/N_0 gain is about 2 dB over QPSK and about 8 dB over 16QAM, for ZF-SIC gain is about 5 dB over QPSK and 2 dB over 16 QAM. Also the 8x8 MIMO performs better than the 4x4 and 2x2 MIMO systems for E_b/N_0 values from 3-25 dB. It is generally observed that for a given SM gain, the high order MIMO system shows better performance in terms of receiver structures used, and BER versus E_b/N_0 criterion, than the corresponding low order MIMO and SISO systems.

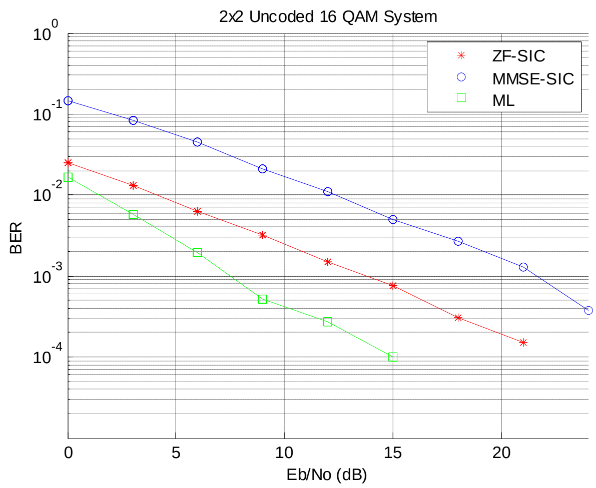

Fig. 9. BER performance of ZF-SIC, MMSE-SIC and ML receiver with 16QAM modulation and M_T=M_R=2 for spectral efficiency of 4 bps/Hz.

V. CONCLUSION

Simulation results of open-loop MIMO systems for uncoded transmission of random binary data blocks at 1 bps/Hz, 2 bps/Hz and 4 bps/Hz, considering appropriate modulation schemes like BPSK, QPSK and 16QAM, and different receiver structures using different appropriate number of transmit and receive antennas for the case of spatial multiplexing of independent data sub-streams are shown and analysed in this chapter. The bit error rate (BER) performance for a range of E_b/N_0 values using ZF-SIC, MMSE-SIC and ML receiver are analyzed for the given spectral efficiency. The ML receiver has shown to achieve better performance in all the cases, and the higher order MIMO performs better than a lower MIMO in all the considered spectral efficiencies.

REFERENCES

[1] P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, "V-BLAST: an architecture for realizing very high data rates over the rich-scattering wireless channel," in *Proc. IEEE ISSSE-98*, Oct. 1998, pp.295-300.

[2] G. J. Foschini, "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multiple Antennas", *Bell Laboratories Technical Journal*, Vol. 1, No.2, Autumn, 1996, pp. 41-59.

[3] I. E. Telatar, "Capacity of multi-antenna Gaussian channels,"AT&T Bell Labs., Internal Tech. Memo, June 1995.

[4] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Commun.: Kluwer Academic Press*, no. 6, pp. 311–335, 1998.

[5] V.S.Pham, M.T.Le, L.Mai, and G.Yoon, "Low Complexity Maximum-likelihood Decoder for VBLAST-STBC scheme in MIMO Wireless Communication Systems," *Vehicular Technology Conference, 2006*, vol.5,pp.2309-2313, 2006.

[6] J. G. Proakis, *Digital Communications*. McGraw-Hill Inc., Third Edition, 1995.

[7] X. Zhu and R. D. Murch, "Performance analysis of maximum likelihood detection in a MIMO antenna system," *IEEE Transactions on Communications*, vol. 50, no. 2, pp.188-191, Feb. 2002.

[8] R. Van Nee, A. Van Zelst, and G. Awater, "Maximum likelihood decoding in a space division multiplexing system," *IEEE VTC'00*, Tokyo, Japan, May. 2000, pp. 6-10.