

## Review of MIMO-OFDM System for Time/Frequency Selective Fading Channel

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### Abstract

Orthogonal frequency division multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO) are the popular technique for transmission of signals over wireless channels. They individually assisting multipath fading environment and improving link reliability without sacrificing bandwidth and also provide high data rate. The combination of OFDM and MIMO seems to be the key technology in next generation high data rate wireless mobile systems. In this paper firstly, MIMO and OFDM technology is introduce. Secondly, we provide an overview of space-time (ST) coding, space-frequency (SF) coding and space-time-frequency (STF) coding techniques for MIMO-OFDM systems which improve the reliability of system further. Finally performances comparison of the different coding techniques for OFDM-MIMO system is done.

### Introduction

Orthogonal frequency divisions multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels because of its advantages like robust against inter symbol interference (ISI) and spectral efficient nature. OFDM has been adopted in several wireless standards such as digital audio broadcasting (DAB), digital video broadcasting standard (DVB-T), the IEEE 802.11a [1] local area network (LAN) standard and the IEEE 802.16a [2]. It is also used in the ADSL standard, where it is referred to as Discrete Multi tone modulation and it is consider as a potential candidate for next-generation (4G and beyond 4G) mobile wireless systems.

The major challenges in future wireless communications system designs are, increased spectral efficiency and improved link reliability. The radio channel constitutes a hostile propagation medium, which suffers from multipath fading and interference from other users [3]. The use of multiple antennas at both ends of a wireless link promises significant improvements in terms of spectral efficiency and link reliability. Multiple-input multiple-output (MIMO) technology has recently become very popular since it can improve link reliability without sacrificing bandwidth efficiency [4] [5] [6].

In a very high data rate MIMO communication system, the radio channel introduces severe inter-symbol-interference. In this case, single-carrier based MIMO systems require highly complex equalization techniques such as a vector-maximum likelihood sequence estimator (MLSE) or a multichannel equalizer. However, multicarrier based MIMO systems, e.g., MIMO-OFDM, permit simple equalization processes by turning the frequency selective fading channel into a set of parallel flat fading channels [7]. The combination of OFDM and MIMO seems to be very promising when aiming at the design of very high-rate wireless mobile systems [8]. While multiple antennas at the transmitter and receiver elevate channel capacity, OFDM converts the wideband frequency selective radio channel into a set of parallel flat-fading channels, thus simplifying signal processing required at the receiver [9]. MIMO-OFDM system ensures very high data rate with reliable transmission link.

### BACKGROUND

#### OFDM

OFDM has many advantages over other transmission techniques. One such advantage is high spectral efficiency. The “Orthogonal” part of the name refers to a precise mathematical relationship between the frequencies of the subchannels that make up the OFDM system.

Each of the frequencies is an integer multiple of a fundamental frequency. This ensures that even though the subchannels overlap they do not interfere with each other. This results in high spectral efficiency.

In OFDM single high data rate stream transform into ‘n’ number lower rate stream because of this each individual data stream experiences flat fading. In other ways OFDM converts a frequency-selective channel into a parallel collection of frequency flat sub channels. The subcarriers have the minimum frequency separation required to maintain orthogonality of their corresponding time domain waveforms, yet the signal spectra corresponding to the different subcarriers overlap in frequency. Hence, the available bandwidth is used very efficiently.

OFDM modulation divides a broadband channel into many parallel subchannels. This makes it a very efficient scheme for transmission in multipath wireless channels. The use of an FFT/IFFT pair for modulation and demodulation make it computationally efficient as well. The use of IFFT and FFT for modulation and demodulation results in computationally efficient OFDM modems. The block diagram of an OFDM modulator and demodulator are shown in Figure1.

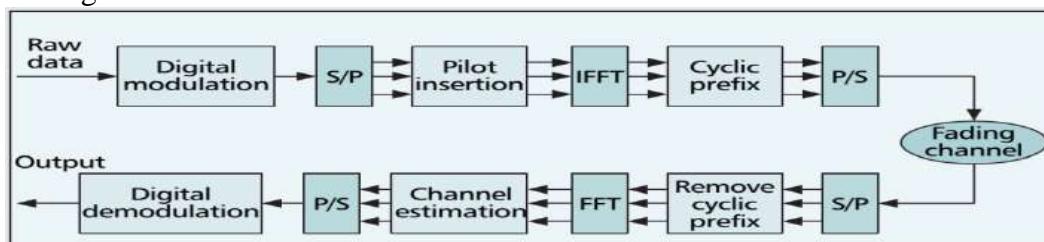


Figure 1. Block diagram of OFDM

### A. MIMO

MIMO systems can be defined simply as having multiple transmitting and receiving antennas. A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scattering environment. MIMO systems may be implemented in a number of different ways to obtain either a diversity gain to combat signal fading or to obtain a capacity gain. Let us assume that the number of transmitting antennas is  $M$ , and the number of receiving antennas is  $N$ . We will first look at the capacity of different antenna systems in order to see the dramatic increases in capacity obtained by using MIMO systems.

For diversity gain, Multiple-Input Multiple-Output (MIMO) - Same signal transmitted by each antenna. The MIMO system can be viewed in effect as a combination of the Multiple-Input Single-Output (MISO) and Single-Input Multiple-Output (SIMO) channels. In this case, it is possible to get approximately an  $MN$ -fold increase in the SNR yielding a channel capacity equal to

$$C \approx B \cdot \log_2(1 + MN \cdot SNR_o) \quad (1)$$

Thus, we can see that the channel capacity for the MIMO system is higher than that of MISO or SIMO. However, it should be noted here that in all four cases the relationship between the channel capacity and the SNR is logarithmic. This means that trying to increase the data rate by simply transmitting more power is extremely costly.

For capacity gain, Multiple-Input Multiple-Output (MIMO) - Different signal transmitted by each antenna. Our assumption here is that  $N, M$ , so that all the transmitted signals can be decoded at the receiver. The big idea in MIMO is that we can send different signals using the same bandwidth and still be able to decode correctly at the receiver. Thus, it is like we are creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to

$$C_{single} \approx B \cdot \log_2(1 + \frac{N}{M} \cdot SNR_o) \quad (2)$$

But, since we have  $M$  of these channels ( $M$  transmitting antennas), the total capacity of the system is

$$C \approx M \cdot B \cdot \log_2\left(1 + \frac{N}{M} \cdot SNR_o\right) \quad (3)$$

Thus, as we can see from (3), we get a linear increase in capacity with respect to the number of transmitting antennas. So, the key principle at work here is that it is more beneficial to transmit data using many different low-powered channels than using one single, high-powered channel.

### B. MIMO-OFDM

Combination of OFDM and MIMO technique achieves spectral efficiency, robust to multipath fading and increased throughput. A MIMO-OFDM system transmits independent OFDM modulated data from multiple antennas simultaneously [10] [11]. At the receiver, after OFDM demodulation, MIMO decoding on each of the subchannels extracts the data from all the transmit antennas on all the subchannels. The block diagram of a MIMO-OFDM system is shown in Figure 2

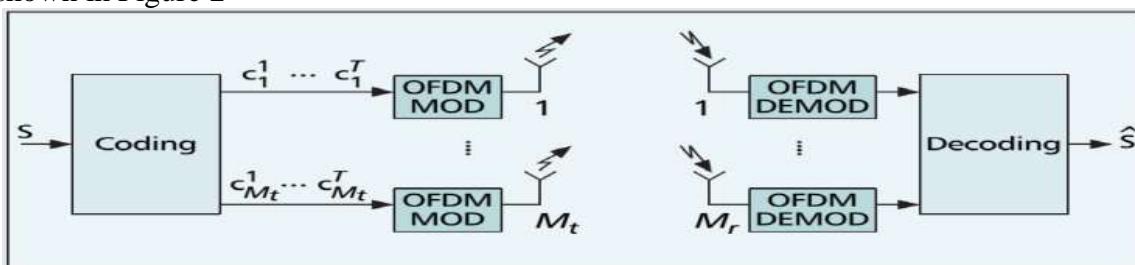


Figure 2. Block diagram of MIMO-OFDM

They transmit independent data (say  $x_1, x_2, x_3, \dots, x_n$ ) on different transmit antennas simultaneously and in the same frequency band. At the receiver, a MIMO decoder uses  $M, N$  antennas. Assuming  $N$  receiving antennas, and representing the signal received by each antenna as we have:

$$\begin{aligned} r_1 &= h_{11}x_1 + h_{12}x_2 + \dots + h_{1n}x_n \\ r_2 &= h_{21}x_1 + h_{22}x_2 + \dots + h_{2n}x_n \\ &\vdots \\ r_n &= h_{n1}x_1 + h_{n2}x_2 + \dots + h_{nn}x_n \end{aligned} \quad (4)$$

As can be seen from the above set of equations, in making their way from the transmitter to the receiver, the independent signals  $\{x_1, x_2, x_3, \dots, x_n\}$  are all combined. Traditionally this "combination" has been treated as interference. However, by treating the channel as a matrix, we can in fact recover the independent transmitted streams  $\{x_i\}$ . To recover the transmitted data stream  $\{x_i\}$  from the  $\{r_i\}$  we must estimate the individual channel weights, construct the channel matrix  $H$ . Having estimated  $H$ , multiplication of the vector  $r$  with the inverse of  $H$  produces the estimate of the transmitted vector  $x$ . This is equivalent to solving a set of  $N$  linear equations in  $N$  unknowns. To improve the error rate performance, multiple antennas can also be used by transmitting the redundant signal using same information sequence. This information sequence is transmitted over the multiple antennas by means of two dimensional coding in space, time and frequency.

### DIFFERENT CODING TECHNIQUES FOR MIMO-OFDM

#### a) STBC CODING FOR MIMO-OFDM

Space Time coding is a powerful scheme that combines time coding with transmit diversity to achieve high diversity performance in wireless systems. Space time coding scheme can in general be classified into two major classes: ST trellis codes and ST block codes. In an ST trellis coding scheme, an information stream is encoded via  $M_t$  convolutional encoders (or via one convolutional encoder with  $M_t$  outputs) to obtain  $M_t$  streams of symbols that are transmitted from  $M_t$  antennas simultaneously. One problem of ST trellis coding is that the decoding

complexity increases exponentially as a function of the diversity level and transmission rate [3]. To overcome this drawback ST block code (OSTBC) was designed, which was first proposed by Alamouti in 1998 [4]. This OSTBC design is also referred as the Alamouti code. Specifically, the information symbols are transmitted in a different order from two transmit antennas with some modification (conjugate and sign) shown in table 1. The Alamouti code can provide the full diversity of 2 for two transmit antennas with a rate of 1. Due to the orthogonality of the code matrix, the Alamouti code has a fast ML decoding property which allows simple single-symbol ML detection.

Table 1 Symbol mapping of STBC scheme.

Time instance	$T_n$	$T_{n+1}$
Antenna 1	$X_n$	$-X_{n+1}^*$
Antenna 2	$X_{n+1}$	$X_n^*$

$X_n$ ,  $X_{n+1}$  are transmitted signal through antenna 1 and 2 at time instance 'n' and  $X_{n+1}^*$ ,  $X_n^*$  are transmitted signal through antenna 1 and 2 at time instance 'n+1'. After the STBC perform on data sequence, block code are OFDM modulated by performing IFFT, cyclic prefix are added and then transmitted through respective transmitter. At receiver first cyclic prefix removed then OFDM demodulation perform and finally estimation of transmitted signal done at space time combiner.

But it is observed that when the channel varies in time domain the maximum likelihood (ML) decoder will experience severe bit error rate (BER) degradation. Combining STBC with OFDM will not resolve the problem because the STBC codeword is transmitted over two consecutive OFDM symbols [5]. The degradation caused by the channel variation in high mobility systems is proportional to the Doppler frequency, which may exceed 20% of the subcarrier spacing [6]-[9].

Several solutions are proposed to enhance the performance of STBC-OFDM systems in time-varying frequency-selective channels. For example, Lee et al. [2] proposed a hybrid STBC-SFBC (STFBC) system to combat both time and frequency selectivity of the channel. Although the STFBC system managed to reduce the BER degradation, the improvement gain is limited and BER floors can be observed at high SNR values. Chung and Phoong [5] proposed a unitary-precoded (UP) STBC system to overcome the channel frequency selectivity. Although the UP-STBC offers good performance in static channels, the system BER increases drastically in time-varying channels. Moreover, the UP increases the system computational complexity due to the additional full length Walsh Hadamard Transforms (WHT) required

### b) SFBC CODING FOR OFDM

In SFBC, frequency coding is performed across antennas. A straightforward way of realizing Space Frequency coding for two transmit antennas is to directly spread the Alamouti code over two sub-channels in one OFDM block. Consider the two symbols  $X_n$  and  $-X_{n+1}^*$  are sent from sub-channels  $k$  and  $l$  of the same OFDM block  $n$  at antenna 1, respectively, where  $k$  and  $l$  denote the indices of two separated sub-channels. Mean-while,  $X_{n+1}$  and  $X_n^*$  are sent from sub-channels  $k$  and  $l$  of the same OFDM block  $n$  at antenna 2, respectively. Table 2 shows SF coding for two transmit antennas.

Table 2 Symbol mapping of SFBC scheme

Frequencies(sub-channels)	$k$	$l$
Antenna 1	$X_n$	$-X_{n+1}^*$
Antenna 2	$X_{n+1}$	$X_n^*$

Space-frequency block coded (SFBC) systems are proposed to combat the channel variations in time-domain because the SFBC blocks are transmitted simultaneously over multiple adjacent subcarriers. However, in severe frequency-selective channels, the channel response at adjacent subcarriers could vary drastically, and hence the condition for the Alamouti decoder to provide reliable performance is no longer valid. Consequently, the system will experience severe BER degradation.

A embedded Alamouti SFBC-OFDM scheme is presented in [7] by S. Lu and B. Narasimhan to resolve the frequency selectivity problem. They integrated their system with the low-complexity finite-impulse-response minimum-mean-square-error frequency-domain equalizer (FIR-MMSE FEQ) to compute the MIMO FIR-MMSE FEQ coefficients, an embedded Alamouti (EA) SFBC-OFDM system is designed to reduce the impact of the inter-carrier interference (ICI) caused by the channel variations by separating the Alamouti codewords by B subcarriers, and using 3-Tap frequency domain equalizer (FDE). Although the EA system has demonstrated considerable improvement over conventional SFBC, the system still highly sensitive to severe frequency-selectivity channels. Moreover, the system has high computational complexity due to the 3-Tap FDE process.

A modified Alamouti SFBC decoder is presented in [8] for MIMO-OFDM to resolve the frequency selectivity problem. This uses the channel frequency variation in consecutive subcarrier to adopt the Alamouti decoder. The main drawback of this technique is that it requires accurate knowledge of the channel response difference across adjacent subcarriers.

A new technique proposed to enhance the robustness of SFBC systems in severe fading environment in [9] by A. Al-Dweik, F. Kalbat, S. Muhamadat, O. Filio, S. M. Ali. This system denoted as the Channel Matrix Shaping (CMS), which guarantees that the channel frequency responses over each SFBC block of two adjacent sub-carriers are identical, i.e. it shape the frequency-selective channel to becomes piece-wise flat. The propose system is based on the 2x2 WHT, which introduces negligible additional complexity and improve the reliability. The main constraint of the proposed system is that its optimal performance is achieved with binary phase shift keying (BPSK) modulation.

### PERFORMANCE COMPARISON

Performance comparisons done for the different coding techniques of STBC and SFBC with conventional STBC and SFBC system in figure 3 presents the BER in time-varying channels for the CMS, STBC, SFBC and UP-STBC systems using  $F_d = 0:1$  and  $0:2$ . It can be noted from the figure that the CMS offers a remarkable BER advantage over the other considered systems. The CMS advantage over conventional SFBC systems becomes more apparent at high SNRs because the BER performance becomes dominated by the channel response difference across pairs of subcarriers in each SFBC block. In general, all considered systems exhibit error floors at different levels. The ICI caused by the Doppler spread is one of the factors that contribute to the error floor in all systems. However, the STBC and SFBC systems suffer from high error floors as compared to the CMS, which is due to the sensitivity of such systems to channel variations in time and frequency domains, respectively. The UP-STBC BER is highly dependent on the Doppler rather than the frequency selectivity of the channel as observed in the figure where the BER drops substantially when the Doppler spread is reduced from  $0:2$  to  $0:1$ .

Figure 5.shows SFBC-OFDM system is designed to reduce the impact of the intercarrier interference (ICI) caused by the channel variations by separating the Alamouti codewords by B subcarriers, and using 3-Tap frequency domain equalizer (FDE). Although the EA system has demonstrated considerable improvement over conventional SFBC, the system still highly sensitive to severe frequency-selectivity channels. Moreover, the system has high computational complexity.

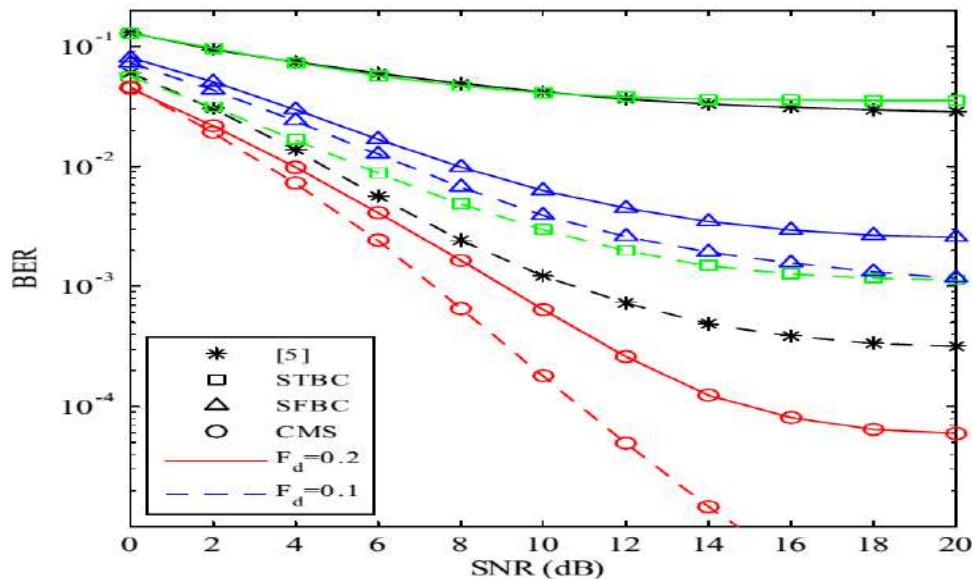


Figure 3 The coded BER of the CMS, STBC, SFBC and UP [9] systems

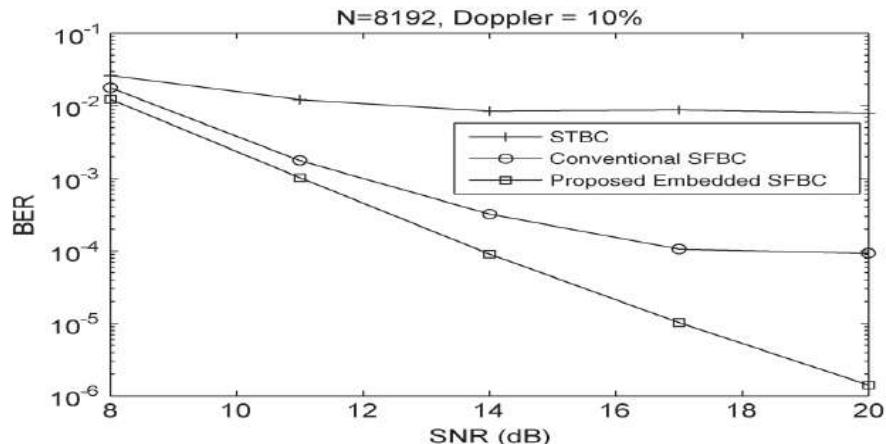


Figure 4. BER comparison for STBC, conventional SFBC, and our proposed embedded SFBC with perfect channel and 10% Doppler spread [7].

Figure 6. shows a hybrid STBC-SFBC (STFBC) system to combat both time and frequency selectivity of the channel. Although the STFBC system managed to reduce the BER degradation, the improvement gain is limited and BER floors can be observed at high SNR values.

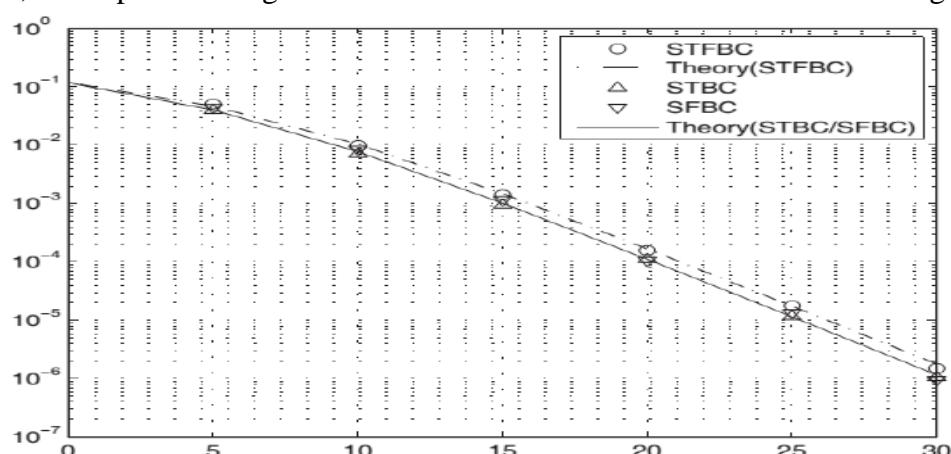


Figure 5. BER performance comparisons in a non-selective fading channel,  $\Delta f=0$ ,  $\tau_{rms}=0\mu s$  [8].

## CONCLUSION

This paper review the different coding for MIMO-OFDM system and compare the performance of conventional STBC,SFBC, UP-STBC, embedded Alamouti (EA)SFBC-OFDM and CSM coding techniques used for MIMO-OFDM system.

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