Multilevel Spatial Multiplexing -Space Time Trellis Coded Modulation System for Fast Fading MIMO Channel

K.Kavitha [#1], H.Mangalam [*2]
[#] Dept. of Electronics and Communication Engineering,
Kumaraguru College of Technology, Coimbatore, India.
[1] kavitha.k.ece@kct.ac.in
[*] Dept. of Electronics and Communication Engineering,
Sri Krishna College of Engineering & Technology, Coimbatore, India.
[2] mangalam@skcet.ac.in

Abstract—Multilevel Space Time Trellis Coded Modulation with antenna grouping, which has been proposed recently, has coding gain and diversity gain, which in turn provide high throughput with considerable low computational complexity. However its performance is limited by predefining the antenna groups per component codes. In this paper Multilevel Spatial Multiplexing-Space Time Trellis Coded Modulation (ML-SM-STTCM) has been proposed, in which antenna group selection is made based on spatial modulation based on trellis coding proposed by Ertugrul Basar and team. This idea maximizes the spatial diversity. Since only selected antennas are used to transmit the signal, and also the antennas with less cross correlation are in the selected groups, we could able to achieve improved BER performance even in the fast fading channel. Since the antenna selection is based on the component code in the system, at the decoder without increase in the computational complexity, we could achieve better error performance. The performance of the proposed system is analysed with Viterbi decoding algorithm and sub optimal sequential decoding algorithm. In this system, the antenna groups are non-overlapping, hence, it needs N_t, the number transmitter antennas, more than what is required at time *t*. The computer simulation reveals that the proposed system gives better BER performance compared to Multilevel Space Time Trellis Coded Modulation (ML STTCM) over fast fading channel with the same computational complexity both at the transmitter and receiver.

Keyword- Multilevel codes, Fast fading channel, MIMO, ML-STTC, ML-SM-STTC, Sequential decoding

I. INTRODUCTION

A robust wireless communication system for a fast fading environment is a highly challenging research problem. The wireless channel suffers with fading, due to multipath effect and Doppler spread, due to relative motion between transmitter and receiver. There are many solutions available to mitigate the impairments caused by the channel. However, the volume of data produced by the high definition multimedia transmissions and the dwindling band width availability makes wireless data transmission is a challenging research topic.

In the recent years Multiple Input Multiple Output (MIMO) [1],[2] system gains attention of the research community, since it provides increase in through put by both coding and diversity gain with the given bandwidth. The important issues in this topic are effective code design and computational complexity. Multilevel coding [6] is one of the solutions to achieve bandwidth efficiency with minimum computational complexity[11]-[15]. And also, it has been proved that by applying spatial Multiplexing we could improve the BER performance further [3]-[5],[16].

In the reference [5] the transmitter antennas divided into groups and data is transmitted through component codes assigned for each antenna group. At the receiver combined array processing is used to decode the sequence, with which they achieved high through put. In the paper [7],antenna subset selection method based on channel state information at the transmitter is proposed and proved that we could achieve increase in throughput.

The Grouped multilevel space time trellis coded system (GMLSTTC) proposed in [8], is an attractive bandwidth efficient, low computational complex system where, they combined multilevel coding, antenna grouping and STTCM. In GMSTTC with multilevel coding they achieved reduced computational complexity. It has been shown in [9] that by introducing beam forming at the transmitter, we could further improve throughput with ML-STTC. However, having CSI at the transmitter is another big issue. In these systems the predefined antenna grouping is considered as limitation to its performance.

In this paper, the Multilevel Space Time Trellis Code is combined with antenna group selection is proposed. The transmitter antennas are divided into groups of low correlated antennas. Only a group of antennas are selected at one signalling time based on trellis based component code [3]. The receiver decodes the sequence using Viterbi algorithm. An approximate branch metric calculation is also proposed to reduce the computational complexity. Further, the system is analysed with sequential decoding algorithm and the simulation results shows that the BER performance is almost same as the Viterbi decoder.

For comparison purpose ML-STTC system with same computational complexity is also simulated and analysed with the proposed system. The results reveal that the BER performance of the proposed system is better compared to ML-STTC system in fast fading environment. This shows that the antenna group selection enhances the diversity gain.

The paper is organized as follows. In Section II the system model for the proposed Multilevel Spatial Multiplexing Space Time Trellis Coded Modulation, encoding and decoding algorithms are given. Section III provides the simulation results and some conclusions are given about the proposed system in Section IV.

II. SYSTEM MODEL

The model of $N_t \times N_r$ two stage Multilevel SM-STTCM system, shown in the Fig.1, is considered. In this paper SM STTC [3] encoder and STTC [2] encoder with the trellis shown in the Fig. 2 is taken as a component codes for analysis. The serial input binary data are demultiplexed by $1 \times n$ demultiplexer and first m_1 bits are given to the SM STTC encoder and the rest (m_2) is given to the STTC encoder.

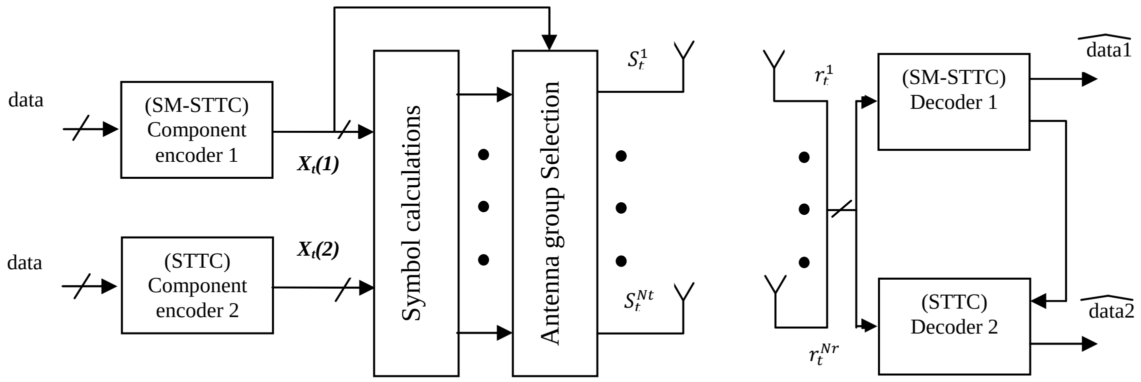

Fig.1 Block diagram of multilevel STTC with Spatial Modulation

A. Encoder

In this system, the number of transmitter antennas N_t needed, is calculated based on the SM-STTC and STTC encoder used. N_t is calculated as $N_t = Pn_t$, where P is the number of signal groups based on SM-STTC encoder and n_t is the number transmitter antenna in the STTC encoder. The signals from N-QAM constellation is grouped into P groups of M-QAM signals, using set partitioning algorithm (N=PM) [9]. In this paper, full diversity component codes are considered for analysis. For example, a two stage system with 4 state, 4-QAM, SM-STTC encoder and 4-state, 4-QAM, $n_t = 2$, STTC encoder, we need 16-QAM signals and 8 transmitter antennas. These 8 antennas are divided in to 4 groups with 2 antennas.

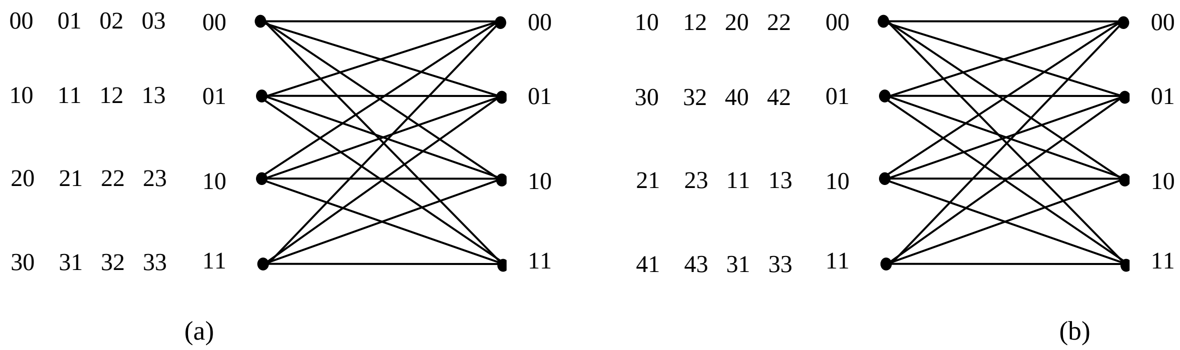

Fig. 2 Trellis diagram of the (a) STTCM and (b) SM-STTCM encoder

In the first level SM-STTC encoder output, the first $log_2(P)$ bits are used to choose the antenna group and the remaining bits are used to select the constellation group. The second stage STTC [2] encoder output is transmitted with the selected antenna /constellation set by the first encoder.

Let, $[n_{s1,}n_{s2,} \dots . n_{sn_t}]$ are the n_t selected antennas numbers among N_t antennas at time t, the transmitted signal from each antenna is calculated as,

$$S_t^i = \begin{cases} d_{x(1)}\ x_t(1,2) + d_{x(2)}\ x_t(2,i), & i \in [n_{s1,}n_{s2,} \dots . n_{sn_t}] \\ 0 & , \quad otherwise \end{cases} \quad , \quad for\ i = 1,2, \dots ., N_t \tag{1}$$

Where, $d_{x(1)}$, $d_{x(2)}$ are the subset distances corresponding to the level1 and level2 encoder. Fig.3 shows the signal groups with sub-set distances.

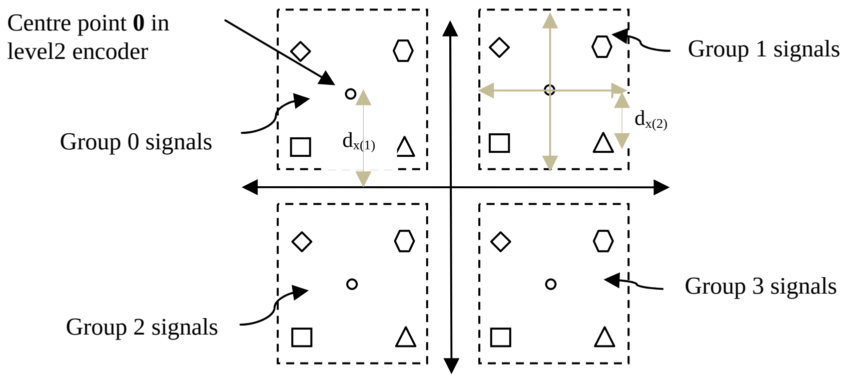

Fig.3 16-QAM constellation diagram with signal grouping for *M*=2,*P*=2 system

In this paper, $d_{x(1)}$=2 ,$d_{x(2)} = 1$ and $\{ x_t(1,2), x_t(2,i) \in \{-1+j, 1+j, -1-j, 1-j\}$ is considered for analysis.

B. Decoder

The signal is transmitted via MIMO channel and the received signal at *j*th antenna at time *t* is give as,

$$r_t^j = \sum_{i=1}^{N_t} h_{ij}^t S_t^i + \eta_t^j, \quad j = 1,2, \dots, N_r \tag{2}$$

Where, h_{ij}^t is the path gain of quasi static flat fading Rayleigh channel and η_t^j is zero mean complex Gaussian random variable with variance $\frac{N_0}{2}$.

The received signal is first decoded with the SM-STTC Viterbi decoder with the trellis shown in the Fig. 2. The *i*th branch metric for the Viterbi algorithm is given as,

$$B_i = \max_{\tilde{X}(2)\in\{X(2)\}}, \sum_{j=1}^{N_r} \left| r_t^j - \sum_{x=1}^{n_t} h_{nsxj}^t [d_{x(1)} x(1,2)^i + d_{x(2)} \tilde{x}(2,x) \right|^2 \tag{3}$$

The proposed simplified branch metric of the *i*th branch, for the first stage decoder is given as,

$$B_i = \sum_{j=1}^{N_r} \left| r_t^j - h_i^t d_{x(1)} x(1,2)^i \right|^2 \tag{4}$$

Where, h_i^t is the sum of path gain of the antennas in the antenna group corresponding to the *i*th branch. With this we could reduce the number of computations by number of branches in the trellis of next level code. For the given example, it is reduced by 16 times compared to the calculation given in the equation 3.

Then, the decoded data is given to the second Viterbi decoder meant for level2 STTC encoder. The *i*th branch metric for the decoder2 is given as:

$$B_i = \sum_{j=1}^{N_r} \left| r_t^j - \sum_{x=1}^{n_t} h_{\widehat{n_{sx}},j} [d_{x(1)} \hat{x}(1,2) \quad + d_{x(2)} x(2,x)^i \right|^2 \tag{5}$$

Where $\widehat{n_{sx}}$ represents the transmitter antenna numbers in the estimated antenna group and $\hat{x}(1,2)$ is the estimated signal group by the first encoder, among N_t transmit antennas and *N*-QAM signals.

The proposed system is based on multi resolution decoding. In the first SM-STTC decoder, the simplified branch metric as given in equation 4, is used, which reduces the computational complexity by 16 times compared for full complexity Viterbi decoder.

The performance of the system is compared with sequential decoding algorithm, [17], [18] with which we could reduce the number of branch metric calculations by number of states in the encoder per decoding stage. The simulation results shows that the proposed system with sequential decoding gives better BER performance compared to ML STTCM system in fast fading channel. From the analysis, it is inferred that with the proposed algorithm, the spatial diversity is enhanced in the transmitter side by selecting different antenna groups at every time *t*. and only n_t transmit antenna is active at a time. By choosing the antennas in the groups, based on the criterion minimizing the correlation among the antennas, we could able to achieve better performance even in a fast fading environment.

III. SIMULATION RESULT

In this section, a simple ML-SM-STTC system with two stages, as shown in the Fig.1 is considered. Two stage ML-SM-STTC system with 4-state, 4-QAM, SM-STTC encoder and 4-state, 4-QAM STTC encoder is considered for the analysis. With the above system we could achieve 4bit/Hz/Sec using 16-QAM and 8 transmitter antennas. To receive the signals 8 receiver antennas are used. For different channel conditions, the BER performance of the proposed algorithm is simulated and analysed.

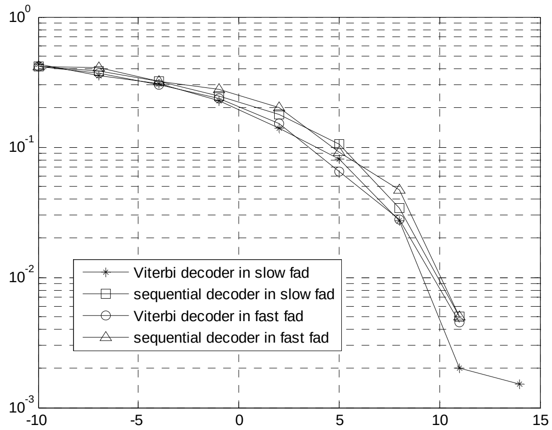

Fig. 4 Performance of the M-SM-STTC system with Viterbi and sequential decoding algorithm

In the Fig.4 the proposed ML-SM-STTC system with Viterbi decoding algorithm and sequential decoding algorithm are compared over frequency non selective slow and fast fading channel. In both the decoding algorithms, the proposed low complex branch metric calculation given in equation.4 is used. The figure shows that the sub optimal sequential decoder gives near performance with full complex decoder. Further, from the simulation results, it is understood that the performance of the system is almost same in both slow and fast fading channels.

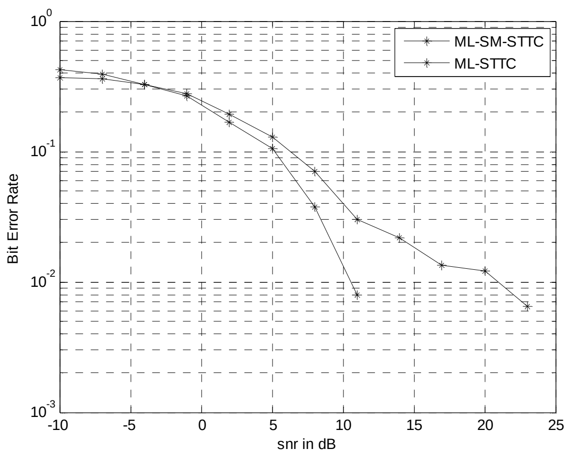

Fig. 5 Comparison of BER Performance for ML-SM-STTC system with ML-STTC.

In the Fig. 5, two stage ML-STTC encoder with 4-state, 4-QAM, 2 transmit antenna, STTC with trellis shown in the Fig. 2 as component codes, is simulated and compared with the proposed ML-SM-STTC system. In the ML-STTC [4] system same component code is used for both the stages. And for comparison purpose, sub-optimal sequential decoding algorithm is used to decode the sequence in each level of ML-STTC system. Both the systems are simulated over fast fading, frequency non selective channel with Doppler spread of 100 Hz. The result shows that the BER performance of the proposed system is better compared to the ML-STTC system with same complexity.

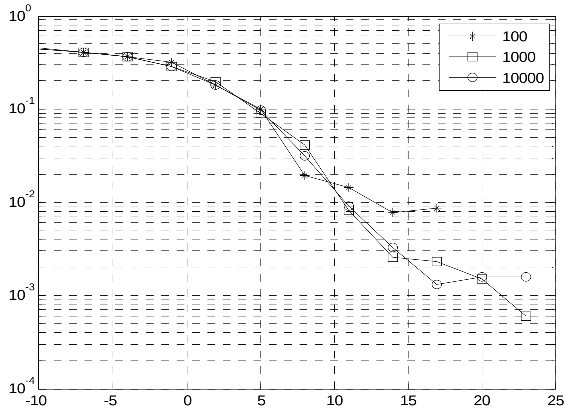

Fig. 6 BER Performance of ML-SM-STTC system with different frame lengths in bits

In Fig.6, the proposed system is simulated over frequency non selective fast fading channel with Doppler spread of 100Hz. In this figure, the system is simulated with different frame lengths in bits. The result shows that BER performance is improving with the frame length.

IV. CONCLUSION

In this paper a low complex Multilevel Spatial Modulation STTC system has been proposed and analysed using computer simulation. In the decoder, computational complexity is minimized by using averaged branch metric and sub optimal sequential decoding algorithm. The proposed system is compared with the ML-STTC system with the same complexity and antenna diversity over fast and slow fading, frequency non selective channel conditions. The results show that the proposed system gives better BER performance compared to ML-STTC system even in fast fading channel. The proposed system is a suitable solution for the mobile systems where Doppler spread is the main issue.

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