Low Density Parity Check (LDPC) for Space Time Frequency Coding in MIMO-OFDM

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***Abstract*— MIMO-OFDM offers significant high data rates transfer without increasing the bandwidth or transmit power. By adopting diversity coding such as Space Time coding (STC), Space Frequency Coding (SFC), Space Time Frequency Coding (STFC), the major challenge of transmitting information over a long distances can be improved in terms of reliability and security of the data due to ISI and ICI. Low Density Parity Check which is introduced by Gallager in 1962 has attracted much attention to the needs of efficient and reliable coding theory in digital data communication system. In this paper together with STFC, the simulation of LDPC under 8, 16 and 64 QAM is conducted in 4x4 MIMO-OFDM over additive white Gaussian noise (AWGN) and Raleigh fading channel. The propose system is analyzed based on BER with signal to noise ratio (SNR). The simulation using Matlab, shows the BER comparison between AWGN and Rayleigh fading channel, which LDPC works better in Rayleigh fading channel while in digital modulations the system outperforms with 8-QAM . The performance of LDPC between MIMO-OFDM and MISO OFDM is also being compared and it is further prove that MIMO performs better than MISO[1].**

Keywords- LDPC, MIMO-OFDM, Space Time Frequency Coding

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique which divides its wide signal bandwidth into many narrowband subchannels. This technique gives a significant increase in data rates in wireless communication system. In conjunction of its robustness to frequency selective fading, high spectral efficiency and low computational complexity, OFDM can transform MIMO channel into a set of parallel frequency[2,3]. MIMO which is known as a capacity booster work perfectly with OFDM system by enhancing the data rates in order to fulfill the future demands. Several companies had developed MIMO-OFDM based solution for IEEE 802.16e WIMAX broadband mobile standard.

MIMO-OFDM support both spatial multiplexing and diversity coding such as Space Time Coding and Space Time Frequency Coding. This paper used Space Time Frequency Coding in order to combine the advantages in MIMO and OFDM systems. STF coding is done across space, time and frequency to achieve maximum diversity gain.

Some data might be interfered by multipath environment and some are completely lost because of the deep fade. Hence, even though most subcarriers maybe detected without errors, the overall BER will be largely dominated by a few subcarriers with small amplitudes [4]. Forward error correction codes such as convolutional codes, Turbo codes, Reed Solomon codes and so on have been applied to OFDM system in order to avoid this problem.

One code that is very close to Shannon limit was proposed by Gallager in 1962 applied to BPSK and 8PSK is Low Density Parity Check. The fundamental of the research was evaluated over an additive white Gaussian noise channel and it has been shown LDPC codes have a large gain with the respect to convolutional code for large packet length [5].

In this paper, I simulated the LDPC under 64 QAM in 4x4 MIMO-OFDM system using Space time Frequency Coding over AWGN and Rayleigh fading channel using Matlab. Moreover, I proposed the algorithm LDPC MIMO-OFDM system with 8 QAM, 16 QAM. The simulation result is shown in BER with signal to noise ratio. The comparison between AWGN and Rayleigh can be observed, which LDPC works better in Rayleigh channel and the system outperforms with 8 QAM. The performance of LDPC between MIMO-OFDM and MISO-OFDM also being compared and it is further proving that in terms of reliability, MIMO performs better than MISO [1].

II. MIMO-OFDM

MIMO is known to be a booster for a high data rate transmission. The combination between MIMO and OFDM is very attractive and has become a most promising broadband wireless access scheme [9].

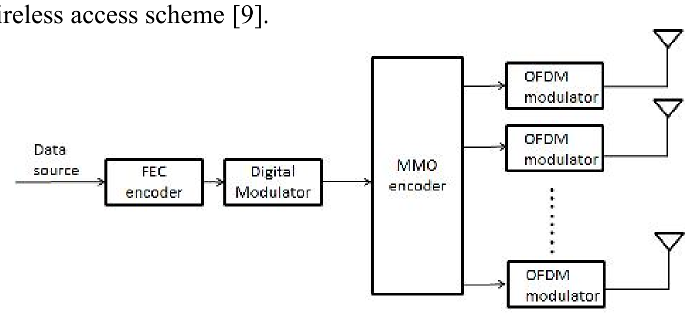

Figure1. A simplified MIMO-OFDM transmitter block

diagram.

Figure 1 shows the block diagram of MIMO-OFDM transmitter. The data source firstly will be encoded by forward error correction (FEC). Next, the encoded data will be modulated into digital mapping constellation by digital modulator which converts the binary data into complex number. After that, the symbol data is encoded by MIMO encoder and the parallel output then will be transmitted to OFDM modulator. Each parallel output corresponds to each transmit antenna. At the OFDM modulator, the symbol data is modulated by IFFT and cyclic prefix is inserted to every OFDM symbol in order to optimize inter-symbol interference (ISI). Afterwards the output is modulated to construct analog data and upconversion process is done.

The design for OFDM receiver is open and there are only transmission standard. So, I assume basic receiver structure is just follow the inverse of the transmission process.

III. STF CODING

Space Time Frequency coding is the extension of Space Time coding system. STFB coding schemes are used to enhanced the system reliability and performance by taking advantage of diversity of space, time and frequency inherent in MIMO-OFDM system [8].

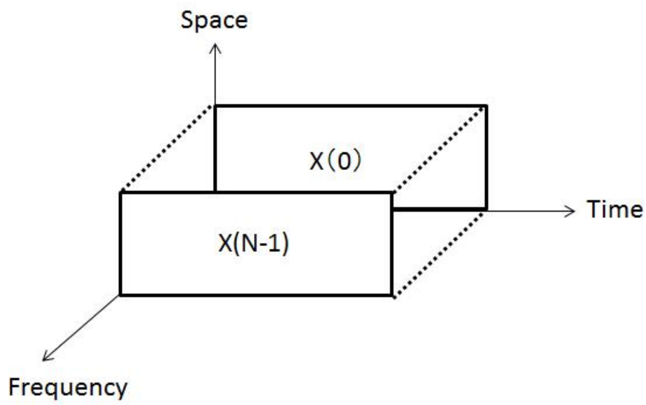

Figure2. STF code Transmission

A. STF Block Diagram

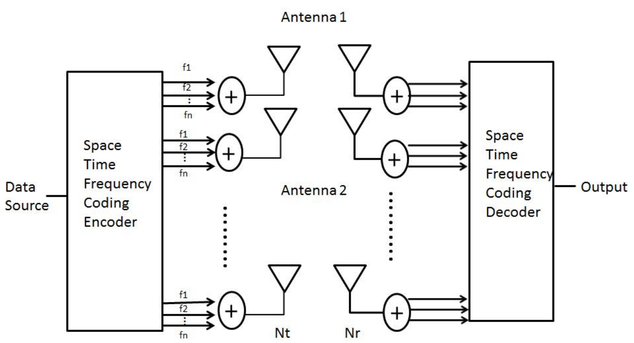

Figure3.STF block diagram. For simplicity purpose, IFFT and other function is not shown.

Assuming Nt antenna and fn tone, the size of encoder is Nt・fn. From the antenna, the signal is transmitted in selective frequency to through mobile radio channel.

B. STF code Structure

STF code uses the same principle of coding as the double Almouti code. Almouti code consists of 2 set of consecutive symbol in the input data stream to be transmitted s1 and s2. For the first time slot, the first antenna transmits s1 and second antenna transmit s2. In the next time slot, antenna 1 transmit s2* and antenna 2 transmit –s1*. Figure 4 shows the summary of the Double Almouti code system.

Table 1. An example of Double Almouti code for 2 transmit antenna.

	Antenna1	Antenna2
Time Slot 1	s1	s2
Time Slot2	s2*	-s1*

Adapting the double Almouti code system in STF coding, basically 2 Almouti code can be applied in 2 different frequencies. The code has property that each symbol transmits through a different equivalent channel with great diversity [1]. Figure 5 shows an example of Double Almouti Code for STF code proposed by [1] using 3 types of consecutive symbol s1,s2, s3 which is transmit from 2 antennas and having 3 types of frequency.

Table 2(a). Double Almouti for STF antenna 1

	Time slot 1	Time slot 2
Frequency 1	s1	s2
Frequency 2	s2	s3
Frequency 3	s3	s1

Table 2(b). Double Almouti for STF antenna 2

	Time slot1	Time slot2
Frequency 1	-s2*	s1*
Frequency 2	-s3*	s2*
Frequency 3	-s1*	s2*

After the coded signals travel through the antennas and transmitted, the signal that received by the receiver will be corrupted by noise. The receiver does some computations to estimate the original data s1, s2. Below computation is the example of using 2 transmit antennas and 2 receive antenna with 2 types of consecutive symbol.

The receive signal r11 and r21 correspond to the time slot 1 while r12 and r22 correspond to time slot 2. h is the channel coefficients and n is the noise correspond to the subcarrier.

For receiver antenna 1

$$r11=h11s1 + h12s2 +n11 \quad (1)$$

$$r12= - h11s2^{*} + h12s1^{*} + n12 \quad (2)$$

For receiver antenna2

$$r21 = h21s1 + h22s2 + n21 \quad (3)$$
$$r22 = -h21s2^{*} + h22s1^{*} + n22 \quad (4)$$

Receiver estimate the symbol s1 and s2 using below equations.

$$X1 = h11^{*}r11 - h12r12^{*} + h21^{*}r21 - h22r22$$
$$= (|h11|^{2}+|h12|^{2}+|h21|^{2}+|h22|^{2})s1 + h11^{*}n11 - h12n12^{*} + h21^{*}n21 - h22n22^{*} \quad (5)$$
$$X2 = h12^{*}r11 - h11r12^{*} + h22^{*}r11 - h21r22^{*}$$
$$= (|h11|^{2}+ |h12|^{2}+|h21|^{2}+|h22|^{2})s2 + h12^{*}n11 - +h11n12^{*} + h22^{*}n21 - h21n22^{*} \quad (6)$$

At last, s1, s2 are derived and passed to the maximum likelihood detector. These equation shows that the receiver fully receive the 2 by 2 system.

IV. Low density parity check (LDPC) code

LDPC codes are now recognized as a good error correcting codes which achieve near Shannon limit performance [6]. LDPC codes have better block error performance than Turbo code, because the minimum distance of an LDPC code increases proportional to the code length with high probability [4]. The advantage suits well for high bit rate transmission that demand low frame error potential.

LDPC codes are using sparse parity check matrix with two different possibilities to present the codes. First is using matrix **H** and the second one is using graphics. LDPC code is described by $m \times n$ parity check matrix **H** as (n,k) LDPC, where $k = n - m$ and the code rate is r=k/n. In the case that the H doesn't have full rank, K> n ~ m and the error performance of an LDPC code becomes worse. Thus, when we construct the Parity-check matrix **H**, we have to ensure that all the rows of the matrix are linearly independent.

Low-density parity-check codes are classified into two groups, regular and irregular LDPC codes. An LDPC code is called regular if w_c is constant for every column and $w_r = w_c \cdot (n/m)$ is also constant for every row. If **H** is low density but the numbers of 1's in each row or column aren't constant the code is called an irregular LDPC code. Irregular LDPC codes have better performance than regular codes.

LDPC codes can be decoded by using a probability propagation algorithm known as the sum product or belief propagation algorithm as presented in [4].

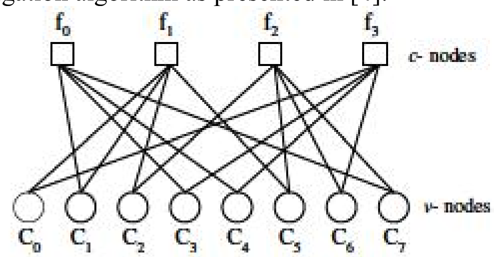

Figure4. Tanner graph corresponding to the parity check matrix **H** for (8,4) code.

Figure 4 is an example of graphical representation of LDPC code from Tanner. This graph contains 2 types of nodes which is called variable nodes (v-nodes) and check nodes (c-nodes). The variable nodes correspond to the n in matrix H dimension while check nodes correspond to the m in matrix H dimension.

V. System model

All the simulations were performs by automation programs using Matlab software. The simulation process is shown in figure 5 for the process in transmitter. Next, the signals are added with noise (AWGN and Rayleigh channel) for propagation interference.

At the receiver the process was the inverse process of transmitter. In the program we added the function of maximum likelihood after STF decoder in order to derive the original data. The result is evaluated base on BER through Signal to noise ratio.

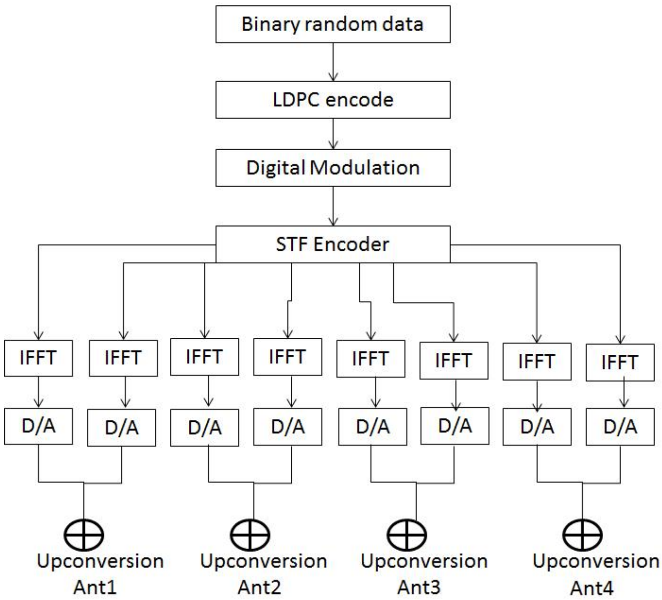

Figure 5. Block Diagram for transmitter using MIMO-OFDM with 4 transmit antenna

A. LDPC Code Parameter

In this paper, LDPC encoder is located at the first process of the system. In this simulation we are using LDPC encoder produced by Matlab. The default program is the sparse parity check matrix of half-rate LDPC code from the DVB-S.2 standard. The parameters for this part are as follows.

Table 3. LDPC encoder parameter by Matlab

Parity check matrix	[32400x64800 logical]
Block Length	64800
Number InfoBits	32400
Number Parity Bits	32400

Encoding Algorithm	'Forward Substitution'

Table 4. LDPC decoder parameter by Matlab

Parity Check Matrix	[32400x64800 logical]
Block Length	64800
Number Info Bits	32400
Number Parity Bits	32400
Decision Type	Hard decision
Output Format	Information part
Number Iterations:	50

B. STF System Structure

From the adaptation of Double Almouti code scheme, the time frequency interleaving for this project are as follows.

Table 5. STF block coding techniques

	(t+T)f1	(t+2T)f2	(t+3T)f3	(t+4T)f4
Ant 1	s1	s2	s3	0
Ant 2	$-s2^*$	$s1^*$	0	s3
Ant 3	$s3^*$	0	$-s1^*$	s2
Ant 4	0	$s3^*$	$-s2^*$	-s1

In this paper, we are using 4 by 4 antennas with 2 different frequency each antenna and 4 timeslot (T). So, the STFBC time frequency interleaving become as follows.

Table 6. The time and frequency interleaving using STF block coding technique. * is conjugate.

	Frequency	T1	T2	T3	T4
Ant1	fc1	s1	s3	s1	s3
Ant1	fc2	$-s2^*$	0	$s2^*$	$s4^*$
Ant2	fc1	s2	0	s2	-s4
Ant2	fc2	$s1^*$	$s3^*$	$-s1^*$	$s3^*$
Ant3	fc1	$s3^*$	$-s1^*$	s3	-s1
Ant3	fc2	0	$-s2^*$	$s4^*$	$-s2^*$
Ant4	fc1	0	s2	s4	s2
Ant4	fc2	$s3^*$	-s1	$s3^*$	$-s1^*$

C. OFDM parameters

There 8 OFDM system in this simulation. Each OFDM hold the same parameter as in table 7.

Table 7. OFDM parameters based on DVB-T standard.

Parameter	8k Mode
Elementary period T	7/64μs
Number of carriers	8192
Number of used carriers	6817
Duration Tu	896μs
Bandwidth	7.608 MHz
Subcarrier spacing	1.116071429 kHZ

VI. SIMULATION RESULT

Figure 6 to 9 show the time domain representation prior to the process in the transmitter. There are 8 types of signals in total which are transmitted by 4 antennas with 2 types of frequency, fc1 and fc 2.

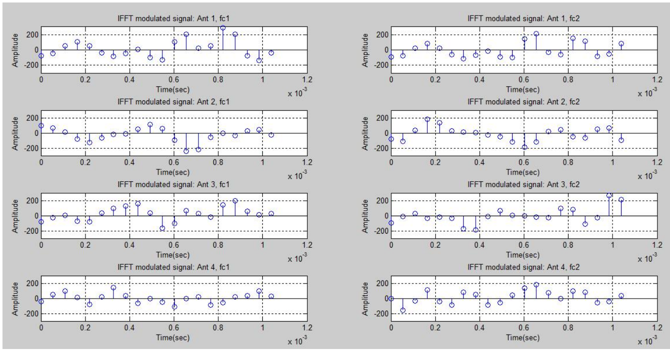

Figure 6. Time response of 8 signal carrier from 4 antennas after IFFT modulation.

In figure 6, we noticed that the signal carriers are the discrete time baseband signal. We can use this signal in baseband discrete time domain simulations but we must understand that the most OFDM drawbacks occur in the continuous time domain. Therefore, we simulate the complex signal carriers to become pulse shape signals in order to produce continuous time signal as shown in figure 7.

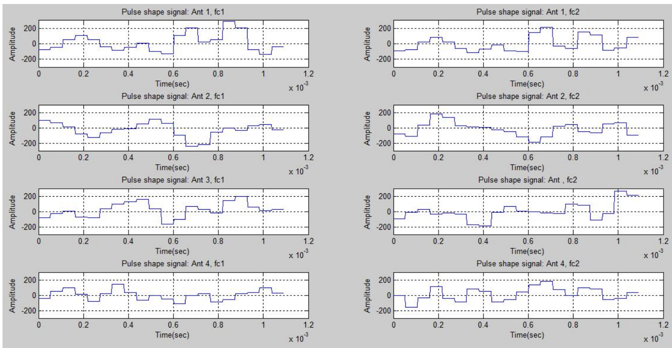

Figure 7. Pulse signals of 8 carriers from 4 antennas.

The next process is reconstruction of digital to analog response signals as shown in figure 8 and lastly the complete signals after the upconversion process are shown in figure 9.

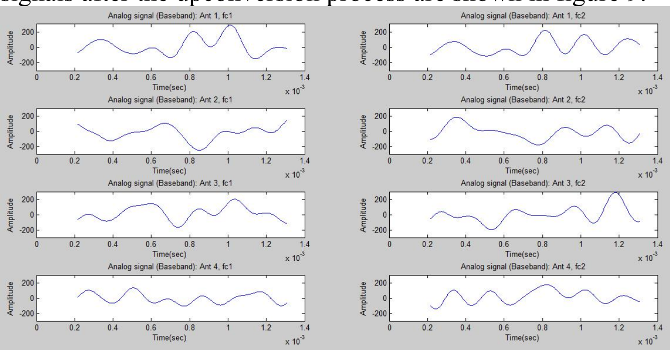

Figure 8. Analog signal (baseband) of 8 signal carriers.

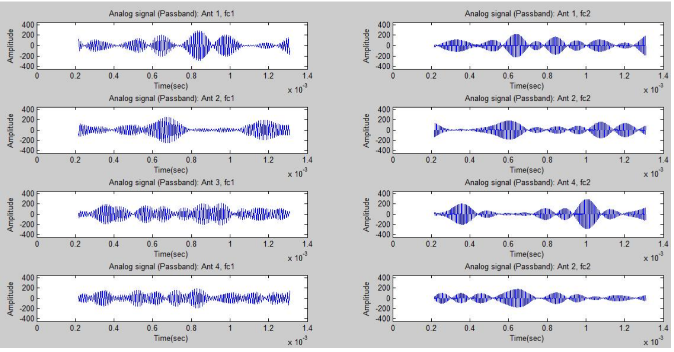

Figure 9. Analog signals (passband) prior to upconversion process transmitted from 4 antennas.

Performance of comparison between MIMO and MISO schemes is shown in figure 10. It is observed that MIMO performs better than MISO.

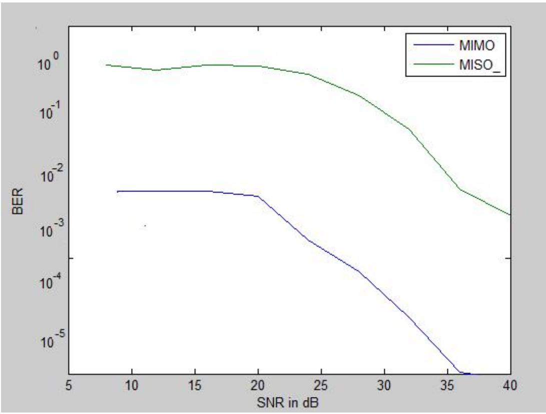

Figure 10. BER performance of LDPC with MIMO and MISO OFDM with AWGN for 64QAM.

The performance of comparison between AWGN and Rayleigh fading channel is shown in figure 11. From the plot, LDPC works better in Rayleigh fading channel.

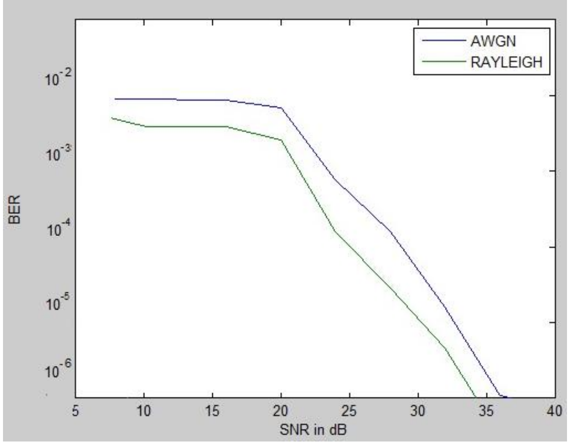

Figure 11. BER performance of LDPC with interference by AWGN and Rayleigh fading channel.

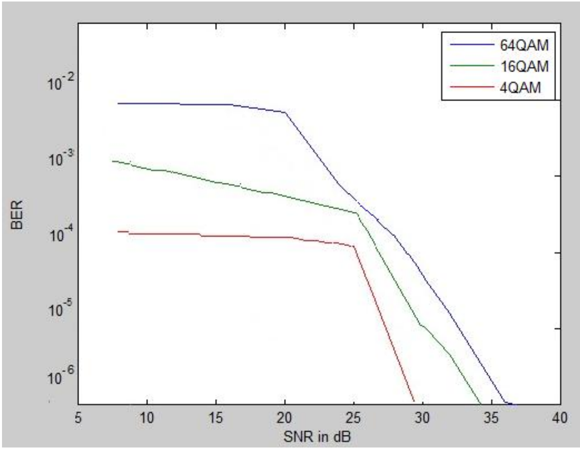

Figure 12. BER performance of LDPC with 8 QAM, 16 QAM and 64 QAM in AWGN channel.

Comparison between the digital modulation (8 QAM, 16 QAM and 64 QAM) is shown in figure 12. The system outperform in 8 QAM even though it has a slow curve at first. The higher number of QAM the worse performance became.

VII. CONCLUSION

In this paper I evaluated the performance of LDPC in MIMO-OFDM using STF diversity coding. The result shows the response to SNR value is convincing, but the value when the BER of 10^{-5} achieved is not as expected, which is, at least SNR below than 10. Other details must be considered in order to achieve intended target such as noise filtering and guard interval optimization. The result of the performance of LDPC in STF coding for MIMO-OFDM could be a reference in the future development. The simulation to observe the BER is done using the continuous time domain signal instead of discrete time signal. This action, more or less give the impact to the performance of the BER as we understand, many drawbacks occur during the continuous time signals.

VIII. FUTURE WORK

1. Investigate the simulation of various pair of antenna for example 2x2, 3x3, 2x3, 3x2 and so on in order to observe the highest performance.
2. Simulate other FEC coding in order to compare the performance of LDPC with other FEC coding such as Turbo Codes, Reed Solomon Code and Convolutional Codes.
3. Simulate this system with other diversity coding such as Space Time Coding and Space Frequency Coding for comparison.

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