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Multiple Antenna Channel Codes for Satellite Communication

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Abstract—**In this paper multiple antenna channel codes, i.e. Space-Time Block Code, Space-Time Trellis Code and Super-Orthogonal Space-Time Trellis Code, are examined in a satellite communication, comparing the gain that the multiple antenna channel coding techniques provide to the communication system. The satellite channel for urban area, modeled as a combination of Rayleigh and log-normal processes with the presence of Additive White Gaussian Noise is also studied. The performance of the communication system is assesed by the commonly used Bit Error Rate (BER)/Signal to Noise Ratio (SNR) diagram. As stated in the results section, the multiple antenna channel codes used in a satellite communication system provides remarkable results as compared to those in terrestrial wireless communications.**

Index Terms—**Satellite communication channels, diversity, space-time codes, fading channels.**

I. Introduction

OWING to the need to transfer information (i.e. voice and data) in a fast, reliable and affordable way, the wireless communication world has been experiencing exponential growth to keep up with todays demand. This is evident in the historical progression growth from the first generation technologies (1G), second generation (2G) technologies, third generation (3G) technologies, and now the much talked about fourth generation (4G) wireless technologies.

Some of the major features of these emerging technologies are the ambitious goal of providing unlimited mobility for the user and guaranteing network service anytime and anywhere. The importance of satellite communications in such a scenario is expected to be very significant, since satellite communication systems have an inherent ability to cover a very wide area.

Although 1G and 2G technologies were based exclusively on terrestrial links i.e. analogue and digital, respectively, more recent technologies e.g. 3G, have developed in them the Satellite part. The Satellite-Universal Mobile Telecommunication System (S-UMTS) stands for the satellite component of the UMTS [1]. As an integral part of UMTS, the S-UMTS will complement the terrestrial UMTS (T-UMTS) and interwork with other technologies to form the core network of the UMTS. The development of the S-UMTS will be important in order to provide the anytime-anywhere service, increased capacity, low complexity mobile teminal and spectral efficiency.

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The S-UMTS implies a network with both terrestrial wireless and satelite communication channels. However, the presence of a satellite segment introduces some key issues in the systems such as ensuring adequate signal to noise ratio and maximizing spectral efficiency.

One way of maximizing spectral efficiency in an hybrid network such as this, is to employ specially designed multiple antenna channel codes at the terestrial part of the network.

Multiple antenna channel codes i.e. Space-Time Block Code (STBC) [2] [3], Space-Time Trellis Code (STTC) [4] and Super-Orthogonal Space Time Trellis Code (SOSTTC) [5] are bandwidth efficient multiple antenna channel codes that can increase system capacity through antenna diversity. These codes use the combination of conventional channel coding design criteria, modulation techniques and multiple antenna diversity techniques in their design. Multiple antenna channel coding schemes give a better error rate performance when compared with an uncoded scheme. These multiple antenna channel codes are discussed briefly later in this paper.

In this paper, the performance of multiple antenna channel codes in a mobile-satellite communication link is studied. The error rate performance of majorly known multiple antenna channel codes i.e. STBC, STTC and SOSTTC is studied in a land mobile satellite channel.

The outline of the paper is as follows. In section II, various land mobile satellite channel models are briefly discussed. The design structure of the various multiple antenna channel codes are given in section III. The system structure is delineated in section IV. Simulation results are presented in section V, while conclusion remark are drawn in section VI

II. Land Mobile Satellite Channel Models

The design of a good communication system begins with a thorough understanding of the communication channel. The objective is to provide reliable communication that meets the QoS objectives, without overdesigning the system. The Land Mobile Satellite Channel (LMSC) is an integral part of the satellite communication system. The LMSC is susceptible to impairments such as, Multipath fading, Shadowing, Doppler shift and Interference.

Multipath fading happens due to the scattering of the signal. Shadowing occurs when the signal is blocked by buildings, trees and hills. These blockages are common features in an urban environment and mountaineous regions. The relative velocity between the satellite and the mobile terminal causes the Doppler Shift. Interference is possible from terestrial systems and other satellite systems and from self-interference, in the form of multiple access environment.

The modelling of LMSC is an active area of research. In [6] and [7] a survey of the LMSC available in literature was done. The four main categories of channel models for LMSC are given as:

- Analytical Models - These channel modelling category uses techniques such as ray tracing to determine the channel model of an LMSC system [8] [9]. Ray-tracing is based on a branch of physics called ray theory. When used to model electromagnetic waves, the waves are approximated by narrow beams. These techniques can accurately model the propagation path of a wave if the objects that interact with the wave have much greater dimensions than the wave length of the wave. However interference and diffraction of a wave cannot be modeled by ray-tracing. One main advantage of the analytical models is that they can accurately derive the physical property of an LMSC but can be computational intensive due to the complexity of such models.
- Empirical Models - These are models that are derived by studying measurement made in a LMS communication system [10]. A model is then created by fitting a certain curve to the measured data. The empirical models can be grouped into vegetative attenuation based models [11] and link budget calculation based models [12]. The vegetative attenuation based model only calculates the losses a radio signal suffers when propagating through tree cover and is therefore not a complete LMSC model on their own, but is usually incorporated into LMSC model for rural and suburban environment. The link budget calculation based models were developed based on getting an approximation of all the losses that the LMS system will experience.
- Statistical Models - These are models formed based of the statistical property of the propagation of signal in an LMS system. Statistical models for LMS systems can be grouped in two main categories:
  - Fading distribution - These type of models are derived for a flat fading LMSC. The Loo's model [13] is an example of such model. The Loo's model assumed that there are two signal distortion component that characterise the LMSC. The line of sight (LoS) component suffers from foliage attenuation and is lognormally distributed, while the multipath component's attenuation is Rayleigh distributed. The mathematical expression describing the channel process h is:

    $$\mathsf{h} = \mathsf{L}e^{j\phi_0} + \mathsf{R}e^{j\phi} \quad (1)$$

    where L is lognormally distributed and is added to R which is Rayleigh distributed and ϕ, ϕ_0 are uniformly distributed between 0 and 2π.

    Other model examples in this category includes: Rice-Lognormal (RLN) model, generalised RLN model, Hwang model and Poca-lognormal model [6].
  - State-orientated modelling - For these models Markov chains are used to choose between different states of the channel. For LMSC these states are usually connected to different fading distribution such as lognormal, Ricean, Rayleigh or even a combination of fading distributions. Examples of such models are Lutz Model [14] and Gillespie model [15].
- Hybrid Models - These models involve in their design combination of the earlier discussed methods. For example, the roadside vegetation attenuation model proposed in [16] is a combination of an empirical model and a statistical model.

III. Multiple Antenna Channel Codes

Multiple antenna channel codes are specially designed channel codes for multiple antenna network. These codes are bandwidth efficient and do not sacrifice diversity over a wireless channel. Brief description of these channel codes is given in the following sections.

A. *Space-Time Block Code*

Alamouti first presented a transmit diversity technique, for two transmit antennas, with a simplified decoding algorithm [2]. This scheme was later called STBC in [3]. Based on these later works, the Alamouti codes were extended to more than two transmit antennas using the theory of orthogonal design. The theory of orthogonal design enables the use of a simple maximum-likelihood decoder that is based on linear combining at the receiver. Based on this theory, two types of STBC can be generated. The first type, real orthogonal design, is based on real constellation such as pulse amplitude modulation, while the second type, complex orthogonal design, is based on complex constellations, e.g. phase-shift keying and quadrature amplitude modulation. The transmission matrix for a two transmit antenna complex orthogonal design is given by:

$$\mathbf{C} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}. \quad (2)$$

B. *Space-Time Trellis Code*

STTC was invented by Tarokh et al. [4] as a way of combining signal processing with a multiple antenna system to produce a system with an improved gain over the earlier transmit diversity schemes [17]. The STTC proposed in [4] was handcrafted and gives the best compromise in terms of constellation size, data rate, diversity advantage and trellis complexity when compared with other space time trellis coded schemes [17].

The encoder system of an STTC is based on a one-input symbol at a time and a sequence of output symbols, whose length represents the number of transmit antennas.

The trellis diagram for a four-STTC is shown in Figure 1. At each time t , the encoder is in a generic state. The input bit streams to the space-time encoder are divided into groups of two bits, a_1a_2 . Each group 00, 01, 10 or 11 then selects one of the four branches originating from the corresponding state. The branches are then mapped for every transmit antenna into one of the four constellation points on the QPSK constellation. The edge labels y_1y_2 in Figure 1 are associated with the four transitions from top to bottom and indicate that symbols y_1 and y_2 are transmitted simultaneously over the first and second antennas, respectively. The encoder moves to the next state after transmission of the couple of symbols. At the decoder, based on the received estimate and using the maximum likelihood (ML) method, a decoding algorithm is then used to search for the best path. Viterbi algorithm is then used to search for the path with the least decoding metric.

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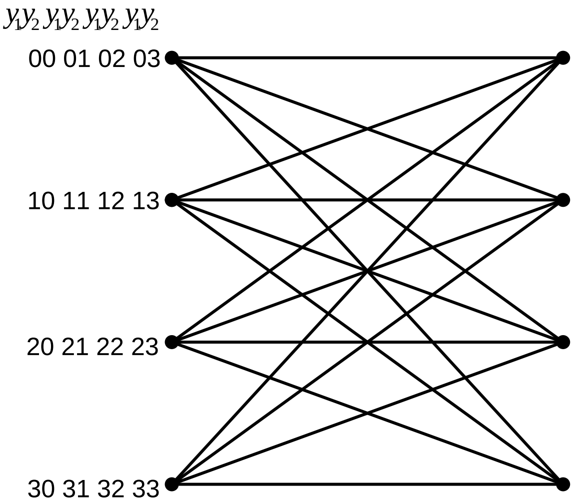

Fig. 1. Four-state QPSK STTC

C. Super-Orthogonal Space-Time Trellis Code

By combining the advantages of both STTC and STBC, a new channel code for multiple antenna systems called SOSTTC was developed [5]. The SOSTTC uses sets of super-orthogonal block codes (SOBC) and set partitioning technique in its construction. The sets of SOBCs are obtained by rotating the original block code by an angle θ. This code gives an improved coding gain and diversity order when compared with other space-time coding schemes, i.e. STTC [4] and STBC [2]. The main idea behind SOSTTC is to consider STBCs as a modulation scheme for multiple transmit antennas and assign an STBC with specific constellation symbols to transitions emanating from a state. For a $\mathrm{T} \times N_t$ STBC, picking a trellis branch emanating from a state is equivalent to transmitting $\mathrm{T}N_t$ symbols from the N_t transmit antennas in T time intervals. By doing so, it is guaranteed that the diversity of the corresponding STBC is preserved.
The SOBC transmission matrix used in the design of SOSTTC for $N_t = 2$ is given by:

$$\mathbf{X}(x_1, x_2, \theta) = \begin{bmatrix} x_1 e^{j\theta} & x_2 \\ -x_2^* e^{j\theta} & x_1^* \end{bmatrix}. \tag{3}$$

In equation (3) $x_i \in e^{j\frac{2\pi\acute{a}}{\mathrm{M}}}$ represent the M-PSK signal constellation. The angular rotation θ is equivalent to $2\pi\acute{a}/\mathrm{M}$ where $\acute{a} = 0, 1, \cdots, \mathrm{M}-1$. Despite the angular rotation of the transmitted signal, the matrix elements of equations (3) are still members of the M-PSK constellation and the signal constellation is not expanded. For BPSK signal constellation, $\theta = 0$ or π while for a QPSK signal constellation, $\theta = 0$ or $\pi/2$ or π or $3\pi/2$. When θ in equation (3) is zero, the Alamouti code is obtained.
The trellis diagram for a two-state and a four-state SOSTTC scheme is given in Figure 2. In the trellises in Figure 2, each path converging and diverging to a state consists of eight parallel paths. The state labels, i.e. $\mathbf{X}_i$ and $\mathbf{Y}_i$ are sets of SOBC given in equation (4).

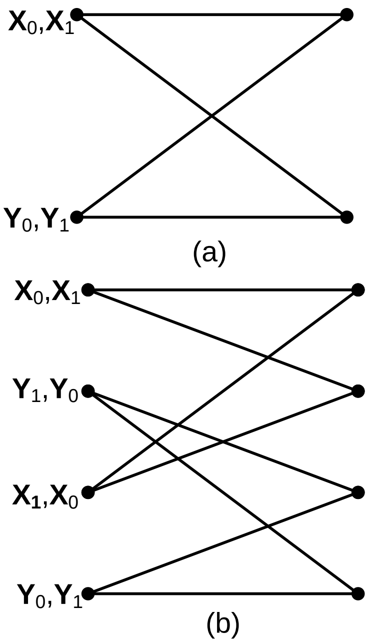

Fig. 2. Two-state (a) and four-state (b) QPSK SOSTTC

$$\begin{aligned} \mathbf{X}_0 &\equiv \{(\pm 1, \pm 1, 0), (\pm j, \pm j, 0)\} \\ \mathbf{X}_1 &\equiv \{(\pm 1, \pm j, 0), (\pm j, \pm 1, 0)\} \\ \mathbf{Y}_0 &\equiv \{(\pm 1, \pm 1, \pi), (\pm j, \pm j, \pi)\} \\ \mathbf{Y}_1 &\equiv \{(\pm 1, \pm j, \pi), (\pm j, \pm 1, \pi)\} \end{aligned} \tag{4}$$

In each set of the SOBC e.g. $\mathbf{X}_i$, eight different block codes are possible. These block codes are obtained by substituting the symbol elements $\{+1, -1, j, -j\}$, for a QPSK symbol constellation into the orthogonal matrix given in equation (3). The corresponding orthogonal block codes are then transmitted on the trellis branch.

IV. System Structure

The general structure of the simulated system can be seen in Figure 3. The data to be transmitted is coded with the multiple antenna channel codes and then send over the Loo's model of the land mobile satellite channel. The Loo's channel model was used as it takes into account the direct as well as the diffuse-multipath component of the channel property. At the receiver, simple maximum likelihood algorithm is used to decode the transmitted signal. The multiple antenna channel codes used in our studies uses two transmit antennas and one receive antenna.

In the next section, simulation results for terrestrial wireless channel are also presented, for the sake of comparison. The terrestrial wireless channel is assumed to contain only diffuse-multipath component and no LOS component. The channel coefficient for the terrestrial wireless channel is modelled as samples of independent complex Gaussian random variables with variance of 0.5 per real dimension, which results in a Rayleigh distribution with variance of 1. The channel estimation is assumed to be perfect at the receiver.

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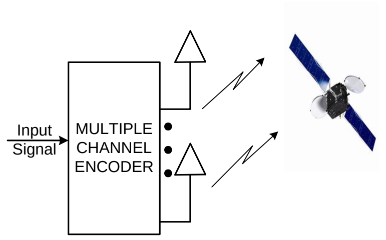

Fig. 3. System Structure

V. Simulation Results

The proposed systems simulation are shown to demonstrate the bit error rate (BER) performance of the multiple antenna channel coded scheme in both terestrial and satellite environment. The wireless channels are assumed to be flat fading. The total power of the transmitted coded symbol was normalized to unity and a frame length of 256 bits used at the transmitter. In Figures 4, 5, 6 and 7, the BER performance of multiple antenna channel codes with and without an LMSC model are given. The Figures show that there is a coding gain advantage of the multiple antenna channel codes in an LMSC environment as compared to the terestrial channel environment (i.e. without LMSC). This is evident in the downward shift of the error rate curves. In the Figures, it is apparent that an uncoded transmission with LMSC yield a better performance than one without LMSC. When multiple antenna channel codes are applied the system performs even better. The performance gain of the multiple antenna channel code in the LMSC environment can be attributed to the coding gain provided by the schemes and the LOS component of the LMSC model.

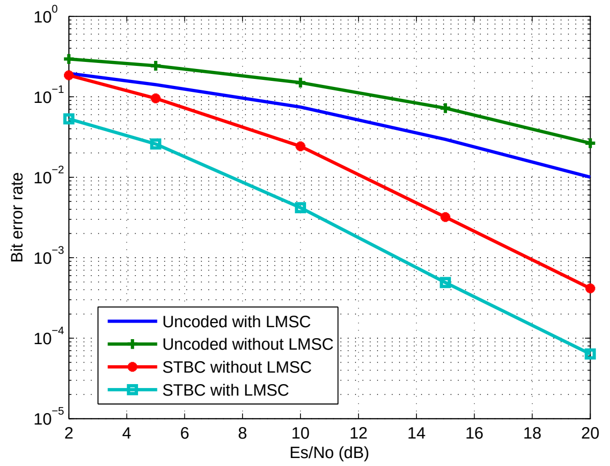

Fig. 4. BER performance of QPSK STBC with and without satellite channel

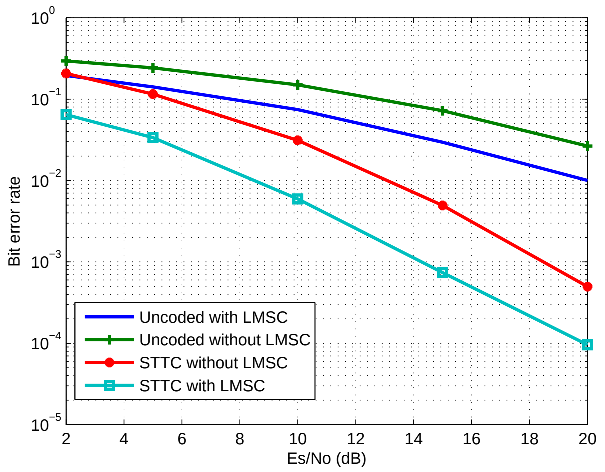

Fig. 5. BER performance of QPSK 4-state STTC with and without satellite channel

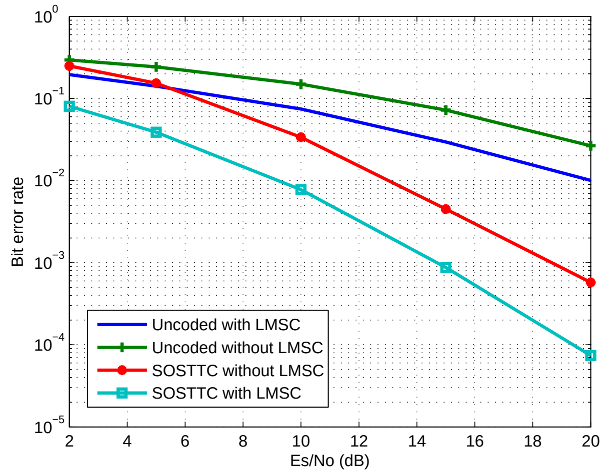

Fig. 6. BER performance of QPSK 2-State SOSTTC with and without satellite channel

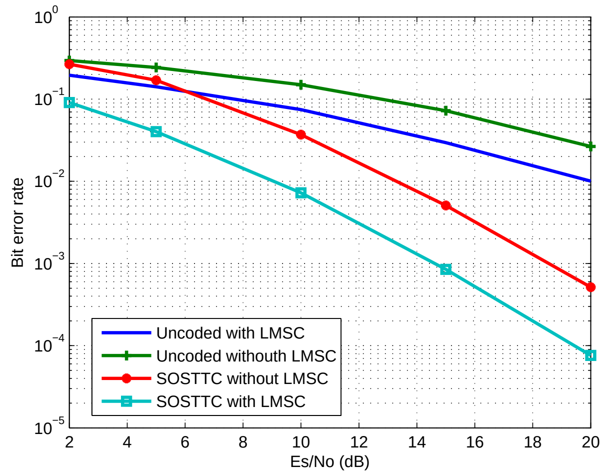

Fig. 7. BER performance of QPSK 4-State SOSTTC with and without satellite channel

VI. Conclusion

This paper examine the BER performance of multiple antenna channel codes, i.e. STBC, STTC and SOSTTC in a satellite channel. The multiple antenna channel codes appears to be quite beneficial in terms of BER performance for the LMSC. The multiple antenna channel codes shows an increased coding gain advantage in the LMSC environment as compared to the terestrial channel environment. The overall conclusion coming out of this study is that satellite communication can profit a lot when multiple antenna channel codes are incoporated in its design.

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