2013 Third International Conference on Advanced Computing & Communication Technologies

MIMO wireless systems: V-BLAST architecture

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Abstract— In this work have a problem of effects of fading. In problem formulation, it is assumed that the capacity gain and link reliability of MIMO (Multi Input Multi Output) systems was maximized that channels between pairs of transmit and receive antennas are independent of each other.

The fading channel in wireless communications degrades the system Bit Error Rate (BER) performance significantly. MIMO channel, which employs multiple transmitters and/or multiple receivers, compensate the BER performance difference between fading channel and Additive White Gaussian Noise (AWGN) channel, because multiple replica of the information mitigates the randomness of fading channel. In this, the space diversity is studied and simulated. Space diversity includes two kinds of diversity: transmitter diversity and receiver diversity. Transmitter diversity means multiple transmitters are employed, which leads to Multiple Input Single Output (MISO) channel. Receiver diversity means multiple receivers are employed, which leads to Single Input Multiple Output (SIMO) channel. Employment of both multiple transmitters and receivers leads to Multiple Input Multiple Output (MIMO) channel. MIMO in conjunction with Space-Time Coding, which provides correlation on both temporal and spatial domain, is necessary for multiple transmitter system. We also describe a Space-Time architecture known as vertical BLAST (Bell Laboratories Layered Space-Time) or V-BLAST. The BER performance of these systems for different diversity are simulated and compared.

I. Introduction

1.1. MIMO wireless systems: - An overview

The limitations of the wireless system to provide a reliable wireless communication. The techniques that improve efficiency and overcome signal fading and interference have the great contribution to the growth of the wireless communication. MIMO systems can be defined simply as having multiple transmitting and receiving antennas, and one of their key features is the ability to turn multipath propagation, traditionally a pitfall in wireless transmission, into a benefit for the user. Independent channel fading caused by multipath between different transmit and receive antenna pairs provides a significant capacity gain over conventional single antenna systems. The capacity gain and link reliability of MIMO systems can be maximized under the assumption that channels between pairs of transmit and receive antennas are independent of each other. This independence between channels arises due to multipath between source and destination. Independence of channels also means that the receiver will have more than one independent copy of the transmitted signal.

There are, diversity and coding are two well known techniques for combating fading. In most scattering environments, antenna diversity is a practical, effective and, hence, a widely applied technique for reducing the effect of multipath fading. The classical approach is to use multiple antennas at the receiver and perform combining or selection and switching in order to improve the quality of the received signal. The major problem with using the receive diversity approach is the cost, size and power of the remote units. The use of multiple antennas and radio frequency (RF) chains makes the remote units larger and more expensive. As a result, diversity techniques have almost exclusively been applied to base stations to improve their reception quality. A base station often serves hundreds to thousands of remote units. It is therefore more economical to add equipment to base stations rather than the remote units. For this reason, transmit diversity schemes are very attractive. The basic idea of transmit diversity systems is to provide the receiver with multiple replicas of the same information bearing signal, where the replicas are affected by uncorrelated multipath fading. This phenomena known as "diversity" is exploited by space-time coding (STC) to provide reliable communication. These error-correcting codes, as the name suggests, use both spatial diversity (that is due to spacing between antennas) and temporal diversity (due to redundancy in time domain). It has been shown that codes can be designed to provide diversity up to $\mathbf{N_T}$x $\mathbf{N_R}$x, where N_T and N_R are the number of transmit and receive antennas, respectively. Diversity can be quantified by the slope of error versus signal to noise ratio graph.

1.2 Over view of paper

It deals with MIMO based space-time coding that provide reliable link. The simulation results allow us to evaluate performance of different space-time codlings.

It discussed space time coding, specifically space time block coding and evaluate performance of Alamouti scheme giving simulation results for different antenna configurations.

978-0-7695-4941-5/13 $26.00 © 2013 IEEE
DOI 10.1109/ACCT.2013.56

The next part of paper concentrates on a recent important extension of antenna diversity, and more specifically the Multiple-Input-Multiple-Output (MIMO) wireless systems specific implementation, V-BLAST. After studying and simulating, it investigated successive interference cancellation receiver known as Vertical Bell Laboratories Layered Space-Time Architecture (V-BLAS). V-BLAST gives better performance compared to linear receivers by detecting the best transmit antenna channel available and then successively canceling interference due to the detected signal. Again here, it include extensive MATLAB simulation results that give the performance of V-BLAST.

Finally, from the simulation, it conclude that MIMO systems will be a key technology for future wireless communication systems, leading to higher data rate and reliability.

II. Multiple Input Multiple Output wireless systems

MIMO systems can be defined simply as having multiple transmitting and receiving antennas. The ideas behind MIMO helped transformed the view that fading should be considered as an enemy. Let assume that the number of transmitting antennas is M, and the number of receiving antennas is N. First look at the capacity of different antenna systems in order to see the dramatic increases in capacity obtained by using MIMO systems.

2.1 Comparison with capacity of conventional multiple antenna systems

The Shannon capacity of different multiple antenna systems is presented. My expectation are approximate, but they give an intuition for the derived benefits in terms of channel capacity when using multiple antennas.

2.1.1 Single-Input, Single-Output (SISO)

This is the conventional system that is used everywhere. Assume that for a given channel, whose bandwidth is B, and a given transmitter power of P the signal at the receiver has an average signal-to-noise ratio of SNR_0. Then, an estimate for the Shannon limit on channel capacity, C, is

$$\mathbf{C \approx B.\ log_2(1 + SNR_0)}$$

2.1.2 Single-Input, Multiple-Output (SIMO)

For the SIMO system, have N antennas at the receiver. If the signals received on these antennas have on average the same amplitude, then they can be added coherently to produce an N2 increase in the signal power. On the other hand, there are N sets of noise that are added incoherently and result in an N-fold increase in the noise power. Hence, there is an overall increase in the SNR

$$\mathbf{SNR \approx N^2.(signal\ power)/N.\ (noise) = N\ .\ SNR_0}$$

Thus, the channel capacity for this channel is approximately equal to

$$\mathbf{C \approx B.log_2(1 + N\ .\ SNR_0)}$$

2.1.3 Multiple-Input, Single-Output (MISO)

In the MISO system, have M transmitting antennas. The total transmitted power is divided up into the M transmitter branches. Following a similar argument as for the SIMO case, if the signals add coherently at the receiving antenna we get approximately an M-fold increase in the SNR as compared to the SISO case. Since there is only one receiving antenna the noise level is the same as in the SISO case. Thus, the overall increase in SNR is approximately

$$\mathbf{SNR \approx M^2.(signal\ power)/M.\ (noise) = M\ .\ SNR_0}$$

Thus, the channel capacity for this channel is approximately equal to

$$\mathbf{C \approx B.log_2(1 + M\ .\ SNR_0)}$$

2.1.4 Multiple-Input, Multiple-Output (MIMO)-

[Same signal transmitted by each antenna]

The MIMO system can be viewed in effect as a combination of the MISO and SIMO channels. In this case, it is possible to get approximately an MN-fold increase in the SNR yielding a channel capacity equal to

$$\mathbf{C \approx B.log_2(1 + MN.SNR_0)}$$

Thus, the channel capacity for the MIMO system is higher than that of MISO or SIMO. However, it should note here that in all four cases the relationship between the channel capacity and the SNR is logarithmic. This means that trying to increase the data rate by simply transmitting more power is extremely costly.

2.1.5 Multiple-Input, Multiple-Output (MIMO)-

[Different signal transmitted by each antenna]

Assumption here is that N =>M, so that all the transmitted signals can be decoded at the receiver. The big idea in MIMO is that we can send different signals using the same bandwidth and still be able to decode correctly at the receiver. Thus, it is like creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to

$$\mathbf{C_{single} \approx B.log_2(1 + (N/M).SNR_0)}$$

But, since have M of these channels (M transmitting antennas), the total capacity of the system is

$$\mathbf{C_{single} \approx M.B.log_2(1 + (N/M).SNR_0)}$$

Thus, it get a linear increase in capacity with respect to the number of transmitting antennas. So, the key principle at work is that it is more beneficial to transmit data using many different low-powered channels than using one single, high-powered channel.

2.2. Basic system model

Consider a single-user communication system with M transmit-antennas and N receive-antennas fig. At the transmitter, the information symbol sequence s_k belonging to the constellation set A, is parsed into blocks S = $[s_1, . . . , s_K]$ of length K. Then, each information symbol block S is uniquely Space Time encoded into

an M x P code matrix C:

$$\mathbf{C} := \begin{bmatrix} \bar{c}_{11} & \bar{c}_{12} & \cdots & \bar{c}_{1P} \\ \vdots & \vdots & \cdots & \vdots \\ \bar{c}_{M1} & \bar{c}_{M2} & \cdots & \bar{c}_{MP} \end{bmatrix} \begin{array}{l} \rightarrow \text{time} \\ \\ \downarrow \text{space} \end{array} \quad \ldots.1$$

Where the (m,p)th element $c`_{mp}$ belongs to the constellation set A_c, whose average energy is normalized to 1. The P columns of C are generated in P successive time intervals with each one of the M entries in a given columns being forwarded to one of the M transmit-antennas simultaneously. We assume quasi-static flat fading channels and perfect timing and synchronization at the receiver, the received sample at the nth receive-antenna is given by M

$$\mathbf{y_{np} = A \sum_{m=1}^{m=M} h_{mn} A_{mp} c_{mp} + w_{np}} \quad \ldots\ldots\ldots\ldots2$$

where, h_{mn} denotes the channel from the m_{th} transmit-antenna to the nth receive-antenna; A_{mn} is the amplitude for $c`_{mp}$; and w_{mp} is a white complex Gaussian variable with variance No/2 per dimension.

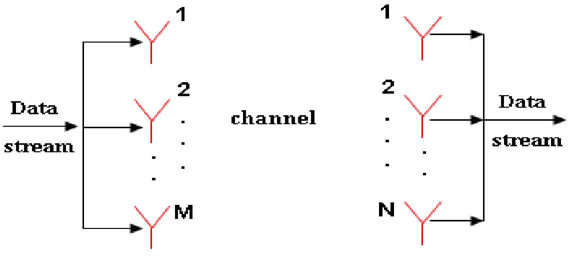

Figure 1. MIMO Antenna Configuration

2.2.1. Channel model

The most commonly used channel model for MIMO systems is independent quasi-static flat Rayleigh fading at all antenna elements. The simplicity of this channel model made the performance analysis of these schemes less complicated.

The basic assumptions behind the independent quasi-static flat Rayleigh fading channel are

1. Large numbers of scatterers are present in the wireless channel so that the signal at any receive antenna of the MIMO system is the sum of several multipath components. Here the distribution of the received signal at each antenna will be complex Gaussian. The amplitude of such complex Gaussian distributed signals is Rayleigh distributed.
2. The channel delay spread, which is a measure of the difference in the TOA of various multipath components at the receiver antenna, is less than the symbol rate. This assumption guarantees flat fading.
3. The channel characteristics remain constant at least for the period of transmission of an entire frame. This assumption accounts for quasi-static fading.
4. The antenna elements at the transmitter and the receiver of the MIMO system are placed far enough (spatially) such that the effect of the channel at a particular antenna element is different from the effect at all other antenna elements. This supports the assumption of independent or spatially uncorrelated fading.

Using all these assumptions, the independent quasi-static flat Rayleigh fading MIMO channel for a system with M transmit and N receive antennas can be represented as

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,n_T} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,n_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n_R,1} & h_{n_R,2} & \cdots & h_{n_R,n_T} \end{bmatrix}$$

where , h^{ij} is the path gain. This is the effect of the channel on signals transmitted from j^{th} transmit antenna and received at the i^{th} receive antenna. As H is a Rayleigh fading MIMO channel, the path gains are usually modeled as zero mean independent complex Gaussian random variables with variance 0.5 per real dimension.

III. V-BLAST Aarchitecture

Theoretical investigations have revealed that the multipath wireless channel is capable of enormous capacities, provided that the multipath scattering is sufficiently rich and is properly exploited through the use of an appropriate processing architecture. In this system space time codes are vertically layered, hence its name. V-BLAST employs zero-forcing equalizer for the detection. This equalizer main purpose is to cancel inter symbol interference. This type of detection is used over other types of detection due to its less complexity. V-BLAST is successful in achieving high spectral efficiencies upto 40 bits / hz.

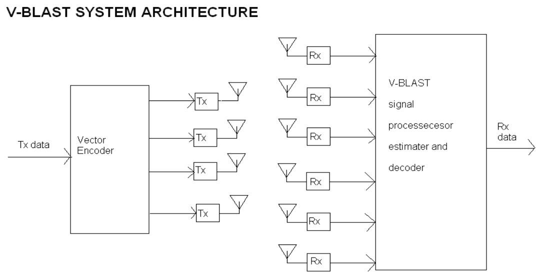

Figure 2 V-BLAST high-level system diagrams

3.1 System Description of V-BLAST

A high-level block diagram of a BLAST system is shown in Fig. 9. A single data stream is demultiplexed into M sub streams, and each sub stream is then encoded into symbols and fed to its respective transmitter. In this system there is M no. of transmitters. Transmitters 1 to M operate co-channel at symbol rate 1/ T symbols/sec, with synchronized symbol timing. Each transmitter is itself an ordinary QAM/QPSK transmitter. The collection of transmitters comprises, in effect, a vector-valued transmitter, where components of each transmitted M-vector are symbols drawn from a QAM/QPSK constellation. It assume that the same constellation is used for each sub-stream, and that transmissions are organized into bursts of L symbols. The power launched by each transmitter is proportional to 1/ M so that the total radiated power is constant and independent of M.

3.2 V-BLAST detection

In what follows, take a discrete-time baseband view of the detection process for a single transmitted vector symbol, assuming symbol-synchronous receiver sampling and ideal timing. Let $\mathbf{a} = (\mathbf{a}_1, \mathbf{a}_2, \ldots, \mathbf{a}_M)^T$ denote the vector of transmit symbols, then the corresponding received N vector is

$$\mathbf{r}_1 = \mathbf{Ha} + \mathbf{v} \quad \text{where v is a Gaussian distributed noise..}$$

One way to perform detection for this system is by using conventional adaptive antenna array (AAA) techniques, i.e. linear combinatorial nulling .Conceptually, each sub stream in turn is considered to be the desired signal, and the remainders are considered as "interferers". Nulling is performed by linearly weighting the received signals so as to satisfy some performance-related criterion, such as minimum mean-squared error (MMSE) or zero-forcing (ZF).For example, zero-forcing nulling can be performed by choosing weight vectors $\mathbf{w}_i$, i =1 , 2 , . . . , M,such that

$$\mathbf{w}_i^T * (\mathbf{H})_j = \alpha_{ij}$$

where (**H**) j is the j-th column of **H**, and α is the Kronecker delta. Thus, the decision statistic for the i–th sub stream is $\mathbf{y}_i = \mathbf{w}_i^T * \mathbf{r}1$.

Using symbol cancellation, interference from already-detected components of **a** is subtracted out from the received signal vector, resulting in a modified received vector in which, effectively, fewer interferers are present. This is somewhat analogous to decision feedback equalization. When symbol cancellation is used, the order in which the components of **a** are detected becomes important to the overall performance of the system.

3.3 Detection algorithm

```
Initialization:   $G = H^+$                              a
                  $i = 1$                                b
Recursion:        $k_i = \text{argmin} \|(G_i)_j\|^2$    c
                  $W_{ki} = (G_i)_{ki}$                  d
                  $Y_{ki} = W^T_{ki} * r_i$              e
                  $a_{ki} = Q(Y_{ki})$                   f
                  $r_{i+1} = r_i + (h)_{ki} * a_{ki}$    g
                  $G_{i+1} = H+/ki$                      h
                  $i = i+1$                              i
```

where $(\mathbf{G}_I)_J$ is the jth row of $\mathbf{G}_I$. Thus, eqn. c determines the elements of S_{OPT} the optimal ordering, discussed below. Eqn. d–f compute, respectively, the ZF-nulling vector, the decision statistic, and the estimated component of **a**. Eqn. g performs cancellation of the detected component from the received vector, and eqn. h computes the new pseudo inverse for the next iteration. Note that this new pseudo inverse is based on a 'deflated' version of **H**, in which columns k1, k2, ..., kI have been zeroed. This is because these columns correspond to components of **a** which have already been estimated and cancelled, and thus the system becomes equivalent to a 'deflated' version of Fig. 1 in which transmitters k_1, k_2, .., k_I have been removed, or equivalently, a system in which $a_{K1} = \ldots = a_{KI} = 0$.

IV. Simulation Results

4.1. Single Input Single Output- Rayleigh Fading & AWGN Channel Model

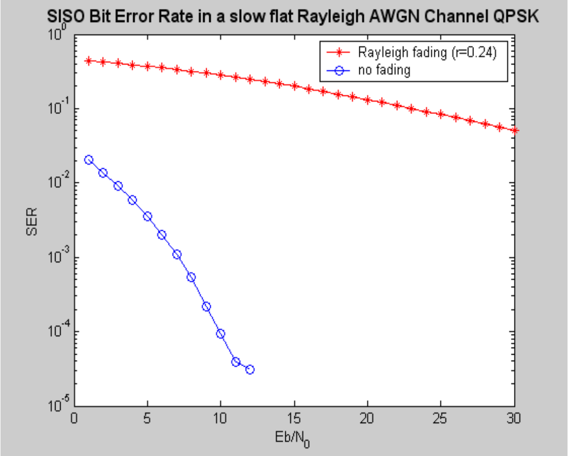

Fig 3 single Input Single Output - Rayleigh Fading & AWGN Channel Model with QPSK modulation

4.2 Multiple Input Multiple Outputs- Space time block coding

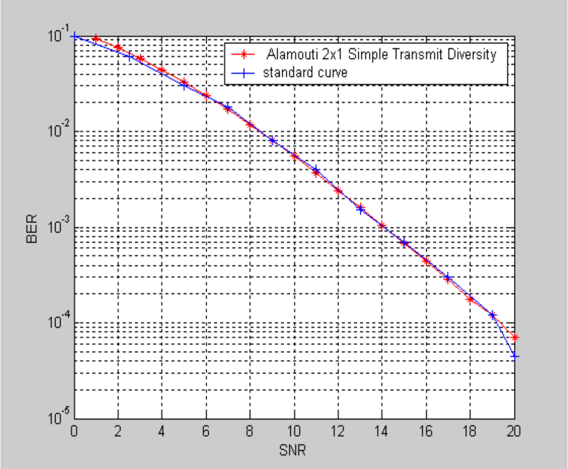

Fig 4 BER performance of Alamouti 2x1 scheme

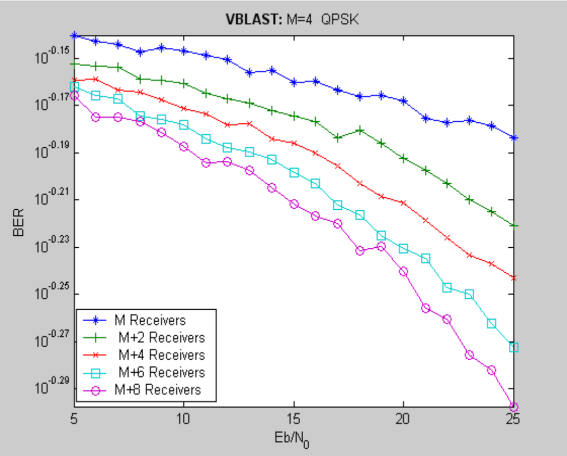

Fig 5 BER performance of V-BLAST with Tx=4, Rx=4,6,8,10,12 with QPSK modulation

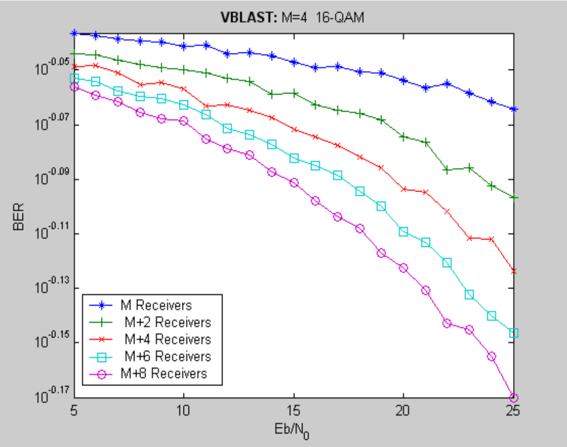

Fig 6 BER performance of V-BLAST with Tx=4, Rx=4,6,8,10,12 with 16-QAM modulation

V. Results

It performed extensive MATLAB simulations to see the performance of STBC and V-BLAST when QPSK/16-QAM is used. Their performance was evaluated in terms of bit error rate [BER] and signal to noise ratio [SNR]. The following results are evident form the simulation results:

- The simulation results conform to their corresponding closed form expressions. There is an excessive degradation in the BER performance due to fading.
- As the number of receiving antenna increases, performance of system improves rapidly.
- In Alamouti scheme as the no. of receiver increases, BER performance improves.

These results hint at the great capacity gains that can be achieved by using MIMO systems.

VI. Conclusions

In this, the MIMO channel is analyzed and simulated. The simulation results allow us to evaluate performance of VBLAST. From the simulation, it concluded that MIMO systems will be a key technology for future wireless communication systems, leading to higher data rate and reliability.

Some extended work in this area can be:

- The implementation of space-time block coding for no. of transmitters >4.
- Measurement of system capacity improvement.

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