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Analysis and comparison of the 4-PSK and 8-PSK STTC over Rayleigh fading Channels for determining Performance

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Abstract

Demands for capacity in wireless communications, driven by cellular mobile, Internet and multimedia services have been rapidly increasing worldwide. On the other hand, the available radio spectrum is limited and the communication capacity needs cannot be met without a significant increase in communication spectral efficiency. Coding techniques designed for multiple antenna transmission are called space-time coding. Space-time coding can achieve transmit diversity and coding gain over spatially uncoded systems without sacrificing the bandwidth. Space-time trellis code (STTC) has been widely applied to coded multiple-input multiple-output (MIMO) systems because of its gains in coding and diversity. Diversity techniques are used to reduce the effect of fading. Space-time trellis code is a bandwidth and power efficient method of communication over Rayleigh fading that realizes the benefits of multiple transmit and receive antennas. In this paper we present analytical performance results for space–time trellis codes over spatially correlated Rayleigh fading channels. In this paper we analyze and compare the 8-PSK STTC over Rayleigh fading Channels for determining Performance.

Keywords

STTC, MIMO, M-PSK, fading

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is an Wireless communications is the transfer of information between two or more points that are not physically connected. Distances can be short, such as a few meter for television remote control, or as far as thousands or even millions of kilometer for deep-space radio communications. It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of wireless technology include GPS units, Garage door openers or garage doors, wireless computer mice, keyboards and Headset (audio), headphones, radio receivers, satellite television, broadcast television and cordless telephones [1]. Demand for capacity in wireless communications, driven by cellular mobile, Internet and multimedia services have been rapidly increasing worldwide. On the other hand, the available radio spectrum is limited and the communication capacity needs cannot be met without a significant increase in communication spectral efficiency. Advances in coding, such as turbo [2] and low density parity check codes [3] made it feasible to approach the Shannon capacity limit [4] in systems with a single antenna link. Significant further advances in spectral efficiency are available through increasing the number of antennas at both the transmitter and the receiver. Multiple-input multiple-output (MIMO) is a multiple antenna system. The MIMO technology exploits the use of multiple signals transmitted into the wireless medium and multiple signals received from the wireless medium to improve the wireless channel performance. The MIMO transmission is an extremely spectrum efficient technology that uses several antennas at both ends of the communication link. The MIMO can also be thought of as a multi-dimensional wireless communications system. Greater spectral efficiency, higher data rates, greater range, an increased number of users, enhanced reliability, or any combination of the preceding factors can be achieved by the MIMO technology. By multiplying spectral efficiency, MIMO opens the door to a variety of new applications and enables more cost-effective implementation for existing applications [5][6].

The remaining of this paper is organized as follows. We discuss STTED in Section 2. In Section 3 we discuss about problem domain. Proposed approach in section4.In section 5 we discuss about result analysis. The conclusions and future directions are given in Section 6. Finally references are given.

2. MIMO Wireless Communication Systems

Demand for capacity in wireless communications, driven by cellular mobile, Internet and multimedia services have been rapidly increasing worldwide. On the other hand, the available radio spectrum is limited and the communication capacity needs cannot be met without a significant increase in communication spectral efficiency. Advances in coding, such as turbo [2] and low density parity check codes [3] made it feasible to approach the Shannon capacity limit [4] in systems with a single antenna link. Significant further advances in spectral efficiency are available through increasing the number of antennas at both the transmitter and the receiver. Multiple-input multiple-output (MIMO) is a multiple antenna system. The MIMO technology exploits the use of multiple signals transmitted into the wireless medium and multiple signals received from the wireless medium to improve the wireless channel performance. The MIMO transmission is an extremely spectrum efficient technology that uses several antennas at both ends of the communication link. The MIMO can also be thought of as a multi-dimensional wireless communications system. Greater spectral efficiency, higher data rates, greater range, an increased number of users, enhanced reliability, or any combination of the preceding factors can be achieved by the MIMO technology. By multiplying spectral efficiency, MIMO opens the door to a variety of new applications and enables more cost-effective implementation for existing applications [5]. In wireless communications, fading is deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modeled as a random process. A fading channel is a communication channel comprising fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading. In wireless communications, signal fading is caused by multipath effect [1]. We consider a baseband space-time coded communication system with n_T transmit antennas and n_R receive antennas, as shown in Figure 1.

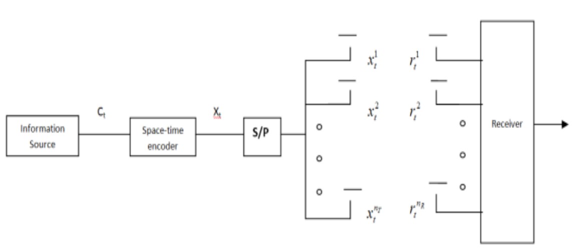

Figure 1: A baseband system model

The transmitted data are encoded by a space-time encoder. At each time instant t, a block of m binary information symbols, denoted by $c_t = \left(c_t^1, c_t^2, \ldots, c_t^m\right)$ is fed into the space-time encoder. The space-time encoder maps the block of m binary input data into n_T modulation symbols from a signal set of $M=2^m$ points. The coded data are applied to a serial-to-parallel (S/P) converter producing a sequence of n_T parallel symbols, arranged into an $n_T \times 1$ column vector $X_t = \left(x_t^1, x_t^2, \ldots, x_t^{n_T}\right)^T$ Where T means the transpose of a matrix. The n_T parallel outputs are simultaneously transmitted by n_T different antennas, whereby symbol $x_t^i, 1 \le i \le n_T$, is transmitted by antenna i and all transmitted symbols have the same duration of Tsec. The vector of coded modulation symbols from different antennas, as shown in (3.2), is called a space-time symbol. The spectral efficiency of the system is $\eta = \frac{r_b}{B} = m \quad bits/\sec/Hz$

Where r_b is the data rate and B is the channel bandwidth. The spectral efficiency in (3.3) is equal to the spectral efficiency of a reference uncoded system with one transmit antenna. The multiple antennas at both the transmitter and the receiver create a MIMO channel. For wireless mobile communications, each link from a transmit antenna to a receive antenna can be modeled by flat fading, if we assume that the channel is memory less. The MIMO channel with n_T transmit and n_R receive antennas can be represented by an $(n_R \times n_T)$ channel matrix H. At time t , the channel matrix is given by

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

Where the ji-th element, denoted by $h_{j,i}^t$, is the fading attenuation coefficient for the path from transmit antenna i to receive antenna j.

In the analysis, we assume that the fading coefficients $h_{j,i}^t$ are independent complex Gaussian random variables with mean $\mu_h^{j,i}$ and the variance 1/2 per dimension, implying that the amplitude of the path coefficients are modeled as Rician fading. In terms of the coefficient variation speed, we consider fast and slow fading channels. For slow fading, it is assumed that the fading coefficients are constant during a frame and vary from one frame to another, which means that the symbol period is small compared to the channel coherence time. The slow fading is also referred to as quasi-static fading. In a fast fading channel, the fading coefficients are constant within each symbol period and vary from one symbol to another.

At the receiver, the signal at each of the n_R receive antennas is a noisy superposition of the n_T transmitted signals degraded by channel fading. At time t, the received signal at antenna j, j=1, 2, … , n_R, denoted by r_t^j , is given by $r_t^j = \sum_{i=1}^{n_T} h_{j,i}^t x_t^i + n_t^j$

Where n_t^j is the noise component of receive antenna j at time t, which is an independent sample of the zero-mean complex Gaussian random variable with the one sided power spectral density of N_0.

Let us represent the received signals from n_R receive antennas at time t by an $n_R \times 1$ column vector.

$r_t = (r_t^1, r_t^1, \ldots, r_t^{n_R})^T$ The noise at the receiver can be described by an $n_R \times 1$ column vector, denoted by n_t . $n_t = (n_t^1, n_t^1, \ldots, n_t^{n_R})^T$ Where each component refers to a sample of the noise at a receive antenna. Thus, the received signal vector can be represented as $r_t = H_t X_t + n_t$ We assume that the decoder at the receiver uses a maximum likelihood algorithm to estimate the transmitted information sequence and that the receiver has ideal channel state information (CSI) on the MIMO channel. On the other hand, the transmitter has no information about the channel. At the receiver, the decision metric is computed based on the squared Euclidean distance between the hypothesized received sequence and the actual received sequence as

$$\sum_t \sum_{j=1}^{n_R} \left| r_t^j - \sum_{i=1}^{n_T} h_j^t, x_t^i \right|^2$$

The Viterbi algorithm selects a code word with the minimum decision metric as the decoded sequence.

The Viterbi algorithm for decoding of received message can be described as follows:

Let the trellis node corresponding to state Sj at time i be denoted Sj,i. Each node in the trellis is to be assigned a value V (Sj,i) based on a metric. The node values are computed in the following manner.

1. Set V (S0,0) = 0 and i = 1.
2. At time i, compute the partial path metrics for all paths entering each node.
3.Set V(Sj,i) equal to the smallest partial path metric entering the node corresponding to state Sj at time i. Ties can be broken by previous node choosing a path randomly. The nonsurviving branches are deleted from the trellis. In this manner, a group of minimum paths is created from S0,0.
4.If i<L+m, where L is the number of input code segments (k bits for each segment) and m is the length of the longest shift register in the encoder, let i = i+1 and go back to step 2. Once all node values have been computed, start at state S0 , time i = L+m, and follow the surviving branches backward through the trellis. The path thus defined is unique and corresponds to the decoded output. When hard decision decoding is performed, the metric used is the Hamming distance, while the Euclidean distance is used for soft decision decoding.

3. Problem Statement

The increasing demand for high data rates in wireless communication due to emerging new technologies makes wireless communication an exciting and challenging field. One of the major problems wireless communication systems face is multipath fading. Diversity is often used to overcome this problem. There are three kind of diversity - spatial, time and frequency diversity. Space-time trellis coding is a technique that can be used to improve the performance of mobile communications systems over fading channel. It is combination of space and time diversity.

Space-Time-Block code provide simple decoding but not coding gain while Space-Time-Trellis code provide full diversity and coding gain at the cost of complex decoding. So work in this thesis at space-Time-trellis-Code using Rayleigh Fading scenario.

4. Literature Survey

In 2010, Kai-Ting Shr, Hong-Du Chen, and Yuan-Hao Huang [7] proposed Space-time trellis code (STTC) that has been widely applied to coded multiple-input multiple-output (MIMO) systems because of its gains in coding and diversity. The complexity of STTC decoding lies in the branch metric calculation in the Viterbi algorithm and increases significantly along with the number of antennas and the modulation order. Consequently, a low-complexity algorithm to mitigate the computational burden is proposed. The complexity analysis provides the necessary information of the proper method (mode) to be employed under different configurations. The STTC decoder is implemented using 0.18 m 1P6M CMOS technology and supports 4 1, 3 1, and 2 1 configurations for

4/8/16-state 4-PSK, 8/16-state 8-PSK, and 16-state 16-QAM STTC schemes. Moreover, two modes are offered for decoding the received symbols under different fading channel conditions. This chip yields a maximum throughput of 11.14 Mbps at a power consumption of 0.43 mW. In conclusion, an STTC decoder was realized in a silicon chip, which the authors believe can improve the reliability of future coded MIMO communication systems.

In 2010, N.Kumaratharan, S.Jayapriya and P.Dananjayan [8] proposed that the combination of multiple antennas and multicarrier code division multiple access (MC-CDMA) is a strong candidate for the downlink of future mobile communications. The study of such systems in scenarios that model real life transmissions is an additional step towards an optimized achievement. Nevertheless, when transmitting over fading channel multi-cell interference occurs and this degrades the performance of the system. Site diversity technique is applied to the system to overcome multi-cell interference. Due to non orthogonality of spreading codes, multi-cell interference is not completely eradicated. To overcome this problem, spreading codes are assigned to each base station. Space time trellis code (STTC) site diversity with multiple input multiple output (MIMO) technique was introduced to reduce multi-cell interference further. In this paper STTC based space time block code (STBC) site diversity technique is proposed to improve the performance of MC-CDMA system. Simulation result shows that STTC based STBC site diversity outperforms STTC site diversity. In this paper, site diversity scheme for MC-CDMA system is proposed using STTC based STBC to improve the performance of mobile terminals in the downlink. With STTC based STBC site diversity technique, the performance of MC-CDMA system is improved with reduction in error rates as it achieves additional diversity gain and coding gain. Simulation results show that STTC based STBC site diversity outperforms STTC based site diversity technique in terms of SER and is best opted for MC-CDMA system.

In 2009, Pierre Viland, Gheorghe Zaharia and Jean-François Helard [9] presented the best space-time trellis codes (STTCs) belong to a specific class of codes. The codes of this class are called “balanced STTCs” because they use the points of the MIMO constellation with the same probability. Therefore, the search of the best codes can be reduced to this class. This paper presents a new and general method to design 2n-PSK balanced STTCs for any number of transmit antennas. This method is simpler than the first method, which was described only for 4-PSK modulation and can be generalized for any configuration of the space-time trellis encoder. Simulation results of new 4-PSK and 8-PSK balanced codes prove the importance of this class. This paper presents a new and simpler method to design balanced space-time trellis codes. It has been shown that the best codes belong to this class. The balanced codes generate the points of the MIMO constellation with the same probability. This new and general method allows designing the balanced STTCs for 2n-PSK modulations and nT transmit antennas. The search for the best codes can be reduced to the class of balanced codes. Furthermore, several new balanced 4- PSK and 8-PSK codes for 3 and 4 transmit antennas which outperform the best previously published codes have also been proposed.

In 2009, Kabir Ashraf and Noor M Khan [10] presented performance comparison of Alamouti space-time codes with different Space-Time Trellis Codes (STTC) codes. The performance comparisons are made on the basis of bit error rate (BER) and symbol error rate (SER) performance metrics over slow Rayleigh fading channel with QPSK modulation scheme. Comparison results show that Alamouti space-time codes outperform the space-time trellis codes (STTC) for less number of receive antennas but with an increase in the number of receive antennas the performance of both of these codes are closer and for most of the cases it is the same for both types of codes. Thus, for large number of receive antennas the results recommend that space-time trellis codes (STTC) be used as they provide an additional advantage of coding gain as compared to the Alamouti space-time codes. Results also show that codes having higher value of minimum determinant show better performance than that of those having less value of minimum determinant.

In 2009, Pierre Viland, Gheorghe Zaharia and Jean-Francois Helard [11] proposed a simple method to design the best 4-PSK space-time trellis codes (STTCs) for any number of transmit antennas. This method called ”coset partitioning” is based on the set partitioning proposed by Ungerboeck for the multiple input multiple output (MIMO) systems. Thus, new 4-PSK codes are designed and compared with good known codes. The simulation results show that these new codes outperform the existing best codes. An efficient method to design the best 4-PSK STTCs with nT transmit anntennas has been presented. This new method is based on the set partitioning proposed by Ungerboeck and an alternative of this work proposed by Calderbank. Based on this new design method, new 4-PSK STTCs with 3 and 4 transmit antennas have been proposed.

In 2007, Thi Minh Hien Ngo, Gheorghe Zaharia, Stephane Bougeard, Jean Francois Helard [12] proposed a new class of 4-PSK Balanced STTC for two transmit antennas. These codes generate the points of the constellation with the same probability. It has been shown that the best STTC belong to this class. Therefore, the systematic search for good codes can be drastically reduced to this class. The design of these balanced codes has been described. A complete list of the best 4-state codes and several 16-state codes for 2 transmit antennas have also been given. All the fully balanced STTC are equivalent, i.e. they have the same rank, trace, product distance and distance spectrum. The simulation results have shown that they outperform the other STTC for 2 transmit antennas.

In 2004, Murat Uysal and Costas N. Georghiades [13] presented analytical performance results for space-time trellis codes over spatially correlated Rayleigh fading channels. Bit-error-probability estimates are obtained based on the derivation of an exact pairwise error probability (PEP) expression using a residue technique combined with a characteristic function approach. They investigate both quasi-static and interleaved channels and demonstrate how the spatial fading correlation affects the performance of space–time codes over these two different channel models. They provide analytical tools for the evaluation of space–time trellis codes operating over Rayleigh fading channels. First, an exact expression for PEP is derived for space–time codes. Based on the derived PEP, analytical estimates for bit-error probability are computed taking into account a small number of error events. The effect of spatial correlation is investigated for both quasi-static and symbol-by-symbol interleaved channels. Our results show that the spatial correlation between the transmit antennas over the interleaved channel only results in a change in coding gain, but does not affect the diversity order. For the quasi-static scenario, full correlation reduces the diversity order, but for a large range of correlation values, the performance of space–time code is observed to be robust to spatial correlation.

In J. N .Pillai and S. H. Mneney [14] proposed Space-Time coded modulation that has been shown to efficiently use transmit diversity to increase spectral efficiency. The adaptively weighted Space-time trellis code based on weighting at the transmitter with channel state information (CSI) at the transmitter has shown to have significant improvement in performance over other systems with a single receive antenna. The main contribution of this work is the analysis of the performance which shows increase in coding gain using the minimum Euclidean distances. Some simulation results of the two schemes are also presented. The adaptively weighted space-time trellis codes with CSI at the transmitter has shown to perform better in terms of coding gain than the standard TSC scheme and has also shown significant coding gain in comparison with other systems with a single receive antenna and comparable complexity. This fact has been further confirmed by the performance analysis using the minimum free Euclidean distances in order to obtain the relative gain in performance. In 2000, Helmut Bolcskei and Arogyaswami J. Paulraj [15] proposed the performance of space-time codes in the presence of spatial fading correlation. Using a channel model incorporating both transmit and receive correlation, the diversity order achieved by a space-time code in the correlated fading case as a function of the diversity order the code achieves in the i.i.d case and the rank of the transmit and the receive correlation matrix. In particular, they quantify the loss in diversity gain and coding gain as a function of angle spread and antenna spacing. They furthermore show that if a space-time code achieves full diversity in the uncorrelated case, the diversity order achieved in the correlated case is given by the product of the rank of the transmit correlation matrix and the rank of the receive correlation matrix. They quantified the loss in average pairwise error probability and studied the impact of the eigenvalue distribution of the correlation matrices on error rate performance. Finally, they provided simulation results.

In 2000, Murat Uysal and Costas N. Georghiades [16] Space-time coding over Rayleigh Fading is proposed. Space-time coding is a bandwidth and power efficient method of communication over fading channels that realizes the benefits of multiple transmit and receive antennas. This novel technique has attracted much attention recently. However, currently the only analytical guide to the performance of space-time codes is an upper bound which could be quite loose in many cases. In this paper, an exact pairwise error probability is derived for space-time codes operating over Rayleigh fading channels. Based on this expression, an analytical estimate for bit error probability is computed, taking into account dominants error events. Simulation results indicate that the estimates are of high accuracy in a broad range of signal-to-noise ratios. In this paper, we provide analytical tools for the evaluation of space-time codes operating over fading channels. First, an exact expression of pairwise error probability is derived for space time codes over rapid fading channels where the path gains are assumed to be constant over one symbol interval. Based on this expression, an analytical estimate for bit error probability is computed, taking into account a small number of error events. Simulation results demonstrate that the estimates are of high accuracy in the SNR range of interest.

In 1998, Siavash M. Alamouti [17] presented a simple two-branch transmit diversity scheme. Using two transmit antennas and one receive antenna the scheme provides the same diversity order as maximal-ratio receiver combining (MRRC) with one transmit antenna, and two receive antennas. It is also shown that the scheme may easily be generalized to two transmit antennas and M receive antennas to provide a diversity order of 2M. The new scheme does not require any bandwidth expansion any feedback from the receiver to the transmitter and its computation complexity is similar to MRRC. A new transmit diversity scheme has been presented. It is shown that, using two transmit antennas and one receive antenna, the new scheme provides the same diversity order as MRRC with one transmit and two receive antennas. It is further shown that the scheme may easily be generalized to two transmit antennas and receive antennas to provide a diversity order of 2M. An obvious application of the scheme is to provide diversity improvement at all the remote units in a wireless system, using two transmit antennas at the base stations instead of two receive antennas at all the remote terminals. The scheme does not require any feedback from the receiver to the transmitter and its computation complexity is similar to MRRC. When compared with MRRC, if the total radiated power is to remain the same, the transmit diversity scheme has a 3-dB disadvantage because of the simultaneous transmission of two distinct symbols from two antennas. Otherwise, if the total radiated power is doubled, then its performance is identical to MRRC. Moreover, assuming equal radiated power, the scheme requires two half-power amplifiers compared to one full power amplifier for MRRC, which may be advantageous for system implementation. The new scheme also requires twice the number of pilot symbols for channel estimation when pilot insertion and extraction is used.

5. Proposed Approach

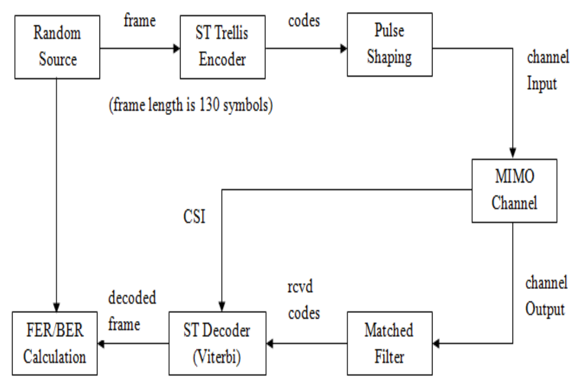

Figure 2: Implementation system model

The implementation system model is shown in Figure 4.4. In this system Random M-PSK symbols are grouped into frames, which consist of 130 symbols each. The space-time encoder takes the frame as input and generates code word pairs for each input symbol simultaneously for all the transmit antennas. Pulse shaping and matched filter are used for simulation over frequency selective fading channels.
These complex signals are transmitted through the MIMO channel. The signals and channels are modelled in base-band, thus modulation/demodulation operations are not carried out. Channels used in this project include flat Rayleigh fading channels and two-ray model frequency selective fading channel.
We assume that perfect channel state information (CSI) is available at the receiver. At the receiver, a maximum likelihood sequence detector is used to decode the received signal. A modified vector Viterbi decoder is employed. Error probability calculation is carried out after decoding each frame.
The algorithm can be described as follows:

1. First the input is applied to the random source. Random M-PSK symbols are grouped into frames, which consists of 130 symbols each.
2. Each frame is applied to the space-time encoder (ST encoder). The ST encoder takes the frame as input and generates codeword pairs for each input symbol simultaneously for all the transmit antennas.
3. Now codeword's are applied to the Pulse shaper. Pulse shaping are used for simulation over frequency selective fading channels and generate channel input.
4. Channel inputs are transmitted through the

MIMO channel. The signals and channels are modeled in base-band, thus modulation/demodulation operations are not carried out. MIMO channel generates the channel output.

5. Channel outputs are applied to the matched filter. Matched filter are used for simulation over frequency selective fading channels and generate received codes.
6. We assume that perfect channel state information (CSI) is available at the receiver. At the receiver, a modified vector Viterbi decoder(discussed in section 2) is used to decode the received codes.
7. Finally, the decoded frames and transmitted frames are applied to the Frame error rate or bit error rate (FER/BER) calculator to calculate the errors.

We assume that the STTC codeword is given by

$$c=\left(c_1^1c_1^2\ldots c_1^{n_T}c_2^1c_2^2\ldots c_2^{n_T}\ldots c_l^1c_l^2\ldots c_l^{n_T}\right)$$

Where l is the frame length. We consider a maximum likelihood receiver, which may possibly decide on an erroneous code word e , given by

$$e=\left(e_1^1e_1^2\ldots e_1^{n_T}e_2^1e_2^2\ldots e_2^{n_T}\ldots e_l^1e_l^2\ldots e_l^{n_T}\right)$$

We can write the difference code matrix, the difference between the erroneous codeword and the transmitted codeword as follows –

$$B(c,e)=\begin{pmatrix} e_1^1-c_1^1 & e_2^1-c_2^1 & \cdots & e_l^1-c_l^1 \\ e_1^2-c_1^2 & e_2^2-c_2^2 & \cdots & e_l^2-c_l^2 \\ e_1^3-c_1^3 & e_2^3-c_2^3 & \cdots & e_l^3-c_l^3 \\ \vdots & \vdots & \ddots & \vdots \\ e_1^{n_T}-c_1^{n_T} & e_2^{n_T}-c_2^{n_T} & \cdots & e_l^{n_T}-c_l^{n_T} \end{pmatrix}$$

The difference matrix $B(c,e)$ has dimension $n_T\times l$. We know that to achieve the maximum diversity order $n_R n_T$ (n_R receive antennas, n_T transmit antennas) matrix $B(c,e)$ must have full rank for all possible codewords c and e . If $B(c,e)$ has minimum rank r over the set of pairs of distinct codewords then the diversity will be $r.n_R$.

Let $A(c,e)=B(c,e)\cdot B^*(c,e)$ be the distance matrix, where $B^*(c,e)$ is the Hermitian of $B(c,e)$.

The rank of $A(c,e)$ is $r\cdot A$ has minimum dimension n_T-r and exactly n_T-r eigen values of A are zero. The non-zero eigen values of A are denoted by $\lambda_1,\lambda_2,\lambda_3,\ldots,\lambda_n$. Assuming perfect channel state information (CSI), the pairwise error probability (PEP) of transmitting c and deciding on an erroneous codeword e at the decoder is given by :

$$P\left(c,e\middle|h_{i,j},i=1,2,\ldots,n_T \text{ and } j=1,2,\ldots,n_R\right)=Q\left(\sqrt{\frac{E_S}{2N_0}d^2(c,e)}\right)$$

Or

$$P\left(c\to e\middle|h_{i,j},i=1,2,\ldots,n_T \text{ and } j=1,2,\ldots,n_R\right)\le\exp\left(-d^2(c,e)E_s/4N_0\right)$$

Where $N_0/2$ is the noise variance per dimension and

$$d^2(c,e)=\sum_{j=1}^{n_R}\sum_{t=1}^{l}\left|\sum_{i=1}^{n_T}h_{i,j}\left(c_t^i-e_t^i\right)\right|^2$$

is the Euclidean distance. For the special case of Rayleigh fading we can assume $K_{i,j}=0$ for all i and j . Then

$$P(c\to e)\le\left(\frac{1}{\prod_{i=1}^{n_T}1+\frac{E_s}{4N_0}\lambda_i}\right)^{n_R}$$

Let r denote the rank of matrix $A(c,e)$. The matrix A has dimension n_T-r and n_T-r eigenvalues of A are zero.

$$P(c\to e)\le\left(\prod_{i=1}^{r}\lambda_i\right)^{-n_R}\left(\frac{E_s}{4N_0}\right)^{-rn_R}$$

We can derive following Design criteria for the STTC to achieve the best performance of a given system .

6. Conclusion

Space-time trellis code has been widely applied to coded multiple-input multiple-output systems because of its gains in coding and diversity. Diversity techniques are used to reduce the effect of fading. We have presented analytical performance results for space–time trellis codes over spatially correlated Rayleigh fading channels. An exact pair wise error probability is derived for STTC operating over Rayleigh fading channels. Based on this expression, an analytical estimate for bit error probability and frame error probability is computed, taking into account dominant error events. In this paper we survey several research aspects which can determine the problem prospective for the future direction. To design STTC for QAM (Quadrature Amplitude

Modulation), may become interesting field for future research. Another active area of research is the combination of space-time codes with orthogonal frequency division multiplexing (OFDM). For high data rate wireless applications OFDM is widely used because of its ability to combat inter symbol interference (ISI). Another interesting research area is iterative decoding for STTCs. Another active area of research is to design STTC for multiple users.

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