Space Time Coding

I.Introduction

Efficient modulation and coding schemes have been developed as a result of the requirement to enable dependable high data rate communication over the wireless channel. Time-varying problems with the wireless channel include multi-path fading, interference, and noise. Diversity in terms of time, frequency, area, polarization, and angle is a useful strategy for preventing wireless channel fading. Link dependability is enhanced as a result. The drawback is that band-width efficiency is lost as a result of time and frequency variety. However, spatial diversity minimizes fading without compromising the valuable bandwidth resource by using many antennas at the transmitter and/or at the reception. Therefore, this idea is becoming more and more well-liked.

Receive diversity strategies have already been utilized to increase uplink performance. These techniques involve using many receiver antennas in conjunction with appropriate combining. However, due of the portable/mobile terminal's size and power constraints, it is challenging to establish receive diversity in the downlink. This has led to the adoption of transmit diversity methods, in which the downlink broadcast from the base station to the portable terminal uses numerous antennas at the transmitter. As seen in Figure 1, a wireless communication system that uses multiple antennas at both the transmitter and the receiver is generally referred to as a multiple input multiple output (MIMO) system. When comparing MIMO wireless systems to single antenna systems, higher channel capacity can be achieved [1].

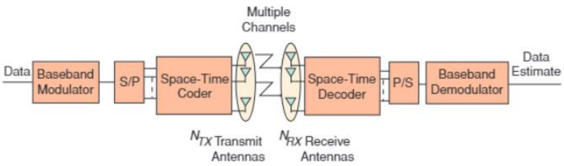

Fig.1 llustration of a general MIMO system

In most situations, the wireless channel suffers attenuation due to destructive addition of multipaths in the propagation media and to interference from other users. The channel statistics are significantly often Rayleigh which makes it difficult for the receiver to reliably determine the transmitted signal unless some less attenuated replica of the signal is provided to the receiver. This technique is called diversity, which can be provided using temporal, frequency, polarization, and spatial resources.

Space time trellis codes

More recently, space–time trellis coding has been proposed which combines signal processing at the receiver with coding techniques appropriate to multiple transmit antennas and provides significant gain. Specific space–time trellis codes designed for two–four transmit antennas perform extremely well in slow fading environments (typical of indoor transmission) and come within 2–3 dB of the outage capacity computed by Telatar and independently by Foschini and Gans. The bandwidth efficiency is about three–four times that of current systems. The space–time codes presented provide the best possible tradeoff between constellation size, data rate, diversity advantage, and trellis complexity. When the number of transmit antennas is fixed, the decoding complexity of space–time trellis coding (measured by the number of trellis states in the decoder) increases exponentially as a function of both the diversity level and the transmission rate.

Similar to trellis coded modulation (TCM) for single antenna systems, STTC uses an encoding trellis. The coding gain of the encoding trellis is determined by the trellis's structure and number of states. To retrieve the transmitted symbols at the receiver, a soft Viterbi decoder is employed. A block of data symbols is fed into the input of a Space-Time Trellis encoder, same like in STBC. The various antennas send out the output symbols. At the conclusion of a burst, the encoder is brought into the zero state by appending a tail of zeros to the input stream (Fig. 2). Examine the trellis above for a constellation using quadrature phase shift keying (QPSK). The outputs that coincide with the state transitions are displayed [2].

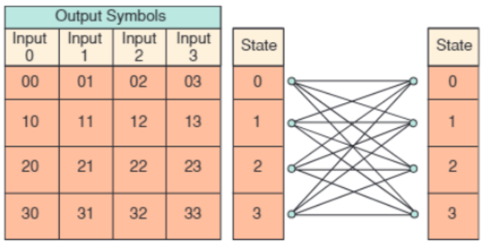

Fig.2 Illustration of a STTC

Space Time Block Coding

When using STBC, a code matrix is created by buffering a block of data symbols. These originate from the several antennas already indicated. At the receiver, the data symbols are identified using the appropriate methods. Designing the code matrix to optimize diversity gain, coding gain, and channel capacity is the difficult part of STBC. Simple receiver detection methods are also crucial for the transmitter code design.

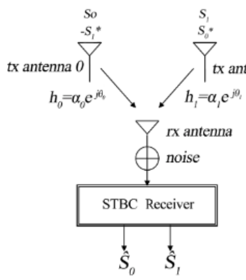

Fig.3 Illustration of a STBC

In addressing the issue of decoding complexity, Alamouti discovered a remarkable scheme for transmission using two transmit antennas. Space–time block coding generalizes the transmission scheme (Fig.3) discovered by Alamouti to an arbitrary number of transmit antennas and is able to achieve the full diversity promised by the transmit and receive antennas. These codes retain the property of having a very simple maximum likelihood decoding algorithm based only on linear processing at the receiver [3].

II.Transmission model

In a wireless communication system with many antennas at the base station, signals are transmitted simultaneously in each time slot. We can express the signals received from antennas as follows:

$$r_t^j = \sum_{i=1}^{n} \alpha_{i,j} c_t^i + \eta_t^j$$

III.Space time block coding

Encoding algorithm

A space–time block code is defined by a pxn transmission matrix G . The entries of the matrix G are linear combinations of the variables x1,x2...xk and their conjugates. The number of transmission antennas is n , and we usually use it to separate different codes from each other.

Decoding algorithm

Maximum likelihood decoding of any space–time block code can be achieved using only linear processing at the receiver. Let's examine an example using the G2 matrix below:

$$\mathcal{G}_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix}.$$

Suppose that there are 2^b signals in the constellation. At the first time slot 2b bits arrive at the encoder and select two complex symbols s_1 and s_2. These symbols are transmitted simultaneously from antennas one and two, respectively. At the second time slot, signals $-s_2^*$ and s_1^* are transmitted simultaneously from antennas one and two, respectively [4]. Then maximum likelihood detection amounts to minimizing the decision metric:

$$\sum_{j=1}^{m} \left(|r_1^j - \alpha_{1,j} s_1 - \alpha_{2,j} s_2|^2 + |r_2^j + \alpha_{1,j} s_2^* - \alpha_{2,j} s_1^*|^2 \right)$$

The minimizing values are the receiver estimates of s_1 and s_2 respectively. We expand the above metric and delete the terms that are independent of the codewords and observe that the above minimization is equivalent to minimizing:

$$\begin{aligned} -\sum_{j=1}^{m} \Big[& r_1^j \alpha_{1,j}^* s_1^* + (r_1^j)^* \alpha_{1,j} s_1 + r_1^j \alpha_{2,j}^* s_2^* + (r_1^j)^* \alpha_{2,j} s_2 \\ & - r_2^j \alpha_{1,j}^* s_2 - (r_2^j)^* \alpha_{1,j} s_2^* + r_2^j \alpha_{2,j}^* s_1 + (r_2^j)^* \alpha_{2,j} s_1^* \Big] \\ & + (|s_1|^2 + |s_2|^2) \sum_{j=1}^{m} \sum_{i=1}^{2} |\alpha_{i,j}|^2. \end{aligned}$$

If we divide the metric into two parts, one of which is a function of only s1 and the other is a function of only s2, we obtain the following two equations:

$$\begin{aligned} & -\sum_{j=1}^{m} \left[r_1^j \alpha_{1,j}^* s_1^* + (r_1^j)^* \alpha_{1,j} s_1 + r_2^j \alpha_{2,j}^* s_1 + (r_2^j)^* \alpha_{2,j} s_1^* \right] \\ & + |s_1|^2 \sum_{j=1}^{m} \sum_{i=1}^{2} |\alpha_{i,j}|^2 \end{aligned}$$

$$\begin{aligned} & -\sum_{j=1}^{m} \left[r_2^j \alpha_{2,j}^* s_2^* + (r_1^j)^* \alpha_{2,j} s_2 - r_2^j \alpha_{1,j}^* s_2 - (r_2^j)^* \alpha_{1,j} s_2^* \right] \\ & + |s_2|^2 \sum_{j=1}^{m} \sum_{i=1}^{2} |\alpha_{i,j}|^2 \end{aligned}$$

If we minimize both metrics, we get the following values:

$$\begin{aligned} & \left| \left[\sum_{j=1}^{m} \left(r_1^j \alpha_{1,j}^* + (r_2^j)^* \alpha_{2,j} \right) \right] - s_1 \right|^2 \\ & + \left(-1 + \sum_{j=1}^{m} \sum_{i=1}^{2} |\alpha_{i,j}|^2 \right) |s_1|^2 \end{aligned}$$

$$\begin{aligned} & \left| \left[\sum_{j=1}^{m} \left(r_1^j \alpha_{2,j}^* - (r_2^j)^* \alpha_{1,j} \right) \right] - s_2 \right|^2 \\ & + \left(-1 + \sum_{j=1}^{m} \sum_{i=1}^{2} |\alpha_{i,j}|^2 \right) |s_2|^2 \end{aligned}$$

IV.Performance analysis

In this section, we analyze the performance of G4 when the energy of different symbols are equal to each other

$$\mathcal{G}_4 = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{pmatrix}.$$

The decoder minimizes the decision metric:

$$\begin{aligned} \Bigg| \Bigg[\sum_{j=1}^{m} \Big(& r_1^j \alpha_{1,j}^* + r_2^j \alpha_{2,j}^* + r_3^j \alpha_{3,j}^* + r_4^j \alpha_{4,j}^* + (r_5^j)^* \alpha_{1,j} \\ & + (r_6^j)^* \alpha_{2,j} + (r_7^j)^* \alpha_{3,j} + (r_8^j)^* \alpha_{4,j} \Big) \Bigg] - s_1 \Bigg|^2 \end{aligned}$$

For decoding s_1 which can be rewritten as $|\breve{s_1} - s_1|^2$where:

$$\begin{aligned} \hat{s}_1 = \sum_{j=1}^{m} \Big(& r_1^j \alpha_{1,j}^* + r_2^j \alpha_{2,j}^* + r_3^j \alpha_{3,j}^* + r_4^j \alpha_{4,j}^* \\ & + (r_5^j)^* \alpha_{1,j} + (r_6^j)^* \alpha_{2,j} + (r_7^j)^* \alpha_{3,j} + (r_8^j)^* \alpha_{4,j} \Big). \end{aligned}$$

By replacing $r_t^j$from in the above equation and simple manipulations, we arrive at

$$\hat{s}_1 = 2 \sum_{j=1}^{m} \sum_{i=1}^{4} |\alpha_{i,j}|^2 s_1 + \Xi_1$$

$$\begin{aligned} \Xi_1 = \sum_{j=1}^{m} \Big(& \eta_1^j \alpha_{1,j}^* + \eta_2^j \alpha_{2,j}^* + \eta_3^j \alpha_{3,j}^* + \eta_4^j \alpha_{4,j}^* \\ & + (\eta_5^j)^* \alpha_{1,j} + (\eta_6^j)^* \alpha_{2,j} + (\eta_7^j)^* \alpha_{3,j} + (\eta_8^j)^* \alpha_{4,j} \Big). \end{aligned}$$

By the last equation, the random variable is a zero-mean complex Gaussian random variable.

V.Simulation and Performance Analysis

Simulation of Bit Error Rate (BER) Calculation using Alamouti Coding

This simulation is designed to calculate the bit error rate (BER) using Alamouti coding in wireless communication. The simulation comprises the following steps[5]:

1. **Data Generation:**
   - The data to be transmitted is generated as a sequence of random complex numbers, each element having a value of +1 or -1. This data is considered the signal used for transmission.
2. **Alamouti Coding (Encode):**
   - The generated data is transformed into an Alamouti matrix. This matrix illustrates how the data is encoded among different antennas during transmission.
3. **Creating a Channel Model:**
   - Using the Rayleigh channel, the simulation models the transmitted signal to reflect real-world conditions. This model represents signal propagation, reflection, and various interactions.
4. **Transmission and Receiver Phase:**
   - Addition of Noise: A noise model representing random noise encountered in actual communication environments is added to the transmitted signal.
   - Signal Processing at the Receiver: Incoming signals at the receiver are processed using the Alamouti algorithm to separate and process the received data.
5. **Error Calculation and Tracking Total Error Count:**
   - The decoded data at the receiver is compared to the original data, errors are calculated, and the total error count is tracked.
6. **Calculation of Bit Error Rate:**
   - The total error count is divided by the total number of transmitted bits to compute the bit error rate (BER).

Graphical Analysis:

The obtained BER values from the simulation are plotted against different Signal-to-Noise Ratio (SNR) levels on a graph. This graph is used to assess communication system performance and visualize the relationship between SNR and BER. Higher SNR values generally correspond to lower BER, while lower SNR values are associated with higher BER. This graph helps understand how communication systems perform under different conditions. Particularly, higher BER at lower SNR indicates that communication systems have a higher error rate under lower quality conditions.

Performance Analysis:

When comparing the bit error rate (BER) performances between the 2T2R and 2T1R antenna configurations, a notable contrast is observed despite both configurations sharing the same number of transmitters. The variation arises due to the discrepancy in receiver antennas.

In the case of 2T2R, with two transmitters and two receivers, the BER graph displays a more favorable performance starting from an SNR level of approximately $10^{-1.5}$, gradually decreasing over roughly 10 units to reach a BER of 10^{-4},. This signifies the 2T2R setup's ability to achieve substantially lower error rates, showcasing its robustness and reliability in signal reception and decoding even in challenging SNR conditions.

Contrarily, the 2T1R configuration, featuring two transmitters and a single receiver, demonstrates a different BER trend. Beginning at an SNR level around 10^-1, the BER only descends to approximately 10^{-2} after progressing roughly 10 units in SNR. This reveals a comparatively higher error rate within this setup due to reduced diversity in signal reception, resulting in a less robust performance in adverse SNR conditions compared to the 2T2R configuration.

Understanding the impact of antenna configurations on communication systems is crucial. Despite having the same number of transmitters, the differing receiver setups significantly influence the system's performance, highlighting the importance of receiver diversity for achieving better error rates, especially in challenging signal-to-noise ratio environments.

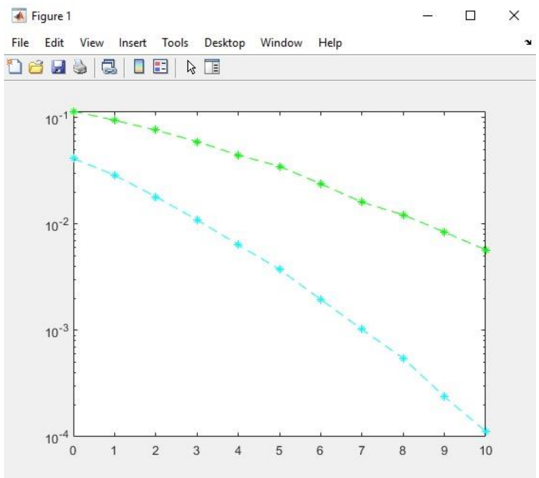

Fig.4 Simulation Results

- 2 receivers and 1 transmitter
- 2 receivers and 2 transmitter

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