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Performance Analysis of Overloaded Mimo-Ofdm Systems Using Iterative Joint Turbo Decoding

[1]Sujethaa N. J, [2]Sivagamasundhari. P
[1]ME/Communication Systems, [2]Assistant Professor,
Department of Electronics & Communication Engineering,
Saranathan College of Engineering, Trichy, Tamil Nadu, India.
Email: *[1]sujijana17@gmail.com, [2]sivagamasundhari-ece@saranathan.ac.in*

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Abstract

The Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) employs turbo codes as its Forward Error Correction (FEC) standard along with multiple input, multiple output (MIMO) systems is used for achieving an excellent error correcting capability and higher throughput. Even if turbo decoding scheme gives adequate performance in ideal MIMO systems, but there is a significant performance degradation in an overloaded MIMO system when the number of transmit antennas is larger than that of receive antennas. In joint turbo decoding, controls of soft information be located accompanied for every permutation of bits from all stream. A super trellis diagram is obtained by combining the trellis diagram of each stream. Experimental results obtained through the joint turbo decoding achieve better performance than the turbo decoding scheme especially in the case of an overloaded MIMO systems. In this paper, BER and throughput for joint turbo decoding scheme is analyzed with different channels (TU channel, Rayleigh fading channel, Rician fading channel) and compared with viterbi decoding. Based on this analysis, joint turbo decoding scheme of MIMO systems with four transmit and two receive antenna of Rician fading channel achieved better performance with BER of 10^{-3} and higher throughput.

Index Terms: *Overloaded MIMO-OFDM, Turbo Codes, Joint decoding, Joint Turbo decoding, Spatial Multiplexing Modulation.*

INTRODUCTION

MIMO-OFDM is the dominant air interference for 4G and 5G broadband wireless communication. It offers significant improves in higher throughput and better reliability. MIMO systems using multiple transmit and receive antenna, can drastically improve the capacity over single-input multiple-output. Based on this, the third generation partnership project (3GPP) long term evolution (LTE) supports MIMO as its standard.

To attain supreme performance, LTE adopts turbo codes as its forward error correction (FEC) code. Turbo codes carry out the performance close to the Shannon limit .Combination of MIMO systems and turbo codes provides high data rate communication with low power consumption. Turbo MIMO has high computational complexity. To overcome this complexity, the soft information is sent to decoding block from detection block to conduct the turbo decoding for each transmitted stream of bits. Labeling this scheme as conventional turbo decoding. MIMO systems need a number of transmit antenna equal to number of receive antenna. On increasing the antenna elements, some mobile terminals support limited number of antennas to the factor limitation. Therefore, for upcoming future an overloaded MIMO system leads a general application.

An overloaded MIMO system faces a difficulty in the performance degradation in the detection process of signal. The detection performance corrupts considerably when the number of transmit antenna is larger than the number of receive antenna. In the detection process, the degradation will occur.

In order to reduce the performance degradation, joint decoding can be applied to perform cooperative decoding between all of the streams. Joint decoding provides a greater performance in the overloaded MIMO system than the hamming code and trellis coded modulation. A joint decoding scheme for turbo codes called as joint turbo decoding in overloaded MIMO-OFDM systems. For the calculation of soft bits, the super-trellis diagram is employed which has low processing time for processing 2^N combination of bits from all streams.

LITERATURE SURVEY

A turbo coded Multiple-Input Multiple-Output (MIMO) system, with linear order of complexity is proposed by a method called Joint Iterative Detection and Decoding (JIDD)[1]. Accurate estimation of soft information should be conditioned and an exponential order of complexity is required for JIDD excellent performance. The proposed method utilizes both posterior probabilities from MIMO detector as well as a priori probabilities from the turbo decoder and soft minimum mean-squared error for symbol level detection is performed .The reliability of the soft symbol is increased and it can separate out the bit-level soft estimation process by using a simple linear method. In this paper, the complexity of the proposed work increases linearly with the number of antennas and modulation orders.

To analyze the performance of an iterative –based decoder, an EXIT chart tool is used and is also used to observe the performance characteristics of the system [2]. The work of this paper is to derive the BER expression for various trajectories: 1. For turbo decoding of the Maximum Ratio Combining (MCR) 2. For turbo decoding in MIMO ZF and MIMO VBLAST 3. For MIMO Beam forming. The work in this paper is valid for all turbo decoding regions like pinch-off, cliff and floor regions and to derive the BER expression accurately.

I. Shubhi and Y. Sanda prσposed a Joint Turbo Decoding for Overloaded MIMO-OFDM for improving the performance of the overloaded MIMO-OFDM [3]. In this paper, soft information on bit combinations from all of the streams is calculated and the throughput is improved up to 2/3bit/s/Hz.

This paper is related to modulation scheme [4]. The coded signal of the turbo encoder are modulated by QPSK and multiplexed by OFDM with the channel bandwidth of 2.5MHz and the subcarrier spacing of 15 KHz and the DFT size is set to 256 with 151subcarriers for the data transmission. The guard interval for the first OFDM symbol is set to 5.21µs and the remaining six symbols are set to 4.69µs.

The effect of joint Modulation and Coding Scheme (MCS) selection on a turbo soft interference canceller (SIC) for OFDM- MIMO multiplexing is done by using adaptive modulation and coding [5]. Iterative interference cancellation is performed by turbo SIC using soft-symbol estimation based on the a posteriori LLR at the Max-Log MAP decoder output after suppressing interference from other streams based on the LMMSE-based signal detection. The modulation level and the coding rate of the turbo code decreases the residual inter-symbol interference is reduced. Hence, the residual interference from the other transmission streams decreases. The total throughput is maximized by considering the residual interference from other streams for the turbo SIC by selecting the best MCS combination of all transmission streams from Joint MCS selection. In this paper, the throughput with 8 MCSs is almost identical to 12MCSs using joint MCS

Author proposed this scheme by the combination of convolutional encoder and the ISI-channel into a single non-linear trellis encoder with binary delay element. However, the total number of states is smaller than the number of states in the super-trellis. In this paper it is possible to reduce the number of states for super-trellis decoding without loss in the performance. Restriction in this paper is the strong bound between the size of the modulation and the code rate.

This paper deals with Joint Maximum Likelihood (ML) decoding in an overloaded MIMO-OFDM [8]. An ideal interleaving and independence among coded symbol spread over subcarriers is assumed. The bit error performance of hamming coded and spatially multiplexed signals is the example for this proposed system is considered. This work improves the outage capacity even if the ergodic capacity of the single receive antenna remains the same.

SYSTEM MODEL

OVERLOADED MIMO-OFDM

MIMO-OFDM system with turbo codes using transmit antenna N_T and receive antenna N_R of a block diagram is shown in figure1. The overloaded case is $N_T > N_R$

TURBO ENCODING

A systematic parallel concatenated convolutional code with two 8-states encoders and one internal interleaver are used in turbo codes of the LTE system. The size of the interleaver is considered which is equal to each stream. Fig 2 shows the trellis diagram of each encoder. S_i denotes the ith memory of the encoder.

The output of the turbo encoder consists of three length N-streams $d_n^{(0)}, d_n^{(1)}, d_n^{(2)}$ which are referred as the “systematic”, ”parity1”, ”parity2” streams, respectively and 12 tail bits due to trellis termination for the input block size of N bits. To boost a higher data rate, a rate matching (RM) function is provided by LTE. Each of the three output streams is rearranged with sub-block interleaver in the rate matching. In the beginning, a single output buffer is formed by placing the rearranged systematic bits, then bit by bit interlacing of the two rearranged parity bit with the total length of 3N+12 bits. For bit selecting and puncturing, the output is passed through a circular buffer.RM function outputs are defined as $b_0, b_1, b_2 \ldots\ldots.., b_{k-1}$, where k is the number of transmitted bits which depends on the desired code rate.

The output of the RM is modulated using QAM modulation with each QAM symbol on the pth transmit antenna, s^p, consists of M bits of b_k^p.

OFDM TRANSMISSION AND RECEPTION

The QAM symbols are arranged from serial to parallel and assigned to L data subcarriers. The OFDM symbol on the pth transmit antenna is given by

$$u^p\,[x] = \sum_{l=0}^{X-1} s^p\,[l]\exp\left(j\frac{2\pi x l}{X}\right) \qquad (1)$$

Where x is the time index(x=0,1,…X-1)

and X is the size of the inverse discrete Fourier transform (IDFT). A cyclic prefix (CP) is added by copying the last part of the OFDM symbol.

At the receiver side, the received signal at the qth receiver antenna is converted into digital samples at the rate of symbol duration time (Ts) and can be written as

$$y^q\ [x] = y^q\ (xT_s) \qquad (2)$$

After removing the CP and the DFT is taken for X samples, the signal on the lth subcarrier can be written as

$$Y^q[l] = y^q[x]\exp(j\frac{-2\pi xl}{X}) \qquad (3)$$

$$Y^q[l] = \sum_{p=0}^{N_T} H^{pq}[l]s^p[l] + W^q[l] \qquad (4)$$

H^{pq}[l] Is the channel frequency response with noise W^q[l] on the sub-carriers.

The DFT outputs of each data subcarrier of the receiver antenna are sent to the detection block for calculating the a priori LLR values.

TURBO DECODING

In the turbo decoding, the first step is to calculate a priori log-likelihood ratio (LLR) value from the signal detection block for each bit. For MIMO-OFDM systems, the a priori LLR values for each subcarrier l in the signal can be obtained by

$$L\ (b_m^p|Y[l]) = \mathrm{Log}\ (\frac{\sum s[l]:b_{m=1}^p \exp(-\frac{1}{\sigma^2}\|Y[l]-H[l]s[l]\|^2)}{\sum s[l]:b_{m=0}^p \exp(-\frac{1}{\sigma^2}\|Y[l]-H[l]s[l]\|^2)}) \qquad (5)$$

The a priori LLR values are set to 0 in the rate recovery process for the bits which are not transmitted due to puncturing, gives total of 3N+12 a priori LLR values. The a priori values are rearranged back after the rate recovery process. To obtain the extrinsic LLR values (L^e), turbo decoder uses the a priori values (systematic, parity1, parity 2) for calculating the forward recursion, α_n , the backward recursion, β_n, and the probabilities of the received signal, γ_n.

In the first decoder, the value of γ_n can be obtained by using the log-BCJR algorithm

$$\gamma_n(\rho',\rho) = L\left(d_n^{(0)}(\rho',\rho)\right) + L(d_n^{(1)}(\rho',\rho)) \qquad (6)$$

The values of α_{n+1} at the state n+1 and β_n at the step n can be attained by

$$\alpha_{n+1(\rho)} = max^*_{\rho'\in\{P'\}}(\gamma_n(\rho',\rho)+\alpha_n(\rho',\rho) \qquad (7)$$

$$\beta_n(\rho') = max^*_{\rho\in\{P\}}(\gamma_n(\rho',\rho) + \beta_{n+1}(\rho)) \qquad (8)$$

max^* is the Jacobian logarithm function. The extrinsic LLR values are calculated with the help of $\alpha_n,\beta_n,\gamma_n$

$$L^e d_n^{(0)} = max^*_{(\rho',\rho)\in\{\tau_n^0\}}\left(\alpha_n(\rho') + \gamma_n(\rho',\rho) + \beta_{n+1}(\rho)\right) - max^*_{(\rho',\rho)\in\{\tau_n^1\}}\left(\alpha_n(\rho') + \gamma_n(\rho',\rho) + \beta_{n+1}(\rho)\right) \qquad (9)$$

This extrinsic value is used as the input for the next decoder.

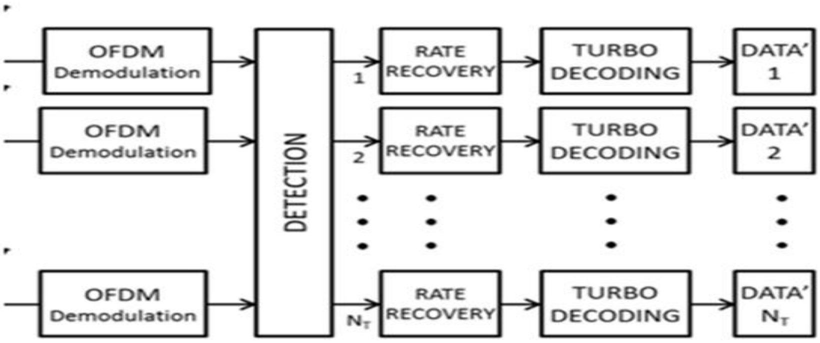


***Fig: 1.** Turbo Decoding*

JOINT TURBO DECODING

The joint turbo decoding minimizes the degradation of the soft input quality obtained from the detection block of the decoder by acquiring the soft input for the entire bit. The soft inputs used in the decoder will be of 2^{N_T}.The a priori LLR values are calculated for one bit combination and this is used as reference point. For each combination of bit, the a priori LLR values are defined as

$$L\,(b_m|\mathrm{Y}[\mathrm{l}]) = \log\left(\frac{\sum s[l]{:}b_m=\hat{\mathrm{b}}_{\mathrm{m}} \exp(-\frac{1}{\sigma^2}\,\|Y[l]-H[l]s[l]\|^2)}{\sum s[l]{:}b_m=\hat{\mathrm{b}}_{\mathrm{m}}(-\frac{1}{\sigma^2}\,\|Y[l]-H[l]s[l]\|^2)}\right) \quad (10)$$

The extrinsic LLR values are acquired by calculating the values of γ_n, β_n, α_n with the inputs (systematic, parity1 ,parity2). In addition, to combine the trellis diagram from all streams, a super-trellis diagram is employed. The super-trellis diagram for 2 transmit antenna example is given. The super-trellis diagram is implemented to combine the trellis diagram from all of streams in a MIMO system.

φ is defined as the state in the super-trellis diagram. The values of γ_n in the first decoder is given by

$$\gamma_n(\varphi',\varphi) = L\left(d_n^{(0)}(\varphi',\varphi)\right) + L(d_n^{(1)}(\varphi',\varphi)) \quad (11)$$

In the forward recursion, the value of α_{n+1} can calculated by

$$\alpha_{n+1(\varphi)=\max^*_{\varphi'\in\{P'\}}(\gamma_n(\varphi',\varphi)+\alpha_n(\varphi',\varphi)} \quad (12)$$

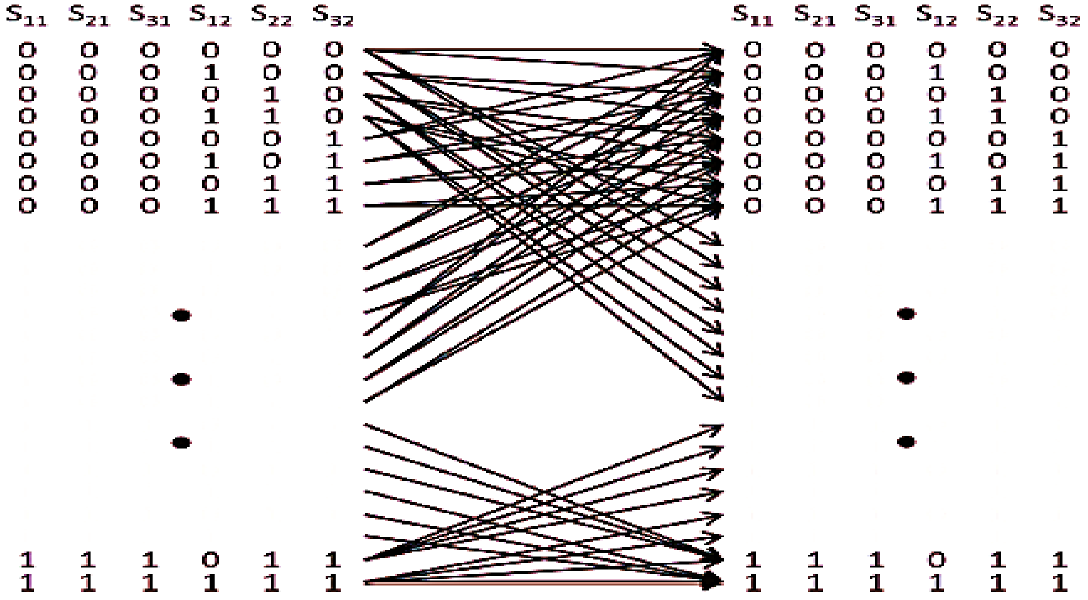


Fig: 2. *Super Trellis Diagram*

In the backward recursion, the value of β_n can be obtained by

$$\beta_n(\varphi') = \max^*_{\varphi\in\{P\}}(\gamma_n(\varphi',\varphi) + \beta_{n+1}(\varphi)) \quad (13)$$

The extrinsic LLR values for systematic bit combination can be obtained by after attaining the values of γ_n , α_n, β_n

$$L^e\left({d_n}^{(0)}\right) = \max_{(\rho',\rho)\epsilon\{T_n^1\}} *(\alpha_n(\rho') + \gamma_n\,(\rho',\rho) + \beta_{n+1}(\rho)) - \max_{(\rho',\rho)\epsilon\{T_n^0\}} * \, (\alpha_n\,(\rho') + \gamma_n(\rho',\rho) + \beta_{n+1}(\rho)) \quad (14)$$

In this, the extrinsic LLR value is used as the soft input for the next decoding process similar to turbo decoding. In the joint turbo decoding, the highest LLR value is selected as the decoder output.

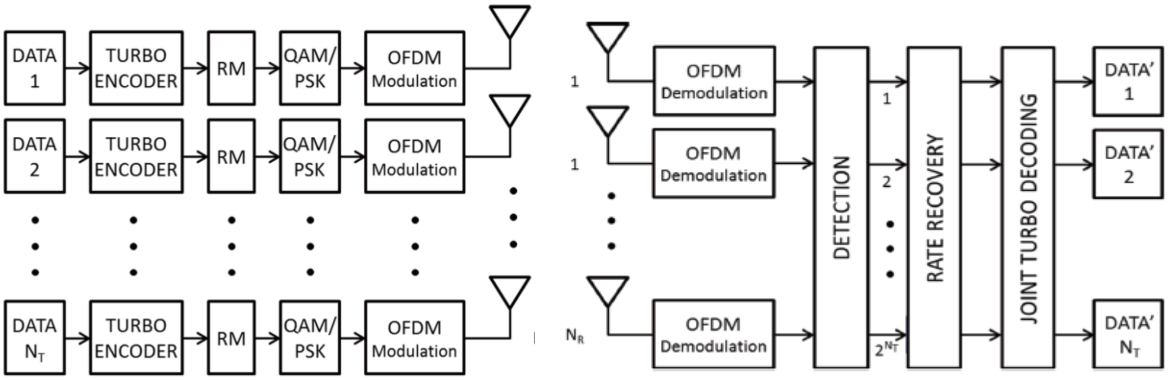


***Fig: 3.** Joint Turbo Decoding*

COMPUTATIONAL COMPLEXITY

The implementation of the super-trellis diagram results in the larger complexity of the joint turbo decoding. The complexity increases exponentially with the number of transmit antenna. Due to larger complexity, additional power consumption is required. The joint turbo decoding process has a larger memory than the turbo decoding. The calculation process for each step in each iteration is conducted in parallel manner. The processing delay is small. The joint turbo decoding has an advantage for the case of an overloaded MIMO. The computational complexity occurs in the detection block, which performs simple add-compare-select operation.

NUMERICAL RESULT

In this simulation, the turbo codes with the rate 1/3 of 8 states memory and the interleaver size in each stream is equal. Then the coded symbols are modulated using 64QAM modulation and OFDM is used for multiplexing. The channel model used in the simulation is typical urban (TU) channel, Rayleigh channel, Rician channel, AWGN channel with perfect channel estimation. In the simulation, the four transmit antennas and two receive antennas are used.

BER

The bit error rate (BER) of joint turbo decoding is compared with viterbi decoding for the different channel using the code rate of 1/3. The BER of the four transmit antenna and single receive antenna scheme is plotted for different channels is shown.

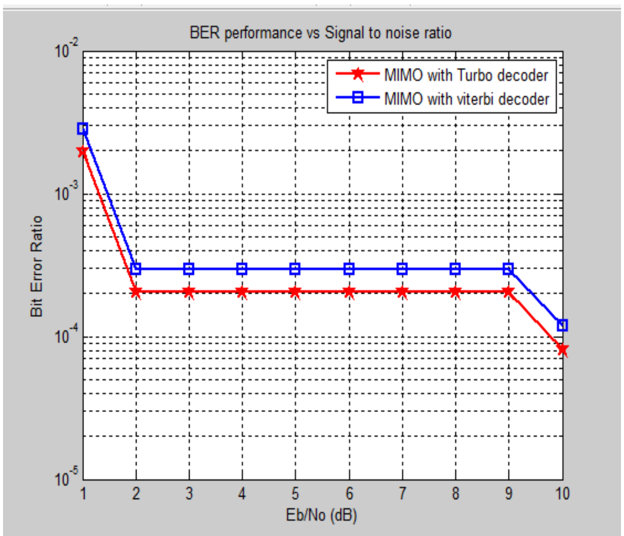


***Fig: 4.** BER performance of Rayleigh channel*

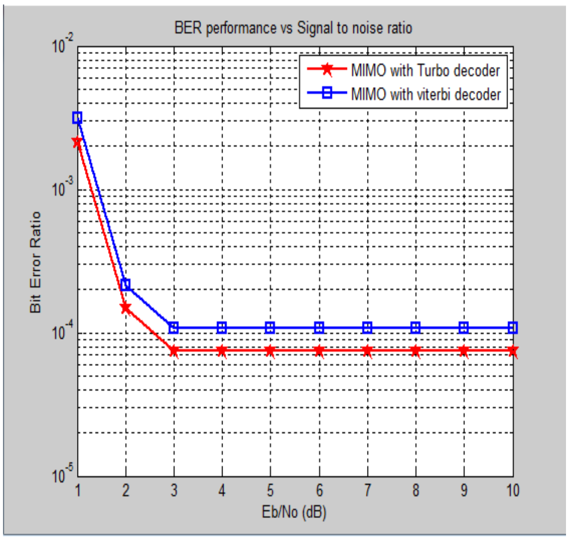


***Fig: 5.** BER performance of TU channel*

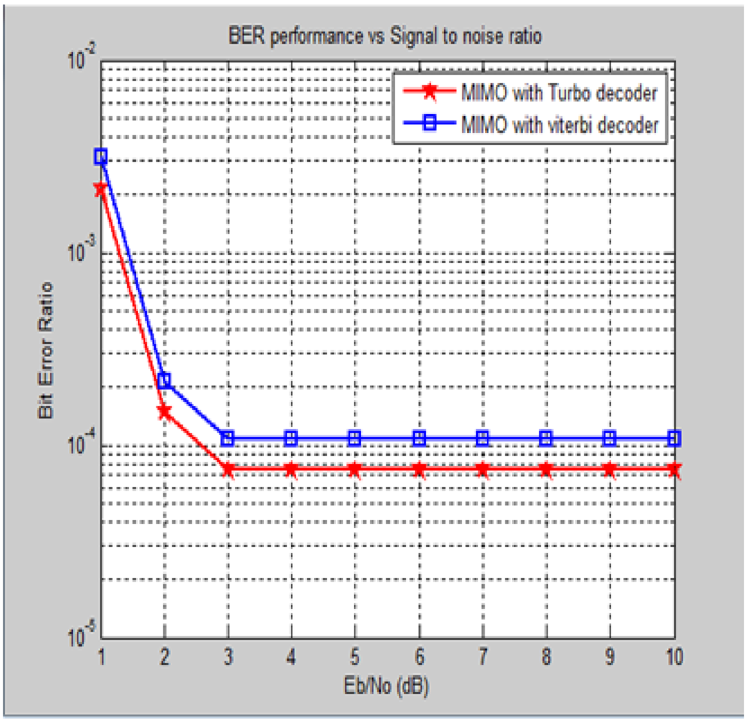
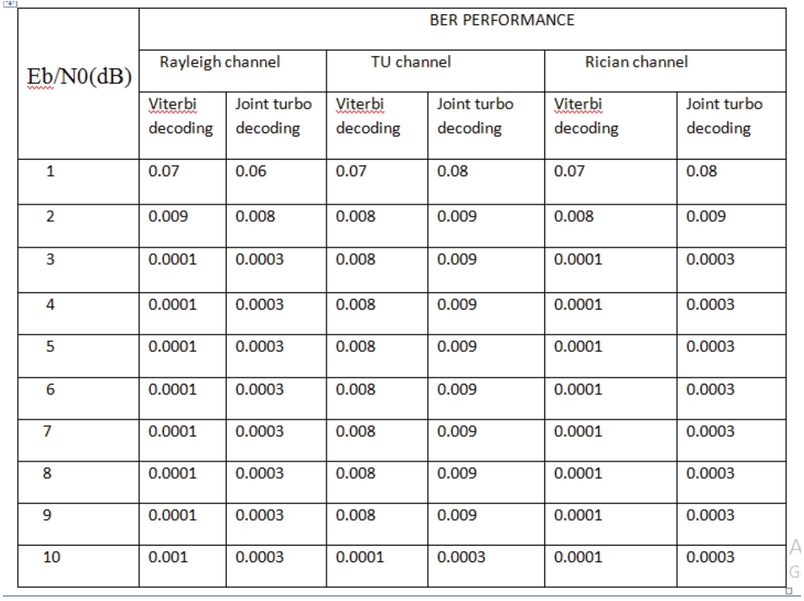


Fig: 6. *BER performance of Rician channel*

The comparison table of BER performance for different channels and for different decoding is also given. The performance gain also increases by increasing the number of transmitting antennas.

Table: 1. *BER Performance of 3 Different channel*



Eb/N0(dB)	BER PERFORMANCE					
	Rayleigh channel		TU channel		Rician channel	
	Viterbi decoding	Joint turbo decoding	Viterbi decoding	Joint turbo decoding	Viterbi decoding	Joint turbo decoding
1	0.07	0.06	0.07	0.08	0.07	0.08
2	0.009	0.008	0.008	0.009	0.008	0.009
3	0.0001	0.0003	0.008	0.009	0.0001	0.0003
4	0.0001	0.0003	0.008	0.009	0.0001	0.0003
5	0.0001	0.0003	0.008	0.009	0.0001	0.0003
6	0.0001	0.0003	0.008	0.009	0.0001	0.0003
7	0.0001	0.0003	0.008	0.009	0.0001	0.0003
8	0.0001	0.0003	0.008	0.009	0.0001	0.0003
9	0.0001	0.0003	0.008	0.009	0.0001	0.0003
10	0.001	0.0003	0.0001	0.0003	0.0001	0.0003

THROUGHPUT

The required Eb/ NO (dB) in the throughput of the MIMO system is given with the BER of 10^{-5} is shown. The throughput performance for four transmit antenna and two receive antenna is plotted for different channel and is shown.

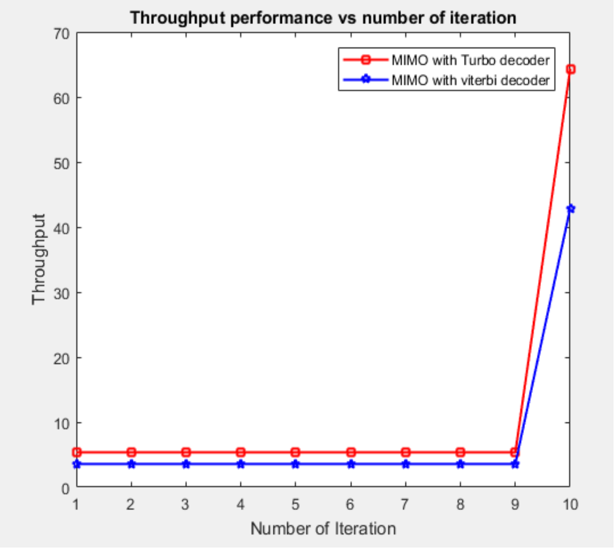


***Fig: 7.** Throughput improvement for Rayleigh channel*

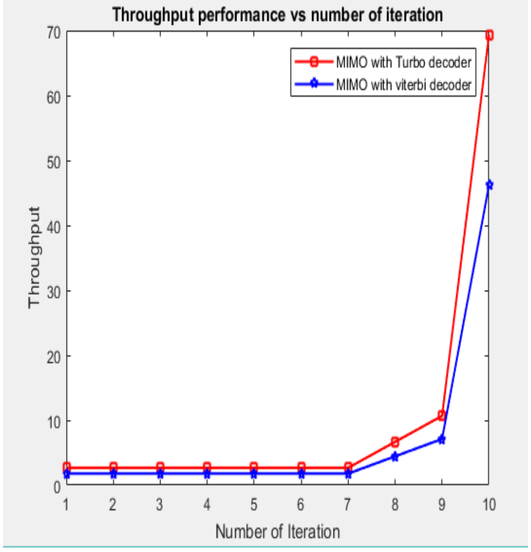


***Fig: 8.** Throughput improvement for TU channel*

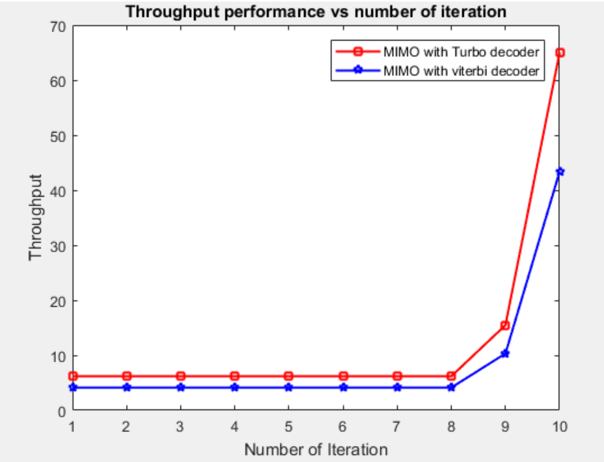
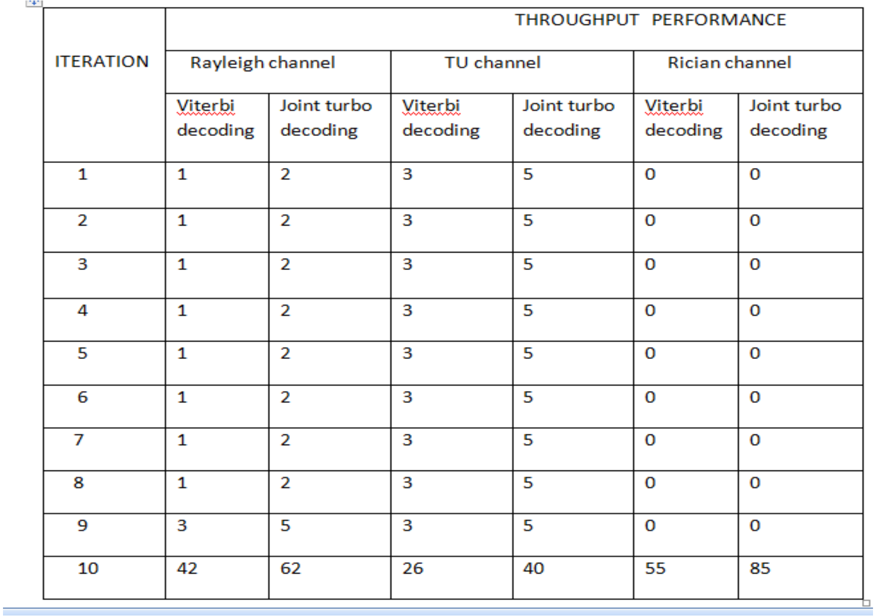


***Fig: 9.** Throughput improvement for Rician channel*

***Table: 2.** Throughput Performance of 3 different channels*



ITERATION	THROUGHPUT PERFORMANCE					
	Rayleigh channel		TU channel		Rician channel	
	Viterbi decoding	Joint turbo decoding	Viterbi decoding	Joint turbo decoding	Viterbi decoding	Joint turbo decoding
1	1	2	3	5	0	0
2	1	2	3	5	0	0
3	1	2	3	5	0	0
4	1	2	3	5	0	0
5	1	2	3	5	0	0
6	1	2	3	5	0	0
7	1	2	3	5	0	0
8	1	2	3	5	0	0
9	3	5	3	5	0	0
10	42	62	26	40	55	85

From the above comparison table, Rician channel for four transmit antenna and two receive antenna of joint turbo decoding has a better throughput performance than the viterbi decoding. The gap between the achievable throughput and the maximum capacity will not increase significantly by adding more transmit antennas.

CONCLUSION

In joint turbo decoding, computation of soft information in favor of all arrangement of bits from every single one streams via a super trellis diagrams be conduct. The experimental results obtained from simulation show the performance of the system. For the case of four transmit and two receive antennas, the performance using interleaver in Rician fading channel, the obtained BER is 10^{-3}. The throughput performance of MIMO systems is found to 85%. The future objective of the work is to reduce PAPR of overloaded MIMO- OFDM system by combination of Hadmard Transform and Hanning Window.

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