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Simulation Study of Some Spatial Multiplexing Techniques for MIMO Wireless Communication Systems

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Abstract — **This paper presents simulation results and comparative analysis of some Spatial Multiplexing Techniques for Multiple Input Multiple Output (MIMO) based Wireless Communication Systems. Performance of various detection schemes are evaluated through MATLAB simulation study. The Bit Error rate and complexity of these schemes is discussed. The simulation is carried out for different modulation schemes. Comparative study shows Maximum Likelihood detection scheme results into best performance. But its computational complexity is very high. Hence there is a need to find less complex techniques which can provide quasi-ML performance.**

Keywords — **Bit Error Rate, MIMO, Rayleigh Fading, SISO, Space Time Block Codes, Spatial Diversity, Spatial Multiplexing, V-BLAST.**

I. Introduction

In the recent years MIMO has drawn significant attention of researchers in the field of wireless communication. Multipath fading is major bottleneck in increasing the data rate and reliability of transfer of information over wireless channel. Channel coding Techniques which are used to improve reliability is insufficient to meet the requirements of modern multimedia communications. It was shown that, if multiple antennas are used at transmitter and or receiver can improve data rate and reliability [1]-[3]. The simple transmit diversity scheme suggested by Alamouti [4] and the space time coding suggested by V. Tarokh et al. [5] triggered research in this area. Several transmission schemes have been proposed that utilize the MIMO channel in different ways. These schemes can be categorized as spatial multiplexing, spatial diversity and Smart Antennas & beamforming techniques [6]. In spatial multiplexing techniques, information is demultiplexed and independently transmitted over multiple antennas. This will increase the data rate i.e. multiplexing gain is achieved but the diversity gain is reduced because of higher error rate. Spatial diversity techniques transmit the same information over multiple antennas improving error rate and in turn diversity gain is achieved. Using beamforming techniques the antenna beam can be steered in certain desired direction so that signal-to-noise ratio is improved at the receiver. In this paper Performance of some spatial multiplexing techniques are studied through MATLAB simulations. There are number of parameters on which performance depends, such as Signal-to-Noise Ratio (SNR), number of transmit and receive antennas, the transmission scheme used, the detection scheme used at receiver, modulation scheme, channel model etc. The rest of the paper is organized as follows. In Section II various spatial multiplexing techniques are described. Section III includes discussion on simulation methodology, assumptions and parameters used for simulations. Simulation results are provided in Section IV. Finally section V contains our conclusions.

II. Spatial Multiplexing Techniques

Spatial Multiplexing (SM) can be used in MIMO systems to achieve higher transmission rate without allocating higher bandwidth or increasing transmit power. At the receiver side, the main challenge resides in designing powerful signal processing techniques, i.e., detection techniques, capable of separating those transmitted signals with acceptable complexity and achieved performance. Different research activities have been carried out to show that the spatial multiplexing concept has the potential to significantly increase spectral efficiency [7]. In general, these techniques assume channel knowledge at the receiver and the performance can be further improved when the knowledge of the channel response is available at the transmitter. However, SM does not work well in low SNR environments as it is more difficult for the receiver to recognize the multiple uncorrelated paths of the signals.

The main challenge in the practical realization of MIMO wireless systems lies in the efficient implementation of the detector which needs to separate the spatially multiplexed data streams. So far, several algorithms offering various tradeoffs between performance and computational complexity have been developed [7]. Several MIMO detection techniques were proposed in the literature. MIMO detection techniques are categorized as Maximum lkeliood detector, linear detectors, successive interference cancelation, and tree-search techniques.

A. Maximum Likelihood Detector

Maximum Likelihood (ML) detector is used if channel is unknown at the transmitter. The computational complexity of ML detector is high [8]. It is optimum in the sense of minimizing bit error rate [9]. If $[x_1,x_2,\dots x_N]$ is transmitted symbol stream, H is channel matrix and r is the received vector, then the estimated symbol stream is given by,

$$\tilde{x} = \arg_{x_k \in \{x_1, x_2 \dots x_N\}} \min \left\| r - Hx_k \right\|^2 \quad \dots\dots\dots \text{(1)}$$

As can be seen from above expression ML detectors will have very high computational complexity.

B. Linear Detectors

The linear techniques include Zero Forcing (ZF) and Minimum Mean Square Error (MMSE). Although linear detection schemes are easy to implement, they lead to high degradation in the achieved diversity order and error performance due to the linear filtering. ZF can be implemented by using the inverse of the channel matrix H to produce the estimate of transmitted vector.

$$\tilde{x} = H^{\dagger} r = H^{\dagger}(Hx + n) = x + H^{\dagger} n \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

But ZF detector suffers from noise enhancement. This is because inversion operation inverts Eigen values of channel matrix and the bad spatial channel paths will enhance the noise. This can be avoided with MMSE detectors [9]. The estimated transmission vector is given by

$$\tilde{x} = \left[\left[\left(H^H H + (\sigma^2 I)\right)^{-1}\right] H^H\right] r \quad \ldots\ldots\ldots (3)$$

C. Successive Interference Cancellation

The linear techniques described above give rise to poor performance. If we are able to detect most reliable symbol of transmitted vector and use it to improve decoding of other elements, performance can be improved. This nonlinear technique is called nulling and cancellation. Nulling can be performed through ZF or MMSE and cancellation is subtraction of interference from already detected symbols. This process is successively repeated till all the symbols in the transmitted stream are detected. These techniques are called Decision Feedback Equalizers (DFE). Thus we can have DFE with ZF or DFE with MMSE.

D. Vertical Bell Lab Layered Space Time Architecture

The Vertical Bell Laboratories Layered Space Time (V-BLAST) scheme was originally proposed by Foschini [1] and has been discussed in details in literature. The main idea behind the V-BLAST architecture (i.e., transmitter) is to demultiplex the data stream into several sub-streams and transmit them simultaneously. At the receiver side, each antenna observes all the transmitted signals, which are mixed due to the environment surrounding the wireless propagation channel. V-BLAST detection algorithm detects the signals one after another in an iterative way [10]. The construction of the filtering matrix can still be based on any of the aforementioned linear criteria, i.e. ZF or MMSE.

VBLAST detection algorithms imply the calculation of the pseudo-inverse of MIMO channel at each detection step. This involves expensive computational requirements and makes VBLAST algorithms enduring computational bottleneck. This computational bottleneck can be avoided using QR Decomposition (QRD) based algorithm such as ZF-QRD and MMSE-QRD. It is shown that QR Decomposition-based algorithms requires only a fraction of the computational efforts required by the V-BLAST detection algorithm [11][12].

E. Tree Search Detectors

The ML detection achieves the best performance and diversity order, but it requires a brute-force search which is exponential in the number of transmit antennas and constellation set size. Several tree-search detection algorithms have been proposed in the literature that achieves quasi-ML performance while requiring lower computational complexity. Sphere Decoding (SD) approach was inspired from the mathematical problem of computing the shortest nonzero vector in a lattice [13][14]. The principle of SD is to search for the closet constellation point to the received signal within a sphere with predetermined radius, where each transmit candidate is represented by a lattice point in a lattice field. The search can be restricted to be in a circle around the received signal just small enough to enclose at least one lattice point or ML solution [15], thus search time can be significantly reduced by eliminating the search of those lattice points lie outside the circle. According to the analysis available in [16], SD can transform the ML detection problem into a tree search and pruning process and achieve quasi-ML performance with polynomial average computational complexity for large range of signal to noise ratios.

The second scheme in the tree search category is the QRD-M, which was proposed to achieve quasi-ML performance while requiring fixed computational effort. QRD-M algorithm can reduce the tree search complexity by selecting only M candidates at each layer instead of testing all the hypotheses of the transmitted symbol [17].

III. Simulation Methodology

The performance of Spatial Multiplexing techniques is evaluated through Bit Error Rate (BER) Vs SNR plot under various conditions and parameters. The simulation parameters can be varied and the effect of the change can be studied on performance of the system. The various parameters used are Number of transmit and receive antenna, modulation technique, Eb/No ratio, Bit error rate, Channel type. In the simulation results discussed in section IV the channel used is Rayleigh Flat Fading channel under AWGN. It is assumed that the CSI is available at the receiver. The methodology used for simulation is as below

i) Generate data
ii) Modulate the data into symbols
iii) Demultiplex the Encoded data and transmit on different antenna
iv) Simulate the Channel and pass the transmitted symbols through it
v) Add noise as per required Eb/No ratio
vi) Process the received symbols as per the detection scheme
vii) Demodulate the symbols and recover the data
viii) Compare recovered data with original data to compute Bit Error rate (BER)
ix) Repeat above steps for different Eb/No ratios and plot the graph.

The number of data items used are depending on frame length which can be varied. Also each BER value is obtained by averaging over number of packets [18] [19].

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IV. Results & Discussion

Simulation Results of spatial multiplexing techniques discussed in section II are obtained and are given below.

A. Maximum Likelihood Detector

This scheme is studied for 2X2 MIMO systems for Rayleigh fading channel under AWGN and BER is plotted along with 1X1 SISO. Two modulation schemes MPSK and MQAM are used for the study. Fig. 1 shows Bit error Rate Vs SNR plot for MPSK Modulation with different values of modulation order i.e. M=2, 4, and 16.

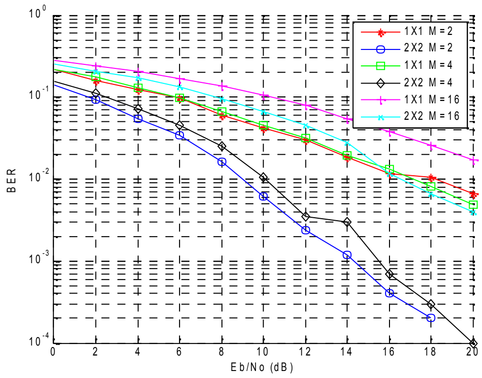

Fig.1. BER of ML Detector with MPSK modulation for 2X2 MIMO System with 1X1 SISO system

Fig. 2 shows Bit error Rate Vs SNR plot for MQAM Modulation for different values of modulation order i.e. M=4, 16 and 32.

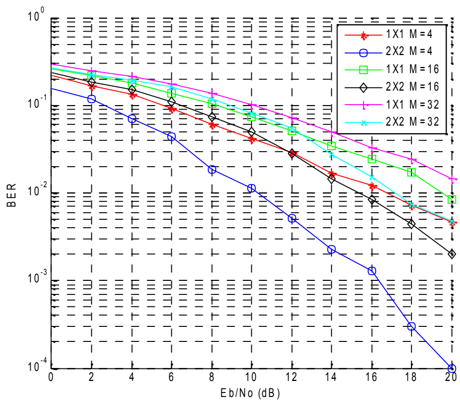

Fig.2. BER of ML Detector with MQAM modulation for 2X2 MIMO System with 1X1 SISO system

Simulation Results show that ML detector performs better for 2X2 MIMO. For example we get an advantage of 7 dB for BER of 10^{-2} with QPSK and QAM modulation in case of 2X2 MIMO over 1X1 MIMO. BER performance of 4X4 MIMO is also evaluated for the two modulation techniques. Fig. 3 shows Bit error Rate Vs SNR plot for MPSK Modulation for two values of modulation order i.e. M=2 and 4.

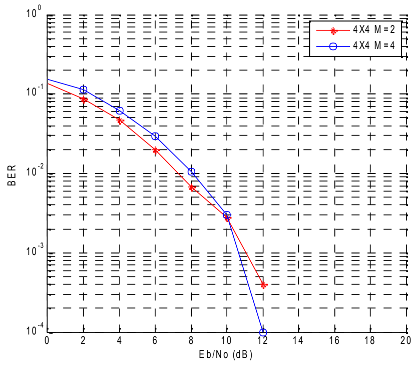

Fig.3. BER of ML Detector with MPSK modulation for 4X4 MIMO System.

Fig. 4 shows Bit error Rate Vs SNR plot for MQAM Modulation for two values of modulation order i.e. M=2 and 4.

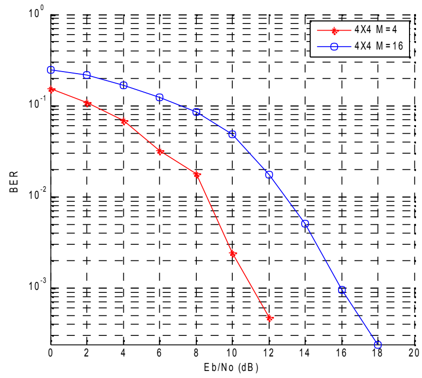

Fig.4. BER of ML Detector with MQAM modulation for 4X4 MIMO System

It can be observed that 4X4 MIMO with ML detector gives improved performance than 2X2 MIMO with ML detector. At high SNR the improvement is more significant because at the probability that receiver can detect the transmitted stream is high at high SNR.

B. Linear Detectors

There are two types of linear detectors viz. ZF and MMSE. This scheme is studied for 2X2 MIMO systems for Rayleigh fading channel under AWGN and BER is plotted along with 1X1 SISO. Two modulation schemes MPSK and MQAM are used for the study. Fig. 5 shows Bit error Rate Vs SNR plot of ZF detector, for MPSK Modulation for the modulation order M=2, 4 and 16.

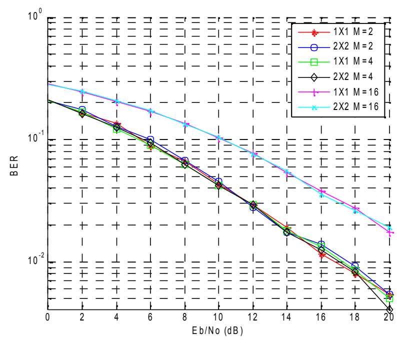

Fig.5. BER of ZF Detector with MPSK modulation for 2X2 MIMO System with 1X1 SISO system

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Fig. 6 shows Bit error Rate Vs SNR plot of ZF detector, for MQAM Modulation with modulation order M= 4, 16 and 32.

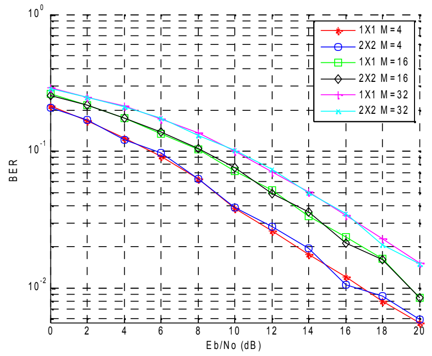

Fig.6. BER of ZF Detector with MQAM modulation for 2X2 MIMO System with 1X1 SISO system

Fig. 7 shows Bit error Rate Vs SNR plot of MMSE detector, for MPSK Modulation with modulation order M=2, 4 and 16.

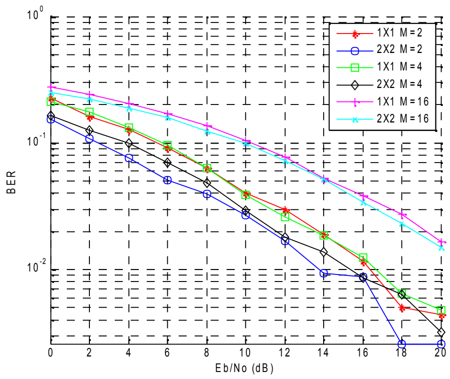

Fig.7. BER of MMSE Detector with MPSK modulation for 2X2 MIMO System with 1X1 SISO system

Fig.8 shows Bit error Rate Vs SNR plot of MMSE detector, for MQAM with modulation order M= 4, 16 and 32.

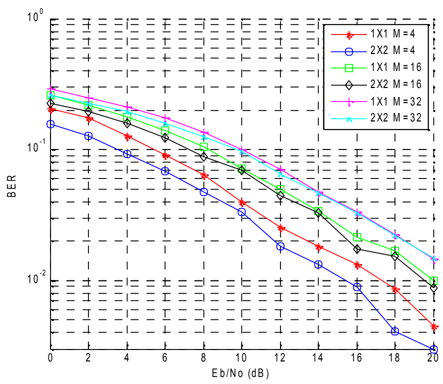

Fig.8. BER of MMSE Detector with MQAM modulation for 2X2 MIMO System with 1X1 SISO system

Simulation Results show that MMSE detector performs better than ZF detector. For example we get an advantage of about 2 to 3 dB for BER of 10^{-2} in case of QPSK and QAM modulation in case of 2X2 MIMO over 1X1 MIMO.

It is also observed that for higher order modulations the performance of ZF and MMSE is similar. At high SNR also MMSE performance approaches that of ZF. The performance curves almost remain linear for all values of SNR as opposed to earlier scheme where the slope of the curves increases at high SNR.

C. Successive Interference Cancellation

This scheme is studied for 4X4 MIMO systems for Rayleigh fading channel under AWGN. Two modulation schemes MPSK and MQAM are used for the study. Fig. 9 shows Bit error Rate Vs SNR plot of the DFE-ZF scheme, for MPSK Modulation with modulation order M=2, 4 and 16.

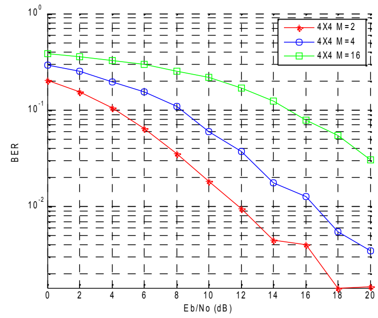

Fig.9. BER of DFE-ZF Detector with MPSK modulation for 4X4 MIMO System.

Fig. 10 shows Bit error Rate Vs SNR plot of the DFE-ZF scheme, for MQAM Modulation with modulation order M=4, 16 and 32.

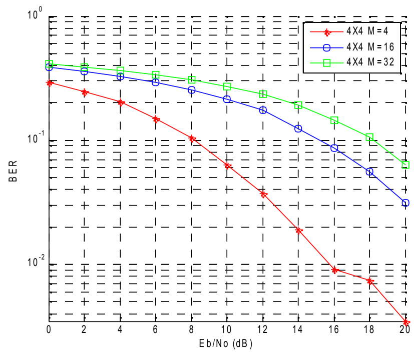

Fig.10. BER of DFE-ZF Detector with MQAM modulation for 4X4 MIMO System.

Fig. 11 shows Bit error Rate Vs SNR plot of the DFE-MMSE scheme, for MPSK Modulation with modulation order M=2, 4 and 16.

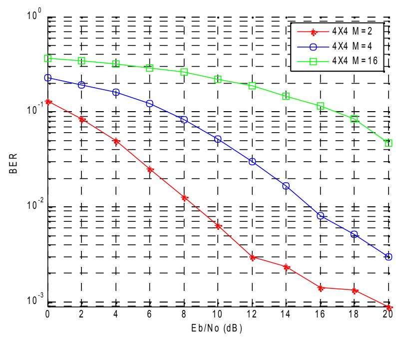

Fig.11. BER of DFE-MMSE Detector with MPSK modulation for 4X4 MIMO System.

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Fig. 12 shows Bit error Rate Vs SNR plot of the DFE-MMSE scheme, for MQAM Modulation with modulation order M=4, 16 and 32.

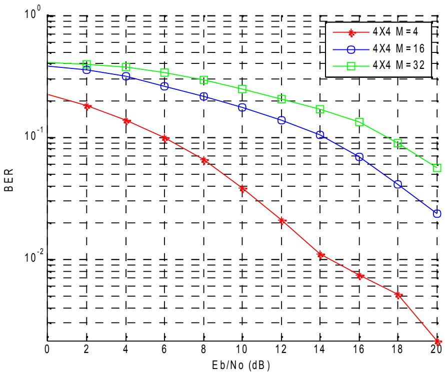

Fig.12. BER of DFE-MMSE Detector with MQAM modulation for 4X4 MIMO System.

Simulation Results show that DFE-MMSE detector performs better than DFE-ZF detector. For example we get an advantage of about 2 to 3 dB for BER of 10^{-2} with QPSK and QAM modulation in case of DFE-MMSE over DFE-ZF. It is also observed that for higher order modulations the performance of ZF and MMSE is similar. At high SNR also both MMSE performance approaches that of ZF. By comparing these results with simple ZF and MMSE schemes, it can be observed that the improvement in performance with DFE-MMSE over DFE-ZF is more significant than the improvement in simple MMSE scheme over ZF scheme.

D. Vertical Bell Lab Layered Space Time Architecture

This scheme is studied for 4X4 MIMO systems for Rayleigh fading channel under AWGN. Two modulation schemes MPSK and MQAM are used for the study. Fig. 13 shows Bit error Rate Vs SNR plot of the VBLAST-ZF scheme, for MPSK Modulation with modulation order M=2, 4 and 16.

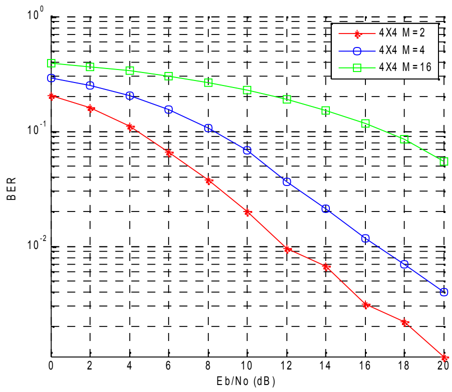

Fig.13. BER of V-BLAST-ZF Detector with MPSK modulation for 4X4 MIMO System.

Fig. 14 shows Bit error Rate Vs SNR plot of the VBLAST-ZF scheme, for MQAM Modulation with modulation order M=4, 16 and 32.

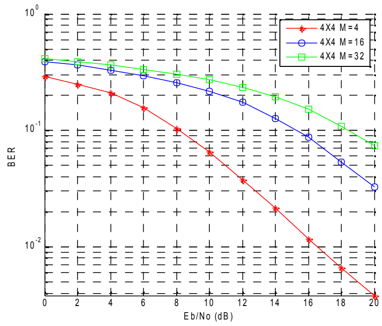

Fig.14. BER of V-BLAST-ZF Detector with MQAM modulation for 4X4 MIMO System.

Fig.15 shows Bit error Rate Vs SNR plot of the VBLAST-MMSE scheme, for MPSK Modulation with modulation order M=2, 4 and 16.

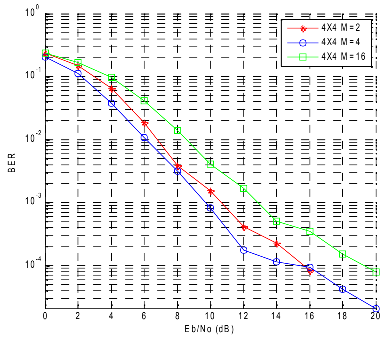

Fig.15. BER of V-BLAST - MMSE Detector with MPSK modulation for 4X4 MIMO System.

Fig.16 shows Bit error Rate Vs SNR plot of the VBLAST-MMSE scheme, for MQAM Modulation with modulation order M=4, 16 and 32.

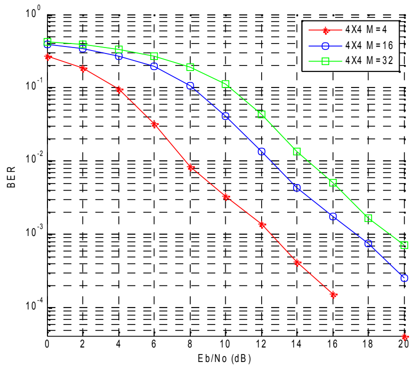

Fig.16. BER of V-BLAST - MMSE Detector with MQAM modulation for 4X4 MIMO System.

Simulation Results show that DFE-MMSE detector performs better than DFE-ZF detector. For example we get an advantage of about 5 to 6 dB for BER of 10^{-2} in case of QPSK and QAM modulation in case of DFE-MMSE over DFE-ZF. It is also observed that for higher order modulations the performance of ZF and MMSE is similar. At high SNR also both MMSE performance approaches that of ZF. It can also be observed that the performance of VBLAST and DFE are almost similar as both schemes are based on successive interference cancellation.

V. Conclusion

Spatial multiplexing (SM) in MIMO based wireless communication system is used to increase the channel capacity and improve spectral efficiency as well. Therefore, the MIMO SM-based system has been one of currently promising techniques that could realize high-speed wireless transmission for future communications networks. The main challenge of MIMO SM-based system is detection. Number of MIMO SM detection techniques such linear, nonlinear and tree based detections are developed. In this study, several MIMO detection techniques have been simulated, analyzed and compared. The ML detection achieves the best performance and diversity order, it requires a brute-force search which is exponential in the number of transmit antennas and constellation set size. In order to achieve quasi-ML performance with a computationally feasible level of complexity, SD and QRD-M detection techniques are proposed. In general, linear detection techniques such as ZF and MMSE have less complexity but the BER performance plots of these techniques demonstrated their relatively poor performance. Nonlinear techniques such as DFE or VBLAST are proposed. But the computational Complexity of these techniques is high. QR Decomposition based algorithms can be used to reduce the computational complexity.

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Author's Profile

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V. K. Kokate

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