Performance Analysis of Alamouti Space-Time Block Codes in MIMO System for ZF, MMSE, SIC and ML Equalizations

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Abstract: This paper is mainly concerned with space-time block codes and their performances under severals detection techniques. The focus is on BER performances for wireless communication systems using space-time block codes. We first present the required background materials, discuss different implementations of space-time block codes using different numbers of transmit and receive antennas, and evaluate the performances of space-time block codes using binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK).Then, we simulate the performances of the different-different detection techniques schemes when employing different number of transmit and receive antennas and when employing different modulation methods. Finally, conclusions are drawn and further research areas are discussed.

Keywords: MIMO, LAN, STC, Wireless

1. Introduction:

In recent years, space-time coding techniques have received much interest. The concept of space-time coding has arisen from diversity techniques using smart antennas. By using data coding and signal processing at both sides of transmitter and receiver, space-time coding now is more effective than traditional diversity techniques. Mostly, traditional diversity techniques are receive diversities. The problem with receive diversity for mobile communications is that the receive antennas had to be sufficiently apart so that the signals received at each antenna undergoes independent fade. Because of that, it is very costly to have more than one antenna in the mobile unit because they meant to be small in size and light in weight. Therefore, the use of transmit diversity in base stations appears to be an attractive method, as more complex base stations can be allowed. Base stations have the advantage of using both transmit and receive diversities when they communicate with each other, the case of multiple input multiple output (MIMO) channels. Moreover, transmit diversity could also be used when base stations need to transmit information to the mobile units which forms the channel of multiple input single output (MISO). In this chapter, we present space-time block codes and evaluate their performance on MIMO fading channels. At first, the two-branch transmit diversity scheme referred to as Alamouti space-time code is introduced and its key features are explained. After that, space-time block codes with a large number of transmit and receive antennas based on orthogonal designs are presented. Space-time block code was designed to achieve the maximum diversity order for the given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm. In addition, space-time block coding provides full diversity advantage but is not optimized for coding gain. The coding and decoding algorithms for space-time block codes with both complex and real signal constellations are explained in details. The performance of space-time block codes on MIMO fading channels using different modulation schemes is evaluated by simulations.

Wireless communication industry has recently turned to a strategy called Multiple- Input Multiple-Output (MIMO). MIMO is the single most important wireless technology as of today. MIMO is a technology evolution where both ends of the wireless link are equipped with antenna array. This can improve the quality (bit-error rate) and the data rate (bits per sec). Therefore, a superior quality of service (QoS) can be achieved, which revenues the wireless provider. Many space-time block codes for different number of transmit/receive antennas have been developed in order to achieve maximum diversity. MIMO takes advantage of multipath interference effect to increase the user and data capacity; it converts it into a positive feature by using the multiple transmitters and/or receivers to increase throughput and reliability. Usually, multiplexing would cause interference, but MIMO uses the additional pathways to transmit more information and then combines the signal at the receiving end; thus provides robustness against multipath fading. MIMO systems can be designed with the receiver knowing the channel state (coherent case) or not (not-coherent case). For the purposes of this thesis the former case will be consider.

2. Related Work:

In 2002 Mr. David Gesbert, Helmut Bolcskei, Dhananjay A. Gore and Arogyaswami J. Paulraj Suggested, "Outdoor MIMO Wireless Channel: Models and Performance Prediction". They Proposed a new model for multiple-input–multiple-output (MIMO) outdoor wireless fading channels and their capacity performance. The proposed model is more general and realistic than the usual independent and identically distributed (i.i.d.) model, and allows us to investigate the behaviour of channel capacity as a function of the scattering radii at transmitter and receiver, distance between the transmit and receive arrays, and antenna beam widths and spacing. We show how MIMO capacity is governed by spatial fading correlation and the condition number of the channel matrix through specific sets of propagation parameters. The proposed model explains the existence of “pinhole” channels which exhibit low spatial fading correlation at both ends of the link but still have poor rank properties, and hence, low ergodic capacity. In fact, the model suggests the existence of a more general family of channels spanning continuously from full rank i.i.d. to low-rank pinhole cases. We suggest guidelines for predicting high rank (and hence, high ergodic capacity) in MIMO channels, and show that even at long ranges, high channel rank can easily be sustained under mild scattering conditions. Finally, we validate our results by simulations using ray tracing techniques. Connections with basic antenna theory are made [5].

In 2003 Mr. Macro Chiani, Moe Z. Win and Alberto Zanella Suggested, "On the Capacity of Spatially Correlated MIMO Rayleigh-Fading Channels". They proposed the capacity distribution of spatially correlated, multiple-input–multiple-output (MIMO) channels. In particular, we derive a concise closed-form expression for the characteristic function (c.f.) of MIMO system capacity with arbitrary correlation among the transmitting antennas or among the receiving antennas in frequency-flat Rayleigh-fading environments. Using the exact expression of the c.f., the probability density function (pdf) and the cumulative distribution function (CDF) can be easily obtained, thus enabling the exact evaluation of the outage and mean capacity of spatially correlated MIMO channels. Our results are valid for scenarios with the number of transmitting antennas greater than or equal to that of receiving antennas with arbitrary correlation among them. Moreover, the results are valid for an arbitrary number of transmitting and receiving antennas in uncorrelated MIMO channels. It is shown that the capacity loss is negligible even with a correlation coefficient between two adjacent antennas as large as 0.5 for exponential correlation model. Finally, we derive an exact expression for the mean value of the capacity for arbitrary correlation matrices [6].

In 2003 Mr. Naofal Al-dhahir Suggested, "A New High-Rate Differential Space-Time Block Coding Scheme". He Proposed a new high-rate differential space-time transmission scheme based on spatial multiplexing of Alamouti-encoded information streams is developed in this letter. At the receiver, joint space-time differential interference cancellation and decoding is performed, realizing diversity and rate gains, without requiring channel knowledge or bandwidth expansion. Our focus is on the case of two information streams with two transmit antennas per stream on flat-fading channels for simplicity. However, the development readily extends to more than two information streams, to more than two transmit antennas per stream, and to frequency-selective channels using previously published techniques [7].

In 2003 Mr. Suhas N. Diggavi, Naofal Al-Dhahir and A.R. Calderbank Suggested, "Algebraic Properties of Space-Time Block Codes in Intersymbol Interference Multiple-Access Channels". They Proposed the multiple-access channel where users employ space–time block codes (STBC). The problem is formulated in the context of an intersymbol interference (ISI) multiple-access channel which occurs for transmission over frequency- selective channels. The algebraic structure of the STBC is utilized to design joint interference suppression, equalization, and decoding schemes. Each of the K users transmits using 〖M 〗_t= 2 transmit antennas and a time-reversed STBC suitable for frequency- selective channels. We first show that a diversity order of 2M_t (v+1) is achievable at full transmission rate for each user, when we have M_r receive antennas, channel memory of v, and an optimal multiuser maximum-likelihood (ML) decoder is used. Due to the decoding complexity of the ML detector we study the algebraic structure of linear multiuser detectors which utilize the properties of the STBC. We do this both in the transform (D-domain) formulation and when we impose finite block-length constraints (matrix formulation). The receiver is designed to utilize the algebraic structure of the codes in order to preserve the block quaternionic structure of the equivalent channel for each user. We also explore some algebraic properties of D-domain quaternionic matrices and of quaternionic block circulant matrices that arise in this study [8].

In 2003 Mr. Harold Artes, Dominik Seethaler and Franz Hlawatsch Suggested, "Efficient Detection Algorithms For MIMO Channels: A Geometrical Approach to Approximate ML Detection". They Proposed It is well known that suboptimal detection schemes for multiple-input multiple-output (MIMO) spatial multiplexing systems (equalization-based schemes as well as nulling-and-cancelling schemes) are unable to exploit all of the available diversity, and thus, their performance is inferior to ML detection. Motivated by experimental evidence that this inferior performance is primarily caused by the inability of suboptimal schemes to deal with “bad” (i.e., poorly conditioned) channel realizations, we study the decision regions of suboptimal schemes for bad channels. Based on a simplified model for bad channels, we then develop two computationally efficient detection algorithms that are robust to bad channels. In particular, the novel sphere-projection algorithm (SPA) is a simple add-on to standard suboptimal detectors that is able to achieve near-ML performance and significantly increased diversity gains. The SPA’s computational complexity is comparable with that of nulling-and-cancelling detectors and only a fraction of that of the Fincke–Phost sphere-decoding algorithm for ML detection [9].

In 2004 Mr. Ben Lu, Guosen yue and Xiaodong Wang Suggested, "Performance Analysis and Design Optimization of LDPC-Coded MIMO OFDM Systems". They Proposed the performance analysis and design optimization of low-density parity check (LDPC) coded multiple-input multiple-output (MIMO) orthogonal frequency-division multiplexing (OFDM) systems for high data rate wireless transmission. The tools of density evolution with mixture Gaussian approximations are used to optimize irregular LDPC codes and to compute minimum operational signal-to-noise ratios (SNRs) for ergodic MIMO OFDM channels. In particular, the optimization is done for various MIMO OFDM system configurations, which include a different number of antennas, different channel models, and different demodulation schemes; the optimized performances compared with the corresponding channel capacity. It is shown that along with the optimized irregular LDPC codes, a turbo iterative receiver that consists of a soft maximum a posteriori (MAP) demodulator and a belief-propagation LDPC decoder can perform within 1 dB from the ergodic capacity of the MIMO OFDM systems under consideration. It is also shown that compared with the optimal MAP demodulator-based receivers, the receivers employing a low-complexity linear minimum mean-square-error soft-interference-cancellation (LMMSE-SIC) demodulator have a small performance loss (1dB) in spatially uncorrelated MIMO channels but suffer extra performance loss in MIMO channels with spatial correlation. Finally, from the LDPC profiles that already are optimized for ergodic channels, we heuristically construct small block-size irregular LDPC codes for outage MIMO OFDM channels; as shown from simulation results, the irregular LDPC codes constructed here are helpful in expediting the convergence of the iterative receivers [10].

3. Methodology:

Another fundamental element of signal processing is detection. Different detection methods with different performance and computational complexity requirements have been reported in the last decades. In this subsection, the fundamental criteria of detection methods and the detection algorithms I considered in the thesis are introduced.

3.1 Maximum Likelihood (ML) Detection

The ML detection algorithm obtains the symbol vector which maximizes the likelihood or log-likelihood function which outputs the most-likely transmitted symbol vector, and also it is equivalent to the solution of a minimum noise energy. As a result, if we know the received symbol vector ***r*** and we want to find the transmitted symbols ***s***, the MAP detection maximizes $p(s/r)$, while the ML detection maximizes $p(r/s)$. Consider the MIMO system derived in the previous section, if the channel matrix ***H*** is known at the receiver, the ML detection is expressed by

$$\hat{s}_{ML} = argmax\|r - H_s\|^2 \quad (1)$$

By searching the candidates symbol vector ***s***, the solution of the ML problem will be obtained. The ML detection method returns the most likely transmitted symbol vector from the receiver in a MIMO system which is an optimal solution with the lowest error rate in the symbol vector. However, the searching task with extremely high computational complexity is sometimes not practical for real MIMO wireless communication systems. In order to solve this problem, several techniques for finding a reduced set of possible solutions in the candidates matrix ***S*** are presented. One of these techniques is the sphere decoder. This sphere decoding method defines the lattice of potential solution and then points the most prominent symbol combination, after determining the point on the lattice the decoder searches the candidates vectors within a predefined-radius sphere so the combinations within the sphere will be tested. The sphere decoder can be seen as an ML decoder with reduced candidates and it is widely used in the practical MIMO networks.

3.2 Linear Detection

Compared to the ML detection and sphere decoder, the sub-optimal linear detection methods require lower computational complexity which have advantages in low battery and less memory length requirement, and are more feasible for practical MIMO systems. The BER performance of a linear detector is always inferior to that of the ML detection; however, the low computational complexity is a significant advantages of implementation a linear receiver offers in MIMO systems.

The most widely used linear detection algorithms are zero forcing (ZF) and minimum mean square error (MMSE) detection.

3.2.1 Zero Forcing(ZF) Detection

Consider an $N \times N$ MIMO system with a single user, The received symbol vector ***r*** in a MIMO system with sufficient statistics for detection is derived as

$$r = \sqrt{\frac{P_T}{N}} H_s + n \quad (2)$$

where ***H*** denotes the $M{\times}N$ channel information matrix, ***s*** denotes the $N{\times}1$ information symbol vector and ***n*** stands for the $M\ {\times}1$ AWGN vector with zero mean and variance σ_n^2 at the receiver. The power at the transmitter is denoted by P_T.

If we consider an $N\ {\times}N$ MIMO system described in (4.2), by using the ZF criterion we can obtain the linear ZF filter matrix which is given by

$$G_{ZF} = (H^H H)^{-1} H^H \quad (3)$$

It is assumed that the channel matrix ***H*** is invertible. After we obtain the ZF filter matrix we can rewrite the filtered received symbol vector as

$$\hat{s}_{ZF} = s + G_{ZF} n$$

(4)

As shown in (4.4), the detected symbol vector contains the original information symbol vector plus the filtered noise vector, and we can obtain the error covariance matrix of ZF detection shown as

$$\Theta_{ZF} = E[(\hat{s}_{ZF} - s)(\hat{s}_{ZF} - s)^H] = G_{ZF G_{ZF}^H} E[nn^H] = \sigma_n^2 G_{ZF} G_{ZF}^H \quad (5)$$

where σ_n^2 stands for the variance of the received noise. It is easy to conclude from (4.4) that the increase of the noise power is due to the ZF filter matrix. Thus, the BER performance of a ZF receiver will be affected and degraded significantly by the increase of energy of the ZF filter matrix.

3.2.2 Minimum Mean Square Error(MMSE) Detection

Another linear detection criterion, named MMSE, is designed in order to solve the problem of noise power increase. The noise vector is considered in the MMSE filter design so that the BER performance degradation is reduced. The linear MMSE cost function is given by

$$G_{MMSE} = argmin\, E[\|G_r - s\|^2] \quad (6)$$

The optimal solution of G_{MMSE}makes (4.6) equal to zero, so that we can obtain the linear MMSE filter matrix given by

$$G_{MMSE} = (H^H H + \sigma_n^2 I_N)^{-1} H^H \quad (7)$$

By comparing (4.3) with (4.7) it is shown that the difference in ZF and MMSE lies in the noise elements $\sigma_n^2 I_N$, and the linear MMSE detector is equivalent to the ZF detector if we extend the channel matrix $H\ To\ \overline{H}$ where

$$\overline{H} = \begin{bmatrix} H \\ \sigma_n^2 I_N \end{bmatrix} \quad (8)$$

The extended channel matrix $\overline{H}$ contains the information of the noise so that it determines the noise application which leads to an enhanced reliability and BER performance. Note that the MMSE filter is also equivalent to the ZF filter when the SNR tends to infinity.

3.3 Successive Interference Cancelation (SIC)

The successive interference cancelation (SIC) technique is a non-linear detection algorithm with sorted cancelation ordering, which achieves a better BER performance compared to the linear detection algorithms at the cost of extra computational complexity. Besides the basic SIC technique introduced in , several advanced SIC detection algorithm have been developed in the recent decade. In, adaptive and iterative multi-branch MMSE decision feedback detection algorithms for MIMO systems are designed which achieves performance close to the ML detector. A multiple feedback SIC strategy is proposed for the uplink of multiuser MIMO systems which introduces constellation points as the candidates to achieve enhanced interference cancelation and can be combined with multi-branch technique to achieve higher detection diversity in .

The SIC detection can be seen as a trade-off between the linear detection and the ML detection which achieves better BER performance compared to the linear detection and lower computational complexity compared to the ML or sphere detection. The key idea of the SIC detection is to introduce layer peeling, which is equivalent to removing the first detected symbol before the detection in the next layer peeling and repeating the process until the last symbol is detected in the existing linear detectors to achieve a BER performance improvement. Instead of detecting the symbol stream simultaneously, by utilization of layer peeling technique, the SIC algorithm detects symbol by symbol, and the interference from the previously detected symbol can be completely removed before the detection of the next one if the data symbols are correctly detected.

Consider the transmitted symbol stream $s = [s_1, s_2, \dots, s_N]$ in (4.2) which contains N symbols, and the receiver which uses an MMSE filter with SIC algorithm to detect the received symbols. The MMSE filter vector for the kth symbol in $\boldsymbol{s}$ is calculated by

$$w_k = \left(\bar{H}_k \bar{H}_k^H + \frac{\sigma_k^2}{\sigma_s^2} I\right)^{-1} h_k \qquad (9)$$

where $\bar{H}_k$ denotes the channel matrix contains the kth to the Nth column in H. In the SIC algorithm, the kth symbol s_k is detected by

$$\hat{s}_k = Q(w_k^H \bar{r}_k) \qquad (10)$$

where

$$\bar{r}_k = \begin{cases} r & , \; k = 1, \\ r - \sum_{i=1}^{k-1} h_i \hat{s}_i & , \; k \geq 2, \end{cases} \qquad (11)$$

By subtracting the detected symbol from the received symbol vector, the remaining symbols are detected without the interference from the detected symbols.

The order and priority of the symbol to be detected has been studied. Basically, the detected symbol is removed through a feedback loop that can be considered as interference to other symbols and improve the BER performance in orders. If s_n contains the highest energy in the received symbol vector and it is correctly detected and subtracted from the received symbol vector which gives $\hat{s}_n = s_n$ the rest of the symbols are released from the most significant interference. However, if $\hat{s}_n \neq s_n$ which means the incorrect detected symbol is removed from the received symbol vector and this leads to an error burst in the overall BER performance. In order to address this error propagation problem, the order of detection needs to be determined carefully which refers to the detection according to the reliability of the received symbol.

The SNR of a symbol can be used to decide the order of detection in a SIC based detector. The SNR of the nth received symbol is derived as

$$SNR_k = \frac{\sigma_s^2}{\sigma_n^2 \|w_k\|} \qquad (12)$$

where w_k stands for the filter vector which is calculated using (4.9). By choosing the layer with the highest SNR, the SIC based detector can determine the order of detection. After detection of the most reliable symbol, this strongest symbol and its corresponding channel vector will be removed from the received symbol vector and the channel matrix. After the first detection, the symbol with the second highest SNR will be detected and removed. The process will be repeated until all the symbols are detected.

The received signal-to-interference-plus-noise ratio (SINR) which considered the influence of the interference and the noise can be used to determine the order of a SIC based detector. The $SINR$ of the kth symbol is derived as

$$SINR_k = \frac{\sigma_s^2 |w_k h_k|^2}{\sigma_s^2 \sum_{n \neq k} |w_n h_n|^2 + \sigma_n^2 \|w_k\|}, \qquad (13)$$

where h_k denotes the kth column of the channel matrix H. The symbol with the highest received SINR will be considered to be the most reliable symbol and will be removed from the received symbol vector after being detected.

4. Result and Discussion:

In this section we compare simulated value of BER for QPSK modulation with 4Tx, 4Rx MIMO Alamouti STBC to theoretical values of BER of different-different SISO, SIMO, MISO and MIMO systems. We also calculated BER for 4Tx, 4Rx MIMO Alamouti STBC using different- different Detection Techniques and compare it to the theoretical values.

Figure 5.18 shows Simulation result of BER for QPSK modulation with 4Tx, 4Rx Alamouti STBC and ZF equalizer in Rayleigh channel. Simulated values of BER for 4Tx, 4Rx Alamouti STBC and ZF equalizer are calculated and then compare this value to the theoretical values of BER for 2Tx, 2Rx, theoretical values of BER for 4Tx, 3Rx MRC and theoretical values of BER for 4Tx, 4Rx Alamouti STBC i.e. shows in figure.

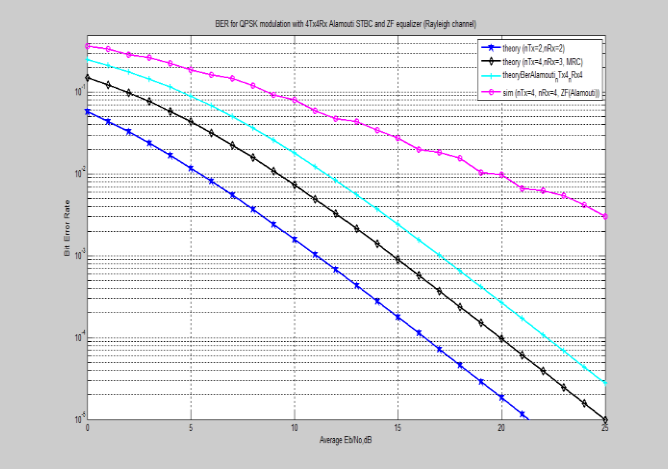

Fig. 1: Simulation of BER for QPSK modulation 4Tx, 4Rx Alamouti STBC and ZF Equalizer in Rayleigh channel

Fig 2 shows Simulation result of BER for QPSK modulation with 4Tx, 4Rx Alamouti STBC and ZF-SIC equalizer in Rayleigh channel. Simulated values of BER for 4Tx, 4Rx Alamouti STBC and ZF-SIC equalizer are calculated and then compare this value to the theoretical values of BER for 2Tx, 2Rx, theoretical values of BER for 4Tx, 3Rx MRC and theoretical values of BER for 4Tx, 4Rx Alamouti STBC i.e. shows in figure.

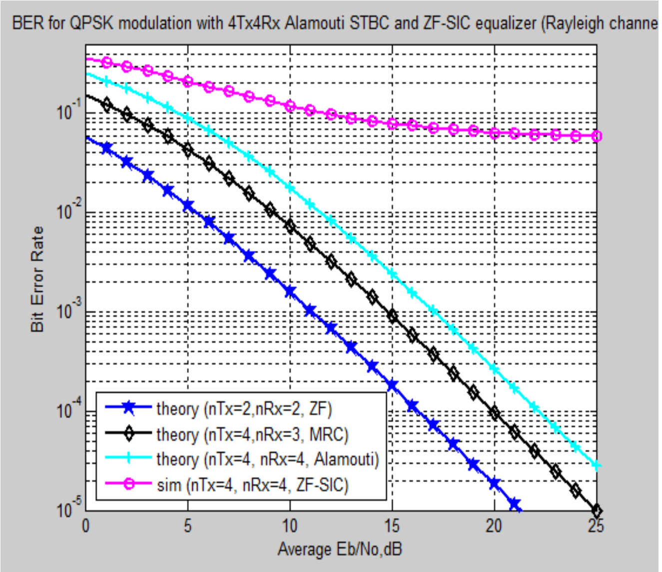

Fig. 2: Simulation of BER for QPSK modulation 4Tx, 4Rx Alamouti STBC and ZF-SIC Equalizer in Rayleigh channel

5. Conclusion:

Space-time coding finds its applications in cellular communications as well as in wireless local area networks. Some of the work on space-time coding focuses on explicitly improving the performance of existing systems (in terms of the probability of incorrectly detected data packets) by employing extra transmit antennas, and other research capitalizes on the promises of information theory to use the extra antennas for increasing the throughput. Speaking in very general terms, the design of space-time codes amounts to finding a constellation of matrices that satisfy certain optimality criteria. In particular, the construction of space-time coding schemes is to a large extent a trade-off between the three conflicting goals of maintaining a simple decoding, maximizing the error performance, and maximizing the information rate. Space-time block codes seem known by their coding and decoding simplicities and their promise to increase the information rate with a very good error performance. These space-time block codes always require a good knowledge of the channel parameters at the receiver. This has motivated a lot of researchers, including us to look for different schemes to estimate the channel parameters.

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