Space-Time Hyper Phase Shift Keying Over Fading Channels

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Abstract

The emerging need for high data rate and coding gain has raised considerable interest in coded modulation schemes. Trellis coded modulation (TCM) is a bandwidth efficient transmission scheme that can achieves high coding gain by integrating coding and modulation. Space-time trellis coding combines channel coding with multiple transmit and multiple receive antennas to achieve bandwidth and power efficient high data rate transmission over fading channels. This paper presents the design of hyper phase shift keying space-time trellis coded modulation (HPSK ST-TCM) for improving the bandwidth efficiency of wireless networks. HPSK offers an improvement in error performance comparable with other modulation schemes for the same energy per bit to noise power spectral density ratio.

Keywords: *Space-time codes, multiple transmit antennas, multiple receive antennas, CPM, hyper phase shift keying, bandwidth efficiency, fading channels*

1. Introduction

Wireless communication systems are emerging, higher data rates with improved quality of service are required. The performance of wireless communications is degraded by signal fading caused by multipath propagation and interference from other users. The effects of fading can be substantially mitigated by the use of diversity techniques [1], where the receiver is afforded multiple opportunities to observe the transmitted signal under varying channel conditions. Diversity and error control codes are known to improve the link quality in communications.

In particular, transmit diversity can be used to increase the transmission rate. Trellis-based transmit diversity schemes to achieve full spatial diversity on fading channels.

Space-time trellis coded modulation can benefit from both diversity and coding gains. They represent a combination of forward error correction, transmit diversity and modulation. The performance criteria for both quasi-static and fast fading channels were derived in [2], characterizing the ST codes with two quantities : the diversity advantage, which describes the asymptotic error rate decrease as a function of the signal-to-noise ratio (SNR), and the coding advantage, which determines the vertical shift of the error performance curve. The performance of space-time trellis codes (STTC) over Nakagami, and Rayleigh fading channels were presented in [3], it was found that significant performance improvements could be achieved with increasing the number of transmit antennas from two to three and four.

The bit error rate (BER) performance evaluation of space-time block codes (STBC) in multiple-input multiple-output (MIMO) wireless communication systems with the help of computer simulation was considered. The research also studied the BER for the two main types of STBC: first, Orthogonal space-time block codes (OSTBC), and the Quasi-Orthogonal space-time block codes (QSTBC), were illustrated in [4]. The orthogonal-like space-time coded continuous phase modulation (CPM) systems for three and four transmit antennas based on orthogonal and quasi-orthogonal space-time codes, were considered in [5]. The simulation results showed that the performance of orthogonal-like space-time coded CPM systems for four transmit antennas is much better than that of the orthogonal space-time CPM systems for two transmit antennas.

In [6], a combination of MIMO structures and orthogonal frequency division multiplexing (OFDM), have been analyzed and compared the performances obtained by orthogonal and non-orthogonal space-time coding schemes.

The error performance of coded orthogonal frequency division multiplexing (OFDM) over fading multipath channels and additive white Gaussian noise (AWGN), was analyzed and improved by providing spatial diversity [7]. With multiple antennas at the transmitter, space-time block codes may be concatenated in order to achieve both space diversity and frequency diversity.

Space-time (ST) trellis coding combined with CPM is an attractive combination based on the advantageous characteristics of CPM being able to be used for low-cost nonlinear amplifiers and the superior error control coding performance of ST codes.

Distributed space-time (ST) minimum shift keying (MSK) trellis codes were investigated in [8,9], for amplify and forward relaying method. MSK is a special form of CPM. ST-MSK trellis codes were designed and their error performances were simulated by computer programs.

ST codes for quaternary continuous phase frequency shift keying (QCPFSK) modulation receivers with large numbers of antennas in quasi-static fading channels were presented in [10]. The ST codes were developed based on the maximizing minimum squared Euclidean distance criterion. The simulation results showed that a significant performance gain could be obtained from the ST codes scheme for CPFSK modulation systems.

Motivated by these trends, in this paper we aim to consider the performance of the STTC system by employing trellis coding in conjunction with M-ary hyper phase shift keying (*M*HPSK) in order to improve the robustness of a high spectral efficiency communications link. *M*HPSK is a spectral efficient modulation technique that uses four orthonormal basis functions to increase the Euclidean distance between different symbols in the four dimensional signal space. An increase in the Euclidean distance between symbols results in improved error performance over traditional modulation techniques such as *M*PSK and *M*QAM where symbols are separated in only two dimensions [11-13].

The outline of this paper is as follows. Section 2 presents a brief overview of MHPSK. Section 3 describes the base-band of ST-HPSK coded system model. Analytical results are presented in Section 4, comparing the performance obtained by different ST schemes for several varieties numbers of transmitter and receiver antennas, under *Rayleigh* fading with AWGN channel, and *Rician* fading with AWGN channel. Finally, Section 5 concludes the paper.

2. Hyper Phase Shift Keying (HPSK) Modulation Scheme

The field of space-time coding and modulation has gained much interest due to the increasing need to transmit reliable information at high rates over wireless channels.

Most communications systems fall into one of three categories: bandwidth efficient, power efficient, and cost efficient. Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth. Power efficiency describes the ability of the system to reliably send information at the lowest practical power level. In most systems, there is a high priority on bandwidth efficiency.

Traditional digital modulation techniques include phase shift keying (PSK), frequency shift keying (FSK), and quadrature amplitude modulation (QAM) have two orthonormal basis functions.

Phase shift keying (PSK) is a large class of digital modulation schemes. PSK is widely used in the communication industry. PSK signals can be graphically represented by a *signal constellation* in a two-dimensional coordinate system with

$$\Phi_1(t) = \sqrt{(2/T)}\ \cos 2\pi f_c t \qquad ; \quad 0 \le t \le T$$

and

$$\Phi_2(t) = -\sqrt{(2/T)}\ \sin 2\pi f_c t \qquad ; \quad 0 \le t \le T \tag{1}$$

where $\Phi_1(t)$ and $\Phi_2(t)$ are orthonormal basis functions, *T represents the symbol duration*, f_c is the carrier frequency.

M-ary PSK signal set is defined as

$$\begin{aligned} S_i(t) &= A \cos\theta\ \cos 2\pi f_c t - A \sin\theta\ \sin 2\pi f_c t \\ &= S_{i1}\, \Phi_1(t) + S_{i2}\, \Phi_2(t) \end{aligned} \tag{2}$$

where A is the amplitude, and θ is the phase signal.

The bit error rate (BER) for M-ary PSK over AWGN channel is defined as [14] :

$$\text{BER} \approx 2\,Q \left\{ \left(\sqrt{2E_s / N_o}\right) \sin(\pi / M) \right\} \tag{3}$$

where E_s/N_o is the average signal-to-noise ratio (*SNR*) per symbol . Q function is defined as :

$$Q(x) = \int_x^{\infty} (1/\sqrt{2\pi})\ \exp(-x^2/2)\, dx \qquad ; \qquad x \ge 1 \tag{4}$$

where

E_s represents the symbol energy and equals $A^2 T/2$ (5)

The bit error rate (BER) for MQAM over AWGN channel is defined as [14] :

$$\text{BER} \approx 4 \left\{ (\sqrt{M} - 1)/\sqrt{M} \right\} Q \left(\sqrt{3E_s / (M-1) N_o} \right) \tag{6}$$

Hyper Phase Shift Keying (HPSK) modulation technique uses four ortho-normal basis functions for binary information modulation as [11,12] :

$$\begin{aligned} \Phi_1(t) &= A\ \cos\{ 2\pi [f_c + 1/(2T)]\, t \} / \sqrt{E_s} \\ \Phi_2(t) &= A\ \sin\{ 2\pi [f_c + 1/(2T)]\, t \} / \sqrt{E_s} \\ \Phi_3(t) &= A\ \sin\{ 2\pi [f_c - 1/(2T)]\, t \} / \sqrt{E_s} \\ \Phi_4(t) &= A\ \cos\{ 2\pi [f_c - 1/(2T)]\, t \} / \sqrt{E_s} \end{aligned} \tag{7}$$

The transmitted signal can be defined as

$$S_n(t) = \sqrt{E_s / 4} \left\{ S_{n1}\Phi_1(t) + S_{n2}\Phi_2(t) + S_{n3}\Phi_3(t) + S_{n4}\Phi_4(t) \right\} \tag{8}$$

The bit error rate for HPSK over AWGN channel is defined by [11]

$$\text{BER} = (1 / \log_2 M) \left[1 - \left\{ 1 - Q\left(\sqrt{\frac{\log_2 (M)\, E_s}{2 N_o}} \right) \right\}^4 \right] \tag{9}$$

Figure. 1, shows the analytical bit error rates for 32PSK, and 32QAM, compared with 32HPSK modulation scheme. It is shown the superiority of HPSK modulation technique over other modulation types.

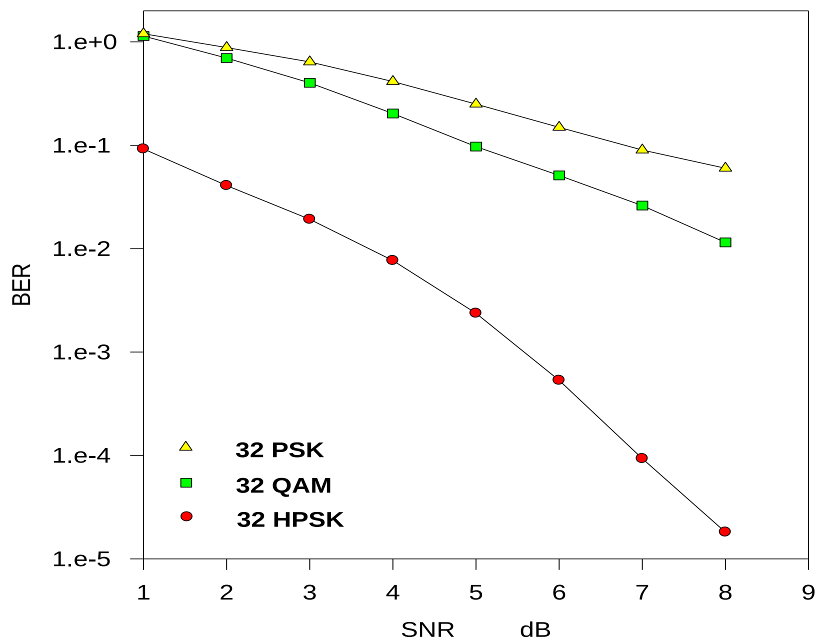

Fig. 1. Analytical BER for 32PSK, 32QAM, and 32HPSK Modulation Schemes

3. Space-time Trellis HPSK Scheme

A common method to combat multipath fading effects, is to use diversity techniques, which replicas of the information signal in various forms to the receiver. One such technique that uses spatial and temporal diversity is space-time coding. Spectral efficiency can be significantly improved by using multiple antennas at both the transmitter with $L_t > 1$ antennas and a receiver with $L_r > 1$ antennas, where L_t and L_r represent the number of antennas at transmitter site, and receiver site, respectively. Space-time trellis codes (STTC) can achieve coding gain, spectral efficiency and diversity advantage on frequency flat fading channels. The block diagram of base-band space-time coded system is shown in Fig. 2. The input to the space-time encoder at each time instant t is a block of $\log_2 M$ binary information symbols. We denote the block as

$$C_t = \left[c_t^1, c_t^2, \ldots\ldots\ldots\ldots\ldots , c_t^{Log2M} \right] \quad (10)$$

The space-time encoder maps the data to modulation symbols drawn from a set of M points. These modulated symbols are fed to a serial-to-parallel converter, which forms the vector

$$x_t = \left[x_t^1, \ x_t^2, \ldots\ldots\ldots\ldots\ldots , c_t^{Lt} \right]^T \quad (11)$$

where ^{T} denotes the transpose of a vector or matrix.

The modulation symbol, x^i_t , for $1 \leq i \leq L_t$, is transmitted from the i^{th} transmit antenna at time instant t.

The received signal on the j^{th} antenna at time t is given by

$$y^j_t = \sum_{i=1}^{L_t} \alpha^t_{i,j} \ s^i_t + n^t_j \quad ; \quad 1 \leq j \leq L_r \quad (12)$$

where y^j_t is the received signal at antenna j at time t, $\alpha^t_{i,j}$ is the complex path loss from transmit antenna i to receive antenna j, s^i_t is the transmitted constellation point corresponding to x_t , and n^t_j is an additive white Gaussian noise (AWGN) sample for receive antenna j at time t. The noise samples are independent samples of a zero-mean complex Gaussian random variable with variance $N_o /2$ per dimension.

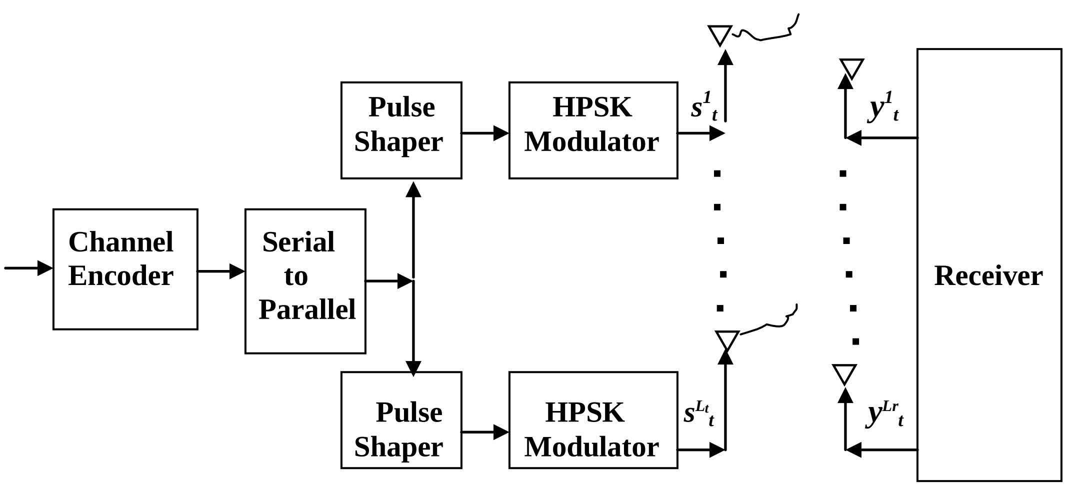

Fig. 2. Base-band Space-time HPSK Coded System

The STTC transmitted codeword is given by [3]

$$s = (s^1{}_1 \, s^2{}_1 \ldots\ldots s^{Lt}{}_1 \quad s^1{}_2 \, s^2{}_2 \ldots\ldots s^{Lt}{}_2 \quad \ldots\ldots\ldots\ldots \quad s^1{}_n s^2{}_n \ldots\ldots s^{Lt}{}_n) \quad (13)$$

where n is the frame length. Considering maximum likelihood receiver, which may possibly decide on an erroneous codeword e, given by

$$e = (e^1{}_1 \, e^2{}_1 \ldots\ldots e^{Lr}{}_1 \quad e^1{}_2 \, e^2{}_2 \ldots\ldots e^{Lr}{}_2 \quad \ldots\ldots\ldots\ldots \quad e^1{}_n \, e^2{}_n \ldots\ldots e^{Lr}{}_n) \quad (14)$$

Assuming perfect channel state information (CSI), the probability of transmitting *S*, and deciding on an erroneous codeword *e* at the decoder is approximated by [5]

$$P(s \rightarrow e \mid \alpha^{t}_{i,j} \;;\; i = 1, 2, \ldots, L_t, j = 1, 2, \ldots, L_r) \leq \exp\left\{ - d^2(s, e)\, E_s / 4\, No \right\} \tag{15}$$

where [2]

$$d^2(s, e) = \sum_{j=1}^{L_r} \sum_{t=1}^{n} \left| \sum_{i=1}^{L_t} \alpha_{i,j} \left\{ e^{i}_{t} - s^{i}_{t} \right\}^{2} \right| \tag{16}$$

The pairwise error probability conditioned on the fading matrix $\alpha^{t}_{j,i}$, is expressed by

$$P(s \rightarrow e \mid \alpha^{t}_{i,j}) = Q\left(\sqrt{(E_s / 2N_o)\, d^2(s, e)} \right) \tag{17}$$

The conditional pairwise error probability of equation (17), can be upper bounded by

$$P(s \rightarrow e \mid \alpha_{i,j}) \leq 0.5 \exp\left(-(E_s / 4N_o)\, d^2(s, e) \right) \tag{18}$$

In order to evaluate the unconditional pairwise error probability, a codeword distance matrix is constructed from the differences between pairs of distinct code sequences. The codeword difference matrix, for the sequences *s*, and *e*, as

$$B(s, e) = \mathrm{e} - \mathrm{s} \tag{19}$$

The difference between the erroneous codeword and the transmitted codeword is defined as

$$B(s, e) = \begin{pmatrix} e^{1}_{1} - s^{1}_{1} & e^{1}_{2} - s^{1}_{2} & \ldots\ldots\ldots\ldots & e^{1}_{n} - s^{1}_{n} \\ e^{2}_{1} - s^{2}_{1} & e^{2}_{2} - s^{2}_{2} & \ldots\ldots\ldots\ldots & e^{2}_{n} - s^{2}_{n} \\ e^{3}_{1} - s^{3}_{1} & e^{3}_{2} - s^{3}_{2} & \ldots\ldots\ldots\ldots & e^{3}_{n} - s^{3}_{n} \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ e^{Lr}_{1} - s^{Lt}_{1} & e^{Lr}_{2} - s^{Lt}_{2} & \ldots\ldots\ldots & e^{Lr}_{n} - s^{Lt}_{n} \end{pmatrix} \tag{20}$$

and the codeword distance matrix, for the sequences s and e, as

$$A(s, e) = B(s, e) \,.\, B^{H}(s, e) \tag{21}$$

where ^{H} denotes the Hermitian or transpose conjugate of a matrix.

The matrix *A(s, e)* is non-negative definite Hermitian, and its eigenvalues λ_i are non-negative too. A unitary matrix *V,* and a diagonal matrix *D*, such that [2,3]

$$D = V\ A(s, e)\ V^{H} \tag{22}$$

The diagonal elements of D are the eigenvalues of $A(s, e)$, which we denote $\lambda_i \geq 0$, for $1 \leq i \leq L_t$. Assuming multipath fading, we let $\alpha^t_{i,j} = \{ \alpha^t_{j,1}, \alpha^t_{j,2}, \ldots\ldots\ldots, \alpha^t_{,j,Lt} \}$ denote the array of fading coefficients that affect the signal on the *j-th* receive antenna.

$$d^2(s, e) = \sum_{j=1}^{L_r} \alpha^t_{i,j} A(s, e)\, \alpha^{tH}_{,j,i}$$

$$= \sum_{j=1}^{L_r} \alpha^t_{,i,j} V^H\; D\; V \alpha^{tH}_{i,j}$$

$$= \sum_{j=1}^{L_r} \sum_{i=1}^{L_t} \lambda_i \; | \beta_{i,j} |^2 \qquad (23)$$

where $\beta_{i,j} = \alpha^t_{i,j}\, v^H_i$ and v_i is the i-th row of V. Recall that $\alpha^t_{i,j}$ are samples of a complex Gaussian random variable with mean $E\, \alpha^t_{i,j}$ [3]. Let

$$K^j = (E\, \alpha^t_{1,j}\, , E\, \alpha^t_{2,,j}\, , E\, \alpha^t_{3,,j}\, , \ldots\ldots.. , E\, \alpha^t_{n,j})$$
(24)

Substituting (23) into (18), the conditional pairwise error probability is bounded by

$$P(s \rightarrow e \mid \alpha_{i,j}) \leq 0.5 \exp \left(- (E_s / 4N_o) \sum_{j=1}^{L_r} \sum_{i=1}^{L_t} \lambda_i \mid \beta_{i,j} \mid^2 \right) \qquad (25)$$

Let $K_{i,j} = | E\, \beta_{i,j} |^2 = | E\, \alpha^t_{i,j} |^2 = | K^j .\; v^H_i |^2$. Thus $\beta_{i,j,}$ are independent *Rician* distributions [2] with pdf

$$P(| \beta_{i,j} |) = 2 \,| \beta_{i,j} | \exp \{ - | \beta_{i,j} |^2 - K_{i,j} \}\; I_o\, (2 | \beta_{i,j} | \sqrt{K_{i,j}}) \qquad (26)$$

for $| \beta_{i,j} | \geq 0$, where $Io\,(.)$ is the zero-order modified Bessel function of the first kind.

Then the pairwise error probability with respect to *Rician* distribution of $| \beta_{i,j} |$ will be derived as

$$P(s \rightarrow e) \leq \prod \left(\prod_{j=1}^{L_r} \prod_{i=1}^{L_t} \frac{1}{1 + (\lambda_i\, E_s / 4\, N_o)} \left\{ \frac{\exp\; - K_{i,j}\; \lambda_i\; E_s / 4\, N_o)}{1 + (\lambda_i\, E_s / 4\, N_o)} \right\} \right) \qquad (27)$$

In the case of *Rayleigh* fading ($E\, \alpha^t_{i,j} = 0$), while $K_{i,j} = 0$ for all *i* and *j* . Then (27) will be re-expressed as

$$P(s \rightarrow e) \leq \left(1 / \prod_{i=1}^{L_t} 1 + (\lambda_i\, E_s / 4\, N_o) \right)^{L_r} \qquad (28)$$

3. Numerical Results

In this section, we perform a numerical analysis for the proposed hyper phase shift keying space-time trellis coded modulation(HPSK ST-TCM). Fig. 3 depicts the BER performance comparisons among on HPSK ST-TCM system for different transmit and receiver antennas, over Rayleigh fading channels. Performance of the HPSK ST-TCM with different Numbers of transmit and receive antennas over Rician fading channels are illustrated in Fig. 4. It was shown that the performance of the HPSK ST-TCM system for larger numbers of transmit and receive antennas is much better than that of smaller numbers of transmit and receive antennas.

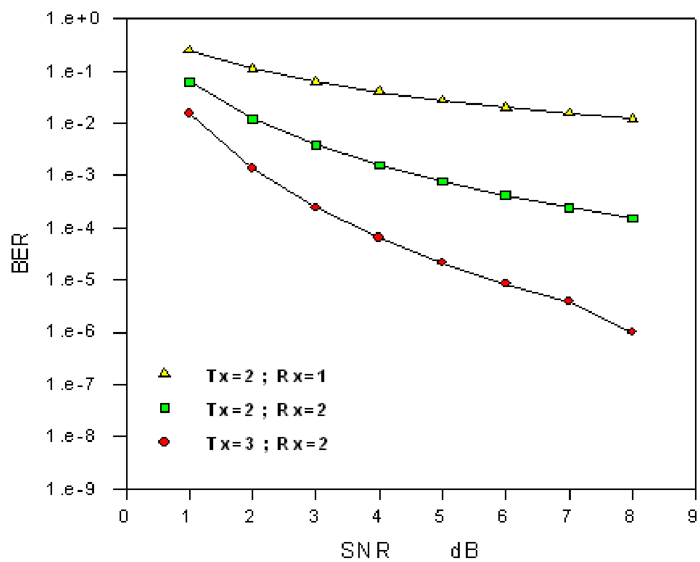

Fig. 3. Performance of the HPSK ST-TCM with different Numbers of Transmit and Receive Antennas over Rayleigh Fading Channels

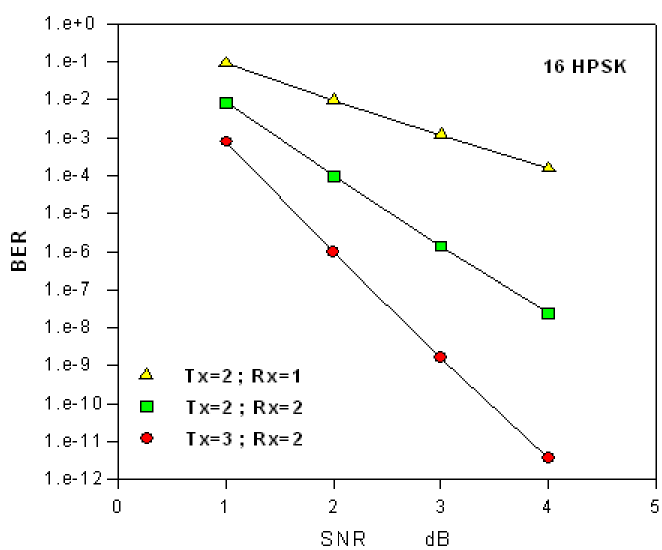

Fig. 4 . Performance of the HPSK ST-TCM with different Numbers of transmit and receive antennas over Rician Fading Channels

5. Conclusions

In this paper, a new family of codes called the Space–time hyper phase shift keying trellis codes (HPSK ST-TCM), using multiple transmit and receive antennas over Rayleigh and Rician wireless channels were considered.

HPSK is an excellent modulation technique that offers an improvement in BER. HPSK ST-TCM can benefit from both diversity and coding gains.

Performance is shown to be determined by matrices constructed from pairs of distinct code sequences. The minimum rank among these matrices quantifies the *diversity gain*, while the minimum determinant of these matrices quantifies the *coding gain*.

It was found that significant performance improvements could be achieved with increasing number of antennas from two to three transmit and receive antennas.

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