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MIMO Technology using V-BLAST Equalization Techniques – Literature Survey

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Abstract: Multiple Input Multiple Output (MIMO) technology is one of the most promising wireless technologies that can increase link reliability, data transmission rate and improves the coverage of system. It increases efficiency for said total transmission power. By using multiple antennas both at transmitter and receiver sides, MIMO technology allow a novel dimension "the spatial dimension" that can reduce the limitations of wireless channels. Inter symbol interference is one the major issues with MIMO technique. There are many schemes that can be applied to MIMO systems to reduce such effects and are known as Equalization techniques. In this paper we focus on the broad spectrum MIMO systems, the Vertical Bell Labs Space-Time design and different types of equalizer like ZF, MMSE, ZF-SIC, MMSE-SIC and ML.

Keyword: MIMO, V-BLAST, ZF, MMSE, ML

I. INTRODUCTION

The use of multiple antennas at the transmitter and receiver in wireless systems is known as multiple-input multiple-output (MIMO). Latest research on wireless communication systems has shown that using multiple antennas at both transmitter and receiver offer the possibility of wireless communication at higher data rates compared to single antenna systems. A number of unique detection algorithms have been planned in order to utilize the high spectral capacity offered by MIMO channels. V-BLAST (Vertical Bell-Labs Layered Space-Time) algorithm is one of them, which uses a layered structure.

This algorithm offers exceptionally superior error performance than conventional linear receivers and still has low complexity. In earlier times, theoretical study on multiple-input multiple-output (MIMO) systems shows that use multiple transmit and receive antennas in a rich scattering communication channel have provided brilliant outcome. They have given a linear boost in system ability and spectral efficiency with respect to the number of transmit antennas as long as the number of receive antennas are greater or equal to the number of transmit antennas [1-2]. In the MIMO communication system, multiple transmission paths can be used to get superior multiplexing gain and diversity. In the V-BLAST transmitter, every antenna transmits its own disjointedly coded symbols and the V-BLAST receiver, uses a spatial area decision feedback equalizer. In this method every symbol is decoded and then fed back to cancel its interference with additional symbols. This process repeats until all the symbols are decoded. The decoding order can be optimized by decoding the symbol with largest signal to noise ratio (SNR) first. Because of this decision feedback arrangement, the V-BLAST system yields a very good spectral efficiency in a scattering rich environment without increasing the transmission bandwidth or power.

II. MIMO SYSTEM MODEL

Let us consider a MIMO communication system having 2 antennas at the transmitter and 2 antennas at the receiver end. Consider we have a transmission sequence as $\{x_1, x_2 \ldots\ldots\ldots\ldots x_n\}$. In typical transmission, we transmit x_1 in the first time slot, x_2 in the second time slot and x_n in the n^{th} time slot. As we have 2 transmit antennas, we may group the symbols into groups of two. In the first time slot, x_1 and x_2 are sent from the first and second antenna. In the second time slot, send x_3 and x_4 from the first and second antenna respectively and in next time slot x_5 and x_6 are sent and so on [13].

Let us consider for 2 x 2 MIMO

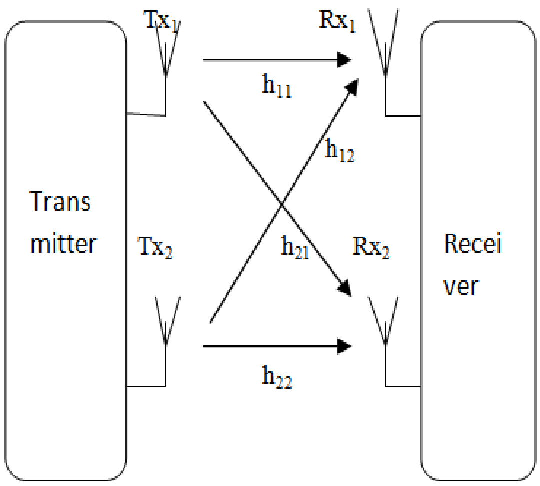

Fig. 1 2 x 2 MIMO System

Here the received signal at Rx_1 is given as

$$y_1 = h_{11}s_1 + h_{12}s_2 + n_1 \quad (1)$$

also the received signal at Rx_2 is given as

$$y_2 = h_{21}s_1 + h_{22}s_2 + n_2 \quad (2)$$

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here y_1 and y_2 are the received signals on 1st and 2nd antenna respectively.

h_{11} = channel from 1st transmit antenna to 1st receive antenna,

h_{12} = channel from 2nd transmit antenna to 1st receive antenna,

h_{21} = channel from 1st transmit antenna to 2nd receive antenna,

h_{22} = channel from 2nd transmit antenna to 2nd receive antenna,

s_1 and s_2 = transmitted symbols and
n_1 and n_2 is the noise on 1st and 2nd receive antennas respectively.

Matrix representation of the above eq^n (1) and (2) is as

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

Further, the received vector is expressed as the following

$$y = Hs + n \quad (4) \ [5]$$

III. RAYLEIGH FLAT FADING CHANNEL

Interference is caused by two or more version of transmitted signals which arrive at different times at the receiver. These signals are called multipath signals. The systems in which bandwidth of transmitted signal is smaller than the coherence bandwidth of channel are called narrow band systems. In such systems flat fading or frequency selective fading takes place. For this Rayleigh distribution is used to illustrate the statistically time-varying nature of the received signal of a flat fading channel. The probability density function of the Rayleigh distribution is given as

$$P_r = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} & r \geq 0 \\ 0 & r < 0 \end{cases} \quad (5)$$

Where
σ = RMS value of the received signal,
σ^2 = the average power.

IV. DIFFERENT EQUALIZATION TECHNIQUES

The V-BLAST detection method is mainly classified as linear detection scheme, non-linear detection scheme and successive interference cancellation detection scheme. ZF and MMSE comes under linear detection scheme while ML is a non-linear detection scheme and are described as following

A) ZERO FORCING (ZF)

In zero forcing equalizer, inverse filter is used to compensate the channel response function. Also we can say that the overall response function at the output of the equalizer is one for the symbol being detected while it has zero response for all other symbols.

As zero forcing is a linear equalizer, it does not consider the noise effects i.e it outcomes in the exclusion of interference from all other symbols in the absence of noise. It works best with high SNR. If W_{ZF} is the zero forcing matrix then it should satisfy the condition

$$W_{ZF}H = 1 \quad (6)$$

Where

$$W_{ZF} = (H^T H)^{-1} H^T \quad (7)$$

Here H is the full rank square channel matrix and H^T is the transpose of the channel matrix.

B. MINIMUM MEAN SQUARE ERROR (MMSE)

MMSE detector seeks to balance between interference cancellation and diminution of noise enhancement [8]. If mean square error between the transmitted symbols and the output symbols of the detector is taken as the performance criterion, MMSE detector is the best choice.
If W_{MMSE} is the minimum mean square error matrix then

$$W_{MMSE} = \left(H^T H + \frac{1}{SNR} I\right)^{-1} H^T \quad (8)$$

At high SNR, MMSE becomes Zero forcing.

C. SUCCESSIVE INTERFERENCE CANCELLA-TION (SIC)

If the symbols are detected successively and the outcome of the previous detected symbol is used to cancel the interference of the next symbol, it leads to the decision directed detection algorithm called Successive Interference Cancellation [12].

SIC algorithm mainly consists of three parts

- Ordering: to find out the T_x stream with lowest error variance.
- Interference Nulling : estimate the strongest signal from the T_x stream by nulling out the weaker signals.
- Interference Cancellation : subtracting the contribution of the detected symbol from the rest received signal vector and go back to the ordering step.
- It further subdivides into two parts
- Zero forcing with Successive Interference Cancellation (ZF-SIC)
- Minimum Mean square Error with Successive Interference Cancellation (MMSE-SIC)

ZF-SIC and MMSE-SIC come close to the capacity of the i.i.d Rayleigh fading Channel.

A. MAXIMUM LIKELIHOOD (ML)

The SIC detection method and linear detection methods have low complexity than the ML detection method. But the performance of ML detection method is superior than other methods discussed so far. This methods works on the principle of max likelihood between the received signal and the product of channel matrix H with the transmitted signal vectors to find out the one with minimum distance.
The ML detection method determines the approximate transmitted signal vector x as the following

$$\hat{x}_{ML} = \underset{\hat{x}}{\operatorname{argmin}} [\![y - Hx]\!]_F^2 \quad (9)$$

Where F is the Frobenius norm and H is the modified channel matrix.

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V. LITERATURE REVIEW

In this section we will study the recent trends in the BLAST architecture and will get to know about the progress in the various equalization techniques.

- Gerard J. Foschini et al. [2] considered a multi-element antenna system that has M and N transmit and receive antennas weakened by additive white Gaussian noise (AWGN) in a flat-fading Rayleigh channel, when channel characteristics are unknown at the transmitter side but known at the receiver side and also invented a codec architecture that can realize the major segment of channel capacity for indoor and fixed wireless. It also shows by using multiple antenna at both transmitter and receiver side capacity grows linearly with n and is huge.
- Eduardo Zacarıas B et al. [4] reviews the main characteristics of three BLAST architecture: D-BLAST, V-BLAST and Turbo-BLAST. Further the architecture, encoding and decoding techniques are explained
- P. Wolniansky et al. [5] presented a description of a wireless communication architecture known V-BLAST, implemented in real time in the laboratory. Using laboratory prototype, they have demonstrated spectral efficiencies of 20 - 40 bps/Hz in an indoor propagation environment at realistic SNRs and error rates. Wireless spectral efficiencies of this magnitude are exceptional, and are moreover unachievable using traditional techniques.
- J. Benesty et al. [6] presented a very basic and efficient algorithm that lessens the complexity by a factor of M. Bell Labs layered space-time (BLAST) wireless systems are multiple-antenna communication schemes that can accomplish very high spectral efficiencies in scattering environments with no raise in bandwidth or transmitted power. The most famous and by far, the most feasible architecture is the so-called Vertical BLAST (V-BLAST). The signal detection algorithm of a V-BLAST system is commutatively very systematic. If the number of transmitter antennas is M and is same as the number of receivers, this complexity is equivalent to M^4 at each sample time.
- Shreedhar. A. Joshi et al. [8] provide a general multiple antenna system (MIMO) with the V-BLAST technique using several detectors (MMSE, ML, ZF and QR) and conclude that the performance is limited by error propagation. They show the benefits of ordering strategy over SIC and PIC cancellation methods. However, the drawback of BLAST algorithms is the propagation of decision errors, unequal diversity advantage for each symbol.
- Ananya et al. [12] presents an in detail analysis of the zero forcing (ZF), minimum mean squared error (MMSE) and Successive Interference Cancellation (SIC) equalizers using Vertical Bell Labs Layered Space-Time (V-BLAST) techniques. Here they study the SIC receiver incorporate ZF and MMSE receivers which gives improved performance with less complexity. Also the Bit Error Rate (BER) is compared using the above mentioned detectors and find that ZF-SIC and MMSE-SIC performance are superior to conventional ZF and MMSE detectors.
- Sukhchain Singh et al. [13] studied the BER performance of Maximum Likelihood (ML) Vertical Bell Labs Layered Space Time Architecture (V-BLAST) using different modulation techniques like BPSK and QPSK, in Rayleigh and Rician Channel. Further different antenna configuration with BPSK and QPSK modulation techniques are considered and find that ML-VBLAST decoding technique using BPSK modulation scheme gives better result than QPSK modulation technique in both the channels. Also more optimal result are observed for 1× 4 antenna for V-BLAST system in rician fading channel and for Rayleigh channel 4 X 4 antenna gives best results for ML-V-BLAST system.

VI. CONCLUSION

This article gives a general idea about the MIMO systems with V-BLAST procedure. An overview of the V-BLAST technique is presented along with various equalization techniques like Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Successive Interference Cancelation (SIC) and Maximum Likelihood (ML). MIMO is a vital technology that enables the wireless industry to deliver a enormous potential. On the other hand, the drawback of BLAST algorithms is the propagation of decision errors and unequal diversity gain.

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