CHAPTER III
MIMO-OFDM SYSTEM

3.1. INTRODUCTION
Several types of diversity techniques are applied in different wireless communication networks. Multi-Input Multi-Output (MIMO) antenna at the transmitter and the receiver is facilitated as one such technique in high performance 4G wireless broadband communication systems. This MIMO technology is one of the varieties of smart antenna technology [27]. This chapter describes the basics of different diversity techniques, MIMO systems and MIMO-OFDM systems.

3.2. DIVERSITY TECHNIQUES
Diversity techniques[98], [99] are used as most common techniques in the wireless mobile communication networks to reduce various channel impairments such as fading and interference. They utilize the random nature of radio transmission by identifying independent signal path for wireless communication. This technique can be employed either at the transmitter or at the receiver or both. They are broadly classified into time diversity, frequency diversity and space diversity.

3.2.1. Time Diversity
Usually, the fading characteristics are different over different time interval in the multipath environment. In this technique, multiple versions of information can be transmitted at different time slots with time separation [47]. By using proper channel coding and interleaving, the worst faded signal is eliminated and good signal is retrieved. But due to delay constraints, this technique is very difficult to implement. A simple arrangement for time diversity is exposed in Fig. 3.1.

Fig. 3.1 Arrangement for Time Diversity
The desired signal S(t) is transmitted at M different time intervals. The interval between transmissions of the same symbol Δt should be at least the coherence time $T_c$. 

24
3.2.2. Frequency Diversity

In the frequency diversity, the signal is transmitted with several frequency carriers or spread over a wide range of frequency spectrum. OFDM technique is an example for the frequency diversity. Proper interleaving and forward error correction are employed to retrieve the original signal with less error. The arrangement for frequency diversity is shown in Fig. 3.2.

![Fig. 3.2 Arrangement for Frequency Diversity](image)

In this diversity, the same symbol \( S(t) \) can be transmitted by \( M \) different carriers. Also, the separation of frequency ‘\( \Delta f \)’ between the same symbol \( S(t) \) should be at least the coherence bandwidth ‘\( \text{BW}_c \)’. Here, the total transmitted power is split among several carriers present in the group.

3.2.3. Space Diversity

In the space diversity technique, the signal is transmitted over different propagation paths with the help of a group of antennas. These antennas can be either connected at the transmitter side or at the receiver side. Based on this, it can be classified into transmit diversity and receive diversity. The main purpose of this diversity is reliable communication between the transmitter and the receiver.

Transmit diversity is one of the space diversity techniques. In this technique, more antennas are present at the transmitter than the receiver. A simple type of this diversity is two antennas at the transmitter and one antenna at the receiver. It is called Multi-Input Single Output (MISO) system. Fig. 3.3 shows the block diagram of MISO system. Here, the redundant signal is transmitted by two antennas at the transmitter. The codes for this MISO are briefed by Alamouti [2].

25
Receive diversity is another space diversity technique in which more antennas are established at the receiver than the transmitter. A simple type of this diversity is one antenna at the transmitter and two antennas at the receiver which is called Single-Input Multi Output (SIMO) system [45]. A simple block diagram of SIMO system is shown in Fig. 3.4.

3.2.4. Polarization Diversity

The polarization diversity technique [47] employs the same information signal which is transmitted and received by either vertically polarized or horizontally polarized or $\pm 45^\circ$ polarized waves. It is used to reduce the selective fading effect.

A simple block diagram of polarization diversity with one transmitter and one dual-polarized receiver with one horizontal antenna and one vertical antenna is shown in Fig. 3.5. Also, an antenna housing arrangement with a set of horizontal, vertical polarized antennas and $\pm 45^\circ$ polarized antennas is shown in Fig. 3.6. One important
parameter used to describe this diversity is correlation coefficient between the received signal envelopes.

![Diagram of Different Polarized Antenna Array](image)

**Fig. 3.6 Housing of Different Polarized Antenna Array**

### 3.2.5. Features of Diversity

The diversity techniques have the following features:

i) There is no need of training overhead either at the transmitter or the receiver side

ii) Better improvement in the link performance

iii) Data rate improvement

iv) Good reliability

### 3.3. MIMO SYSTEM

In the early wireless systems, antenna arrays were used to provide diversity to minimize the co-channel interference. Then, beam-forming and spatial diversity techniques (transmit diversity and receive diversity) [23] were introduced to improve the data link in the wireless system. In the mid 1990’s, multiple transceiver antennas were used for parallel multiplexing. This is the beginning of MIMO system. The MIMO is a wireless technology in which multiple number of transmitting antennas and multiple number of receiving antennas are effectively combined to carry the data through a variety of signal paths. This technique has the capability to increase the data rate and channel capacity [46]. The redundancy will be greater by increasing the number of transmitting antennas [51].
Consider a MIMO system [5] which has multiple number of antennas ‘m’ at the transmitter and multiple number of antennas ‘n’ at the receiver. It has transmit-diversity as well as receive-diversity. Here, each antenna at the receiver receives signal from all the transmitting antennas. A simple block diagram [52] of this MIMO system is shown in Fig. 3.7.

Let it be assumed the channel between the transmitter and the receiver is a time-independent narrow band channel. The direct link between the transmitting antenna 1 and the receiving antenna 1 is specified as $h_{11}$. Likewise, the direct links between the other transmitting and the receiving antennas are specified as $h_{22}$, $h_{33}$, etc. Also, the indirect link between the transmitting antenna 1 and receiving antenna 2 is denoted as $h_{21}$. Similarly, the other indirect links are described by the corresponding $h$ parameters. The channel matrix $H$ with the dimension of $n \times m$ is shown in Equation (3.1).

\[
H = \begin{bmatrix}
h_{11} & h_{12} & h_{13} & \ldots & h_{1m} \\
h_{21} & h_{22} & h_{23} & \ldots & h_{2m} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
h_{n1} & h_{n2} & h_{n3} & \ldots & h_{nm}
\end{bmatrix}
\]  

(3.1)

Let the transmitting vector, channel matrix, receiving vector and the noise be specified as $X$, $H$, $Y$ and $N$ respectively. The received signal is given by the Equation (3.2).

\[
Y = HX + N
\]  

(3.2)

The two main forms of MIMO are spatial multiplexing and spatial diversity. The spatial diversity is usually referred to as transmit-diversity or receive-diversity.
This diversity can improve the signal to noise ratio and reliability of the link. In the spatial multiplexing technique, the same data stream cannot be sent by the multiple transmitting antennas. Instead of this, original data is split into several independent data streams which are transmitted by multiple transmitting antennas. This technique is mainly used to improve the data rate and channel capacity. This technique has been applied in very high rich scattering environments. Fig. 3.8 shows the representation of spatial multiplexing at the MIMO transmitter in which a 3-bit data 101 is split as 1, 0, 1 and transmitted by 3 independent antennas.

![Fig. 3.8 MIMO Transmitter with Spatial Multiplexing](image)

### 3.4. MIMO-OFDM SYSTEM

Multi-Input Multi-Output – Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is considered as an excellent technique for the 4G wireless broadband communication system due to several features such as high spectral efficiency, high data capacity, etc.[101]. The main purpose of using OFDM in a MIMO channel is that OFDM modulation changes the frequency-selective MIMO channel into a set of parallel frequency flat MIMO channel. The block diagram of MIMO-OFDM system is shown in Fig. 3.9.

The input bit-stream of data is encoded by channel encoder and MIMO encoder. Then, each parallel output symbol stream of the MIMO encoder is processed by the separate OFDM modulator. In this modulation process, pilot insertion, Inverse Fast Fourier Transform (IFFT) modulation, CP insertion and preamble attachment have been done [110]. Finally, each modulator output data stream can be transmitted by several transmitting antennas. In the receiver side, the symbol streams from the multiple receiving antennas are synchronized and the CPs and the preambles are
extracted. Then, each symbol stream is demodulated by OFDM demodulator with FFT. Finally, the pilot extraction, channel decoding and detection process have been done to retrieve the original data.

3.4.1. MIMO-OFDM Frame Structure

A simple structure of the MIMO-OFDM frame is shown in Fig. 3.10.

![Fig. 3.9 Block Diagram of MIMO-OFDM System](image)

![Fig. 3.10 MIMO-OFDM Frame Structure](image)

The MIMO-OFDM frame is structured in such a way that data and pilot symbols are transmitted over sub-carriers. This frame has 10 slots. Each slot starts with one
preamble and 8 OFDM symbols. This preamble is used for time synchronization. Each OFDM symbol in a slot is attached with a CP, which is used to reduce the ISI.

3.4.2. Signaling Schemes of MIMO-OFDM
The two basic signaling schemes used in MIMO-OFDM system are

i) Space –Time Coding
ii) Spatial Multiplexing

In the MIMO-OFDM spatial multiplexing, independent data streams are transmitted tone-by-tone basis by multiple number of transmitting antennas with uniform transmit power [82]. Even though, the OFDM eliminates the ISI in this scheme, the computational difficulty is still a higher one. This complexity can be minimized with the help of matrix valued transfer function which is smooth across the tones. Also, the complexity can be reduced by the channel inversion in the Minimum Mean Square Error (MMSE) receiver. The channel capacity of MIMO-OFDM system can be improved by increasing the number of transmitters and receivers [60].

The space-time coding [98] and [118] is mainly used to improve the link reliability by coding over the different number of transmitters, while the spatial multiplexing is used to increase the channel capacity. In the space time coding, the receiver should have the perfect channel knowledge. The performance of the Space Time Coded (STC) MIMO-OFDM can be improved by the proper pulse shaping of OFDM symbols transmitted through the terrestrial channels [79]. The Space Time Trellis Code (STTC) and linear or orthogonal Space Time Block Code (STBC) are used for the coding purpose. The STBC can provide full diversity without coding gain when compared with STTC [30]. Also, the linear STBC has very simple encoding and decoding procedure. One of the popular STBC’s is the Alamouti code. A complex orthogonal STBC for two transmit antennas was developed by Alamouti [2]. In this encoder, the two consecutive symbols $x_1$ and $x_2$ are encoded by the matrix shown in Equation (3.3).

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}$$  \hspace{1cm} (3.3)$$

The Alamouti encoder for two MIMO transmit antennas is shown in Fig.3.11.
The Alamouti encoded signal is transmitted by two transmit antennas over two symbol periods. During the first symbol period, the two symbols $x_1$ and $x_2$ are simultaneously transmitted by two antennas. During the second symbol period, $-x_2^*$ is transmitted by the first antenna and $x_1^*$ is transmitted by the second antenna. The Alamouti codeword is a complex orthogonal matrix which is shown in Equation (3.4).

$$XX^H = \begin{bmatrix} |x_1|^2 + |x_2|^2 & 0 \\ 0 & |x_1|^2 + |x_2|^2 \end{bmatrix} = (|x_1|^2 + |x_2|^2)I_2$$

(3.4)

Where $I_2$ is the $2 \times 2$ identity matrix.

### 3.4.3. Features and Limitations of MIMO-OFDM System

A few features of MIMO-OFDM are shown below.

i) It has very high spectral efficiency.

ii) It has capability to increase the data rate by the spatial multiplexing scheme.

iii) It has a highly reliable quality link.

iv) It can improve the channel capacity and coverage area.

Some of the Limitations of the MIMO-OFDM system are given below.

i) Antenna spacing must be appropriate depending on the type of channel.

ii) Complexity is more due to multiple number of transmitters and receivers.

### 3.5. SUMMARY

This chapter illustrates the necessity of diversity techniques and different types of diversity techniques utilized in wireless communication systems. The concept of MIMO system has been discussed. Also, the significance of MIMO-OFDM system and its representation and various signaling schemes are described in this chapter. This chapter provides an overall idea about the MIMO-OFDM systems.