JOINT CHANNEL ESTIMATION AND DATA DETECTION FOR ALAMOUTI STBC WITH NO CSI

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Abstract—Wireless networks have quickly become part of everyday life. Wireless LANs, cell phone networks, and personal area networks are just a few examples of widely used wireless networks. However, wireless devices are range and data rate limited. The research community has spent a great deal of effort on finding ways to overcome these limitations. One method is to use Multiple-Input Multiple-Output (MIMO) links. The multiple antennas allow MIMO systems to perform precoding (multi-layer beamforming), diversity coding (space-time coding), and spatial multiplexing. Beamforming consists of transmitting the same signal with different gain and phase (called weights) over all transmit antennas such that the receiver signal is maximized. Diversity consists of transmitting a single space-time coded stream through all antennas. Spatial multiplexing increases network capacity by splitting a high rate signal into multiple lower rate streams and transmitting them through the different antennas. In spatial multiplexing, the receiver can successfully decode each stream given that the received signals have sufficient spatial signatures and that the receiver has enough antennas to separate the streams. The result of using these MIMO techniques is higher data rate or longer transmits range without requiring additional bandwidth or transmits power. This paper presents a detailed study of diversity coding for MIMO systems. Different space-time block coding (STBC) schemes including Alamouti STBC for 2 transmit antennas as well as Alamouti STBC for 4 and 6 receive antennas are explored. Finally, these STBC techniques are implemented in MATLAB and analyzed for performance according to their bit-error rates using BPSK, QPSK, 16-QAM, 64-QAM & M-PSK modulation schemes.

Index Terms—Alamouti, Space Time Block Coding (STBC), Beamforming, Multiple-Input Multiple-Output (MIMO), Channel State Information (CSI).

I. INTRODUCTION

IT has come a long way since Tesla, using Maxwell and Hertz's work on transmission of electromagnetic waves, demonstrated the transmission of information through a wireless medium using such waves [1]. The Second World War originates much interest in this area, giving way to many of the theoretical foundations of communications. Claude Shannon's work in 1948, which provided an upper bond to the error free data rate under the signal-to-noise ratio (SNR) constraint, appeared during that time. Wireless networks widely used today include: cellular networks, wireless mesh networks (WMNs), wireless Local Area Networks (WLANs), personal area networks (PANs), and wireless sensor networks (WSNs). The increasing demand for these networks has turned spectrum into a precious resource. For this reason, there is always a need for methods to pack more bits per Hz. A particular solution that has caught researcher's attention is the use of multiple antennas at both transmitter (TX) and receiver (RX). Such a system is called a Multiple-Input Multiple-Output (MIMO) system. Advantages of MIMO systems include [1], [3]:

- *Beamforming* - A transmitter receiver pair can perform beamforming and direct their main beams at each other, thereby increasing the receiver's received power and consequently the SNR.
- *Spatial diversity* - A signal can be coded through the transmit antennas, creating redundancy, which reduces the outage probability.
- *Spatial multiplexing* - A set of streams can be transmitted in parallel, each using a different transmit antenna element. The receiver can then perform the appropriate signal processing to separate the signals.

It is important to note that each antenna element on a MIMO system operates on the same frequency and therefore does not require extra bandwidth. Also, for fair comparison, the total power through all antenna elements is less than or equal to that of a single antenna system, i.e.

$$\sum_{k=1}^{N} p_k \leq P \tag{1}$$

Where N is the total number of antenna elements, p_k is the power allocated through the k^{th} antenna element, and P is the power if the system had a single antenna element [4]. Effectively, (1) ensures that a MIMO system consumes no extra power due to its multiple antenna elements.

As a consequence of their advantages, MIMO wireless systems have captured the attention of international standard organizations. The use of MIMO has been proposed multiple times for use in the high-speed packet data mode of third generation cellular systems (3G) [1], [3] as well as the fourth generation cellular systems (4G) [5], [6], [7]. MIMO has also influenced wireless local area networks (WLANs) as the IEEE 802.11n standard exploits the use of MIMO systems to acquire throughputs as high as 600*Mbps* [8], [9].

This paper provides a brief background on MIMO systems including the system model, capacity analysis, and channel models. Focus is then given to spatial diversity, specifically to space time block codes (STBC). We discuss Alamouti's STBC as well as other orthogonal STBC for 3 and 4 transmit antennas and finally show simulation results and analysis.

The paper is organized as follows. In Section II, important general background information on MIMO is provided. Next, different STBC techniques are explained in Section III. The simulation methodology is discussed in Section IV. Results and analysis are presented in Section V. Finally, Section VI concludes this paper.

II. BACKGROUND

Traditional wireless systems are affected by multipath propagation. In MIMO systems, however, this multipath effect is exploited to benefit the user. In fact, the separability of parallel streams depend on the presence of rich multipath. The reason for this effect will become apparent as the System Model is described in Section II-A below.

A. System Model

MIMO systems are composed of three main elements, namely the transmitter (TX), the channel (*H*), and the receiver (RX). In this paper, N_t is denoted as the number of antenna elements at the transmitter, and N_r is denoted as the number of elements at the receiver. Figure 1 depicts such MIMO system block diagram. It is worth noting that system is described in terms of the channel. For example, the Multiple-Inputs are located at the output of the TX (the input to the channel), and similarly, the Multiple-Outputs are located at the input of the RX (the output of the channel).

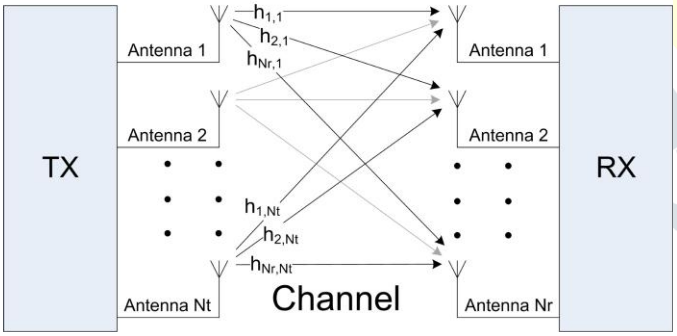

Fig. 1.Multiple-Input Multiple-Output system block diagram.

The channel with N_r outputs and N_t inputs is denoted as a $N_r \times N_t$ matrix:

$$\boldsymbol{H} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_t} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r,1} & h_{N_r,2} & \cdots & h_{N_r,N_t} \end{pmatrix} \qquad (2)$$

Where each entry $h_{i,j}$ denotes the attenuation and phase shift (transfer function) between the j^{th} transmitter and the i^{th} receiver. It is assumed throughout this paper that the MIMO channel behaves in a "quasi-static" fashion, i.e. the channel varies randomly between burst to burst, but fixed within a transmission. This is a reasonable and commonly used assumption as it represents an indoor channel where the time of change is constant and negligible compared to the time of a burst of data [10].

The MIMO signal model is described as

$$\vec{r} = \boldsymbol{H}\vec{s} + \vec{n} \qquad (3)$$

where ~*r* is the received vector of size $N_r \times 1$, *H* is the channel matrix of size $N_r \times N_t$, ~*s* is the transmitted vector of size $N_t \times 1$, and ~*n* is the noise vector of size $N_r \times 1$. Each noise element is typically modeled as independent identically distributed (i.i.d.) white Gaussian noise [1], [4] with variance $N_t/(2 \cdot SNR)$ [11]. An explanation for this model is as follows. The transmitted signals are mixed in the channel since they use the same carrier frequency. At the receiver side, the received signal is composed of a linear combination of each transmitted signal plus noise. The receiver can solve for the transmitted signals by treating (3) as a system of linear equations [3]. If the channel *H* is correlated, the system of linear equations will have more unknowns than equations. One reason correlation between signals can occur is due to the spacing between antennas. To prevent correlation due to the spacing, they are typically spaced at least $\lambda_c/2$, where λ_c is the wavelength of the carrier frequency [1]. The second reason correlation can occur is due to lack of multipath components. It is for this reason that rich multipath is desirable in MIMO systems. The multipath effect can be interpreted by each receive antenna being in a different channel. For this reason, the *rank* of a MIMO channel is defined as the number of independent equations offered. It is important to note that

$$rank(\boldsymbol{H}) \le min(N_r, N_t) \qquad (4)$$

and therefore the maximum number of streams that a MIMO system can support is upper-bounded by $min(N_r,N_t)$.

Since the performance of MIMO systems depends highly on the channel matrix, it is important to model the channel matrix realistically. The following section provides an overview of typical channel models used for computer simulations.

B. Channel Models

Channel models for MIMO systems can be either simple or very complex, depending on the environment modeled and the desired accuracy. There are two different techniques for modeling MIMO channels. One method is to calculate the MIMO channel matrix according to a physical representation of the environment. The channel matrix in such a physical model would depend on physical parameters such as the angle of arrival (AOA), angle of departure (AOD), and time of arrival (TOA) [12]. In [13], Molisch presents a physical MIMO model and provides typical physical parameters for both macro and microcell environments. As expected, these type of deterministic models are highly complex. Another technique to model MIMO channels, is to model the channel analytically. Such a model treats all channels between each transmit antenna to each receive antenna as SISO channels. This type of model assumes that the channels are independent and identically distributed (i.i.d.). However, depending on the environment modeled, this assumption is rarely true. The reason is that MIMO channels can experience spatial correlation between links [12]. It is possible to generate a MIMO channel with a specific correlation matrix. The channel correlation matrix is usually measured in the field and it is tied to the environment setup such as antenna element patters, spacing between antennas, and surrounding reflectors [12]. Since one of the main goals of this paper is to compare the performance of different STBC schemes, the channel model is chosen such that the correlation does not interfere with the performance of such. Next, two channel models are discussed for the case of non-line-of-sight (NLOS) and the case of line-of-sight (LOS) respectively.

1) NLOS Environment: A typical model used in research to model NLOS scenarios is the Rayleigh model. The Rayleigh model assumes NLOS, and is used for environments with a large number of scatterers. The Rayleigh model has independent identically distributed (i.i.d.) complex, zero mean, unit variance channel elements and is given by [10]:

$$h_{ij} = \frac{1}{\sqrt{2}}\left(\mathrm{Normal}(0,1) + \sqrt{-1}\cdot\mathrm{Normal}(0,1)\right) \quad (5)$$

This model results in an approximation which improves as the spacing between antennas become large compared to the wavelength λ.

2) LOS Model: The MIMO channel matrix for the LOS scenario is given by [12]:

$$\boldsymbol{H} = \sqrt{\frac{K}{1+K}}\boldsymbol{H}_{LOS} + \sqrt{\frac{1}{1+K}}\boldsymbol{H}_{NLOS} \quad (6)$$

Where;

$$K(dB) = 10\log_{10}\frac{P_{LOS}}{P_{NLOS}} \quad (7)$$

In (6), H_{LOS} is a rank-one matrix corresponding to the LOS component, and the H_{NLOS} corresponds to the NLOS components. In (7), P_{LOS} is the power due to the LOS component, and P_{NLOS} is due to the power of the NLOS component [12]. The H_{NLOS} component is usually modeled as (5) [3]. In SISO systems, the higher the K factor, the smaller the fade margin needed. For MIMO systems, the higher the K factor, the more dominant the rank-one H_{LOS} component will be, and consequently, the less dominant the H_{NLOS} component will be. However, for the scenario of rich multipath, simulations and measurements have shown that the LOS component rarely dominates [3].

III. SPACE-TIME BLOCK CODING

One of the methodologies for exploiting the capacity in MIMO system consists of using the additional diversity of MIMO systems, namely spatial diversity, to combat channel fading. This can be achieved by transmitting several replicas of the same information through each antenna. By doing this, the probability of loosing the information decreases exponentially [3]. The antennas in a MIMO system are used for supporting a transmission of a SISO system since the targeted rate of is that of a SISO system. The *diversity order* or *diversity gain* of a MIMO system is defined as the number of independent receptions of the same signal. A MIMO system with N_t transmit antennas and N_r receive antennas has potentially *full diversity* (i.e. maximum diversity) gain equal to N_tN_r.

The different replicas sent for exploiting diversity are generated by a space-time encoder which encodes a single stream through space using all the transmit antennas and through time by sending each symbol at different times. This form of coding is called Space-Time Coding (STC). Due to their decoding simplicity, the most dominant form of STCs are space-time block codes (STBC). In the next sections, we discuss different STBC techniques which will be then compared for performance in Section V.

A. Alamouti's STBC

In [14], Alamouti published his technique on transmit diversity. Historically, Alamouti's scheme was the first STBC [4]. The simplicity and structure of the Alamouti STBC has placed the scheme in both the W-CDMA and CDMA-2000 standards [3]. The Alamouti STBC scheme uses two transmit antennas and N_r receive antennas and can accomplish a maximum diversity order of $2N_r$ [14]. Moreover, the Alamouti scheme has *full rate* (i.e. a rate of 1) since it transmits 2 symbols every 2 time intervals. Next, a description of the Alamouti scheme is provided for both 1 and 2 receive antennas, followed by a general expression for the decoding mechanism for the case of N_r receive antennas.

1) Description: As mentioned earlier, Alamouti STBC uses two transmit antennas regardless of the number of receive antennas. The Alamouti scheme encoding operation is given by (8). In this paper, the rows of each coding scheme represents a different time instant, while the columns represent the transmitted symbol through each different antenna. In this case, the first and second row represent the transmission at the first and second time instant respectively. At a time t, the symbol s_1 and symbol s_2 are transmitted from antenna 1 and antenna 2 respectively. Assuming that each symbol has duration T, then at time $t + T$, the symbols $-s_2^*$ and s_1^*, where $(\cdot)^*$ denotes the complex conjugate, are transmitted from antenna 1 and antenna 2 respectively.

$$\mathcal{G}_2 = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix} \quad (8)$$

2) Case of 1 *Receive Antenna:* The reception and decoding of the signal depends on the number of receive antennas available. For the case of one receive antenna, the receive signals are [14]:

$$\begin{aligned} r_1^{(1)} &= r_1(t) = h_{1,1}s_1 + h_{1,2}s_2 + n_1^{(1)} \\ r_1^{(2)} &= r_1(t+T) = -h_{1,1}s_2^* + h_{1,2}s_1^* + n_1^{(2)} \end{aligned} \quad (9)$$

where r_1 is the received signal at antenna 1, $h_{i,j}$ is the channel transfer function from the j^{th} transmit antenna and the i^{th} receive antenna defined in Section II, n_1 is a complex random variable representing noise at antenna 1, and $x^{(\kappa)}$ denotes x at time instant κ (i.e. at time $t + (\kappa - 1)T$).

Before the received signals are sent to the decoder, they are combined as follows [14]:

$$\begin{aligned} \tilde{s}_1 &= h_{1,1}^* r_1^{(1)} + h_{1,2} r_1^{*(2)} \\ \tilde{s}_2 &= h_{1,2}^* r_1^{(1)} + h_{1,1} r_1^{*(2)} \end{aligned} \quad (10)$$

and substituting (9) in (10) yields:

$$\begin{aligned} \tilde{s}_1 &= (\alpha_{1,1}^2 + \alpha_{1,2}^2)s_1 + h_{1,1}^* n_1^{(1)} + h_{1,2} n_1^{*(2)} \\ \tilde{s}_2 &= (\alpha_{1,1}^2 + \alpha_{1,2}^2)s_2 - h_{1,1} n_1^{*(2)} + h_{1,2}^* n_1^{(1)} \end{aligned} \quad (11)$$

where $\alpha_{i,j}^2$ is the squared magnitude of the channel transfer function $h_{i,j}$.The calculated $\tilde{s}_1$ and $\tilde{s}_2$ are then sent to a Maximum Likelihood (ML) decoder to estimate the transmitted symbols s_1 and s_2 respectively [14].

3) Case of 2 Receive Antennas: For the case of two receive antennas, the received symbols are [14]:

$$\begin{aligned} r_1^{(1)} &= h_{1,1}s_1 + h_{1,2}s_2 + n_1^{(1)} \\ r_1^{(2)} &= -h_{1,1}s_2^* + h_{1,2}s_1^* + n_1^{(2)} \\ r_2^{(1)} &= h_{2,1}s_1 + h_{2,2}s_2 + n_2^{(1)} \\ r_2^{(2)} &= -h_{2,1}s_2^* + h_{2,2}s_1^* + n_2^{(2)} \end{aligned} \quad (12)$$

and the combined signals are [14]:

$$\begin{aligned} \tilde{s}_1 &= h_{1,1}^* r_1^{(1)} + h_{1,2} r_1^{*(2)} + h_{2,1}^* r_2^{(1)} + h_{2,2} r_2^{*(2)} \\ \tilde{s}_2 &= h_{1,2}^* r_1^{(1)} + h_{1,1} r_1^{*(2)} + h_{2,2}^* r_2^{(1)} + h_{1,1} r_2^{*(2)} \end{aligned} \quad (13)$$

Which, after substituting (12) becomes:

$$\begin{aligned} \tilde{s}_1 &= (\alpha_{1,1}^2 + \alpha_{1,2}^2 + \alpha_{2,1}^2 + \alpha_{2,2}^2)s_1 \\ &\quad + h_{1,1}^* n_1^{(1)} + h_{1,2} n_1^{*(2)} + h_{2,1}^* n_2^{(1)} + h_{2,2} n_2^{*(2)} \\ \tilde{s}_2 &= (\alpha_{1,1}^2 + \alpha_{1,2}^2 + \alpha_{2,1}^2 + \alpha_{2,2}^2)s_2 \\ &\quad - h_{1,1} n_1^{*(2)} + h_{1,2}^* n_1^{(1)} - h_{2,1} n_2^{*(2)} + h_{2,2}^* n_2^{(1)} \end{aligned} \quad (14)$$

4) Decoding decision statistic for N_r receive antennas: The ML decoder decision statistic decodes in favor of s_1 and s_2 over all possible values of s_1 and s_2 such that (15) and (16) are minimized where ψ is given by (17) for $N_t = 2$ [15], [11].

$$\left| \left[\sum_{i=1}^{N_r} (r_i^{(1)} h_{i,1}^* + r_i^{*(2)} h_{i,2}) \right] - s_1 \right|^2 + \psi |s_1|^2 \quad (15)$$

$$\left| \left[\sum_{i=1}^{N_r} (r_i^{(1)} h_{i,2}^* - r_i^{*(2)} h_{i,1}) \right] - s_2 \right|^2 + \psi |s_2|^2 \quad (16)$$

$$\psi = \left(-1 + \sum_{i=1}^{N_r} \sum_{j=1}^{N_t} |h_{i,j}|^2 \right) \quad (17)$$

Alamouti STBC does not require CSI at the transmitter. Also, the Alamouti STBC can be used with 2 transmit antennas and 1 receive antenna while accomplishing the full diversity of 2. This is an important characteristic of Alamouti STBC as it reduces the effect of fading at mobile stations while only requiring extra antenna elements at the base station, where it is more economical than having multiple antennas at the receivers [14]. However, if having more antennas at the receivers is not a problem, this scheme can be used with 2 transmit antennas and N_r receive antennas while accomplishing a $2N_r$ full diversity. The case space time block codes for $N_t > 2$ is discussed in the following section.

IV. PROPOSED METHODOLOGY

1. Joint channel estimation and data detection for Alamouti STBC with no channel state information

The decoding of space-time codes requires the knowledge of channel state information at the receiver, which is usually difficult to obtain. All space-time schemes assume ideal channel state information. However, channel parameters are normally not known in practice due to changing environments and thus need to be estimated.

There is a substantial literature addressing the channel estimation issue for MIMO systems. There are several coherent STC schemes that do require channel information at the receiver, ranging from standard training based techniques that relay on pilot symbols in the data stream to blind and semi-blind estimations. In semi-blind the observations corresponding to data and pilot are used jointly. Other non-coherent STC schemes do not require the channel information at the receiver. These are called differential STC schemes; they suffer a significant performance penalty from coherent techniques. The non-coherent techniques are more suitable for rapidly-fading channels that experience significant variation within the transmission block. For quasi-static or slow-varying fading channels, training-based channel estimation at the receiver is very common in practice.

A channel estimator extracts from the received signal an approximation to the fade coefficients during each data frame. This can be done using training or pilot symbols or sequences to estimate the channels from each of the transmit antennas to each receive antenna. The advantage of pilot symbol insertion is that it neither requires a complex signal process nor does it increase the peak factor of the modulated carrier. One method of MIMO channel estimation is to turn off all transmit antennas apart from antenna i at some time instant and to send a pilot signal using antenna i . The fade coefficients h ij are then estimated for all j. This procedure is repeated for all i until all the coefficients are estimated. The general system including channel estimation using pilot symbols is shown in Figure 2.

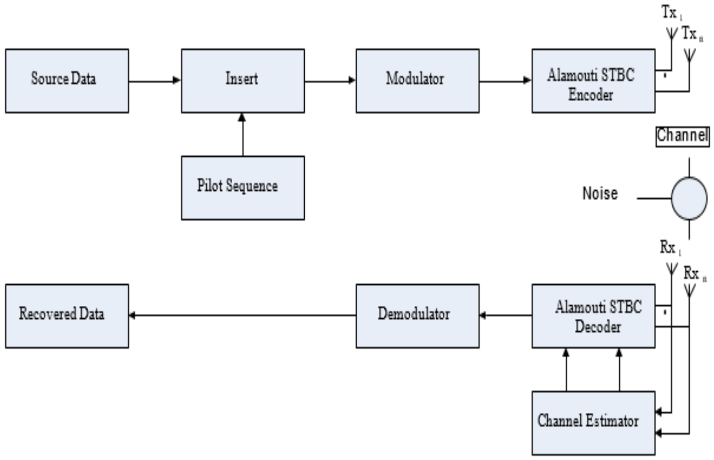

Figure 2: System model for channel estimation using pilot symbols.

2. Joint detection with no CSI and separate channel estimation for Alamouti STBC using real signal constellations

Decoding of space-time codes requires the knowledge of channel state information at the receiver, which is usually difficult to obtain. Most Alamouti STBC schemes assumed ideal channel state information. However, channel parameters are normally not known in practice due to changing environments and thus need to be estimated.

Channel estimation for space-time coded wireless communications has thus been widely studied. A channel estimator extracts the fade coefficients from the received signal approximations during each data frame. This can be done using training or pilot symbols or sequences to estimate the channel for each of the transmit antennas to each receive antenna.

The following components were modeled, through the simulations:

1. Complex information symbols signals
2. Flat-fading channels (Rayleigh fading model)
3. Additive White Gaussian Noise
4. Delay spread
5. Fourier transforms and inverse Fourier transforms
6. Cyclic prefix (CP)
7. Signal reversal

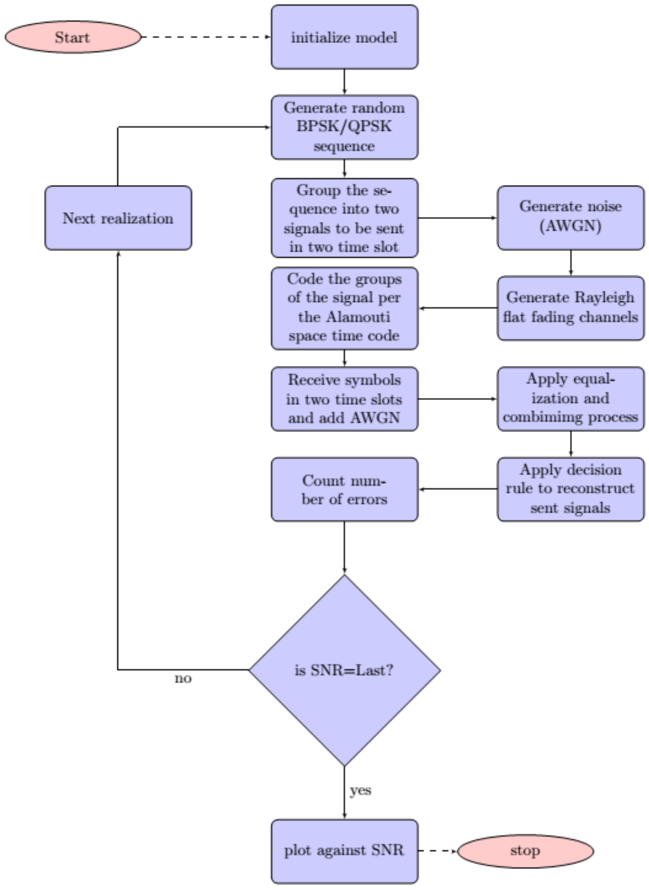

Figure 3: Proposed Algorithm for Implementation of Joint Detection with No CSI and Separate Channel Estimation for Alamouti STBC

V. SIMULATIONS

The performance of space-time block codes depends on the type of modulation and the number of transmit and receive antennas used. Complex modulations give better bit-error-rate performance than real modulations and it is especially true when the number of transmit antennas is larger than two. As an example, if space-time block codes with four transmit antennas and complex modulation scheme are used, then a four by eight (rate of 1/2) transmission matrix will be used. This would give a better performance than the same space time block code with real modulation of rate of one. However, space-time block code with real modulation would have better bandwidth efficiency performance than complex modulation. This is because space-time block codes with real modulation require transmitting less data than space-time block codes with complex modulation. On the other hand, space time block codes with larger number of transmit antennas always give better performance than space-time block codes with lower number of transmit antennas. This is true because lager number of transmit antennas means larger transmission matrices which means transmitting more data. This would give the receiver the ability to recover the transmitted data. Moreover, with larger number of receive antennas, the same transmitted data would be received by more than one receive antenna. This is an advantage because if one receive antenna did not recover the transmitted data correctly, the second receive antenna could. The chance that at least one out of two receive antennas would receive the transmitted data uncorrupted is always higher than if there is only one receive antenna.

Many simulations have been done on the performance of different space-time block codes using different types of modulation schemes and different numbers of transmit and receive antennas. In our simulation on the different implementations of space-time block codes, the channel coefficients are always assumed flat Rayleigh.

VI. RESULTS AND ANALYSIS

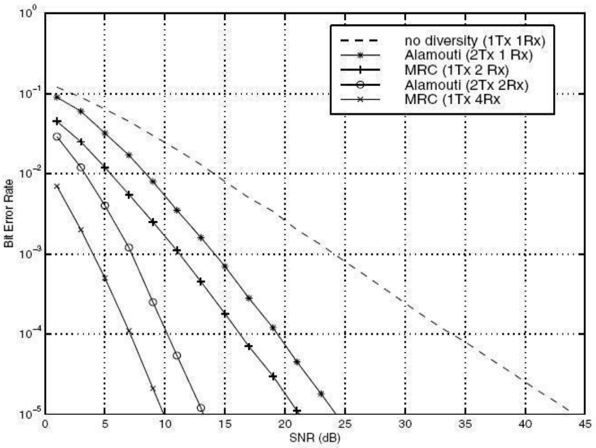

Figure 4: The performance of Alamouti scheme using BPSK modulation

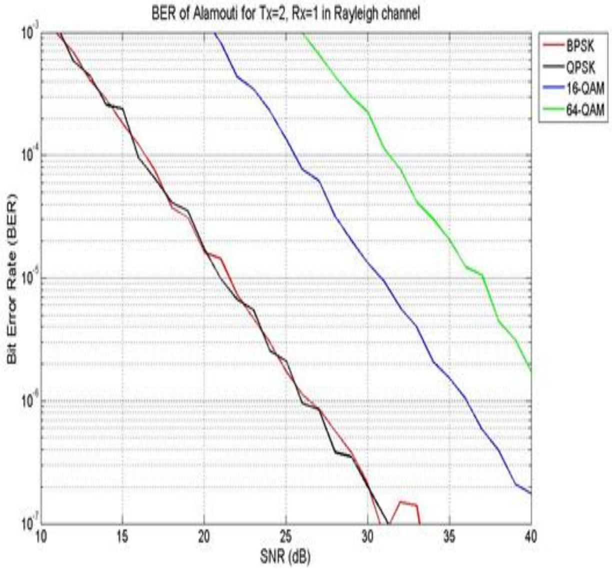

Figure 5: The performance of Alamouti scheme for 2x1

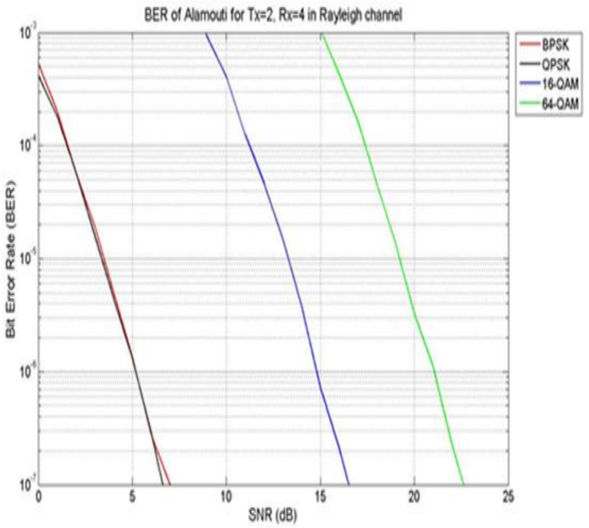

Figure 6: The performance of Alamouti scheme for 2x4

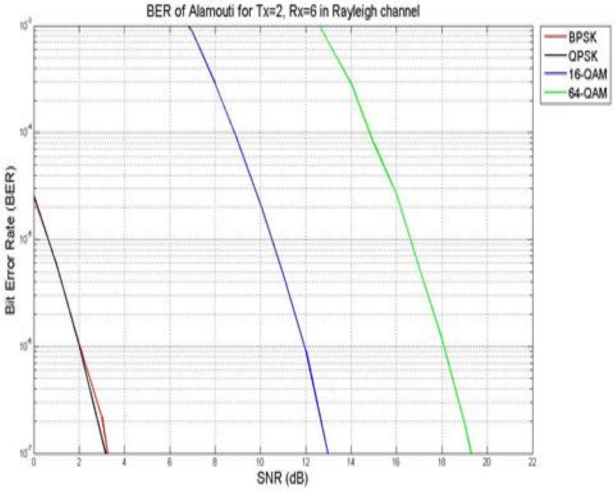

Figure 7: The performance of Alamouti scheme for 2x6

The bit-error-rate (BER) verses signal-to-noise-ratio (Eb/No (dB)) performance for Alamouti transmit diversity scheme on slow fading channels is evaluated by simulation [10]. In the simulation, it is assumed that the receiver has the perfect knowledge of the channel coefficient. It is also assumed that the fading is mutually independent from each transmit antenna to each receive antenna and the total transmit power is the same for all cases.

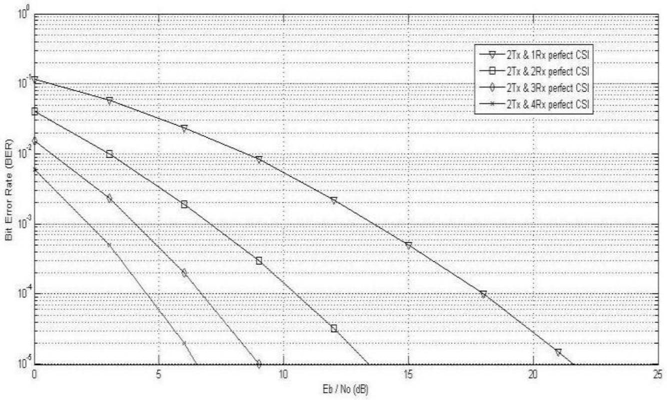

Figure 8: The performance of Alamouti scheme for two transmit and M receive antennas using BPSK modulation

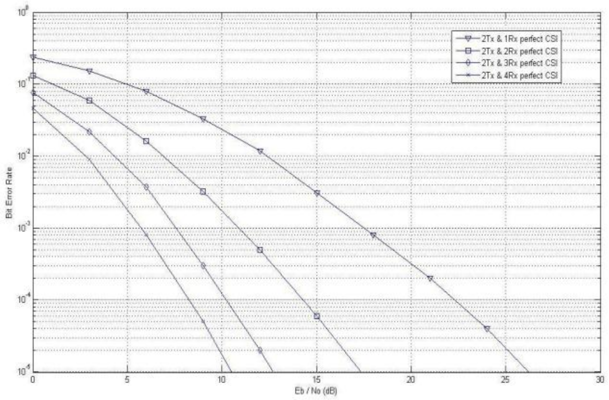

Figure 9: The performance of Alamouti scheme for two transmit and M receive antennas using QPSK modulation

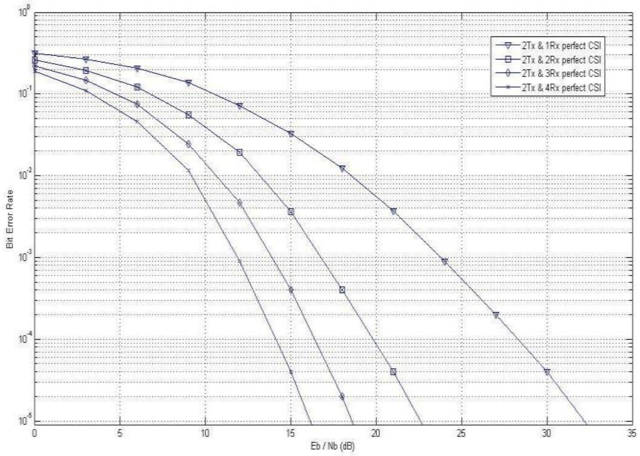

Figure 10: The performance of Alamouti scheme for two transmit and M receive antennas using 16-QAM modulation

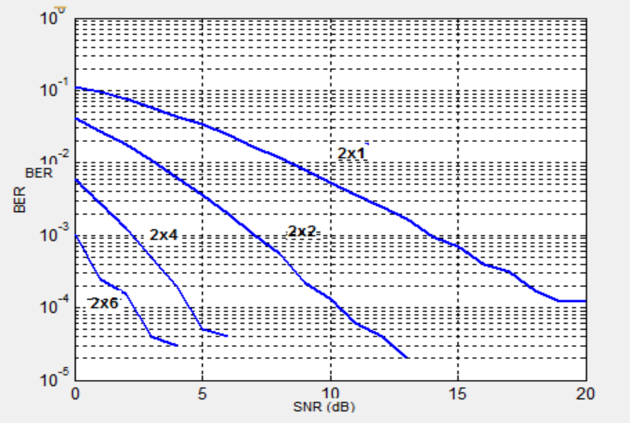

Figure 11: Proposed Alamouti STBC scheme with two transmit and M receive antennas using M-PSK modulation

Table 1 summarizes the bit-error-rate performance of Alamouti space-time block codes using BPSK, QPSK, 16-QAM & M-PSK modulation.

Modulation Scheme	Number of Tx : Rx	SNR (dB) for BER 10^{-2}	SNR (dB) for BER 10^{-3}	SNR (dB) for BER 10^{-4}
BPSK	2:1	8-9	13-14	18-19
	2:2	3-4	7	11-12
	2:4	1-2	3-4	5-6
QPSK	2:1	11-12	16-17	22-23
	2:2	6-7	11-12	14
	2:4	3-4	6	8-9
16-QAM	2:1	17-18	23-24	27-28
	2:2	13-14	16-17	19
	2:4	8-9	12-13	14
M-PSK	2:1	7-8	12-13	17-18
	2:2	2-3	6-7	10-11
	2:4	1-2	2-3	4-5

VII. CONCLUSION

From the table above, it is very clear that the best bit-error-rate performance was given by Alamouti space-time block codes using BPSK, QPSK, and 16-QAM. The performance of space-time block codes with BPSK modulation is better than the performance of Alamouti space-time block codes with QPSK modulation by approximately 4 dB. The performance of Alamouti space-time block codes with QPSK modulation is better than the performance of Alamouti space-time block codes with 16QAM modulation by approximately 5~6 dB. The BER performance of Alamouti space-time block codes that employs 16-QAM modulation method is worse than the BER performance of Alamouti space-time block codes that employs QPSK modulation method. This worse in performance is due the number of bit 16-QAM modulation method takes when compared with the number of bits QPSK modulation method take. This is also true when the performance of space-time block codes that employs QPSK modulation method is compared with the performance of space-time block codes that employs BPSK modulation method. In all of the modulation techniques M-PSK modulation technique performs best in all cases, as observed from table

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