# Channel Estimation for Space-Time Trellis Coded-OFDM Systems Based on Non-overlapping Pilot Structure

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***Abstract* — The performance of space time trellis coded orthogonal frequency division multiplexing (STTC-OFDM) systems relies on accurate channel state information at the receiver for proper decoding. One method of obtaining channel state information is by inserting known pilot symbols periodically at the transmitted symbols. This paper investigates the performance of the STTC-OFDM system when non overlapping pilot structures are employed in channel estimation at the receiver. In this paper, the Frame Error Rate (FER) and Bit error rate performance of the STTC-OFDM scheme under various channel delay spread is compared with the case when channel state information is present at the receiver.**

***Index Terms*— Space time trellis codes, frequency selective channel, comb-type estimation, OFDM**

## I. Introduction

Next generation communication systems promise to offer a variety of multimedia services which requires reliable transmission at high data rate over wireless links. Multiple antennas when combined with orthogonal frequency division multiplexing (OFDM) is a promising technology in achieving spectral efficiency and throughput in wireless networks. Various forms of multiple antenna OFDM schemes have been proposed in the literature. These schemes include space time trellis coded-OFDM, space time block coded –OFDM and super-orthogonal space time trellis coded-OFDM schemes. The performance of the schemes as demonstrated in the literature assumes ideal channel state information, which is usually difficult to obtain, especially for time variant dispersive fading channels. This paper focuses on the space time trellis coded OFDM schemes.

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In the earlier works, various forms of STTC-OFDM schemes have been investigated in the literature [1] [2]. In [1] the STTC-OFDM scheme with no interleavors over quasi-static frequency selective fading channel was considered. The performance analysis of STTC-OFDM under various channel conditions in terms of the coding gain was presented. Through the analysis, two extreme conditions that produce the largest minimum determinant for a STTC-OFDM over multiple-tap channels were pointed out. The analysis show that the performance of the STTC-OFDM under various channel condition is based on: 1) the minimum determinant tap delay of the channel and 2) the memory order of the STTC. New STTC-OFDM schemes were later designed in [2] taking into account some of the designed criteria shown in [1].

The STTC-OFDM schemes are capable of achieving near optimal diversity gain when the receivers have perfect knowledge of the channels. In practice, the channel parameters have to be estimated at the receivers. Channel estimation techniques for conventional OFDM schemes have been studied in the literature extensively [3] [4]. However, channel estimation for STTC-OFDM schemes is complicated by the fact that signals transmitted simultaneously from multiple antennas become interference for each other during the channel estimation process. In [5], a decision-directed minimum mean square error (MMSE) channel estimator for space time coded-OFDM transmit diversity systems was proposed. The work noted that the MMSE channel estimation approach has a shortcoming of high complexity. The work later proposed the use of significant tap catching [6] method as a way of reducing the complexity of the decision-directed minimum mean square estimator. The significant tap catching approach only considers taps with large power impulse response. This method selects $M_o$ taps with large power among $K_o$ taps and set the unselected taps to zero. The estimator then estimates the channel response corresponding to the selected $M_o$ taps.

Although the significant tap catching approach reduces the complexity of the decision-directed minimum mean square estimator, this was at the expense of degradation in the channel estimation of the scheme. In [7], it was proposed that instead of estimating the multiple time varying channel impulse response using the decision-directed algorithm that would require the MMSE solution as in [5], the channel could be estimated by interpolating a set of estimated channel impulse response obtained by periodically inserting pilot symbols on the transmitted OFDM symbols. The pilot symbols are constructed to be non-overlapping and evenly distributed in frequency to allow for simultaneous sounding of the multiple channels. In this paper we use the approach in [7] to estimate the channel of the STTC-OFDM scheme but without the modified chirp sequence. The paper is organized as follows. Section II introduces the system model and in Section III, the channel estimation of the space time trellis coded OFDM scheme based on the non-overlapping pilot symbol and the time domain interpolation technique is described. In section IV, simulation results are shown to demonstrate the performance of the channel estimation algorithm. Finally, conclusions are drawn in Section V.

## II. SYSTEM MODEL

An OFDM transmission system with $N_t$ transmit antennas, $N_r$ receive antennas and $N$ sub-carriers are considered.

Each transmitted frame consists of $N_t$*$N$ M-PSK space time trellis coded symbol where the encoded symbol $s_i(n)$ represent the symbol transmitted from sub-carrier $n$ ( $n \in \{0,1,2,\ldots,N\text{-}1\}$) at the $i^{\text{th}}$ transmit antenna. After matched filtering, sampling and fast Fourier transform (FFT), the received signal at the $j^{th}$ received antenna, on the $n^{\text{th}}$ sub-carrier is given by

$$r_j(n) = \sum_{i=1}^{N_t} G_{ij}(n) s_i(n) + \eta_j(n) \qquad (1)$$

where $G_{ij}(n)$ is the channel frequency response from the $i^{\text{th}}$ transmit antenna to the $j^{\text{th}}$ receive antenna for the $n$th sub-carrier and $\eta_j(n)$ is the noise component at the receive antenna $j$ and sub-carrier $n$. The noise components are independently identical complex Gaussian random variables with zero-mean and variance $N_o/2$ per dimension. The time domain channel impulse representation between the transmit antenna $i^{th}$ and the receive antenna $j^{th}$ can be modeled as a $K_o$ tapped-delay line.

The channel response at time $t$ with delay $\tau_s$ can be expressed as

$$g_{ij}(\tau_s, t) = \sum_{k=0}^{K_o-1} \tilde{g}_{ij}(k,t) \partial\left(\tau_s - \frac{n_k}{N\Delta f}\right) \qquad (2)$$

where $\partial(\bullet)$ is the Kronecker delta function, $K$ denotes the number of non-zero taps, $\tilde{g}_{ij}(k,t)$ is the complex amplitude of the $k^{th}$ non-zero tap with delay of $n_k/N\Delta f$. Also, $n_k$ is the normalized time delay for the $k^{\text{th}}$ tap and $\Delta f$ is the tone spacing of the OFDM system. In (2) $\tilde{g}_{ij}(k,t)$ is modeled by the wide-sense stationary (WSS) narrowband complex Gaussian processes with power $E\left[\left|\tilde{g}_{ij}(k,t)\right|^2\right] = \sigma_k^2$, which is normalized as $\sum_k^{K_0-1} \sigma_k^2 = 1$. The time index $t$ in (2) can be omitted since we assume that the channel in one STTC-OFDM frame is static i.e. a quasi-static channel.

For an OFDM system with proper cyclic prefix, proper sampling and tolerable leakage, the channel response is expressed as

$$G_{ij}(n) = \sum_{k=0}^{K_o-1} g_{ij}(k) \exp(-j2\pi \bullet n \bullet n_k / N) \qquad (3)$$

where $g_{ij}(k)$'s for $k$=0,1,2,…,$K_o$-1 are narrowband zero-mean complex Gaussian processes for different $i$ and $j$.

## III. CHANNEL ESTIMATION OF STTC-OFDM

### *A System Description*

Channel state information can be obtained through two types of methods. One is called the training-based (i.e. Pilot symbol assisted) channel estimation [7], which is based on the pilot data sent at the transmitter and known a-priori at the receiver. The other is called blind channel estimation [8], which explores the statistical information of the channel and certain properties of the transmitted signals. Though the blind estimation method has no overhead loss, it is only applicable to slowly time varying channel due to its need for long data record and has high complexity. Pilot symbols assisted channel estimation has been shown in literature to be very attractive for wireless link where the channel is time varying. The two main pilot approaches to channel estimation are; 1) Block-type pilot channel estimation and 2) Comb-type pilot channel. The estimations for the block-type pilot arrangement can be based on least square (LS), MMSE and modified MMSE. The comb-type pilot channel estimation is an algorithm that estimates the channel at pilot frequencies and interpolation for the data sub-carrier. The estimation at the pilot sub-carrier can be based on LS, MMSE or Least Mean-Square (LMS) while the interpolation to obtain the channel at the data sub-carrier can depend on linear interpolation, second order interpolation, low pass interpolation, spline cubic interpolation and time domain interpolation. The time domain interpolation has been proven to give lower bit-error (BER) when compared with linear interpolation [9].

Since the different signals from the STTC-OFDM scheme tends to interfere with each other, pilot symbols can be constructed for this scheme to avoid this form of interference and thus, simplify the task of channel estimation at the pilot mode. An obvious choice is to have the pilot symbols at the transmitter to non-overlapping. Figure 1 shows the pilot symbol patterns for a two transmit STTC-OFDM scheme.

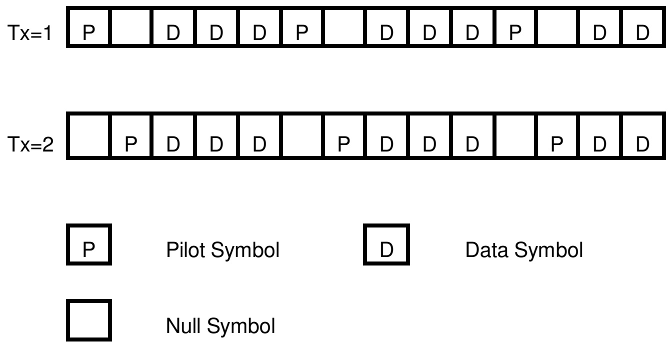


**Figure 1: Pilot Symbol pattern for STTC-OFDM with $N_t$=2**

Since the pilot symbols are known at the receiver and, during the pilot instant, each received symbol contains only the contribution from one transmitter, the least square estimate at that instant can be easily calculated.

The estimate of the channel at pilot instant *p* based on the least square estimation is given by

$$\tilde{G}_{ij}(p) = \frac{r_j(p)}{s_i(p)} \qquad (4)$$

where $\tilde{G}_{ij}(p)$ is the estimate of the channel frequency response for the $i^{th}$ transmit antenna to the $j^{th}$ receive antenna , $r_j(p)$ is the received signal for the $j^{th}$ and $s_i(p)$ is the known pilot symbol for the $i^{th}$ transmit antenna.

*B Time Domain Interpolation*

The time domain interpolation is a high-resolution interpolation based on zero-padding and DFT/IDFT [10]. After obtaining the estimated channel at various pilot instances, we first convert it to time domain by IDFT

$$H(p) = \sum_{k=0}^{N_p-1} \tilde{G}_{ij} e^{j\frac{2\pi * n * p}{N_p}} \qquad p = 0,1,\dots,N_p-1 \qquad (5)$$

where $N_p$ is the total number of inserted pilot.

The basic multi-rate signal processing properties [11] can be used to interpolate the signal by transforming the $N_p$ point into N point with the following method

$$Y = \frac{N_p}{2} + 1$$

$$H_N = \begin{cases} H_p, & 0 \le n < Y-2 \\ 0, & \frac{N_p}{2} \le N - Y \\ H_p(n-N+2Y-1) & -Y \le n-N < -1 \end{cases} \qquad (6)$$

The estimate of the channel at all frequencies is obtained by

$$\tilde{G}_{ij}(n) = \sum_{n=0}^{N} H_N(p)\, e^{-j\frac{2\pi * p * n}{N}}, \quad 0 \le n \le N-1 \qquad (7)$$

## IV. Simulation Results

In this section, we compare the error rate of a 16-state STTC-OFDM (whose trellis is shown in Figure 2) scheme under various delay spreads using the non-overlapping pilot symbol to estimate the channel with the scenario when channel state information is present at the receiver.

The entire wireless channels involved are quasi-static Rayleigh channels with average power of unity. The total power of the transmitted coded symbol was normalized to unity. We assumed an equal-power, two path channel impulse response (CIR), where the CIR taps are separated by a delay spread. The maximum Doppler frequency was 200Hz. The entire multipath channel undergoes independent Rayleigh fading and the receiver is assumed to have perfect knowledge of the channels for the case where the channel has perfect channel state information (CSI) at the receiver and for the estimated channel scenario, non-overlapping pilots are inserted at every uniform distance of six symbol.

The STTC-OFDM system is assumed to have a bandwidth of 1 MHz, 120 OFDM subcarriers, $N_t$ = 2 while $N_r$ = 1 and $K_o$ = 2.

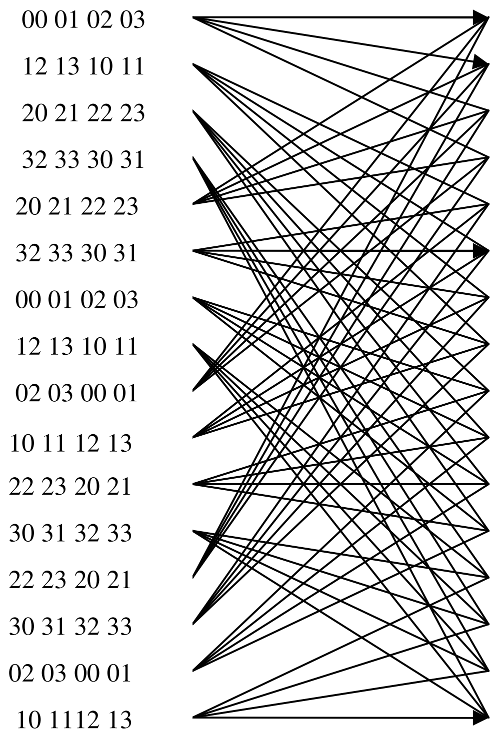


**Figure 2: QPSK 16-state Space time trellis code**

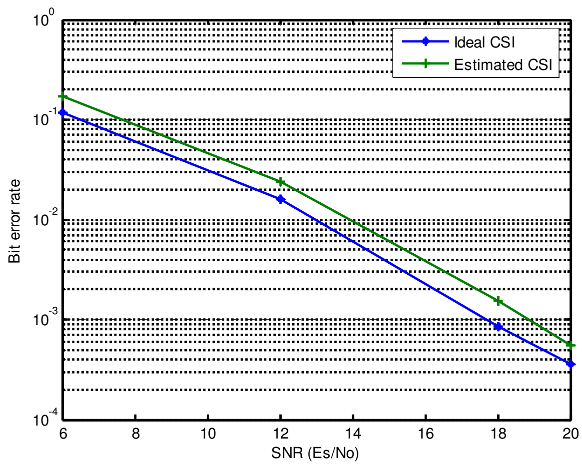


**Figure 3: Performance comparison of the BER of 16-state STTC-OFDM systems with ideal CSI and estimate CSI with no delay spread**

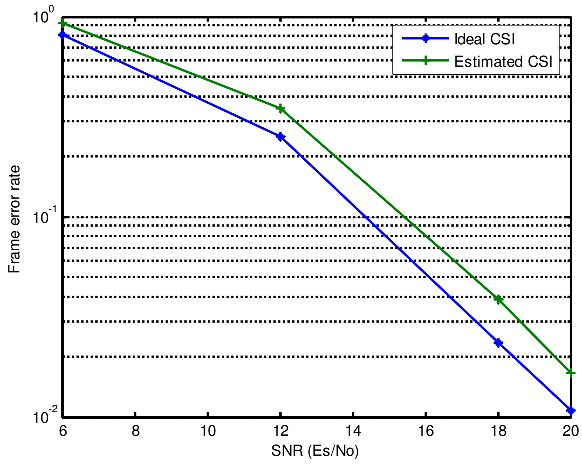


**Figure 4: Performance comparison of the FER of 16-state STTC-OFDM systems with ideal CSI and estimate CSI with no delay spread**

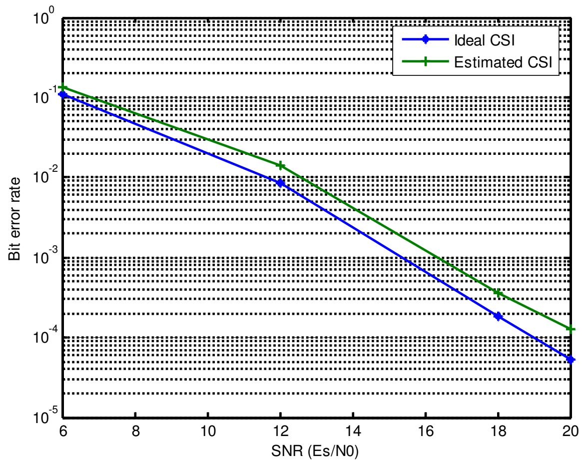


**Figure 5: Performance comparison of the BER of 16-state STTC-OFDM systems with ideal CSI and estimate CSI with 5μs delay spread**

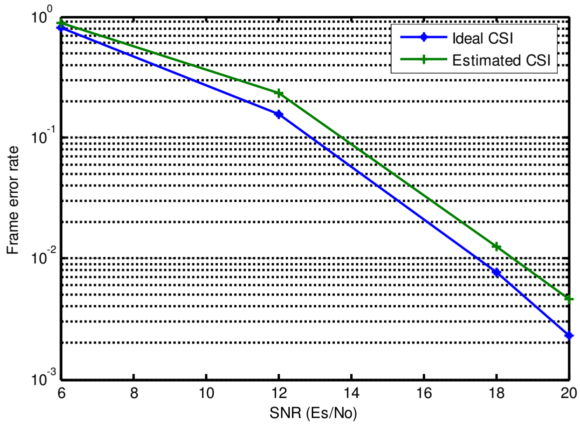


**Figure 6: Performance comparison of the FER of 16-state STTC-OFDM systems with ideal CSI and estimate CSI with 5µs delay spread**

Figures 3, 4, 5 and 6 shows the performance comparison of the BER and the FER for the 16- state STTC-OFDM systems for various delay spread scenarios.

The figures show an error rate degradation of approximately 1dB when compared with the ideal channel state information of the STTC-OFDM for various delay spread scenarios. Also the result shows that an increase in coding gain is obtained when there is an increase in the delay spread.

## V. Conclusion

This paper shows the performance comparison of a 16-state STTC-OFDM scheme for various delay spread scenarios when non-overlapping pilot structure is used to estimate the channel. The results show a simplified method of estimating channel parameters for transmit diversity schemes.

## References


[1] Y. Hong, J. Choi, and X. Shao, “Performance analysis of space time trellis coded OFDM over quasi-static frequency selective fading channel,” in Proc. IEEE ICIC-PCM, Singapore, pp. 1-5, Dec. 2003.

[2] Hong, J. Choi, and X. Shao, “Robust space time trellis codes for OFDM systems over quasi-static frequency selective fading channels,” in Proc. IEEE PIMRC, Beijing, China, vol. 1, pp. 434-439, Sept. 2003.

[3] J. J. van de Beek, O. Edfors, M. Sandell, S.K. Wilson, and P.O. Borjesson, “On channel estimation in OFDM systems,” in Proc. IEEE Global Telecommunication Conference, vol. 3, pp. 815-819, Chicago, July 1995.

[4] P. Hoecher, S. Kaiser, and P. Robertson, “Pilot-symbol aided channel estimation in time and frequency,” in Proc. IEEE Globecom Communications Theory Mini-Conference, vol. 3, pp. 90-96 USA, November 1997

[5] Y. Li, N. Seshadri, and S. Ariyavisitkul, “Channel estimation for OFDM systems with transmitter diversity in mobile wireless channels,” IEEE Journal on Selected Areas in Communications, vol. 17, no. 3, pp. 461-471, 1999.

[6] Y. Li, “Simplified channel estimation estimation for OFDM systems with multiple transmit antennas,” IEEE Transaction on Wireless Communication, vol. 1, pp. 67-75, January 2002.

[7] K. F. Lee and D. B. Williams, “Pilot-Symbol-Assisted Channel for Space-Time Coded OFDM Systems,” EURASIP Journal on Applied Signal Processing, vol. 5, pp. 507-516, 2002.

[8] Wei Bai *et. al.*, “Blind channel estimation in MIMO-OFDM systems,” IECE Transaction on Communication, vol. E85-B, no. 9, pp. 1849-11853, October 2002.

[9] Y. Shen, and E. Martinez, “Channel estimation in OFDM systems,” Freescale semiconductor Inc., Application notes.

[10] Y. Zhao and A.Huang , “A novel channel estimation method for OFDM Mobile Communications Systems based on pilot signals and transform domain processing,” in Proc. IEEE 47th Vehicular Technology Conference, pp. 2089-2093, USA, May 1997.

[11] A. V. Oppenhein and R. W. Schafer, “Discrete-Time Signal Processing”, New Jersey, Prentice-Hall Inc., 1999.


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