CHAPTER - 6

Higher MIMO performance with OFDM Multiplexing Scheme
CHAPTER VI
HIGHER ORDER MIMO PERFORMANCE WITH OFDM
MULTIPLEXING SCHEME

6.1 2x2 MIMO with OFDM multiplexing scheme

The combination of MIMO signal processing with OFDM is regarded as a promising solution for enhancing the data rates of next-generation wireless communication systems operating in frequency-selective flat fading Rayleigh environments. To realize this extension of OFDM with MIMO, a number of changes are required in the baseband signal processing. An overview is given for the necessary changes in time and frequency synchronization. The complete MIMO-OFDM processing is implemented in a system with 2X1, 2X2, 4X1 and 4X2 antennas using BPSK and QPSK modulation and its performance of BER versus SNR has been evaluated with simulation results. The results from with this MIMO OFDM system show that on average, a significant improvement in SNR around 2dB is observed between 2X1 and 2X2 as well as in 4X1 and 4X2 MIMO systems.

A potential disadvantage of MIMO is its complexity, particularly the broadband time-domain version of MIMO. In the presence of delay-spread, a MIMO receiver (space-time equalizer) is quite complex. The Solution is MIMO OFDM which simplifies the implementation of MIMO without loss of capacity, avoids inter-symbol-interference by modulating narrow orthogonal carriers, and each narrow-band carrier is treated as a separate MIMO system with zero delay-spread [62].

To increase the data transmission, a combination of both modulation and multiplexing in MIMO is required. Unlike general multiplexing technique it is applied to only one independent channel, where a set of signals from the same source is divided or spitted into a number of independent channels (sub-set of the main signals) and each modulated by separate carrier, and then multiplexed into an OFDM signal for transmission [63]. Each independent sub-set channel can be multiplexed either by frequency or code division multiplexing. The characteristics of OFDM sub-channels depict the orthogonality of the sub-carriers, where each sub-channel of the main signal in fact multiplied by a carrier which is orthogonal to each other. Carriers are nothing but sine or cosine wave; and the area under one sine and one cosine wave is simply zero. Orthogonal carrier means if the first carrier frequency is f1 the second carrier will be 2xf1, the third carrier will be 3xf1, and so on. This kind of orthogonality of the carriers allows simultaneous transmission of sub-carriers in a
tightly spaced bandwidth without interfering from each other because each carrier is orthogonal to each other making the result of their multiplication a zero \[^{[64]}\]. Normally, OFDM signals are sent via one transmitting antenna. When generated OFDM signal is transmitted through a number of antennas in order to achieve diversity or cap any gain (higher transmission rate) in MIMO-OFDM can be realized. The advantage of MIMO OFDM is less interference, diversity gain, increase data capacity, power efficiency and bandwidth gain.

6.1.1 MIMO OFDM Transmitter

![MIMO OFDM Transmitter Diagram](image)

Figure: 6.1. MIMO OFDM Transmitter

6.1.2 MIMO OFDM Receiver

![MIMO OFDM Receiver Diagram](image)

Figure: 6.2. MIMO OFDM Receiver

6.1.3 MIMO-OFDM Working

Like any other communication system MIMO-OFDM system also has transmitter and receiver but the antennas are more than one both at transmit and receive end. MIMO system can be implemented in various ways, if we need to take the diversity advantage to combat fading then we need to send the same signals through various MIMO antennas and at the receiving end all the signals received by MIMO antennas will receive the same signals
traveled through various path. In this case the entire received signal must pass through un-
correlated channels. If we are inserted to use MIMO for capacity increase then we can send
different set of data (65) (not the same set of data like diversity MIMO) via a number of
antennas and the same number of antennas will receive the signals in the receiving end. For
MIMO to be efficient antenna spacing need to be done very carefully- at least half the wave
length of the transmitting signal. But the limitations of MIMO-OFDM are antenna spacing
must be appropriate depending on the type of channels and it has very complex transmitter
and receiver.

OFDM is a technique that divides a frequency band into a number of orthogonal (i.e.,
parallel) narrowband sub-channels. A single data stream is divided into several paralleled
stream and each of the data stream(or sub-set) is multiplied by either a specific carrier
frequency or code and then all the parallel data stream is combined together using IFFT to
make OFDM symbol for transmission. If each individual parallel data is multiplied by
frequency then it is called OFDM. OFDM is a special type of FDM. Unlike FDM, signals are
not multiplied by a single carrier in OFDM- each sub-set of carrier creates a sub-channel for
communication which has the advantage of less prone to interference since each sub-carrier
frequency is kept orthogonal to each as other. Thus, huge bandwidth efficiency due to
reduced carrier spacing (orthogonal carriers overlap), simple Equalization simplified, or
eliminated, OFDM signals are resistant to fading, scalable data transfer rate in different
channel conditions, single frequency Networks are possible (broadcast application) (66).

OFDM is a Multi-Carrier Modulation technique in which a high rate bit-stream is split into
(say) N parallel bit-streams of lower rate and each of these are modulated using one of N
orthogonal sub-carriers. For a given bandwidth, the symbol rate for a single carrier
transmission is very high, where as for OFDM signal it is N times lower, where N is the
number of subcarriers used. The lower symbol rate leads to low ISI. Also using guard period
at the start of each symbol removes any ISI shorter than its length. If the guard period is long
enough, then all the ISI can be removed (67).

6.1.4 MIMO- OFDM Principle
The basic principle is the insertion of a guard interval, called cyclic prefix (CP), which is a
copy of the last part of the OFDM symbol (Figure. 1c), and has to be long enough to
accommodate the delay spread of the channel. The use of the CP turns the action of the
channel on the transmitted signal from a linear convolution into a cyclic convolution, so that
the resulting overall transfer function can be diagnosed through the use of an IFFT at the transmitter and an FFT at the receiver (Figure 1b). Two signals are orthogonal if their dot product is zero. That is, two signals multiply them together and if their integral over an interval is zero, then two signals are orthogonal in that interval. This results in no interference between the carriers, allowing them to be spaced as close as theoretically possible.

6.1.5 Guard time and Cyclic extension
Guard Time is introduced in-order to eliminate the ISI almost completely. Making the guard time duration larger than that of the estimated delay spread in the channel, merits in the guard period when left empty, the orthogonality of the sub-carriers no longer holds, i.e., ICI. OFDM is bandwidth efficient, since the parallel sub carriers are overlapping but orthogonal to each other without causing interference. Using CP, it robust the multipath fading and insusceptible to most forms of impulse noise because of parallel transmission.

6.1.6 OFDM modulation
MIMO technology will predominantly be used in broadband systems that exhibit frequency-selective fading and, therefore ISI. OFDM modulation turns the frequency-selective channel into a set of parallel flat fading channels. Figure 1 depicts the schematic of a MIMO-OFDM system. Consequently, the overall frequency-selective channel is converted into a set of parallel flat fading channels, which drastically simplifies the equalization task. However, as the CP carries redundant information, it incurs a loss in spectral efficiency, which is usually kept at a maximum of 25 percent. In general, OFDM has tighter synchronization requirements than single-carrier (SC) modulation and direct-sequence spread spectrum (DSSS), is more susceptible to phase noise, and suffers from a larger peak-to-average power ratio.

6.1.7 Constellation Diagram

Figure 6.3: Constellation diagram.
The MIMO-OFDM simulation is carried out using MATLAB 9 software.

In the MIMO case, increasing the number of transmitting and receiving antennas, on the one hand, increases the total number of degrees of freedom for communication and, on the other hand, results in an increase in channel uncertainty. Since the total available transmit power is split uniformly across transmitting antennas, increasing the number of transmit antennas results in a smaller SNR per degree of freedom which leads to the existence of a finite optimum (in the sense of capacity (maximizing) number of transmit antennas. Increasing the number of receive antennas, on the other hand, yields an increase in the receive SNR and is hence always beneficial.

6.1.8 Results and Discussions

6.1.8.1 MIMO-OFDM Performance for BPSK modulation

The effect of modulation schemes on MIMO-OFDM system has been investigated. The simulated results are obtained for 2x1 and 2x2 MIMO system using OFDM multiplexing and BPSK modulation with ZF detection system by computing the BER variation as a function of SNR. The Figure 6.4(a) and 6.4 (b) shows the plot of SNR performance for 2x1 MIMO and 2x2 MIMO systems.

![Figure 6.4: BER Vs SNR plot for (a) 2x1 MIMO and (b) 2x2 MIMO with OFDM multiplexing and BPSK modulation](image)

It can be seen from the Figures 6.4(a),(b) that at BER of $10^{-3}$ point for 2x1 MIMO the SNR is ~11 dB and for 2x2 MIMO the SNR ~8dB respectively. The SNR value indicated for 2x2 MIMO is the lowest and an improvement of SNR ~3dB compared to 2x1 MIMO system suggesting that the 2x2 MIMO with OFDM multiplexing and BPSK modulation exhibits best SNR performance.
6.1.8.2 MIMO performance with OFDM multiplexing and QPSK modulation

The simulated results are obtained for 2x1 and 2x2 MIMO system using OFDM multiplexing and for QPSK modulation with ZF detection system by computing the BER variation as a function of SNR. The Figure 6.5(a) and 6.5 (b) shows the plot of SNR performance for 2x1 and 2x2 MIMO systems for QPSK modulation.

![MIMO OFDM BER Plot for 2x1 with QPSK Modulation](image1)

![MIMO OFDM BER Plot for 2x2 with QPSK Modulation](image2)

Figure. 6.5: BER Vs SNR plot for (a) 2x1 MIMO and (b) 2x2 MIMO with OFDM multiplexing and QPSK modulation

It can be seen from the Figures 6.5(a) and 6.5(b) that at BER of $10^{-3}$ point for 2x1 MIMO the SNR is $\sim 15$ dB and for 2x2 MIMO the SNR $\sim 12$ dB respectively. It can be found from the Figure that there is an improvement of SNR $\sim 3$ dB between the two MIMO systems with OFDM multiplexing and QPSK modulation.

Further it can be noticed that between BPSK and QPSK modulation schemes for 2x1 and 2x2 MIMO –OFDM system, the results indicate that the BPSK modulation shows better SNR performance $\sim 3$ dB compared to QPSK modulation and the BPSK modulation scheme is better suited for 2x2 MIMO-OFDM systems.

6.1.8.3 Higher MIMO system performance with OFDM multiplexing

The simulated results of SNR performance for the 2x1 MIMO, 2x2 MIMO, 4x1 MIMO and 4x2 MIMO systems with OFDM multiplexing and for both BPSK and QPSK modulation are shown in Figure 6.6 (a) and 6.6 (b).
It can be seen from the Figure 6.6 that for both lower (2x2) and higher (4x2) MIMO systems with OFDM modulation, the BER variation with SNR are identical and the SNR value remains same for both the MIMO systems. Further at BER $10^{-3}$ point, for BPSK modulation both 2x2 and 4x2 MIMO–OFDM systems show that SNR $\sim 8$ dB and for QPSK modulation the SNR $\sim 12$ dB. The results suggests that the SNR behavior is independent of the order of the MIMO system and the MIMO-OFDM multiplexing combination with BPSK modulation exhibits the best SNR performance $\sim 8$ dB by for the MIMO-OFDM system.

### 6.2 4x4 MIMO system with OFDM multiplexing and Markov Chain Monte Carlo Receiver system.

A detailed analysis of the performance of 4x4 MIMO antenna system has been carried out using OFDM techniques. The transmission characteristics are determined for BPSK and 16-QAM digital modulation. AWGN has been used for the channel. On the receiver side, Markov Chain Monte Carlo (MCMC) receiver techniques have been employed for computing the BER performance. The simulation results show that, for BER of $\sim 10^{-4}$, the SNR achieved are significantly higher. The results indicate for BPSK modulation the SNR $\sim 9$ dB, and for 16-QAM modulation the SNR $\sim 13$ dB. The MIMO-OFDM multiplexing scheme show a overall improvement of $\sim 4.0$ dB for BER values of $10^{-4}$ between BPSK and 16-QAM modulation. A comparison of the performance of present MIMO-OFDM multiplexing system with MIMO-CDMA system and common MCMC receiver indicates that, the MIMO-OFDM Multiplexing exhibits a better BER performance for 16-QAM digital modulation. The simulations results are presented and discussed in this chapter.
MIMO wireless systems use multiple antenna elements at transmit and receive to improve capacity over single antenna topologies in multipath channel characteristics play key role in determining communication performance. OFDM can be used in conjunction with a MIMO transceiver to increase the diversity gain and/or the system capacity by exploiting spatial domain. Because the OFDM system effectively provides numerous parallel narrowband channels, MIMO-OFDM is considered a key technology in emerging high-data rate systems [69,74].

The combination MIMO-OFDM is beneficial since OFDM enables support of more antennas and larger bandwidths since it simplifies equalization dramatically in MIMO systems. By adopting MIMO and OFDM technologies, indoor wireless systems could reach data rates up to several hundreds of Mb/s and achieve spectral efficiencies of several tens of bits/Hz/s, which are unattainable for conventional single-input single-output systems. The enhancements of data rate and spectral efficiency come from the fact that MIMO and OFDM schemes are indeed parallel transmission technologies in the space and frequency domains, respectively [70]. MIMO-OFDM when generated OFDM signal is transmitted through a number of antennas in order to achieve diversity or to gain higher transmission rate then it is known as MIMO-OFDM. The present study involves a number of procedures namely simulations of the 4X4 MIMO transmission system, OFDM multiplexing, Digital modulation and computation and comparison of BER for different SNR. The aim of present work is to study the performance of MIMO systems with OFDM multiplexing and digital modulation techniques which gives better BER performance for MCMC receiver using MATLAB simulation [77].

In a basic communication system, the data are modulated onto a single carrier frequency. The available bandwidth is then totally occupied by each symbol. This kind of system can lead to ISI in case of frequency selective channel. The basic idea of OFDM is to divide the available spectrum into several orthogonal sub channels so that each narrowband sub channels experiences almost flat fading. OFDM is becoming the chosen modulation technique for wireless communications. OFDM can provide large data rates with sufficient robustness to radio channel impairments. In an OFDM scheme, a large number of orthogonal, overlapping, narrow band sub-carriers are transmitted in parallel. These sub-carriers divide the available transmission bandwidth. The separation of the sub-carriers is such that the efficiency of spectral utilization is high [71]. With OFDM, it is possible to have overlapping sub channels in the frequency domain, thus increasing the transmission rate. The use of FFT
technique to implement modulation and demodulation functions makes it computationally more efficient.

The attractive feature of OFDM is the way it handles the multipath interference at the receiver. Multipath phenomenon generates two effects: Frequency selective fading and Inter-symbol interference (ISI). The "flatness" perceived by a narrowband channel overcomes the frequency selective fading. On the other hand, modulating symbols at a very low rate makes the symbols much longer than channel impulse response and hence reduces the ISI. Insertion of an extra guard interval between consecutive OFDM symbols can reduce the effects of ISI even more but leads to low system capacity. To combat the effect of frequency selective fading, MIMO is generally combined with OFDM technique, which transforms the frequency-selective fading channels into parallel flat fading sub channels, as long as the CP inserted at the beginning of each OFDM symbol is longer than or equal to the channel length.

In this case, the signals on each subcarrier can be easily detected by a one-tap frequency domain equalizer (FDE) \(^{[73]}\). In cases where a short CP is inserted for increasing bandwidth efficiency, or because of some unforeseen channel behavior, the effect of frequency-selective fading cannot be completely eliminated, and inter-carrier interference (ICI) and inter-symbol interference (ISI) will be introduced. In this case, the signals on each subcarrier can be easily detected by a one-tap time domain equalizer (TDE). Equalization techniques are thus important in MIMO-OFDM systems \(^{[72, 75, 76]}\).

OFDM is an alternative wireless modulation technology to CDMA. OFDM has the potential to surpass the capacity of CDMA systems and provide the wireless access method for 4G systems. OFDM is a modulation scheme that allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments.

### 6.2.1 Markov chain Monte Carlo (MCMC)

Methods (which include random walk Monte Carlo methods) are a class of algorithms for sampling from probability distributions based on constructing a Markov chain that has the desired distribution as its equilibrium distribution. The state of the chain after a large number of steps is then used as a sample of the desired distribution. The quality of the sample improves as a function of the number of steps.

Usually it is not hard to construct a Markov chain with the desired properties. The more difficult problem is to determine how many steps are needed to converge to the stationary distribution within an acceptable error. A good chain will have rapid mixing; the stationary
distribution is reached quickly starting from an arbitrary position described further under Markov chain mixing time.

Typical use of MCMC sampling can only approximate the target distribution, as there is always some residual effect of the starting position. More sophisticated MCMC-based algorithms such as coupling from the past can produce exact samples, at the cost of additional computation and an unbounded running time.

The most common application of these algorithms is numerically calculating multi-dimensional integrals. In these methods, an ensemble of "walkers" moves around randomly. At each point where the walker steps, the integrand value at that point is counted towards the integral. The walker then may make a number of tentative steps around the area, looking for a place with reasonably high contribution to the integral to move into next. Random walk methods are a kind of random simulation or Monte Carlo method. Whereas the random samples of the integrand used in a conventional Monte Carlo integration are statistically independent, those used in MCMC are correlated. A Markov chain is constructed in such a way as to have the integrand as its equilibrium distribution $^{68,71}$.

Multi-dimensional integrals often arise in Bayesian statistics, computational physics, computational biology and computational linguistics, so Markov chain Monte Carlo methods are widely used in those fields.

6.2.2 MIMO-OFDM and MCMC Receiver

The receiver first must estimate and correct for the frequency offset and the symbol timing, e.g., by using the training symbols in the preamble. Subsequently, the CP is removed, and the $N_c$-point discrete fourier transformation (DFT) is performed per receiver branch. MIMO detection has to be done per OFDM subcarrier. Therefore, the received signals of subcarrier are routed to the $i^{th}$ MIMO detector to recover $N_t$ the data signals transmitted on that subcarrier. Next, the symbols per TX stream are combined, and finally, de-mapping, de-interleaving ($[!]^{-1}$), and decoding are performed for the $N_t$ parallel streams and the resulting data are combined to obtain the binary output data. Figure 1 represents block diagram of MIMO-OFDM receiver.

6.2.3 Implementation

MCMC Detector

When the number of transmit antennas increases, i.e., as $N$ increases, the dimension of $d$ becomes large, and hence summation become cumbersome. In order to develop
computationally efficient methods for calculation of $P(d_k = |y, \lambda_2^2)$, Monte Carlo integration methods and the Gibbs sampling procedures are used.

### 6.2.4 Results and Discussions

The simulation results are obtained for the performance of MIMO - OFDM system using different modulation techniques for AWGN channel using MATLAB 9. The BER values as function of SNR are determined for BPSK and 16-QAM modulation.

The BER values determined as a function of SNR for BPSK modulation using MATLAB simulation. The Figure 6.7(a) and 6.7(b) shows the SNR performances as a function of BER for 4X4 MIMO system with OFDM multiplexing using BPSK and 16 QAM modulation schemes.

![Figure 6.7: BER Vs SNR plot for 4x4 MIMO-OFDM with MCMC detector (a) BPSK modulation (b) 16-QAM modulation.](image)

It can be seen from the Figure 6.7 (a) that for 4x4 MIMO systems with OFDM multiplexing and BPSK modulation the BER variation with SNR is similar to that of 2x2 MIMO- OFDM systems. At BER $10^{-3}$ point, the 4x4 MIMO-OFDM system with BPSK modulation and Monte Carlo detection shows the best SNR performance ~ 7 dB which is found to be the same as the SNR value observed for the lower (2x2) MIMO system using OFDM multiplexing and BPSK modulation with ZF Detection . Further it is seen from the Figure 6.7 (b) that for 4x4 MIMO-OFDM with 16- QAM modulation using a MCMC detection system at BER values $10^{-3}$ point, the achievable SNR ~11dB.

The results presented for 4x4 MIMO with OFDM multiplexing and MCMC detection and 2x2 MIMO with OFDM multiplexing and ZF detection suggests that the SNR performance is independent of the order of the MIMO system and the detection system. The MIMO-OFDM multiplexing combination with BPSK modulation exhibits the best BER performance by achieving lowest SNR~7 dB for both lower and higher MIMO system.
The results of the analysis carried out in this chapter have been published in the following International Journal papers.
