5
V-BLAST ALGORITHM AND ARCHITECTURE

5.1 INTRODUCTION

This chapter gives information about various types of representation of V-BLAST schemes and completes V-BLAST architecture, algorithm which has been implemented in this project.

5.2 SPATIAL MULTIPLEXING SCHEMES

Spatial multiplexing scheme exploits the rich scattering wireless channel allowing the receiver antennas to detect the different signals simultaneously transmitted by the transmit antennas. This method uses multiple antennas at the transmitter and the receiver in conjunction with rich scattering environment within the same frequency band to provide a linearly increasing capacity gain in the number of antennas. Hence, the concept of spatial multiplexing is different from that of space-time coding method, which permits to efficiently introduce a space-time correlation among transmitted signals to improve information protection and increase diversity gain. The basic spatial multiplexing scheme is illustrated in figure: 5.1.

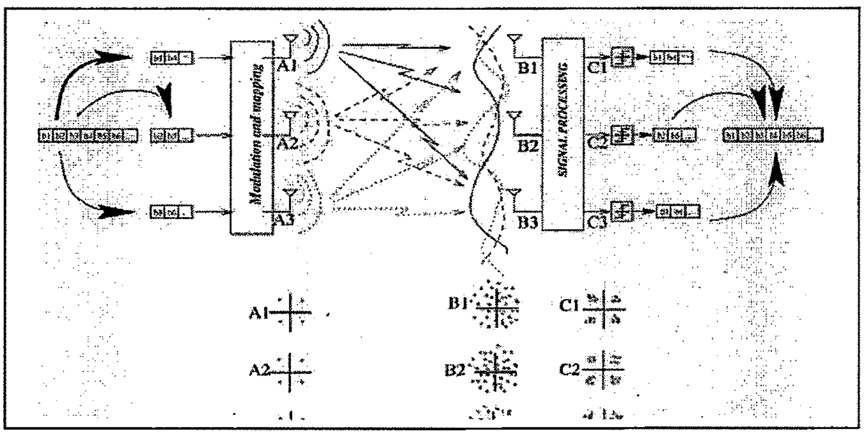

Figure:5.1 Basic Spatial Multiplexing Schemes with 3 transmit and 3 receive antennas

5.3 LAYERED SCHEMES

In V-BLAST systems Layered schemes are use both the side of communication system i.e. at transmission side and reception side.

5.3.1 Layered Schemes in Transmitter Side

Figure: 5.2 represented the Layered scheme in transmission techniques. Here each sub-stream i.e. layer is transmitted using by all antennas; this all layers correspond to one or more coding blocks.

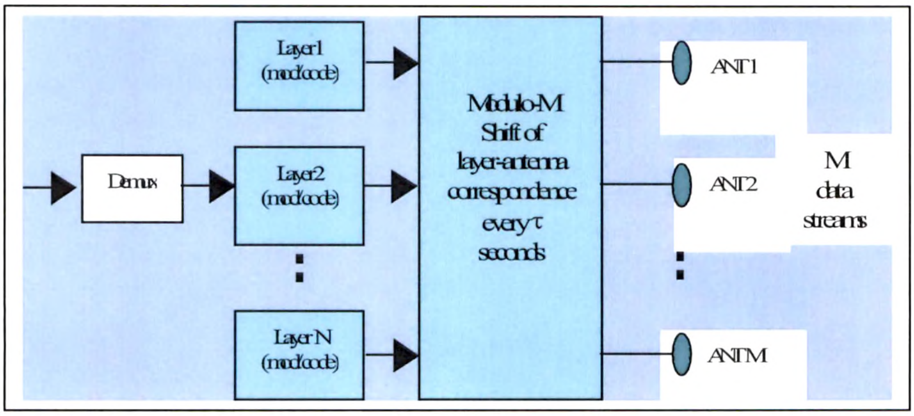

Figure: 5.2 Transmission techniques for the Layered scheme

5.3.2 Layered Schemes in Receiver (Detector) Side

In detectors side i.e. receivers are underlying layers detected, after that all signals are reconstructed and cancelled. Finally overlying layers exhibit interfering signals to be suppressed. By using Layered scheme maximizes SINR. Figure: 5.3 represented how this layered scheme is working in detectors

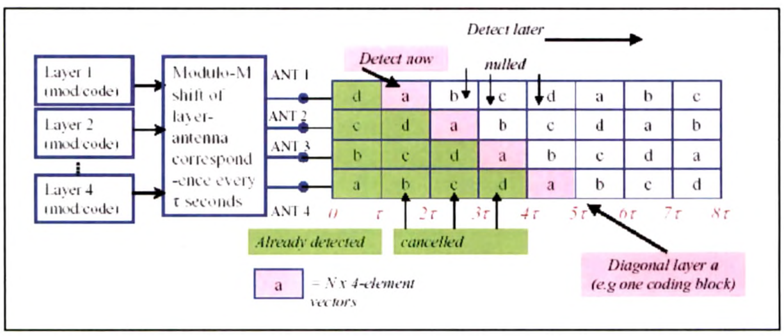

Figure: 5.3 Receiving techniques for the Layered scheme

5.4 COMPARISON OF V-BLAST WITH D-BLAST

Basically, two approaches for the transmission over MIMO systems;

(1) V-BLAST,

(2) D-BLAST.

Generally, spatial multiplexing is often referred to as V-BLAST. However, due to its complex coding procedure, Vertical Bell Laboratories Layered Space- Time architecture (V-BLAST) has been proposed as a simplified version. In V-BLAST, channel coding may be applied to individual antennas (sub-layers), corresponding to the data stream transmitted from each transmit antenna, while in D-BLAST coding processing is applied not only across the time but also to each sub-layer, which implies higher complexity. As shown figure: 5.4 simplified diagram of comparison of V-BLAST with D-BLAST.

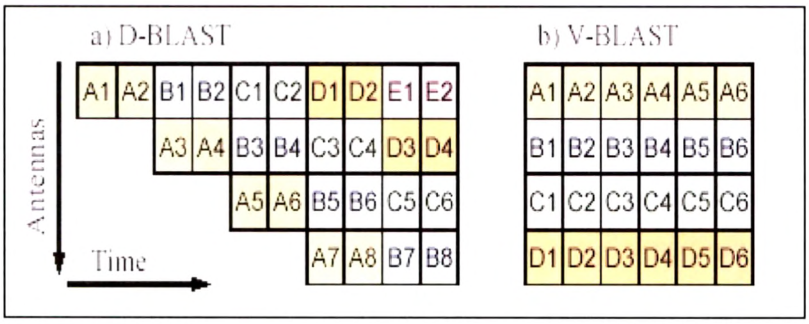

Figure: 5.4 Transmit coding scheme comparison between (a) D-BLAST and (b) V-BLAST

The figure shows that the essential difference between D-/V-BLAST is the vector encoding process. In D-BLAST system, redundancy between the sub-streams is introduced by using specialized inter-sub-stream block coding, and code blocks organized along diagonals in space-time leads higher spectral efficiencies. On the other hand, in V-BLAST system, de-multiplexing followed by independent bit-to-symbol mapping of each sub-stream, so no coding is required. These are the implemental advantages of V-BLAST.

The concept of LST architectures was first time introduced in the literature by Foschini and the described method is known as the diagonal Bell Labs Layered Space-Time (D-BLAST) architecture. A similar, and a slightly less complex architecture, called vertical BLAST (V-BLAST) was proposed later for practical implementation of systems targeting very high data rates. Both share the same basic structure with a limitation $M_R \geq M_T$. The difference lies in the way the user data stream is multiplexed to transmit antennas. Even though it has been proved that the D-BLAST architecture has greater capacity upper bound than the V-BLAST architecture, the V-BLAST type LST architectures are considered here due to the ease of implementation.

5.5 GENERAL ASSUMPTIONS FOR V-BLAST

- M antennas at both the transmitter and N at the receiver
- Transmitter has no knowledge on channel characteristics
- Rich Rayleigh fading scattering environment
- Narrow band (flat fading) channel
- Tx power constrained to P (single antenna power: P/M)
- Noise: complex AWGN with power N at each Rx antenna
- Average SNR equals >= P/N
- Normalized MxN MIMO channel impulse response matrix (H) With average gain of unity for each matrix element (each element is Rayleig fading)
- Long burst assumption (many symbols) with static channel During burst

5.6 V- BLAST ARCHITECTURE

It is basically an ordered SCR, which at every stage chooses to demodulate the layer with the highest, SNR. The V-BLAST high-level block diagram is illustrated in Figure: 5.5. The received vector with size $n_R \times 1$ is modeled by

$$r = Ha + n \qquad (1)$$

Where H represents the channel matrix with dimension $n_R \times n_T$, whose element, hi,j represents the complex fading coefficient for the path from transmit j to receive antenna i. These fading coefficients are modeled by an independent zero mean complex Gaussian random variable with variance 0.5 per dimension. a denotes the vector of

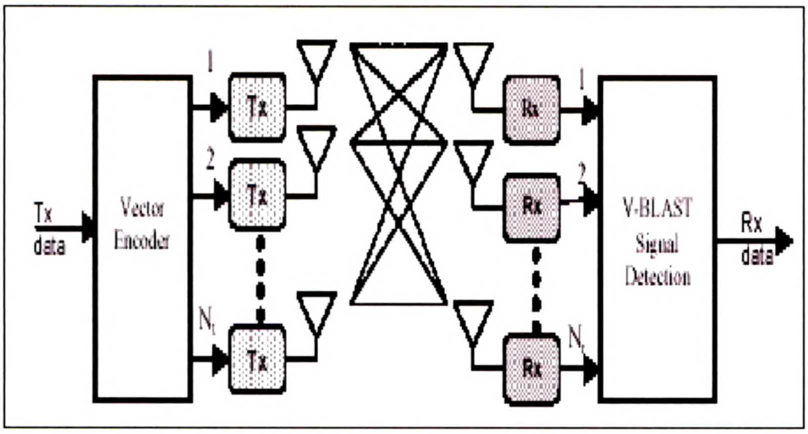

Figure: 5.5 V-BLAST system diagram

Transmitted symbols with dimension $n_R \times n_T$, n represents a complex vector of independent samples of AWGN over each received antenna with zero mean and variance σ_n^2. The nulling matrix G is described in Eq. (2) and (3) for the ZF and MMSE criteria with the form of pseudo-inverse of the channel matrix H.

$$G = (H^+ H)^{-1} H^+ \quad (2)$$

$$G = \left(H^+ H + \frac{\sigma_n^2}{\sigma_d^2}\right)^{-1} H^+ \quad (3)$$

Here σ_n^2/σ_d^2 is the inverse of signal-to-noise ratio at each receive antenna. H^+ represents the conjugate transpose matrix of channel matrix H.

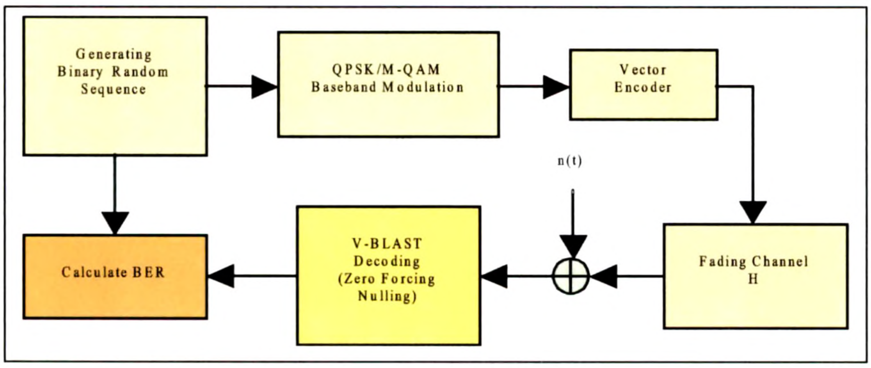

Figure 5.6 Block Diagram for V-BLAST

Figure: 5.6 describe a block diagram for V-BLAST scheme. To decode the transmitted symbols of the first layer, the receiver needs to estimate the channel matrix using pilots. The fading channel characteristics are assumed to be known perfectly at the receiver. The transmitter consists of a binary random generator, a QPSK/QAM base band modulator and a vector encoder. The binary random generator generates the transmitted bits. These bits are modulated in the QPSK/QAM modulator using the complex envelope form. It is assumed that each symbol has an ideal rectangular pulse shape and may be sampled with a single point per symbol. The vector encoder maps the symbols to each antenna. In the channel block, the transmitted symbols undergo Rayleigh fading and additive noise. Rayleigh fading channel coefficients are generated with two independent Gaussian random variables with unit variance. The phase delay is distributed uniformly between -π andπ. In addition, the channel is assumed to be quasi-stationary, that is, the channel coefficients do not vary during the given period time. The receiver is made up of decoding processing and an error rate calculation block. PIC does not need to consider the ordering issue since it cancels out all other paths interference in the same stage.

5.7 V-BLAST ALGORITHM

Theoretically, ML detection would be optimal for V-BLAST detection. However, it's too complex to implement. For example, in the case of 4 transmit antennas and 16-QAM modulation; a total of 16^4 = 65536 comparisons would have to be made for each transmitted symbol. Therefore, V-BLAST performs a non-linear detection that extracts data streams by a ZF (or MMSE) filter $w(k)$with ordered successive interference cancellation (OSIC). Co channel Interference traditional approaches require nulling vector being orthogonal to N-1 rows of $\boldsymbol{H}$ whereas OSIC requires nulling vector being orthogonal to N-i undetected components per iteration i, and *Zero -Forcing* (ZF) is the de-correlating receiver where $\boldsymbol{H}^{\dagger}$ is Moore-Penrose pseudo inverse of $\boldsymbol{H}$

$$w(k) = H^{\dagger} = (H^{*}H)^{-1} H^{*} \tag{4}$$

Detection order depends on which subset of (M-i) rows w_{ki} should be constrained by; since each component of the signal uses the same constellation, the component with the smallest w_{ki} will dominate the error performance. At each symbol time, it first detects the "strongest" layer (in the sense of SNR and **w** =

E_s/N_o at the receiver branch), then cancels the effect of this strongest layer from each of the received signals, and then proceeds to detect the "strongest" of the remaining layers, and so on. It is assumed that the receiver perfectly knows the channel matrix H, which can be accomplished by classical means of channel estimation, e.g. insertion of training bits in the transmitted TDMA frames.

Following notations are used in the algorithms:

⇒ The vector $a \in C^M$ is a column vector with complex elements a_i, $i = 1,2,\dots M$. Likewise $H \in C^{N\times M}$ is a matrix with complex elements H_{ij}, $I = 1,2,\dots N$, $j = 1,2,\dots M$

⇒ $\mathbf{H}_j$ denotes the j column of Matrix **H**.

⇒ $\mathbf{H}_{kj}$ denotes the matrix obtained by zeroing the $k_1, k_2,\dots, k_i$ column of **H**.

⇒ $\mathbf{G} = \mathbf{H}^+$ denotes the Moore-Penrose pseudo inverse of **H**.

⇒ $w_i^T = \mathbf{G}_i$ denotes the i row of the matrix **G**.

⇒ **H′** denotes the new matrix obtained by permuting the channel matrix **H** according to a given permutation.

⇒ $\mathbf{B'}_k = (\mathbf{H'}_M, \mathbf{H'}_{M+1},\dots\mathbf{H'}_{M-k+1})$ denotes the last k columns of **H′** after permuted according to an inversing ordering.

⇒ $\mathbf{y} = (y_1, y_2, \dots y_M)^T$ denotes the detected signal in receiver.

⇒ $\hat{\mathbf{a}} = (\hat{a}_1, \hat{a}_2, \dots \hat{a}_M)^T$ denotes the detected signal after slicing operation in receiver.

⇒ $(\bullet)^T$ denotes the transpose operation of a matrix.

⇒ $(\bullet)^H$ denotes the conj-transpose operation of a matrix.

⇒ $(\bullet)^\dagger$ denotes the Moore-Penrose pseudo inverse operation of a matrix.

⇒ $Q(\bullet)$ denotes slicing operation.

⇒ **Index** = $sort\downarrow(\bullet)$ denotes permuting a matrix according to the plus ordering of the norm of each column, that is, from large to small, where **index** = $(index_1, index_2, \dots, index_{total\_num})$ is the returned index of the permutation.

⇒ **Index** = $sort\uparrow(\bullet)$ denotes permuting a matrix according to the minus ordering of the norm of each row, that is, from small to large.

⇒ *Sort* ((•), index) denotes permuting a matrix (•) according to the given **index.**

A low-complexity sub-optimal algorithm for ZF V-BLAST detection consists of four recursive steps describe as follows:

1) Ordering: Determine the optimal detection order corresponds to choosing $\mathbf{w}_{ki}$ the row of $\mathbf{w}$ (k) with minimum Euclidian norm. **W** (k) is referred to as mulling matrix and $\mathbf{w}_{ki}$ as nulling vector.

2) Nulling: Use the nulling vector $\mathbf{w}_{ki}$ to null out all the "weaker" signals and obtain the "strongest" (high SNR) transmitted signal

$$y_{ki} = \mathbf{w}_{ki}^{T}\mathbf{r} \tag{5}$$

3) Slicing: The estimated value of the strongest transmit signal is detected by slicing to the nearest value in the signal constellation A.

$$\hat{a}_{ki} = \arg\{\min \left|\left|a - y_{ki}\right|\right|^2\}$$

4) Canceling: Since the strongest transmit signal has been detected (assume $\hat{a}_{ki}=a_{ki}$), its effect should be cancelled from the received signal vector to reduce the detection Complexity for remaining transmit.

$$\mathbf{r} = \mathbf{r} - \hat{a}_{ki}\mathbf{h}_{ki} \quad (\mathbf{h}_{ki} \text{ is the } k\text{-th column of } \mathbf{H})$$

$$\mathbf{H} = \mathbf{H} - \mathbf{h}_{ki} \quad (k\text{-th column of } \mathbf{H} \text{ is zeroed})$$

Iteration: $i = i + 1$, and return to step 1 (i = 1, ... M-1)

This algorithm implemented with a zero Forcing receiver. First, we let the ordered set $S= \{k_1,k_2,...k_{NT}\}$ be a detection order of sub-streams. According to the basic SIC algorithm, the ZF V-BLAST detection algorithm can be described as a recursive procedure, including determination of the optimal ordering.

- Initialization

1. $i \leftarrow 1$
2. $r_1 = r$
3. $G_1 = \mathrm{H}^{+}$
4. $K_1 = \arg\min_{j} \left\|(G_1)_j\right\|^2$

- Recursion

1. $w_{k1} = (G_i)_{ki}$
2. $y_{ki} = w_{ki}^T r_i$
3. $\hat{a}_{ki} = Q(y_{ki})$
4. $r_{i+1} = r_i - \hat{a}_{ki}(H)_{ki}$
5. $G_{i+1} = H_{ki}^{\pm}$
6. $K_{i+1} = \underset{j \notin \{k_1,\ldots,k_i\}}{\operatorname{argmin}} \left\| (G_{i+1})_j \right\|^2$
7. $i \leftarrow i+1$

Please note that in recursion step 3 (and 6) $\underset{j}{\operatorname{argmin}} \left\| (G_i)_j \right\|$ is used to pick the strongest symbol. This is the due to the reason that the row j of G, which has the minimum 2-norm, corresponds to the j-th column of **H**, which will have the maximum 2-norm.

The algorithm spends most of its time in steps (5) and (6) where the nulling vectors and optimal ordering are computed, and both of the steps involve the computation of matrix pseudo inverse. Numerically, the most stable way to compute the pseudo inverse is using the Singular Value Decomposition. We consider only multiplications and additions of complex numbers as an operation.

Finding the optimal decoding order (step 6) can use the results of step 5 and does not require computing the pseudo inverse or inverse again. Thus, the complexity of the nulling vector and optimal ordering computation grows as a fourth power of the number of antennas.

5.8 SUMMARY

In this chapter we briefly discuss V-BLAST algorithms which is used in detection users signal in MIMO based environment. We discuss every V-BLAST step used in the detection of signal.