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PERFORMANCE COMPARISON OF MULTI-INPUT MULTI-OUTPUT CODED ORTHOGONAL FREQUENCY-DIVISION MULTIPLEXING (MIMO-COFDM) WITH CHANNEL ESTIMATION ALGORITHMS

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Abstract: Multi Input Multi Output Coded Orthogonal frequency-division multiplexing (MIMO-COFDM) is one of the efficient techniques to transmit the digital data using different carrier frequencies which are orthogonal to each other. COFDM has high bandwidth efficiency and more combat to Inter Symbol Interference (ISI), but suffers from more frequency offsets especially in multipath channel environment and large Crest factor (CR) [3]. **T**his paper aims to analyze the performance of COFDM by using Forward Error Correction codes such as Convolution code (CONV), Turbo code, Reed Solomon code (RS), Low Density Parity Check (LDPC)code), polar code, upgraded convolution code [16], upgraded polar code (proposed codec) for encoding the digital data and transmit that digitally coded data through Quadrature Phase Shift Keying (QPSK) Modulation technique under Rayleigh fading channels with Additive white Gaussian Noise (AWGN). Channel estimation algorithms [4] namely Least Square (LS), Minimum Mean Square Estimation (MMSE)and Modified Least Square (MOD-LS) (proposed channel estimation algorithm) are used to mitigate the channel distortion.
Key words: Multi Input Multi Output Coded Orthogonal frequency-division multiplexing (MIMO-COFDM), Convolution code, Turbo code, Reed Solomon code (RS), Low Density Parity Check (LDPC)code, polar code, upgraded convolution code [16], upgraded polar code (proposed codec) Quadrature Phase Shift Keying (QPSK), AWGN, Rayleigh fading channels. Least Square (LS), Minimum Mean Square Estimation (MMSE)and Modified Least Square (MOD-LS) (proposed channel estimation algorithm).

1. INTRODUCTION

COFDM is a digital multi-input and multi output modulation technique. N number (a positive integer) of coded data signals propagated through a common communication channel without interfering with one another if modulation of sub carriers is done through orthogonal waveforms. Although the individual bit rates of sub carriers are low, the total symbol rate is the sum of individual sub carrier bit rates, hence the overall symbol rate equal to near the Nyquist rate and hence more bandwidth efficiency. The orthogonal property of sub carriers allows overlapping spectrum and no need of guard bands between the sub carriers leads to more spectrum efficiency and thus reduces ISI.

Bit Error Rate (BER) is the ratio of number of errors to number of transmitted bits in a stipulated time. Lesser the BER better is the channel code performance. spectral efficiency is a performance measure that describes how effectively a given bandwidth is utilized over a communication channel. channel capacity is defined as the amount of bit rate that a noisy channel can reliably transmitted the information on a noisy channel.

Channel coding techniques reduces channel errors occurred during transmission at the cost of increased overheads, so over all bit rate is reduces and hence reduces spectral efficiency. Automatic Repeat request (ARQ) demands retransmission of transmitted data causes throughput decreases although data delivery ratio increases. FEC schemes [9] error-control codes (e.g., CC, Turbo, RS, LDPC, polar code, upgraded convolution code [16] and upgraded polar code (proposed codec)) can detect and correct errors with high probability of reliable transmission. These codes introduce redundant bits in the transmitted data stream and decode the received bit stream with low BER (13), but this method lowers the spectral efficiency Convolutional codes encode binary data either into bit or symbol of any length. Block codes encodes data into symbols of fixed length decided by polynomial characteristics.

This paper aims to analyze the BER performance ,channel capacity, spectral efficiency, execution time of COFDM by using Forward Error Correction codes such as Convolution code[5] , Turbo code, Reed Solomon code (RS)and Low Density Parity Check (LDPC)code ,polar code, upgraded convolution code [16] and upgraded polar code (proposed codec) for encoding the digital data and transmit that digital coded data through Quadrature Phase Shift Keying(QPSK)Modulation technique through Rayleigh fading AWGN channel along with Channel estimation algorithms such as Least Square(LS),Minimum Mean Square Estimation[6] (MMSE)and Modified Least Square(MOD-LS) proposed channel estimation algorithm..

2. System Model

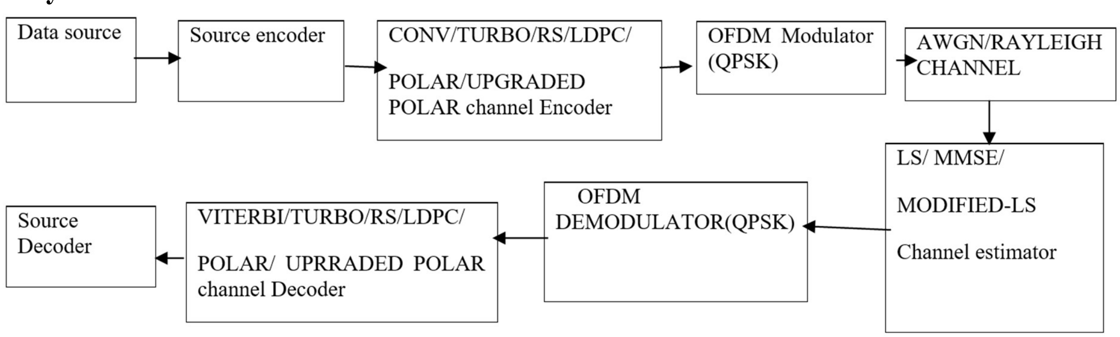


Figure-a: COFDM communication method of implementation

Transducer converts physical data into electrical signal. Source encoder translates electrical signal into binary data stream. FEC encoder encodes binary data stream into encoded bits or symbols.

Quadrature Phase Shift Keying (QPSK) modulation modulates the encoded data with M=4. An OFDM [11] carrier signal is the sum of a several sub-carriers which are orthogonal, with baseband data on each subcarrier being modulated independently by QPSK (Quadrature Phase Shift Keying modulation modulates the encoded data with M=4). RF carrier modulates QPSK modulated composite data and transmits through the channel towards receiver.

AWGN, Rayleigh fading Channels [7] add noise to OFDM modulated signals.

AWGN, Rayleigh fading Channel estimations can be done by using channel estimation algorithms namely Least Square (LS), Minimum Mean Square Estimation (MMSE) and Modified Least Square (MOD-LS) are used to mitigate the channel distortion.
OFDM & QPSK demodulators demodulates received signal and decoded by corresponding decoders.
Convolution code: (n, k), n number of code bits, k number of message bits and n-k redundant bits are added. It consists of memory element as a shift register and Exclusive-OR gate and generator polynomials.' k 'input bits shifted bit by bit towards right in to shift registers until the end of the input bits, based on 'n' generator polynomials and previous bits in shift registers' n 'code words generated. (k/n) is code rate. Viterbi decoder decodes the received bits after OFDM&QPSK demodulation. In this paper uses code rate of ¾, constrained length of 7 and puncture pattern of [1;1;1;0;0;1].
Turbo code: Turbo encoder is formed by Two convolution encoders concatenated parallelly [2]. and generates two parity bits and one systematic bit, therefore code rate is 1/3. bit puncturing based on predefined pattern can be used to improve code rate. It uses interleavers to randomize the input bit patterns. Turbo decoder uses iterative decoding structure based on soft input and soft output MAP. This Turbo code employs two different decoding techniques. The BCJR decoder in the feedback path utilizes extrinsic information bits as prior information bits in every iteration and Viterbi decoder in the feed forward path utilizes interleaved extrinsic information along with input to improve the performance. Each successive iteration moves towards stabilized soft output of the Viterbi decoder to retrieve errorless transmitted data.
Reed-Solomon (RS (N,K)) codes[10], are block codes designed to correct burst errors by adding overhead bits to input data stream. Design of RS code based on code g(x) and field generator polynomials p(x) for generating Galois Field Array, redundant bits .RS code with GF (8) used, code rate is 0.8.

Low Density Parity Check codes (LDPC): are linear block codes to correct burst [1] and random errors. LDPC codes possess low complexity hardware design and high bit rates. parity check matrix with size of N-K by N is used for its design. The LDPC decoder is to compute the marginal a posterior probability for each iteration. This paper uses LDPC (32400, 64800), hence code rate is 1/2.

Polar code: the polar codec uses $\log_2(N)$ parallel encoders. The buffer stores the total message and then interleaves and maps the message bits according to the pattern based on the values of message length K and rate matched length **E**. The interleaver is excluded when the link direction to uplink. This paper uses K=132 and E=256

Upgraded polar codec:
(1) The message to be transmitted is first converted into source code.
(2) Network security can be established by applying cryptography techniques to source code [9].
(3) the encrypted symbol undergoes channel coded fixed number of integers varying from 0 to 15[16].
(4) Each encrypted data is encoded by polar code with message length of 132 and rate matched

length of 256 with code rate 0.42. This encrypted polar code then encoded into a predetermined number integer patterns varying from 0 to 7.

(6) Upgraded polar decoder uses narrow band filters to tune to these frequencies corresponding to integers

(7) polar decoder decodes these integers into encrypted symbols. These are decrypted using decrypting algorithms and then by source decoder converts it into original message

AWGN channel: Additive White Gaussian Noise distorts the transmitted signal which is introduced in the channel provided that if the channel possess continuous frequency band

Rayleigh Fading channel: Transmitted signal received by the receiver is due to reflections and refractions from objects. Hence received signal is combination of all multipath signals. In this paper three multi paths [0 1e-4 2e-4] and path gains [0 -1 -9], Doppler frequency(fd) spread (15) of 1 Hz to 200Hz are used

LEAST SQUARE ALGORITHM (LS): LS [11] is a standard method in regression system to approximate the result for over determined systems. Consider each single equation and process the received signal by minimizing the sum of the squares of the errors occurred.

Modified LEAST SQUARE ALGORITHM (Modified-LS) (proposed algorithm): This approach follows the LS Algorithm, modification is that next estimation of channel can be obtained by averaging the present and previous channel estimations, and this process repeated for a predetermined number of iterations.

MINIMUM MEAN SQUARE ERROR (MMSE): MMSE [12] is also a standard estimation method in which the mean square error can be minimized, which is a common measure of estimator quality for a dependent one. In

Baysian setting, the term MMSE refers to the estimation of quadratic loss function. Under that case, this estimator estimates posterior mean of the parameter

Table 1: OFDM Parameter specifications

Simulation Parameters	Parameter specifications
Coding Schemes	Convolution (3/4), Reed-Solomon (0.8), Turbo0.32), LDPC(0.5)/Polar(0.46)/Upgraded polar code (0.42)
Modulation	QPSK
Pilot carriers	6
Number Of Bits	10400
Maximum Doppler shift	100Hz
Number Of antennas	2
SNR	0-39 DB
AWGN, Rayleigh	AWGN, Rayleigh
FFT Size	128
Channel Estimation Algorithms	LS, MMSE, MODIFIED LS

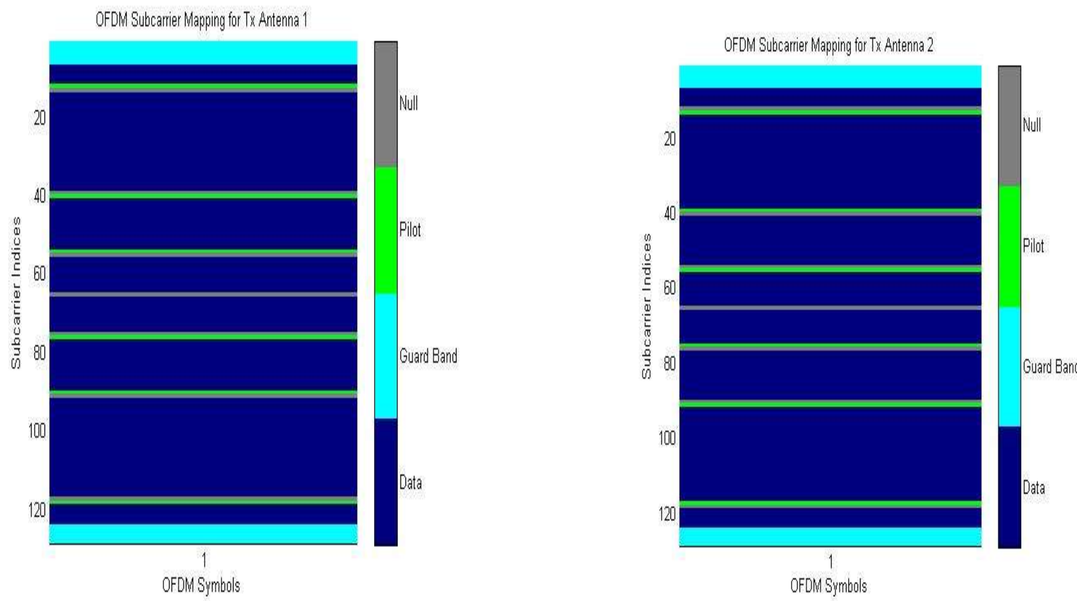
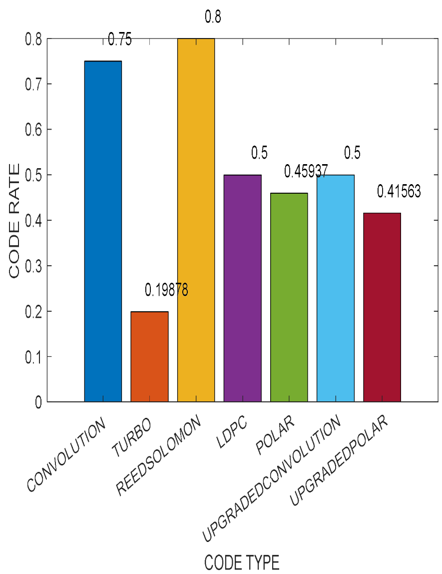


Figure-b: COFDM frame format for two Antennas.

3.**Simulation Results and discussions**

This section presents the results obtained by the software package developed in MATLAB (14). A text data is converted into ASCII code, and then this code is converted in to binary code This binary code is used as source code in each case of COFDM. Analysis of COFDM with various codes namely Convolution, Reed-Solomon, Turbo, LDPC, polar code, upgraded convolution code [16] and upgraded polar code (proposed codec) can be done in terms of BER vs. Signal to Noise(SNR) ,spectral efficiency, channel capacity, Code rates and execution time .This chapter compares the BER plots for AWGN and multipath channel (Rayleigh-faded channel with different Doppler frequency shifts (fd), multipath delays are considered using OFDM with OPSK modulation scheme. This paper also presents BER VS. Signal to Noise (SNR) plots in multipath channel (Rayleigh-faded with AWGN channel) by varying Doppler frequency shifts (fd) and multipath delays using channel estimation algorithms of LS, MMSE, Modified –LS (proposed).



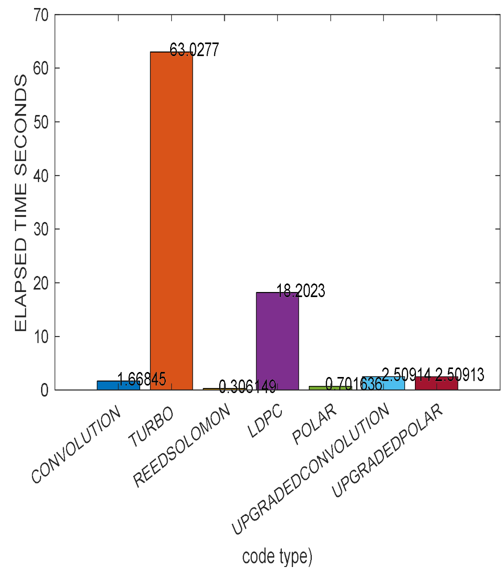


Figure-c: Coded OFDM code rates for various codes. Figure-d: Coded OFDM execution time various codes

Table2: COFDM Bit error rate performance in Rayleigh channel with modified -LS channel estimation algorithm for various codes with three multipath delays with SNR=20DB.

	BER OF						
Doppler frequency	CONVOL	TURBO	RS	LDPC	POLAR	UPGRADED CONVOLUTION	UPGRADED POLAR
1	0.1173	0.0442	0.0448	0.0374	0	0	0
26	0.3486	0.0442	0.0910	0.0884	0.0765	0	0
51	0.3588	0.0442	0.0871	0.0850	0	0.0075	0
76	0.2738	0.0442	0.0871	0.0833	0.1309	0	0
101	0.2006	0.0442	0.0551	0.0578	0	0	0
126	0.2142	0.0442	0.0512	0.0510	0.0272	0	0
151	0.5	0.0442	0.1487	0.1836	0.5289	0.3182	0.0850
176	0.4761	0.0442	0.1128	0.1071	0.1190	0.0927	0

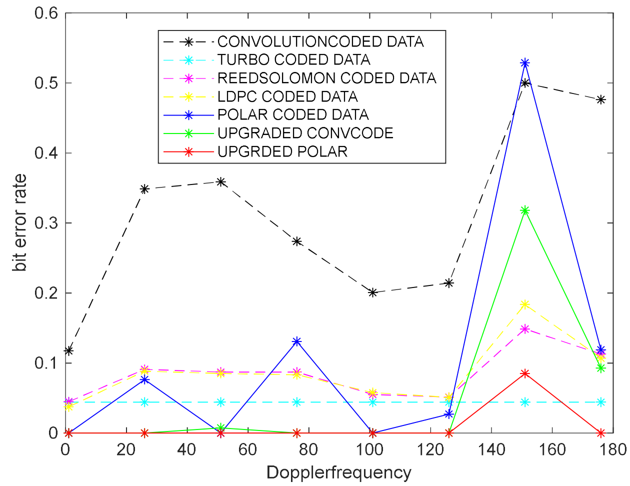


Figure-e: COFDM Bit error rate performance in Rayleigh channel with AWGN noise using modified -LS channel estimation algorithm

From figure e and table 2. it is observed that upgraded polar coded- OFDM performs well (attains zero BER at 25 DB.) for all doppler frequency variations compared to other codes but inferior in code rate (0.42) and moderate execution time

Consider channel band width of 1.75MHz
sampling frequency Fs of (1.75MHz*8/7=2MHz)2MHz,
FFT size of 128.
Subcarrier spacing(Δf) =Fs/ FFT size=2MHz/128=15625Hz.
Total symbol time = (1/(Δf)) +time for delay and synchronization
= (64+2) µsec.
channel capacity/symbol while not considering channel coding (C_M)
= number of active(data)subcarriers * $\log_2 M$ *Fs.
=104*2*2MHz=3.15MHz.
where M is modulation order.
Total channel capacity/symbol(C) = (C_M)*code rate.
Spectral efficiency = Total channel capacity per symbol(C)/Band width.
Band width Efficiency = (subcarrier separation*(number of data carriers +DC carrier)/Bandwidth) *100.
= (15625*105/1.75MHz) *100=93%

Table3. Performance evaluation of Coded OFDM

Band width=1.75MHz, OFDMQPSK modulation					
Codec OFDM	Code rate	Channel capacity in MHz	spectral efficiency bits/sec/Hz	execution time	BER (RAYLEIGH CHANNEL) SNR=25 DB fd=25Hz

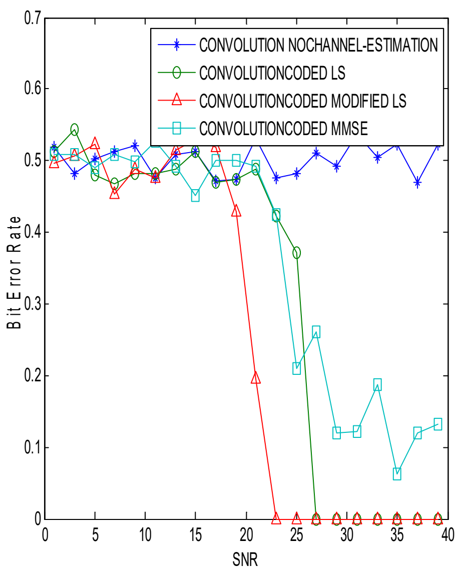
CONVOLUTION	0.75	2.3625	1.35	1.67	0.3486
TURBO	0.32	1.008	0.576	63.02	0.0442
REED SOLOMN	0.8	2.52	1.44	0.31	0.0910
LDPC	0.5	1.575	0.9	18.02	0.0884
POLAR	0.46	1.45	0.829	0.70	0.0765
UPGRADED CONVOLUTION	0.5	1.575	0.9	2.51	0
UPGRADED POLAR	0.42	1.32	0.75	2.51	0

From Table 3, the COFDM code with higher the code rate has higher channel capacity and spectral efficiency but lowers the BER. Upgraded polar code is mostly used where low BER is needed.

Table4. shows CONVOLUTION-OFDM and REED SOLOMAN -OFDM BER performance in Rayleigh channel with fd=25Hz and three multipath delays by varying SNRs.

	CONVOLUTION -OFDM CODE				REED SOLOMAN -OFDM				
SNR	NOCHANNEL ESTIMATION	LS	MODIFIED LS	MMSE	NOCHANNEL ESTIMATION	LS	MODIFIED LS	MMSE	MMSE
1	0.5213	0.4901	0.4802	0.5002	0.4011	0.4621	0.4101	0.4610	
6	0.5011	0.4611	0.5100	0.4901	0.4001	0.5000	0.4100	0.4012	
11	0.4827	0.4600	0.4501	0.5002	0.3900	0.4001	0.3302	0.3915	
16	0.5021	0.5099	0.5003	0.42040	0.2301	0.3120	0.2103	0.2312	
21	0.4812	0.5011	0.4001	0.5003	0.155	0.1501	0.0504	0.1551	
26	0.5223	0.3098	0	0.2011	0.1201	0.0502	0	0.1212	
31	0.4413	0	0	0.1	0.0803	0.0	0	0.0	

				200		21 3		802	
36	0.4544	0	0	0.0 500	0.0612	0	0	0.0 601	



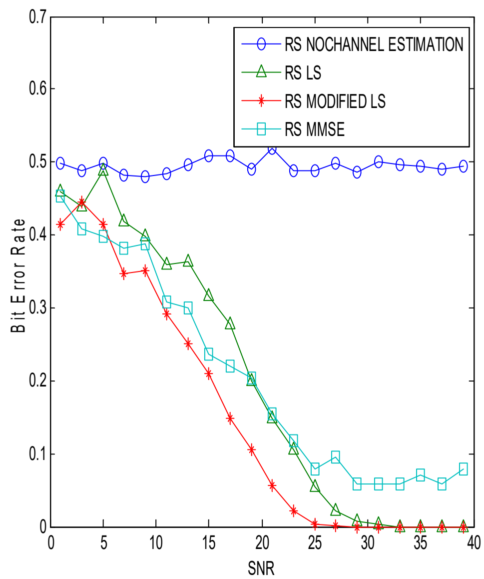


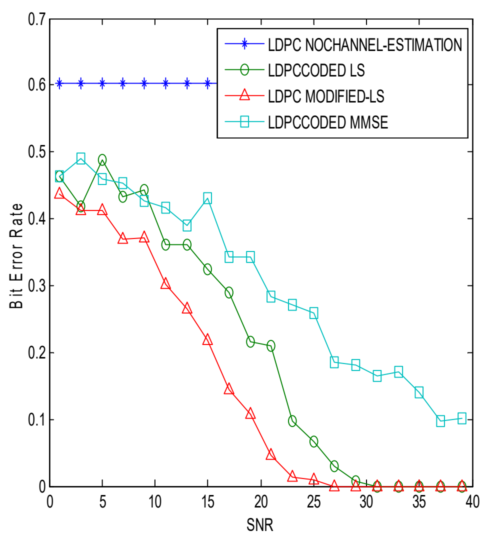
Figure-f: CON-OFDM BER performance in Rayleigh Using various Channel estimation algorithms.

Figure-g: RS-OFDM BER performance in Rayleigh using for various Channel estimation algorithms.

Table5. shows LDPC-OFDM and TURBO -OFDM BER performance in Rayleigh channel with fd=25Hz and three multipath delays by varying SNRs.

	LDPC -OFDM CODE				TURBO -OFDM				
SNR	NOCHANNEL ESTIMATION	LS	MODIFIED LS	MMSE	NOCHANNEL ESTIMATION	LS	MODIFIED LS	MMSE	MMSE
1	0.6	0.4 61 2	0.4205	0.4 615	0.7101	0.5 21 0	0.5201	0.5 201	
6	0.6	0.4 90 1	0.4010	0.4 511	0.7000	0.5 10 2	0 . 4 6 0 2	0.5 102	
11	0.6	0.4	0.3812	0.4	0.7001	.04	0.4205	0.4	

		513		415		803		801	
16	0.6	0.3211	0.2001	0.4123	0.7201	0.4201	0.3801	0.4202	
21	0.6	0.0801	0.0203	0.2601	0.6902	0.3100	0.0500	0.3021	
26	0.6	0.0214	0	0.201	0.700	0.0901	0	0.0910	
31	0.6	0	0	0.1901	0.7002	0	0	0	
36	0.6	0	0	0.0600	0.6801	0	0	0	



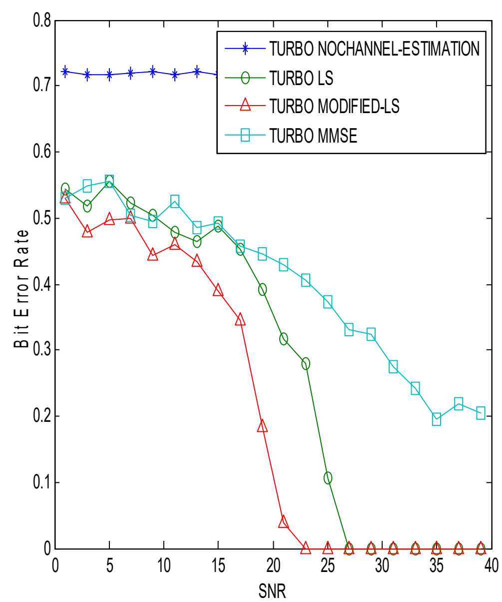
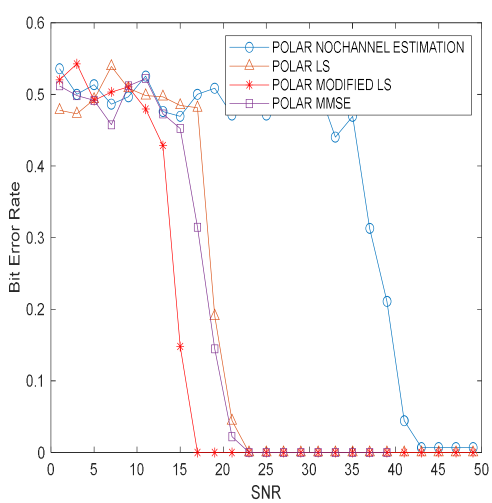


Figure-h: LDPC-OFDM BER performance in Rayleigh Figure-i:Turbo-OFDM BER performance in Rayleigh
Using various Channel estimation algorithms. using for various Channel estimation algorithms.

Table6. shows POLAR-OFDM and UPGRADED POLAR -OFDM BER performance in Rayleigh channel with fd=25Hz and three multipath delays with varying SNRs

	POLAR -OFDM CODE				UPGRADED POLAR -OFDM				
SN	NOCHANNEL ESTIMATION	LS	MODIFIED	MMS	NOCHANNEL ESTIMATION	LS	MODIFIED	M	MMSE

R			LS	E			LS	MS E	
1	0.5119	0.5187	0.4983	0.4966	0.4966	0.4643	.04932	0.4473	
6	0.4847	0.5051	0.4881	0.4847	0.5102	0.5204	0.4609	0.4762	
11	0.4932	0.4949	0.4507	04677	0.4921	0.4711	0.5051	0.5051	
16	0.4898	0.4864	0	0.4201	0.4813	0.4609	0	0.4456	
21	0.5340	0	0	0.0068	0.2041	0.2670	0	0.1837	
26	0.4864	0	0	0	0	0	0	0	
31	0.4912	0	0	0..408	0	0	0	0	
36	0.3673	0	0	0	0	0	0	0	



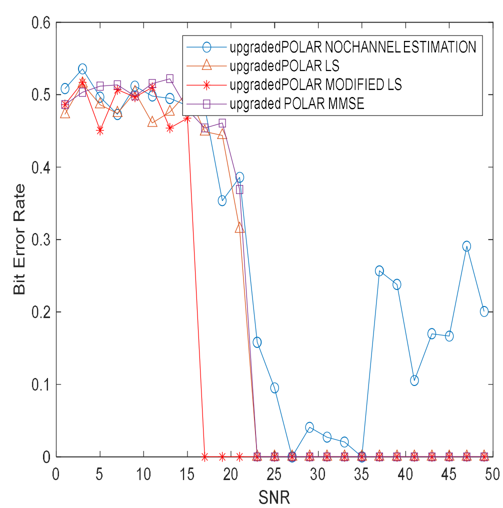


Figure-j: POLAR-OFDM BER performance in Rayleigh Using various Channel estimation algorithms.

Figure-k: UPGRADED POLAR-OFDM BER in Rayleigh using for various Channel estimation algorithms.

From figures f, g, h, i j and k it is observed that Modified LS Algorithm performs good compared to LS and MMSE algorithms. Modified LS Algorithm attains zero BER at SNR of 23 DB , 25 DB whereas LS attains 31 DB ,32 DB for convolution code and RS codes respectively . Hence almost SNR of 6 DB gain achieved by modified LS over LS algorithm. LDPC, TURBO, POLAR, UPGRADED POLAR coded- OFDM performs well under Modified LS channel estimation Algorithm attains zero BER at 28 DB ,23DB,15DB,15DB and LS achieves zero BER 33DB,28DB ,23DB,23DB respectively. Hence almost SNR of 5 DB gain achieved by modified LS over LS algorithm

CONCLUSIONS

Performance of COFDM has been analyzed by different coding techniques (CONV, RS, TURBO, LDPC, POLAR, UPGRADED POLAR) and by different channel estimation schemes (LS, MMSE, Modified LS). LDPC code performs well at low SNRs (although it attains zero BER at 11 DB. REED SOLOMON OFDM performs well as it exhibits a good compromise between spectral efficiency and BER. Upgraded polar coded- OFDM performs well (attains zero BER at 25 DB.) for all doppler frequency variations compared to other codes but inferior in code rate (0.42) and moderate execution time. Upgraded polar code is mostly used where low BER is needed especially in multipath channels with more doppler frequency variations.
MODIFIED –LS channel estimation algorithm performs well over LS and MMSE for all coding schemes. At low SNR's MMSE performs good over LS but less performance than MODIFIED-LS. Modified LS Algorithm attains zero BER at SNR of 23DB, 25 DB whereas LS attains 31 DB ,32 DB for convolution code and RS codes respectively. Hence almost SNR of 6 DB gain achieved by modified LS over LS algorithm. LDPC, TURBO , POLAR, UPGRADED POLAR coded- OFDM performs well under Modified LS channel estimation Algorithm attains zero BER at 28 DB ,23DB, and LS achieves zero BER 33DB,28DB respectively. Hence almost SNR of 5 DB gain achieved by modified LS over LS algorithm.

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