

Capacity Of MIMO System With Optimally Ordered Successive Interference Cancellation

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ABSTRACT

In wireless communications, spectrum is a scarce resource and hence imposes a high cost on the high data rate transmission. It has been demonstrated that multiple antenna system provides very promising gain in capacity without increasing the use of spectrum, reliability, throughput, power consumption and less sensitivity to fading, hence leading to a breakthrough in the data rate of wireless communication systems. The vertical Bell labs layered space-time (V-BLAST) system is a multi-input multi-output (MIMO) system designed to achieve good multiplexing gain. In this paper, we study the V-BLAST MIMO system architecture, with optimally ordered successive interference cancellation (SIC) receiver in ZERO FORCING EQUALIZATION (ZF) and simulate this structure in Rayleigh fading channel. Based on bit error rate, we show the performance of this receiver, indicates that the ordered SIC detector most effectively balances the accuracy of symbol detection. SIC receiver based on ZF combined with symbol cancellation and optimal ordering improves the performance with lower complexity. Finally, the paper addresses the current questions regarding the integration of MIMO system in practical wireless systems and standards.

Keywords: MIMO, V-BLAST, ZF, OPTIMALLY ORDERED SIC.

1. INTRODUCTION

During the past few years, a new dimension to future wireless communication is opened, whose ultimate goal is to provide high data rates to universal personal and multimedia communication. To achieve such an objective, the next generation personal communication networks will need to be support a wide range of services which will include high quality voice, data, facsimile, still pictures and streaming video. These future services are likely to include applications which require high transmission rates of several Mega bits per seconds (Mbps). The data rate and spectrum efficiency of wireless mobile communications have been significantly improved over the last decade or so. Recently, the advanced systems such as 3GPP LTE and terrestrial digital TV broadcasting have been sophisticatedly developed using OFDM and CDMA technology. In general, most mobile communication systems transmit bits of information in the radio space to the receiver. The radio channels in mobile radio systems are usually multipath fading channels, which cause inter-symbol interference (ISI) in the received signal.

To remove ISI from the signal, there is a need of strong equalizer which requires knowledge on the channel impulse response (CIR)[1]. Equalization techniques which can combat and exploit the frequency selectivity of the wireless channel are of enormous importance in the design of high data rate wireless systems. On the other hand, the popularity of MIMO communication channels, rapidly time varying channels due to high mobility, multi-user channels, multi-carrier based systems and the availability of partial or no channel state information at the transmitter and/or receiver bring new problems which require novel equalization techniques. [2] Hence, there is a need for the development of novel practical, low complexity equalization techniques and for understanding their potentials and limitations when used in wireless communication systems characterized by very high data rates, high mobility and the presence of multiple antennas.[10]. The time span over which an equalizer converges is a function of the equalizer algorithm, the equalizer structure, and the time rate of change of the multipath radio channel.[3] In 1996, Raleigh and Cioffi and Foschini proposed new approaches for improving the

efficiency of MIMO systems, which inspired numerous further contributions [11]–[13] for two suitable architectures for its realisation known as Vertical Bell-Labs Layered Space-Time(VBLAST), and Diagonal Bell-Labs Layered Space- Time BLAST (D-BLAST) algorithm has been proposed by Foschini, which is capable of achieving a substantial part of the MIMO capacity. It is capable of achieving high spectral efficiency while being relatively simple to implement. This structure offers highly better error performance than other existence detection method and still has low complexity. The basic motive was to increase the data rate in a constrained spectrum. The promises of information theoretic MIMO analysis for the channel capacity were the main trigger for this enthusiasm and also ignited the study of related areas such as MIMO channel modelling , Space- Time signal processing, Space-Time coding, etc. The objective of such multi-channel dia-gonalization is to partition or distribute multi-user signals into disjoint space and resultant channel gains are maximized to optimize the overall system capacity under the constraint of a fixed transmit power . Also improve the quality (BER) or potential of achieving extraordinary data rates [2,7] by transferring the signals in time domain and space domain separately, without consuming more frequency resources , frequency diversity due to delay spread, higher spectral efficiency and without increasing the total transmission power or bandwidth [14]-[18] of the communication system.

2. MIMO SYSTEM

MIMO systems are an extension of smart antennas systems. Traditional smart antenna systems employ multiple antennas at the receiver, whereas in a general MIMO system multiple antennas are employed both at the transmitter and the receiver. The addition of multiple antennas at the transmitter combined with advanced signal processing algorithms at the transmitter and the receiver yields significant advantage over traditional smart antenna systems - both in terms of capacity and diversity advantage. A MIMO channel is a wireless link between M transmits and N receive antennas. It consists of MN elements that represent the MIMO channel coefficients. The multiple transmit and receive antennas could belong to a single user modem or it could be distributed among different users. The later configuration is called distributed MIMO and cooperative communications.

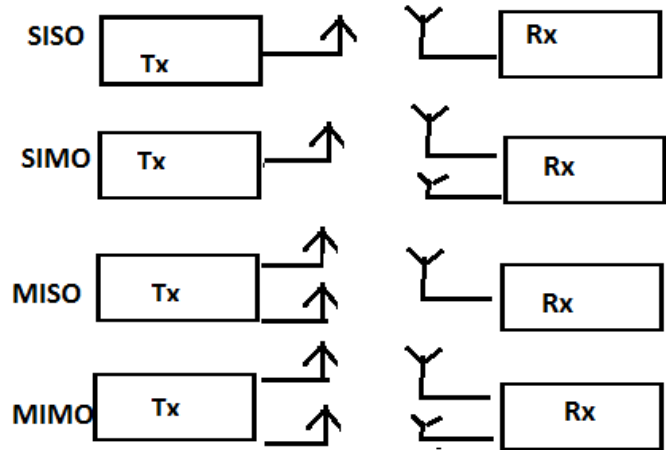


Figure1 Functions of MIMO

3.CHANNEL CAPACITY OF MIMO SYSTEM

To mitigate the problem of “impairment” in Multipath propagation, diversity techniques were developed. Antenna diversity is a widespread form of diversity. Information theory has shown that with multipath propagation, multiple antennas at both transmitter and receiver can establish essentially multiple parallel channels that operate simultaneously, on the same frequency band at the same total radiated power. Antenna correlation varies drastically as a function of the scattering environment, the distance between transmitter and receiver, the antenna configurations, and the Doppler spread. Recent research has shown that multipath propagation can in fact “contribute” to capacity. Channel capacity is the maximum information rate that can be transmitted and received with arbitrarily low probability of error at the receiver. A common representation of the channel capacity is within a unit bandwidth of the channel and can be expressed in bps/Hz. This representation is also known as spectral (bandwidth) efficiency. MIMO channel capacity depends heavily on the statistical properties and antenna element correlations of the channel. Representing the input and output of a memory less channel with the random variables X and Y respectively, the channel capacity is defined as the maximum of the mutual information between X and Y :

$$C = \max_{p(x)} I(X;Y) \dots\dots\dots(1)$$

A channel is said to memory less if the probability distribution of the output depends only on the input at that time and is conditionally independent of previous channel inputs or outputs. P(x) is the probability distribution function (pdf) of the input symbols X.

For the MIMO system, we have M antennas at transmitter and N antennas at receiver.

We analyze the capacity of MIMO channel in two cases:

3.1 Same signal transmitted by each antenna

In this case, the MIMO system can be view in effect as a combination of the SIMO and MISO channels:

$$\text{SNR} = \frac{N^2 M^2 \cdot \text{signal power}}{N \cdot M \cdot (\text{noise})} = M \cdot N \cdot \text{SNR}$$

So the capacity of MIMO channels in this case is:

$$C_{\text{MIMO}} = B \cdot \log_2 [1 + M \cdot N \cdot \text{SNR}] (\text{BPS/Hz}) \dots (2)$$

Thus, the channel capacity for the MIMO systems is higher than that of SIMO and MISO system. But in this case, the capacity is increasing inside the log function. This means that trying to increase the data rate by simply transmitting more power is extremely costly.

3.2 Different signal transmitted by each antenna

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 we are creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to:

$$C_{\text{MIMO}} = B \cdot \log_2 \left[1 + \frac{N}{M} \text{SNR} \right] (\text{BPS/Hz}) \dots (3)$$

But we have M_T of these channels, so the total capacity of the system is:

$$C_{\text{MIMO}} = M \cdot B \cdot \log_2 \left[1 + \frac{N}{M} \text{SNR} \right] (\text{BPS/Hz}) \dots (4)$$

Roughly, with $N \geq M$, the capacity of MIMO channels is equal to:

$$C_{\text{MIMO}} = M \cdot B \cdot \log_2 [1 + \text{SNR}] (\text{BPS/Hz}) \dots (5)$$

Thus, we can get linear increase in capacity of the MIMO channels with respect to the number of transmitting antennas. So, the key principle at work here is that it is more beneficial to transmit data using many different low-powered channels than using one single, high-powered channel. In the practical case of time-varying and randomly fading wireless channel, it shown that the capacity of $M \times N$ MIMO system for known Channel is

$$C_{\text{MIMO}} = B \cdot \log_2 \left| \det \left[I_N + \frac{\text{SNR}}{M} \mathbf{H}\mathbf{H}^* \right] \right| (\text{BPS/Hz}) \dots (6)$$

We can see that the advantage of MIMO systems is significant in capacity. As an example, for a system which $M = N$ and $\frac{\mathbf{H}\mathbf{H}^*}{M} \rightarrow I_N$

Therefore, the capacity increases linearly with the number of transmit antennas .

$$C_{\text{MIMO}} = M \cdot B \cdot \log_2 [1 + \text{SNR}] (\text{BPS/Hz}) \dots (7)$$

MIMO is best when SNR and angular spread are large but for Small angular spread or presence of a dominant path (e.g. LOS) reduce MIMO performance. In multipath using multiple antennas at both TX and RX multiplies capacity: C increases by K bps/HZ for every 3 dB SNR increase for MIMO and C increases by 1 bps/HZ for every 3dB of SNR increase for SIMO, MISO or SISO (at high SNR). Where K represents the number of nonzero (i.e., positive) Eigen values of $\mathbf{H}\mathbf{H}^*$.

4. V-BLAST ARCHITECTURE

One of the earliest communication systems that were proposed to take advantage of the promising capacity of MIMO channels is the BLAST architecture. It achieves high spectral efficiencies by spatially multiplexing coded or uncoded symbols over the MIMO fading channel. Symbols are transmitted through M antennas. Each receiver antenna receives a superposition of faded symbols. The ML decoder would select the set of symbols that are closest in Euclidean distance to the received N signals. However, it is hard to implement due to its exponential complexity. More practical decoding architectures were proposed in the literature.

4.1. V-BLAST Technique

A data stream is demultiplexed into M sub-streams termed layers. For V-BLAST at each transmission time, layers are arranged horizontally across space and time across the M transmit antennas and the cycling operation of D-VLAST is removed before transmission is shown in Fig.2. At the receiver, as mentioned previously, the received signals at each receive antenna is a superposition of M faded symbols plus additive white Gaussian noise (AWGN). Although the layers are arranged differently for the two BLAST systems across space and time, the detection process for both systems is performed vertically for each received vector. Without loss of generality, assume that the first symbol is to be detected. The detection process consists of two main operations:

I) *suppression of Interference (nulling)*: The suppression operation nulls out interference by projecting the received vector onto the null subspace (perpendicular subspace) of the subspace spanned by the interfering signals. After that, normal detection of the first symbol is performed.

II) *Interference cancellation (subtraction)*: The contribution of the detected symbol is subtracted from the received vector.

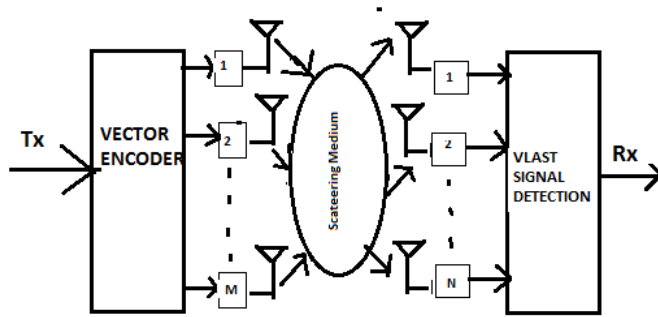


Figure 2: Block Diagram of V-BLAST Architecture.

5. PERFORMANCE ANALYSIS OF MIMO TECHNOLOGY USING V-BLAST

5.1 Zero Forcing Equalization using V-BLAST with Optimally ordered SIC:

In classical Successive Interference Cancellation(SIC), the receiver arbitrarily takes one of the estimated symbols, and subtract its effect from the received symbol y_1 and y_2 . However, we can have more intelligence in choosing whether we should subtract the effect of \hat{x}_1 first or \hat{x}_2 first. To make that decision, let us find out the transmit symbol (after multiplication with the channel) which came at higher power at the receiver. The received power at the both the antennas corresponding to the transmitted symbol \hat{x}_1 is, $P_{x_1} = |h_{1,1}|^2 + |h_{2,1}|^2$. The received power at the both the antennas corresponding to the transmitted symbol x_2 is, $P_{x_2} = |h_{1,2}|^2 + |h_{2,2}|^2$. If $P_{x_1} > P_{x_2}$ then the receiver decides to remove the effect of \hat{x}_1 from the received vector y_1 and y_2 and then re-estimate \hat{x}_2 . Else if $P_{x_1} < P_{x_2}$ the receiver decides to subtract effect of \hat{x}_2 from the received vector y_1 and y_2 , and then re-estimate \hat{x}_1 .

6. RESULT

Zero Forcing equalizer performs well only in theoretical assumptions that are when noise is zero. Its performance degrades in mobile fading environment. Zero forcing with Successive interference cancellation improves the performance of equalizer. This process improves the estimator performance on the next component compared to the previous one. Compared to Zero Forcing equalization alone case, addition of successive interference cancellation results in around 2.2dB of improvement for BER. Zero forcing with Successive interference cancellation with optimal ordering ensures that the reliability of the symbol which is decoded first is guaranteed to have a lower error probability than the other symbol. Compared to Zero Forcing

equalization with successive interference cancellation case, addition of optimal ordering results in around 2.0 db of improvement for BER.

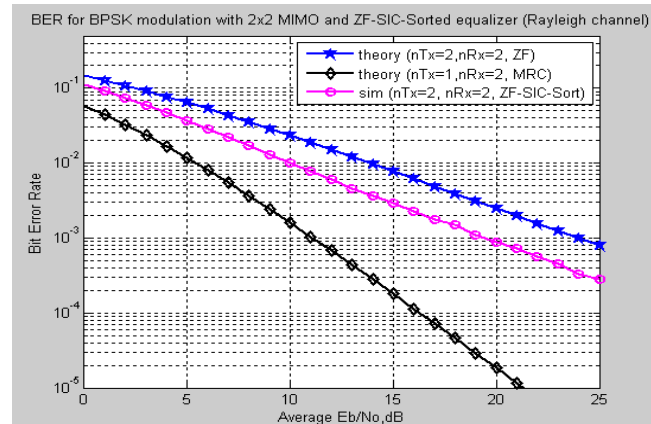


Figure 3: BER plot for MIMO equalized by ZF-SIC with optimal ordering

7. CONCLUSION

In this paper, we provide a general multiple antenna system, the general V- BLAST system and analyzed the performance of V-BLAST with ZF detector in Rayleigh fading channels. We first provide a comprehensive summary of capacity for single-user MIMO channels. This indicate that the capacity gain obtained from multiple antennas heavily depends on the amount of channel knowledge at either the receiver or transmitter, the channel SNR, and the correlation between the channel gains on each antenna element. We then focus attention on the capacity regions for MIMO broadcast and multiple accesses under known channels or unknown channels. In contrast to single-user MIMO channels, capacity results for these multiuser MIMO channels are quite difficult to obtain, even for constant channels. We summarize capacity results for the MIMO broadcast and multiple access channels for channels that are either constant or fading with perfect instantaneous knowledge of the antenna gains at both transmitter(s) and receiver(s). Doing successive interference cancellation with optimal ordering ensures that the reliability of the symbol which is decoded first is guaranteed to have a lower error probability than the other symbol. This results in lowering the chances of incorrect decisions resulting in erroneous interference cancellation. Hence gives lower error rate than simple successive interference cancellation. MIMO is an important key for enabling the wireless industry to deliver on the vast potential and promise of wireless broadband.

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