CHAPTER THREE

Research Methodology

3.1 Introduction

In this chapter the proposed path loss model will be discuss, also the parameters which used to calculate SNR will be illustrated, Moreover, MIMO capacity, and the resulting data rate will be discussed and finally the simulation scenarios will be explained.

3.2 Path Loss Model

Many models exist for wireless communication and produce a wide range of values when applied to the scenario under consideration, it will be illustrated below.

3.2.1 Free Path Loss Model

Free space propagation model is used to predict the signal strength at the receiving node when there is a clear Line of Sight (LOS) path between the transmitting and the receiving node.

Let d denote the distance in meters between the transmitter and receiver. When non-isotropic antennas are used with a transmit gain of $G_t$and a receive gain ofG_r, the received power at distance$d$, $P_r(d)$, is expressed by the well-known Friis equation [30], given as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (3.1)$$

where$P_t$represents the transmit power (watts), λ is the wavelength of radiation (m), and L is the system loss factor which is independent of propagation environment. The system loss factor represents overall attenuation or loss in the actual system hardware, including transmission line, filter, and antennas. In general, L> 1, but L =1 if we assume that there is no loss in the system hardware. It is obvious from Equation (3.1) that the received power attenuates exponentially with the distance d. The free-space path loss, $PL_F(d)$ (3.2), without any system loss can be directly derived from Equation (3.1) with L = 1 as

$$PL_F(d)[dB] = 10\log\left(\frac{P_t}{P_r}\right) = -10\log\left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right) \tag{3.2}$$

In fact, a more generalized form of the path loss model can be constructed by modifying the free-space path loss with the path loss exponent n that varies with the environments. This is known as the log-distance path loss model(3.3), in which the path loss at distance d is given as

$$PL_{LD}(d)[dB] = PL_F(d_0) + 10n\log\left(\frac{d}{d_0}\right) \tag{3.3}$$

where d_0 is a reference distance at which or closer to the path loss inherits the characteristics of free-space loss in Equation (3.3). As shown in Table 3.1, the path loss exponent can vary from 2 to 6, depending on the propagation environment. Note that n=2 corresponds to the free space. Moreover, n tends to increase as there are more obstructions.

Table 3.1 Path Loss Exponent [31].

Environment	Path loss exponent (***n***)
Free space	2.0
Urban area cellular radio	2.7 3.5
Shadowed urban cellular radio	3.0 5.0
In building line of sight	1.6 1.8
Obstructed in building	4.0 6.0
Obstructed in factories	2.0 3.0

The free space path loss is not applicable to the scenario under consideration because it present ideal values , but it serves as a baseline for comparison with the other models that will be presented below.

3.2.2 Okumura/Hata Model

The Okumura model has been obtained through extensive experiments to compute the antenna height and coverage area for wireless communication systems [32]. It is one of the most frequently adopted path loss models that can predict path loss in an urban area. The path loss at distance d in the Okumura model (3.4) is given as

$$PL_{ok}(d)[dB] = PL_F + A_{MU}(f,d) - G_{Rx} - G_{Tx} + G_{AREA} \qquad (3.4)$$

Where $A_{MU}(f,d)$ is the medium attenuation factor at frequency f, G_{Rx} and G_{Tx} are the antenna gains of Rx and Tx antennas, respectively, and GAREA is the gain for the propagation environment in the specific area.
The Okumura model is not applicable to our scenario because This model mainly covers the typical mobile communication system characteristics with a frequency band of 500 -1500 MHz, and an antenna height of 30 m to 1000 m.

3.2.3 Green-Obaidat Model

Green-Obaidat developed a simplified and accurate path loss equation for calculating the path loss for 802.11 WLAN line-of-sight links with antennas between 1 and 2.5 meters in height [33]. It was experimentally studied under conditions similar to ours, hence it is the most suitable model for our scenario. The Green and Obaidat path loss equation(3.5) is given by:

$$PL_{GO} = 40log_{10}d + 20log_{10}f - 20log_{10}h_t h_r \quad (3.5)$$

where d is the separation distance and h_t and h_r are the heights of the transmit and receive antennas, respectively. According to our scenario the heights of the transmit and receive antennas are equal to two meter.

3.3 Signal to Noise Ratio (SNR)

The Signal to noise ratio(SNR) depends on the distance (D) between the transmitter and the receiver [34].

$$SNR(D) = \frac{P_t G_t G_r}{L(D) F\ B\ N_0} \quad (3.6)$$

where P_t is the transmit power, G_t,G_r are the transmit and receive antenna gains, $L(D)$is the path loss, F, B are the noise figure and bandwidth of the receiver, respectively, and N_0 is the noise spectral density. Following we discuss this parameters in details, except $L(D)$ that we discussed in section 3.1 above.

3.3.1 Transmit Power (P_t)

P_t (power transmitted) - the RF power present at the output of the transmitter. BecauseP_t is a separate term from antenna gain in the purest sense it represents only the energy incident onto the antenna. It is only a measure of the power delivered by the transmitter's final amplifier stage. Output for transmitters in the ISM band frequency range is nominally up to 20 dBm, In this work we have chosen P_t equal to 20 dBm (100 mWatt).

3.3.2 Transmit and Receive Antenna Gains (G_t,G_r)

G_t, G_r (gain of transmit and receive antennas) the antenna performance relative to a standard “reference antenna”. The gain of an antenna describes how much greater the radiated energy is in some direction and at some distance from this antenna, compared to what it would be at that same direction and distance from an isotropic antenna. The antenna gain does not increase the actual power coming from the transmitter. Rather it is a measure of the concentration of a portion of the total available radiated power into a given direction, In this work we have chosen GT,GR equal to 10.9 dBi when using 2.4 GHz, and G_t,G_r equal to 13.5 dBi when using 5 GHz.

3.3.3 Noise Figure (F)

The noise figure is measures of degradation of the signal-to-noise ratio (SNR) between the input and output, caused by components in a radio frequency (RF) signal chain. It is a number by which the performance of a radio receiver can be specified, with lower values indicating better performance, we’ve chosen$F$ equal to 4 dB.

3.3.4 Bandwidth (B)

Bandwidth is the range of frequencies in which the antenna remains effective. According to IEEE, bandwidth is “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard". In this work we have chosen two values to the bandwidth 20 MHz and 40 MHz, according to the available bandwidth in 802.11 standard.

3.3.5 The Noise Spectral Density (N_0)

noise spectral density (N0) is the noise power per unit of bandwidth , $N_0 = kT$, where k is Boltzmann's constant in joules per Kelvin, and T is the receiver system noise temperature in Kelvin's N0 is a constant and equal to $4(10^{-21})$.

3.4 Channel Capacity

In this section we discuss the capacity of a single antenna system and multiple antenna system.

3.4.1 Capacity of a SISO Channel

All system designs strive for a target capacity of throughput. For SISO channels, the capacity is calculated using the well-known Shannon equation. Shannon defines capacity for an ergodic channel that data rate which can be transmitted with asymptotically small probability of error [35]. The capacity of such a channel is given by (3.7) in terms bits/sec/Hz.

$$C = log_2(1 + SNR) \tag{3.7}$$

This capacity is based on a constant data rate and is not a function of whether channel state information is available to the receiver or the transmitter. This result is applicable only to ergodic channels, ones where the data rate is fixed and SNR is stable.

3.4.2 Capacity of a SIMO, MISO Channel

Before we go on to discuss the capacity of a MIMO channel, we explain the capacity of a channel that has multiple receivers or transmitters but not both.

We modify the SNR of a SISO channel by the gain factor obtained from having multiple receivers [35].

$$C_{SIMO} = log_2\left(1 + \left||h|\right|^2 SNR\right) \tag{3.8}$$

Where the term is $\left||h|\right|^2$ equal to$h_1^2 + h_2^2 + \cdots + h_{N_R}^2$). The channel consists of only NR paths and hence the channel gain is constrained by

$$\left||h|\right|^2 = N_R \tag{3.9}$$

Substituting (3.9) into (3.8) gives the ergodic capacity of the SIMO channel as

$$C_{SIMO} = log_2(1 + N_R\, SNR) \tag{3.10}$$

This mean that we are increasing the SNR by a factor of NR.

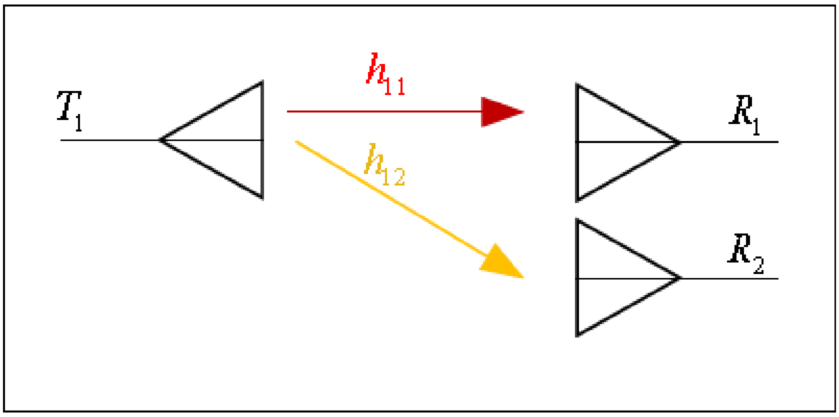

Figure 3.1: A Single In–Multiple Out (SIMO) Channel

The capacity of the MISO channel is given by equation (3.11).

$$C_{MISO} = log_2\left(1 + \frac{||h||^2\ SNR}{N_T}\right) \tag{3.11}$$

Where$||h||^2$ is equal to ($h_1^2 + h_2^2 + \cdots + h_{N_R}^2$) If the transmitter has no knowledge of the channel, the equation devolves in to a SISO channel, because $||h||^2 = N_T$and Equation (3.11) becomes:

$$C_{MISO} = log_2(1 + SNR) \tag{3.12}$$

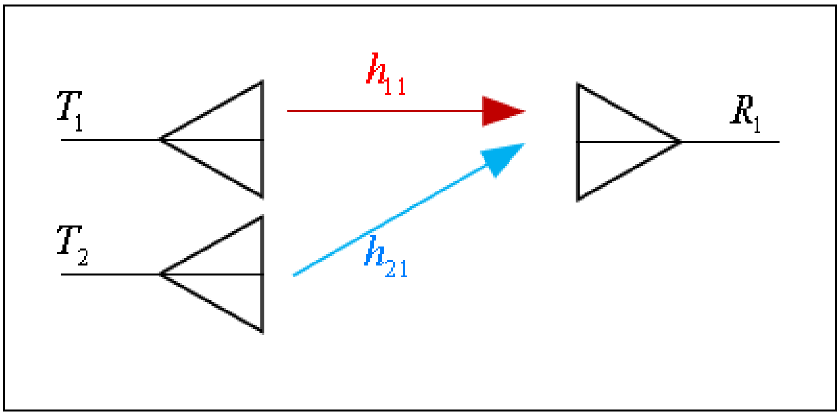

Figure 3.2: A Multiple In–Single Out (MISO) Channel

3.4.3 Capacity of a MIMO Channel

Compared to a conventional single antenna system, the channel capacity of a multiple antenna system with NT transmit and NR receive antennas can be increased by the factor of min(NT, NR) without using additional transmit power or spectral bandwidth. Fig. 3.3 shows a schematic overview of a MIMO system.

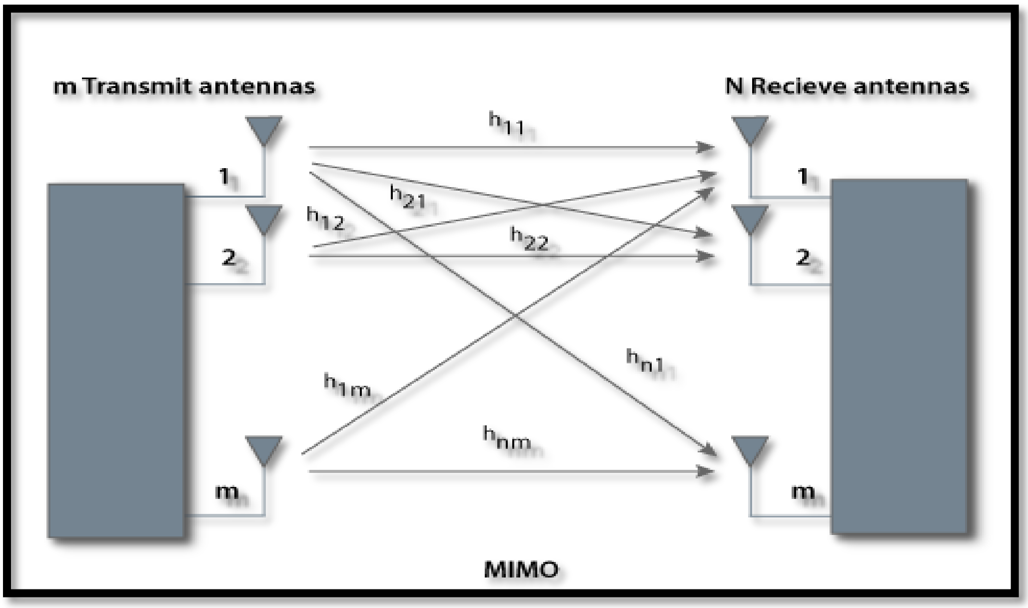

Figure 3.3: A Wireless MIMO System with M Transmitting and N Receiving Antennas.

Consider an Mt×Mr MIMO system with Mt transmit antennas and Mr receive antennas. Let H denote the channel matrix relating the vector of transmitted signals to the vector of received signals. Assuming that the channel state is unknown at the transmitter, it is well-known that the capacity of this system for a fixed H is given by [35].

$$C = \log\det(I + H\, SNR/M_t) \qquad (3.13)$$

The Figure 3.4 show the comparison of SISO and MIMO systems using the same power. MIMO capacity increases linearly with the number of antennas, where SISO/SIMO/MISO systems all increase only logarithmically.

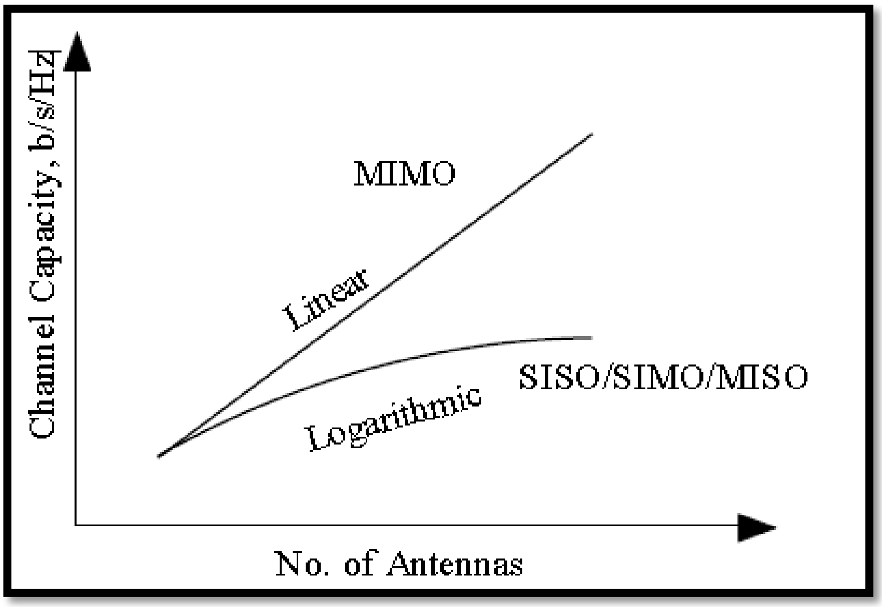

Figure 3.4 MIMO Offers a Way to Increase Capacity without Increasing Power

3.5 Data Rate

The number of bits that are conveyed or processed per unit of time. it can be calculated by dividing equation (3.13) to channel bandwidth (BW).

3.6 Simulation Scenario

The different values of distance has been chosen, then the path loss PL(D) was calculated accordingly, using Green- Obaidat equation (3.5).

One of equation (3.5) parameter is carrier frequency, which in 802.11n Wi-Fi standard have two values, 2.4 GHz & 5 GHz. The path loss was computed for each frequency and plotted with distance values. Plotting the path loss $PL(D)$ vs. distance with two available values for frequency allow us to evaluate the effect of changing the frequency to the path loss.

Using equation (3.6) we will proceed as follows. For a given distance (D), we evaluate the average SNR. Channel Bandwidth is one of the SNR parameter which also have two values in 802.11n Wi-Fi standard, 20 MHz & 40MHz, due to this, we evaluated the SNR values in four cases:

- Using 2.4 GHz frequency with 20 MHz Bandwidth.
- Using 2.4 GHz frequency with 40 MHz Bandwidth.
- Using 5.0 GHz frequency with 20 MHz Bandwidth.
- Using 5.0 GHz frequency with 40 MHz Bandwidth.

We then evaluate the capacity using equation (3.13) vs. distance functions for MIMO systems with different numbers of transmit and receive antennas and with the different cases of computed SNR, Plotting the capacity vs. distance curves of different systems in a single figure allows us to evaluate the distance increase afforded by using multiple antennas, as is seen in the next chapter.

Finally we evaluate the data rate, and plotted it vs. distance, the resulted figure let us examine the effect of using multiple antenna technologies to the data rate.

3.7 Simulation Software

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python.

"MATLAB® is the high-level language and interactive environment used by millions of engineers and scientists worldwide. It lets you explore and visualize ideas and collaborate across disciplines including signal and image processing, communications, control systems, and computational finance" [36].