5.1 Basic WiMAX Modeling with System Parameters

This chapter of the thesis presents one of the most innovative approach of the research work i.e. implementation of various Antenna Diversity algorithms in WiMAX system modeling along with real time transmission of image and speech signals. The basic modeling of traditional WiMAX system along with detailing of every block has been already discussed in the Chapter-2. By taking that stuff as a platform, here through the implementation of various antenna diversity techniques, the overall system performance improvement has been proved at the constant value of channel SNR and also of the other parameters. For sake of reference, the channel is assumed to be ideal AWGN channel with no multi path fading effects. The effects of fading over the system performance have been elaborated in the following sections of this chapter. For the comparative analysis perspective, the same AWGN channel is used for the modeling of WiMAX system along with antenna diversity techniques using SNR = 24dB and AWGN power = 0.1W.

Apart from the above channel parameters, the various parameters of different blocks of the system and their multiple specifications have already been discussed and checked in detail in the Chapter-4, which has been summarized here in form of a Table 5.1. By setting all these block parameters to their specified value; the modeling of WiMAX with antenna diversity has been done that is explained in the upcoming sections.
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>MODEL PARAMETER</th>
<th>WIMAX SISO</th>
<th>WIMAX SIMO</th>
<th>WIMAX MISO</th>
<th>WIMAX MIMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Model set-up</td>
<td>MATLAB -R2009a</td>
<td>MATLAB -R2009a</td>
<td>MATLAB -R2009a</td>
<td>MATLAB -R2009a</td>
</tr>
<tr>
<td>2</td>
<td>AWGN SNR</td>
<td>24dB</td>
<td>24dB</td>
<td>24dB</td>
<td>24dB</td>
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<tr>
<td>3</td>
<td>AWGN PWR</td>
<td>0.1W</td>
<td>0.1W</td>
<td>0.1W</td>
<td>0.1W</td>
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<tr>
<td>4</td>
<td>Image matrix size</td>
<td>256 x 256</td>
<td>256 x 256</td>
<td>256 x 256</td>
<td>256 x 256</td>
</tr>
<tr>
<td>5</td>
<td>Samples/Frame</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>Generator polynomial of PN sequence generator</td>
<td>[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1]</td>
<td>[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1]</td>
<td>[1 0 0 0 0 0 0 0 0 0 0 0 1 1]</td>
<td>[1 0 0 0 0 0 0 0 0 0 0 0 1 1]</td>
</tr>
<tr>
<td>7</td>
<td>Initial states of PN sequence generator</td>
<td>[0 0 0 1 1 1 0 1 1 1 1 0 0 0 0 0 0 1]</td>
<td>[0 0 0 1 1 1 0 1 1 1 0 0 0 0 0 1]</td>
<td>[0 0 0 1 1 1 0 1 1 1 0 0 0 0 0 1]</td>
<td>[0 0 0 1 1 1 0 1 1 1 0 0 0 0 0 1]</td>
</tr>
<tr>
<td>8</td>
<td>Codeword length N of RS Encoder</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
<tr>
<td>9</td>
<td>Message length K of RS encoder</td>
<td>239</td>
<td>239</td>
<td>239</td>
<td>239</td>
</tr>
<tr>
<td>10</td>
<td>RS encoder rate</td>
<td>3/4</td>
<td>¾</td>
<td>3/4</td>
<td>¾</td>
</tr>
<tr>
<td>11</td>
<td>Convolution encoder input vector length k</td>
<td>171</td>
<td>171</td>
<td>171</td>
<td>171</td>
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<tr>
<td>12</td>
<td>Convolution encoder output vector length n</td>
<td>131</td>
<td>131</td>
<td>131</td>
<td>131</td>
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<tr>
<td>13</td>
<td>Native rate of convolution coder</td>
<td>5/6</td>
<td>5/6</td>
<td>5/6</td>
<td>5/6</td>
</tr>
<tr>
<td>14</td>
<td>Puncture vector</td>
<td>([1 0 1 0 1; 1 1 0 1 1], 10, 1)</td>
<td>([1 0 1 0 1; 1 1 0 1 1], 10, 1)</td>
<td>([1 0 1 0 1; 1 1 0 1 1], 10, 1)</td>
<td>([1 0 1 0 1; 1 1 0 1 1], 10, 1)</td>
</tr>
<tr>
<td>15</td>
<td>QAM modulation order</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>QAM normalization factor</td>
<td>1/√2</td>
<td>1/√2</td>
<td>1/√2</td>
<td>1/√2</td>
</tr>
<tr>
<td>17</td>
<td>OFDM symbol time</td>
<td>64μs</td>
<td>64μs</td>
<td>64μs</td>
<td>64μs</td>
</tr>
<tr>
<td>18</td>
<td>Bandwidth</td>
<td>1.5 to 20 MHz</td>
<td>1.5 to 20 MHz</td>
<td>1.5 to 20 MHz</td>
<td>1.5 to 20 MHz</td>
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<tr>
<td>19</td>
<td>NFFT</td>
<td>256</td>
<td>256</td>
<td>256</td>
<td>256</td>
</tr>
<tr>
<td>20</td>
<td>No. of cyclic prefix</td>
<td>1/8</td>
<td>1/8</td>
<td>1/8</td>
<td>1/8</td>
</tr>
<tr>
<td>21</td>
<td>OFDM training sequence</td>
<td>N.A.</td>
<td>N.A.</td>
<td>200 bits</td>
<td>200 bits</td>
</tr>
<tr>
<td>22</td>
<td>OFDM pilot carriers</td>
<td>55 bits</td>
<td>55 bits</td>
<td>55 bits</td>
<td>55 bits</td>
</tr>
<tr>
<td>23</td>
<td>Alamouti encoder parameter</td>
<td>N.A.</td>
<td>N.A.</td>
<td>2 Tx Antenna</td>
<td>2 Tx Antenna</td>
</tr>
<tr>
<td>24</td>
<td>Rx antenna for Alamouti decoder</td>
<td>N.A.</td>
<td>N.A.</td>
<td>1 Rx Antenna</td>
<td>2 Rx Antenna</td>
</tr>
<tr>
<td>25</td>
<td>Samples of speech signal</td>
<td>16000</td>
<td>16000</td>
<td>16000</td>
<td>16000</td>
</tr>
</tbody>
</table>
From the quick view of Table 5.1, some of the parameters like modulation order, amount of cyclic prefix, etc. can be viewed as the important parameters of the system. As such these parameters can have multiple no. of values but after certain experimentations that have been discussed in Chapter-4, their optimum value can be derived. For example, the modulation order can be 2 or 4 or 16 or 64, but here through out the modeling, 4-QAM has been considered as a modulation scheme because if we reduce the modulation order beyond certain limit then data rate would be very slow and if it increases beyond certain limit then though data rate can be increased, simultaneously BER would get degraded because of more no. bits per sample result in interference among one another. Secondly if the effect of cyclic prefix is considered then here the value of 1/8 has been chosen. If it is increased to 1/4 then no doubt the redundancy in time will increase which results in improved BER because of minimization of ISI but the requirement of bandwidth will also increase. Through out this modeling, due to cyclic prefix equal to 1/8, required bandwidth would be smaller one which is the upper hand but BER is going to be degraded that is imposing limit on system performance. This limit of low value of CP has been overcome by the implementation of various antenna diversity techniques which is one of the most important motivations behind this research. Due to space diversity, at low value of CP, BER can be improved by retaining all constant parameters. Hence this table is the most important source behind the modeling of WiMAX system along with diversity environment as it is supplying the optimized values of each and every parameter.
Further as this chapter is solely centered around the idea of real time modeling of WiMAX system by transmitting real image and speech signal, initially the samples of image and speech are getting converted to corresponding bits. So to initiate the modeling, following kind of image and speech as shown in Figure-5.1 & 5.2 respectively have been used for the transmission purpose through the WiMAX model. As an input, the image of leaf with the size 256x256 in first case and speech with duration 2 sec in second case are made to transmit through the various blocks of WiMAX transceiver. Figure-5.3 shows the QAM symbols of the original data before transmission has taken place. In scattered plot the samples are finely concentrated. After reception their movement across axis provides the idea of errors in information due to channel behavior.
At the receiver side, the same image and speech would be retrieved with the disturbances caused by WiMAX channel. The received image or speech with deterioration will be compared with the original image and speech as shown in Figure-5.1 & 5.2 and the system BER will be measured.

5.2 Modeling and Experimentations using Real Time Image Transmission

5.2.1 Modeling of WiMAX- SISO System

The following Figure-5.4 shows the most basic model of the WiMAX system with traditional antenna system i.e. single transmitter and single receiver antenna which would be considered to be the reference model for the next three models. Here no diversity is implemented in the physical layer. As shown in Figure-5.5, the main distinguishing feature of the model is the WiMAX-SISO channel which is simple AWGN channel same as the traditional WiMAX model except one change that is the presence of external noise source. Here the data coming at the output of OFDM block gets added with additional noise (same for all configuration for comparative analysis) developed by the noise generator so as to make this model compatible with the next WiMAX-SIMO model wherein virtually two paths for realizing multiple output have been created by bifurcating the output of channel into two parts.

Figure-5.3 QAM symbols
Figure-5.4 Modeling of WiMAX SISO using real time image transmission

Figure-5.5 WiMAX SISO channel
As per the snapshot of WiMAX-SISO model, the whole logic implementation as a system prototype can be explained briefly in the following steps as the detailed block level description has already been discussed in the chapter-2.

Step 1: Through image input block the image of the dimension (256x256) would be fetched and converted into bit stream 280 bits.

Step 2: 35 bytes (280 bits) will be fed to the input of scrambler which is a generic linear feedback shift register with EX-OR gate. The output is randomized data of 35 bytes to which hex byte of zero is added.

Step 3: The 36 bytes (288 bits) will be fed as input to the RS encoder which will give 40 bytes (320 bits) of data with redundancy added for error correction at the receiver on the other side.

Step 4: The Convolution Encoder will double this input bytes and will produce 80 bytes (640 bits) of data as the rate is 5/6 of this encoder.

Step 5: Puncturing will remove bits as per order mentioned in the standard hence the data rate will increase. For 4-QAM puncturing configuration is 1/2, which produces total of 48 bytes (384 bits) as mentioned in the block Diagram.

Step 6: The interleaver consists of permutation equations which help in error correction as it spreads the data over distributed carriers in bunch of 192 data carriers of OFDM symbol of total 256 carriers.

Step 7: These 48 bytes (i.e. 384bits) will be fed to 4-QAM data mapping which will produce 192 complex data which will be carried over 192 data carriers. In 4-QAM 2 bits are converted to one complex data as per the constellation diagram.
Step 8: The symbol is formed after embedding pilot, DC and guard carriers. WiMAX consists of OFDM symbol of 256 carriers in total consisting of 192 data, 8 pilots, 1 DC and rest of the carriers as guard carriers.

Step 9: These 256 values are fed to the IFFT module which will produce time domain complex data.

Step 10: Cyclic prefix is added which helps to overcome effect of the delay spread is added to OFDM symbol.

Step 11: After CP is added to each symbol, the data of (288x1) integer will be transmitted through WiMAX-SISO channel.

The reverse process takes place in the receiver with through the FFT, de mapping, de-interleaving, decoding and de randomization blocks and final image would be reconstructed through the logic of output image block. According to the process discussed in above mentioned steps, the simulation would be performed and BER would be calculated by the comparison of input and output images which has been elaborated in the following section.

5.2.2 Simulation Results and Discussion

The Snap shot of Figure-5.6 indicates the values at the end of each and every block after MATLAB simulation. The simulation results have taken for the 635880 total numbers of bits by transmitting image of the dimension (256x256).

QAM symbols variations; output image and corresponding BER are shown in Figure-5.7, 5.8 & 5.9. It can be seen that out of 635880 bits, 85048 bits are lost. This happens because of the large amount of fluctuations of the QAM symbols from the mean value that accounts for large distortion in output image as compared to input image. The BER of the system is also very high value i.e. 0.133 which is never be a satisfactory value for the fruitful transmission.
This phenomenon becomes the motivation for the implementation of antenna diversity techniques in the WiMAX system through which the system performance in terms of BER would be drastically increased at the same value of channel SNR. The next section elaborates the implementation of antenna diversity techniques in WiMAX system.
5.2.3 Modeling of WiMAX- SIMO System

This section discusses the effect of receiver diversity on the performance of WiMAX system in terms of bit error rate improvement and quality of the received image signal.

The first step toward using diversity is to use a single input multiple output configurations, e.g., one transmit and two receive antennas as shown in Figure-5.10. This configuration is called single input multiple output (SIMO). In a flat fading channel with 1 transmit antenna and 2 (L) receive antennas; the channel model is as follows:

\[ y_l[m] = h_l[m]x[m] + w_l[m], \text{ Where } l = 1, \ldots, L \]

The noise \( w_l[m] \) independent across the antennas. We would like to detect \( x[1] \) based on \( y_1[1], \ldots, y_L[1] \). If the antennas are spaced sufficiently far apart, then we can assume that the gains \( h_l[1] \) are independent Rayleigh, and we get a diversity gain of \( L \). Based on the averaging of noise power at receiver, the WiMAX SIMO model is shown in Figure-5.10.
Figure 5.10 Modeling of WiMAX SIMO using real time image transmission

Figure 5.11 WiMAX SIMO channel
Here in this case the same basic blocks of WiMAX model with no diversity are to be utilized with the modification in channel parameters. As this is WiMAX – SIMO system, to realize receiver diversity, the channel is SIMO channel which comprises of single path at the transmitter side and two paths at the receiver side. To get the advantage of receiver diversity in the improvement in BER, the model performs averaging at the receiver side. The rest of the process at the transmitter and receiver side will remain the same.

As shown in the snap shot of Figure-5.11 WiMAX-SIMO channel, it basically comprises of single AWGN channel which would be duplicated into the two paths for realizing the structure of multiple i.e. two receiver antennas over here and through two noise generators additional noise would be added to output signal of AWGN channel via two adders. The (288x1) data matrices of two adders are received and processed through the blocks of OFDM demodulation, de-mapping, decoding and image reconstruction back.

As it has been already discussed in detail in chapter-3 regarding how the performance of the system is improving with the implementation of receiver diversity, it can be briefly stated that through WiMAX-SIMO, by receiving same data through different receivers, the overall error rate can be minimized due to the process of averaging noises by multiple receiving antennas. The things would be verified by performing simulation over MATLAB and then comparing the results of the output images to that of the WiMAX-SISO system.

5.2.4 Simulation Results and Discussion

The simulated model of WiMAX SIMO is shown in Figure-5.12. The Snap shot indicates the values at the end of each and every block after MATLAB simulation.

For the comparative analysis, the simulation results have taken for the 635880 total numbers of bits as taken in WiMAX SISO model by transmitting image of the dimension (256x256).QAM symbols variations; output image and corresponding BER are shown in Figure-5.13, 5.14 & 5.15.
Figure-5.12 Simulated model of WiMAX SIMO

Here in case of WiMAX – SIMO system, again by transmitting same no. of bits i.e. 635880, total 82572 bits are getting lost, which is comparatively lower than that of WiMAX – SISO system because of the implementation of antenna diversity at the receiver side in the system.

Figure-5.13 QAM symbols variations
This is due to the fact that at the receiver side, due to two antennas, averaging would be performed and that will reduce BER from 0.134 in SISO to 0.12 in SIMO. The degradation in image quality at the receiver side is improved as compared to that of WiMAX – SISO.

5.2.5 Modeling of WiMAX- MISO System
The next step toward diversity utilization is to use a multiple input single output configurations, e.g., two transmit antennas and one receive antenna. This configuration is called multiple inputs single output (MISO) as shown in Figure-5.16. Now consider the case when there are L transmits antennas and 1 receive antenna, the MISO channel. This is common in the downlink of a cellular system since it is often cheaper to have multiple antennas at the base station than to having multiple antennas at every handset. This is the transmit diversity scheme proposed in several third generation cellular standards.
To realize WiMAX – MISO model, almost all blocks are identical to previous two models except the inclusion of Space Time Encoder-Decoder and framing-de framing. Irrespective of the block level formation, the logic and the data values at the output of the port after the QAM block is getting differed drastically in the realization of WiMAX-MISO system as two receiver structures have to be realized for the prototype. Basically in the transmitter diversity scheme, to increase the capacity with lower bit error rate, the most elegant space time coding scheme is utilized which is known as Alamouti coding in which the data would be transmitted by taking the complex conjugate of itself. In this model Alamouti encoder and decoder are implemented using the MISO Encoder and combiner blocks. The combining involves simple linear processing using the orthogonal signaling employed by the Alamouti encoder.

Initially the image having dimension of (256x256) has been fetched that would be
converted into the stream of bits through the process of randomization. After constructing bit stream of dimension (280x1), the similar stages of FEC coding and QAM mapping would be performed which as a whole gives output of (192x1) bits. Now from here onwards, the actual logic of implementation of Tx diversity in WiMAX system commences. It has been already discussed that in WiMAX-MISO system, two transmit antennas are going to transmit the same information through the wireless channel due to the fact that out of multiple no. of paths, at least one such path can be obtained from the all which is having minimum amount of distortion or disturbance over the transmitted data thereby minimizing the effects of errors introduced due to channel at low value of SNR. To implement this logic virtually over MATLAB simulation, for 2x1 system two transmitted paths must be realized out of which one would be better than the other in terms of BER of received data. This is the stage where WiMAX-MISO system differs from the previous two systems in which throughout the transmission and reception; the blocks deal with single dimension data.

Here in this case for realizing two transmitter designs, before applying to the channel, data must be bifurcated into two parts i.e. it must be converted into two dimensions. For implementing the above mentioned logic, after performing quadrature amplitude modulation, data stream with dimension (192x1) will be given to block of “framing” where the duplication can take place by means of serial to parallel conversion of incoming bit stream. The snap shot of internal structure of framing is shown in the following Figure-5.17.

![Figure-5.17 WiMAX MISO framing](image-url)
Initially the incoming data of dimension (192x1) is padded with zero bits so as to make it (400x1) which would be given to serial to parallel converter that makes the WiMAX-MISO model different from the previous two models. After parallel conversion of data from this block, the data would be now of two dimension (2-D). The output of this block would be (200x2) dimension.

The data of dimension (200x2) is applied to the sub block named “input packing” where the constant matrix having value [0 0] would be appended with the data of (200x2) which in turn would be converted to a form (201x2). This matrix is reordered by means of U-Y selector block so as to make it compatible for the further processes of coding and modulation. The output dimension will remain same as (201x2) only.

![Alamouti Encoder](image)

**Figure-5.18 WiMAX MISO Alamouti encoder**

The output of framing block with dimension (201x2) is now given to one of the most important block named “Alamouti Encoder” of WiMAX-MISO system. The snap shot of Figure-5.18 shows the internal architecture of the same block.

Initially the input data of (201x2) dimension which is frame based format is given converted into sample based format with the same dimension. Now these (201x2) samples are given to MISO encoder block which encodes the input message using an orthogonal space time block codes. Here it is rate 1 encoder as 2 transmitter antennas have been used. Along with the combination of MISO encoder and U-Y selector the output would be bifurcated into the two streams of (201x2) dimension matrices. The logic of STBC has already explained in chapter 3. As a brief, the STBC coding works for the
complex conjugate values. This encoder converts the data into its complex conjugates. Finally the two bifurcated data corresponds to multiplication of one data with complex conjugate of the other and multiplication of second data with the complex conjugate of the first. Mathematically it can be represented as,

\[ r_0 = \frac{1}{\sqrt{2}} s_0 h_1 + \frac{1}{\sqrt{2}} s_1 h_2 + n_0 \]

\[ r_1 = \frac{-1}{\sqrt{2}} s_1^* h_1 + \frac{1}{\sqrt{2}} s_0^* h_2 + n_1 \]

Where, \( r_0 \) and \( r_1 \) are the outputs of MISO coder, \( S_0 \) and \( S_1 \) are two real inputs, \( S_0^* \) and \( S_1^* \) are their complex conjugates respectively, \( h_1 \) and \( h_2 \) form channel transfer function matrix and \( n_0 \) and \( n_1 \) are additional noise. These data would be again made frame based by means of the block sample to frame converter.

This is how the two separate stream of data with dimension (201x2) would be generated which are given to two separated OFDM transmitter blocks. The Figure-5.19 shows the snap shot of pair of OFDM transmitter for two individual transmissions.

Before initiating the exact process of OFDM, the incoming Alamouti coded data of (201x2) dimension is first padded with some additional bits for the process of real time transmission and synchronization. As shown in the snap shot of first OFDM transmitter, the (201x2) data matrix would be concatenated by training sequence named as “p_even” which is known as a long training sequence, necessary in the receiver for the channel estimation. The “p_even” training sequence is mathematically represented as,

\[ P_{EVEN}(k) = \begin{cases} \sqrt{2} \text{con}(P_{ALL}(k)) & \text{k mod 2}=0 \\ 0 & \text{k mod 2} \neq 0 \end{cases} \]

where \( P_{\text{all}} \) is the total training sequence of the dimension (201x2) which is numerically represented by,

The above bit stream of total training sequence can be represented by,
\[ P_{\text{ALL}} = \sqrt{2} * \sqrt{2} \text{ conj} (P_{\text{ALL}}(k)) \]

In equation the factor \( \sqrt{2} \) equates the root mean square power with that of the data section. The additional factor of \( \sqrt{2} \) is related to the 3dB boost.

---

**Figure-5.19 WiMAX MISO OFDM transmitters**
The few samples of actual data stream of P-even training sequence is given by,

\[ [1.414 - 1.414i, 0.000 + 0.000i, -1.414 - 1.414i, 0.000 + 0.000i, 1.414 - 1.414i, 0.000 + 0.000i, 1.414 + 1.414i, 0.000 + 0.000i, 1.414 - 1.414i, 0.000 + 0.000i, .......] \]

Here every even symbol of total training sequence has been considered and the odd symbols have been replaced by complex no. having value zero. This is how total 100 even training symbols are repeated more or less similar to the sample sequence along with 100 zero symbols.

Another training sequence shall be used when transmitting space-time coded (STC) downlink bursts. Because the STC scheme achieves diversity by transmitting with two antennas, a training sequence has to be transmitted from both transmit antennas simultaneously. Thus, the first antenna transmits a training sequence using P_even and the same transmitted from the second antenna is set according to the sequence P_odd. Again, like P_even, it is derived from the sequence total sequence, but using, in this case, a subset of odd subcarriers. This odd training sequence is concatenated with the incoming (201x2) data in the second OFDM transmitter as the output of it is going to be transmitted by second antenna. The odd training sequence is represented by,

\[ P_{ODD}(k) = \begin{cases} 0 & k \mod 2 = 0 \\ \sqrt{2} \cos(P_{ALL}(k)) & k \mod 2 \neq 0 \end{cases} \]

The few samples of actual data values of P_odd sequence is mathematically given by,

\[ [0.000 + 0.000i, 1.414 - 1.414i, 0.000 + 0.000i, 1.414 + 1.414i, 0.000 + 0.000i, 1.414 - 1.414i, 0.000 + 0.000i, 1.414 - 1.414i, 0.000 + 0.000i, 1.414 - 1.414i, .......] \]

Here also 100 odd training symbols along with 100 zero symbols get repeated more or less similarly as the sample sequence.

The output of both the concatenators is now three dimensional data with value (201x3) which is further processed with the addition of pilot carriers that will work as guard band. The concatenate block named “add guard bands” simply combines the 3-D data coming from previous block with two pilot carriers i.e. upper frequency pilot carriers having dimension (28x3) and lower frequency pilot carriers having dimension (27x3). Pilot symbols can be used to perform frequency offset compensation at the receiver. As a whole net (256x3) OFDM subcarriers would be generated which are same as the case
with WiMAX-SIMO and WiMAX-SISO except here the data is 3D rather than 1D. This data matrix is further given to U-Y selector block which simply performs the reordering of the data. This reordered (201x3) data is now processed to Inverse Fast Fourier Transform (IFFT) and element wise gain would be applied to it. Then after to remove ISI and to improve BER, the data would be appended by 32 bits cyclic prefix whose effects and variations have already been explained in the previous chapters. Here the cyclic prefix value is set as 1/8. Now the data with dimension (288x3) is applied to “parallel to serial” converter block which will make single dimension data as (864x1) which would be transmitted by first antenna with even training sequence.

Figure-5.20 WiMAX MISO channel
The same process has been performed by the respective blocks of OFDM transmitter and finally the same data with dimension (864x1) would be transmitted by second antenna with odd training sequence.

Now to realize the transmission virtually, the “WiMAX MISO channel” has been modeled in MATLAB which comprises of two AWGN channel for two different transmitting antennas respectively. The Figure-5.20 shows the snap shot of the WiMAX MISO channel.

As shown in the snap shot of WiMAX MISO channel, to realize two transmitters and one receiver logic, the output from the two OFDM transmitter blocks would be given to two separate AWGN channels via two adders whose outputs are addition of incoming (864x1) data bits and two random noise generators. These blocks of random noise generators are utilized over here for the comparative analysis purpose. The two separate AWGN channels are transmitting the data so as to virtually realize propagation of same data through two transmitting antennas. The output of channel totally depends upon the existing channel SNR.

Now as the modeling is all about WiMAX-MISO system, there must be single receiver. So to implement the same logic, the outputs of both the AWGN channels get added and that (864x1) data would be further processed through receiver blocks of WiMAX.

As per the actual model shown in Figure-5.16, the first block of receiver is OFDM demodulator whose snap shot is shown in Figure-5.21.

![OFDM Receiver Diagram]

**Figure-5.21 WiMAX MISO OFDM receiver**

Here the data with dimension (864x1) received from WiMAX-MISO channel is first converted to 3D data by means of serial to parallel converter block. The output would be
(288x3) from which the cyclic prefix of 32 bits that has been added to increase redundancy and to eliminate ISI would be removed by the block named U-Y selector. The output of (256x3) bits would be given to FFT block for converting it to frequency domain and progressively applied to gain block. Finally the sample based data would be converted to frame based format and the additional (28x3) and (27x3) pilot carriers added as guard band have been removed by U-Y selector block to get original (201x3) data bits. This data is now further processed reversed to that of the transmitter i.e. now it is given to the block of “Alamouti decoder” for performing space time decoding. The snap shot of the same is shown in the Figure-5.22.

As it has been already discussed in the OFDM transmitter block that the training sequences are concatenated with the incoming (201x2) data for the channel estimation and synchronization purpose, here at the Alamouti decoder, by means of the same even and odd training sequences, the process has been initiated. The output of OFDM receiver with dimension (201x3) would be combined with even and odd training sequences of the same nature to that of the transmitter side by the block “space time block combiner”. The detailed internal structure of the same has also been included in the same snap shot.

The logic implemented inside the “space time block combiner” can be explained by means of following steps:

Step-1: Three signals i.e. output of OFDM receiver with (201x3) dimension, even training sequence with (201x1) dimension and odd training sequence with (201x1) dimension are received by STB combiner block.

Step-2: The additional (100x1) zero bits which have been placed in the even training sequence at odd no. place and the same zero bits which have been placed in the odd training sequence at even no. place will be removed by means of two U-Y selector blocks. The output of both U-Y selector blocks will be of dimension (100x1).

Step-3: The actual data i.e. the output of OFDM receiver with dimension (201x3) would be bifurcated into three parts to have it in 1D by means of the block “select column” that simply divides the data and training sequences.
Step-4: The two even and odd training sequences are differentiated and reordered in the specific manner same to that of the transmitter side by means of U-Y selector respectively and processed for the channel estimation purpose.
Step-5: From (201x2) data, the single dc bit would be removed that has been inserted at the transmitter side as a constant and straightforward the output of (200x2) dimension would be applied to the “Alamouti decoder”.

Step-6: Simultaneously the even and odd training sequences would be process through multiple matrix transpositions and framing as a part of channel estimations and finally the two outputs of the dimension (200x2) would be concatenated and finally the matrix of dimension (200x2x2) would be applied to the block “Alamouti decoder” which is already having the other input of data as explained in step-5.

Step-7: The Alamouti decoder block combines the received signal and channel estimate inputs in accordance with the structure of the orthogonal space time block code. It is rate 1 here as no. of transmitting antennas is 2. Here as the system is WiMAX-MISO, so the receiver antenna is one and for one receive antenna, the received signal input is a 2-D matrix along with corresponding 2-D channel estimate input. The final output of (200x2) dimension is now applied to the block of de framing as shown in Figure-5.23.

The Alamouti decoded data is now converted into its actual transmitted form to retrieve the transmitted image signal back by means of de framing. The 2-D data would be converted to 1-D by means of parallel to serial converter whose output will be (400x1) dimension. Then after the original QAM modulated data with dimension (192x1) can be retrieved by removing the additionally padded zero bits from the data stream of (400x1).

At last similar to two previous models, the process of QAM demodulation, viterbi
decoding and RS decoding would be performed in a same manner and output image of dimension (256x256) will be reconstructed with some amount of distortion according to the channel conditions. That comparative analysis between input and output image has been elaborated in the following section of simulation results and discussion.

5.2.6 Simulation Results and Discussion
The Figure-5.24 shows the snap shot of simulated model of WiMAX-MISO system. At each and every block the port dimensions are indicated. Along with simulated model, the QAM symbols variations, output image and BER calculator are included in Figure-5.25, 5.26 & 5.27 respectively, to visualize the performance of WiMAX-MISO system.

As per the simulation results, it can be observed that out of 635880 bit, the no. of bits which are getting lost is reducing drastically to 17131 as compare to WiMAX-SISO and
WiMAX-SIMO model. In this way, the acquired BER will also decrease to 0.026. This is because as the signal will travel through two independent channels, making sure that reliable communication is possible as long as one of the paths is strong and received signal quality gets enhanced and the quality of output image would be much better.

Figure-5.25 QAM symbols variations

Figure-5.26 Output image
The next section of this chapter elaborates the final task of the research work i.e. implementation of transmit and receive diversity in the WiMAX system along with real time image transmission.

5.2.7 Modeling of WiMAX- MIMO System

Multiple Input Multiple Output involves the transmission of two streams using two or more than two spatially separated antennas. The streams are received at the receiver by using spatially separated antennas. The streams are then separated by using the space time processing, which forms the core of the MIMO technology as shown in Figure-5.28. It can be observed from the snap shot of WiMAX-MIMO system that transmitter part of the system is more or less identical to WiMAX-MISO system and the main difference lies with the implementation of receiver block. Again with the transmission of image signal, the working of this model is considered to be real time in nature.

As shown in the snap shot, it can be verified that each and every block of transmitter section is performing the same task with same logic and with same dimensions of output data. A very brief of working of this model can be explained with the following hierarchy.
1. Input image of dimension (256x256) would be captured and converted into the bits by means of “input image” block and by adding necessary overhead bits (280x1) dimension data would be retrieved.

2. Then after randomizer encrypt the data and output of it i.e. (288x1) bits encoded through the series combination of RS encoder and convolution encoder whose final output would be (384x1) data.

3. This data stream is modulated by means of QAM modulator which will give data with 1-D dimension i.e. (192x1).

4. As per the basic requirement of transmit diversity (2 antennas for this case), framing would be performed which will give output of dimension (201x1). It will work exactly same as that of the WiMAX-MISO system.
5. Now as shown in Figure-5.29, the main task of system with transmit diversity will be performed by the block “Alamouti encoder” in which the logic of Alamouti coding has been implemented. If this block is compared with the same block of WiMAX-MISO system, then just one change would be observed that is in that case with the cascade combination of OSTBC encoder and two U-Y selector, the two stage conversion of the logic has been implemented and the output was of dimension (201x2), while over here, the two stage logic is embedded as a MATLAB function inside the block “MIMO ENCODER” which performs the complex conjugation of two data streams and does the logic of Alamouti coding i.e. multiplication of first no. along with conjugate of second no. and multiplication of second no. along with conjugate of first no. These two separate streams are applied to two separate OFDM transmitters.

![Alamouti Encoder Diagram](image)

*Figure-5.29 WiMAX MIMO Alamouti encoder*

6. The Alamouti coded data is forwarded to two separate OFDM transmitters shown on Figure-5.30. It’s exactly identical to that of the WiMAX-MISO system. These two OFDM transmitters perform same function of appending even and odd training sequences for the synchronization during the real time transmission, addition of guard bands and insertion of (32x1) cyclic prefix in the data stream to increase the redundancy for eliminating the chances of ISI during transmission. At last the 3-D data would be converted into 1-D matrix with dimension (864x1) exactly identical to that of the WiMAX-MISO system. The detailed working has already been explained in the previous section.
7. The two streams of data with dimension (864x1) and with two different training sequences are now going to be transmitted through two different wireless channels (WiMAX MIMO channel) in a specific manner. Here we are not considering the effect of multipath fading environment that is why both the channels are modeled as AWGN channels. The snap shot of both the channels is shown in Figure-5.31.
As per the snapshot of MIMO channel, the highly indicative difference is the presence of two additional adders i.e. adder1 and adder2 as comparison with the MISO channel in which these two initial adders were not present. Basically in MISO system the receiver is just one so at last in the output of channel, the two same data travelling through two different paths get combined by default but here in case of MIMO system, two realize multiple receivers (here 2 receivers), the output of two AWGN channels remain separate and separately applied to two different OFDM receivers. So if the top two adders are not placed then two data travelling in two different paths can never get combined which overrule the MIMO logic i.e. Alamouti
logic. By means of the top two adders, by default the two data gets combined and then that combined data will be processed through two random noise generator’s output and transmitted through two separate AWGN channels. This logic makes excellent analogy with the real time MIMO scenario.

8. The output of both the channels is transferred to the separate OFDM receivers which perform the exactly same function to that of the WiMAX-MISO model. The Figure-5.32 shows the snap shot of OFDM receiver wherein the function of removal of cyclic prefix, FFT and removal of guard bands is performed.

![OFDM Receiver](image)

**Figure-5.32 WiMAX MIMO OFDM receivers**

9. The Alamouti coded data streams from the OFDM receivers are now applied to Maximum Likelihood (ML) Alamouti decoder shown in Figure-5.33, so as to step in towards the retrieval of image signal. The block of M.L. Alamouti decoder reconstructs the original (200x2) data matrix by means of complex processes of channel estimation and STB combining. The architecture of block to realize the logic is very complex and it has been deliberately illustrated in the following snap shots.

As it has been already discussed that for channel estimation purpose, the training
sequences are required, here along with (201x3) data matrix, two training sequences are processed and finally the 2-D data would be reconstructed.

Figure 5.33: WiMAX MIMO Alamouti decoder
Here again the initial four U-Y selector remove the addition (100x1) zero bits from even and odd training sequences which are making those two training sequences distinguished from each other. Simultaneously the two multi port selectors named as “select column” simply differentiate the data and training sequences. After this the two training sequences are given to channel estimation block whose output is used to implement the decoding logic by means of complex conjugation of channel transfer function and maximum likelihood detection. At last the decoded data with (200x2) dimension is retrieved.

10. Now as shown in Figure-5.34, this decoded data (200x2) is de-framed by performing parallel to serial conversion and removing the additional zero bits that were added at the transmitter side. The output data would be of dimension (192x1).

![De-Framing](image)

**Figure-5.34 WiMAX MIMO de-framing**

11. At last over binary data RS decoding, viterbi decoding and output image retrieval kind of processes would be performed and by doing MATLAB simulation, the output and input image comparison and BER calculation would be performed. After simulation the model of WiMAX-MIMO has been shown in following snap shot.

### 5.2.8 Simulation Results and Discussion

The simulated model of Figure-5.35, justifies the signal values at each and every port of the blocks. If the things are compared with the previous model of WiMAX-MISO, then just one difference can be recognized that multiple output paths from the channel and their respective multiple OFDM receivers along with the Maximum Likelihood decoding of Alamouti coded data. Again the MATLAB simulation has been performed by passing real time (256x256) image signal through the model and output image is going to be
compared graphically by means of scattering plot and numerically by means of the reading of BER calculator. The QAM symbols variations; received image and BER calculator are shown in Figure-5.36, 5.37 and 5.38 respectively.

Simulation has been performed by transmitting the same image input i.e. the same no. of bits i.e. 635880. Due to multiple transmitting and receiving antennas, for same no. of transmitting bits the lost bits no. reduces vary greatly to 62 which will again improve the BER to very considerable amount up to 0.00009. So as compare to WiMAX – SISO the performance of WiMAX – MIMO is far better and quality of output image is also tremendously improved as MIMO as because with the implementation of transmit diversity, signal fads independently making sure that reliable communication is possible as long as one of the paths is strong, and with the implementation of receive diversity, received image quality gets enhanced by averaging over multiple independent signals. Hence MIMO technique exploits the advantages of MISO and SIMO diversity techniques.
Figure 5.36 QAM symbols variations

Figure 5.37 Output image

Figure 5.38 BER calculator
5.2.9 Comparative Analysis
The vital aspect of comparative analysis leads to the implementation of diversity principles in 3G and 4G wireless communication networks.

Figure-5.39 Comparative analysis of WiMAX SISO v/s SIMO v/s MISO v/s MIMO
It can be seen from the simulation results that for SISO WiMAX system, with the same channel SNR=24dB of AWGN channel, the fluctuation of the QAM symbols from the mean values are changing and hence the received image contains higher noise i.e. bit loss of 85048 bits and in turn BER equal to 0.133 as compared to that of diversity models. With the implementation of first stage receiving diversity (SIMO), BER performance is improved to 0.129 and bit loss is reduced to 82572 as compared to SISO antenna system. This is due to the fact that with the implementation of two received antennas, averaging of noise power would be performed which surely decreases the achieved BER and improved the quality of received image. Similarly with the implementation of transmit diversity (MISO) along with Alamouti coding scheme, the received image is improved as compare to WiMAX – SISO. The total no. of bit loss will be reduced to 17131 bits out of the same 635880 total no. of bits and BER will be improved to 0.026 in WiMAX-MISO. It introduces the redundancy in space through the addition of multiple antennas, and redundancy in time through channel coding, enabling us to exploit diversity in the spatial dimension, as well as obtaining a coding gain.

Finally if the performance of all four WiMAX systems is considered, then it can be clearly stated that among four, WiMAX – MIMO is having the best performance in regards to quality and BER as compare to WiMAX-SISO, WiMAX-SIMO and WiMAX-MISO. In WiMAX MIMO, the diversity gain is the improvement in link reliability obtained by receiving replicas of the information signal through independently fading links, branches, or dimensions. In this way, the lowest BER equal with just bit loss of 62 bits is achieved and the quality of received image is dramatically improved in the WiMAX MIMO system as MIMO technique exploits the advantages of MISO and SIMO diversity techniques.

5.3 Modeling and Experimentations using Real Time Speech Transmission

This section of the chapter analyses the performance of the WiMAX system with real time speech signal as an input. As explained in the previous sections that WiMAX system is not limited to just data transfer but it can also process the real time image signal. With the implementation of antenna diversity techniques, the performance can be improved in
terms of error rates. Here in this section, the same process can be done by passing the real
time speech signal through the same WiMAX model with the implementation of various
diversity techniques. Here First of all, 16000 samples of speech input signals are taken
for the process. Then turn by turn for same no. samples, transmit and receive diversities
will be applied with the same WiMAX model and comparative analysis can be
performed.
The following section deals with the WiMAX models with various antenna diversity
techniques by passing the speech signal as an input signal.

5.3.1 Modeling of WiMAX- SISO System
Figure-5.40 shown below indicates the snap shot of WiMAX-SISO model with real time
speech transmission after the MATLAB simulation. The analysis has been done based on
comparison between input and output speech signals and on the reading of BER
calculator.

Here again the same pattern of transmission and reception can be observed as that of the
WiMAX modeling using diversity with image as an input signal. Let’s take a brief review
of the same. Initially the “speech input” block converts the real time speech samples into equivalent no. of bits i.e. matrix of (280x1). This data matrix is passed through the different processes of transmission i.e. FEC coding, modulation and OFDM modulation and finally (288x1) data output would be passed through the WiMAX channel. This (288x1) data matrix again exposed to the reverse processes of demodulation and decoding and finally the “speech output” block tries to recreate the original speech back which is highly distorted as compare to the original speech. The amount type of distortion can be very well understood by the following section of simulation results and discussion based upon it.

5.3.2 Simulation Results and Discussion
As the system does possess no diversity mechanism, the no. of loss bits seems to be higher one and the corresponding BER is also of noticeable amount. The QAM symbols variations; received speech and BER calculator are shown in Figure-5.41, 5.42 and 5.43 respectively. By transmitting 280280 no. of total bits, 36614 bits are getting lost and because of that the quality of output speech is degrading in a drastic amount as compared to that of input speech. The bit error rate obtained at channel SNR=24dB is 0.130.

![Figure-5.41 QAM symbols variations](image-url)
The quality of speech and BER can be improved with the application of antenna diversity in the same model with the transmission of same no. of bits in terms of speech signal and also keeping all the parameters of every block constant. The subsequent sections illustrates the effect of receive diversity, transmit diversity and transmit-receive diversity by passing real time speech signal.

5.3.3 Modeling of WiMAX- SIMO System

Figure-5.44 shows the simulated diagram of WiMAX-SIMO system. Here for SIMO system, the same speech signal to that of the first case has been transmitted and due to averaging at the receiver side among the multiple paths, the quality of receive speech and in turn BER is improved in a significant amount.
Here if the model is compared with the WiMAX-SIMO model with image as an input signal discussed in section-5.2.3, exactly same processes would be encountered over the speech signal. At the end of wireless channel, the incoming data at the end of OFDM modulation would be bifurcated into two paths to realize two receiver antenna terminology. Two matrices of same dimension (288x1) are given to OFDM demodulator block and further through demodulation and decoding phases, the output speech would be reconstructed. Finally to deduce the performance of the system, the output image would be compared with the input image and through the scattering plot of received OFDM symbols, BER would be calculated. That simulation part has been discussed in the following section.

### 5.3.4 Simulation Results and Discussion

Figure-5.45, 5.46 and 5.47 illustrate the QAM symbols variations; received speech and BER calculator respectively. As seen from the available simulation results of input-output speech and BER calculator, for the same no. transmitted bits i.e. 280280 bits, the total no. loss bits are decreasing from 36614 to 30436 thereby increasing the quality of receive speech and also improving the BER to 0.108.
Figure-5.45 QAM symbols variations

Figure-5.46 Original speech and received speech

Figure-5.47 BER calculator
5.3.5 Modeling of WiMAX- MISO System

The snap shot of Figure-5.48 illustrates the implementation of transmit diversity along with real time speech transmission. Each and every parameter of all blocks are kept constant and by transmitting same speech signal at same channel SNR, the quality of output speech is getting improved thereby improving system BER due to the logic that out of multiple transmitting paths, at least one path with minimum distortion can be achieved.

Here if this system is compared with WiMAX-MISO system with real time image transmission, then more or less all the blocks and all the processes remain the same except nature and type of input signal. In this system, in place of image signal, speech is taken as an input signal which would be converted into data matrix of (280x1) bits. Further the same sequence of encoding/decoding, modulation/demodulation, framing/de
framing and Alamouti coding/decoding would be encountered here for speech processing and advantages of transmit diversity implementation would be gained that is much better BER can be achieved as compared to the traditional model of WiMAX. The improvement in system performance due to implementation of receive diversity is discussed in the following section of simulation result and discussion.

5.3.6 Simulation Results and Discussion

Figure-5.49, 5.50 and 5.51 illustrate the QAM symbols variations; received speech and BER calculator respectively. According to the simulation results, out of 280280 bit, just 6229 bits are getting lost and hence the BER is improving to 0.022. The fluctuations in the OFDM symbols as depicted by output scattered diagram are comparatively very small with respect to WiMAX-SISO system. Hence the quality of output speech is not that much deteriorating as compared to input speech.

![Scatter Plot](image)

**Figure-5.49 QAM symbols variations**
Figure-5.50 Original speech and received speech

Figure- 5.51 WiMAX MISO modeling using real time speech input

5.3.7 Modeling of WiMAX- MIMO System

Figure-5.52 depicts the simulated snap shot of WiMAX-MIMO system. Here in this case with the implementation of antenna diversity at both the ends of system, the highest quality of transmission along with lowest BER can be achieved by exploiting advantages of both WiMAX-SIMO and WiMAX-MISO. The system is exactly same as the system described in section 5.2.7 i.e. WiMAX-MIMO with image input except speech as an input. Again the input speech signal will pass through the various blocks of coder/decoder, modulator/demodulator, framing/ de framing, Alamouti coding/decoding, etc. and according to the behavior of the wireless channel; the output speech signal with the least distortion can be achieved. The following section illustrates the same.
5.3.8 Simulation Results and Discussion

By observing the input-output speech signals, scattering plot of OFDM symbols and reading of BER calculator given in Figure-5.53, 5.54 and 5.55 respectively, it can be concluded firmly that WiMAX-MIMO is having the strong potential to be known as the highly efficient modern wireless communication system with all the excellent qualities. Here out of same no. transmitting bits i.e. 280280 bits, only 134 bits with 0.0004 BER which is a negligible amount are getting lost due to MIMO architecture in WiMAX system. The quality of output speech can be considered more or less same as that of the input speech and the fluctuations in the OFDM symbols are not at all haphazard in the movement. They are highly concentrated giving maximum resolution and perfection.
The following section deals with the all four models of WiMAX with speech as an input from comparative analysis point of view.
5.3.9 Comparative Analysis of Simulation Results

The comparative analysis of all diversity techniques using speech input signal is shown in Figure-5.56.
As shown in experimental results, one fine observation can be derived that with the implementation of receive diversity, transmit diversity and both transmit-receive diversities in WiMAX model with speech input signal, step by step the BER is getting better and system performance is seen to be drastically changed.

As shown in comparative snap shot of simulation results, it can be summarized that:

- At the channel SNR=24dB, and with all constant system parameters, WiMAX-SISO channel deteriorates 36614 bits out of 280280 bits, leading to the worst BER of 0.13. In this way, received speech is mostly destroyed due to multipath fading effects.

- While WiMAX-SIMO channel reduces the degradation in the performance of the system by BER of 0.108 i.e. lost bits are 30436. In this way, averaging over two noisy received signals at receiver, the system performance is improved.

- In case of WiMAX-MISO, the no. of bits lost still reduces to 6229 leading to comparatively better BER of 0.022. In this way, with the implementation of transmit diversity, coding gain of system is improved and received signal gets at least one optimum path and produces much better system performance in terms of received bits and quality of image.

- Finally, WiMAX-MIMO system provides the excellent performance in terms of BER among the all with real time speech transmission. Just 134 bits out of 280280 bits are getting lost leading to the lowest BER-0.0004 and highest performance. Hence with the implementation of transmit and receive diversity techniques, system performance is drastically improved and output speech quality is almost same as the input speech quality.

From the discussions of sections 5.2 and 5.3, it has been very effectively proved that the WiMAX model with diversity designed in this research work just not only supports data but also real time image and speech signals with the same amount of efficiency and accuracy. This is the main characteristics of this design which makes it suitable for the practical implementation. Still to make it much more versatile for the current practical scenario, one more innovation has been applied that is the performance analysis and simulation of same WiMAX model under real time fading environment rather than AWGN environment. The following section deals with the idea of implementing the same fact.
5.4 Modeling of WiMAX System in Fading Environment

This section analysis the same model of WiMAX that has been thoroughly discussed in the previous sections of this chapter. To visualize and understand the effects of real time environment over system performance, it’s highly required to analyze the real time fading channels i.e. Rayleigh channel and Rician channel. In real life scenario, it’s not possible to have unified distribution of fading over a whole communication channel.

5.4.1 Modeling and Experimentation of WiMAX System in Rayleigh Fading Environment

The modeling of WiMAX system with Rayleigh channel is the finest realization of real time wireless system showing the practical consideration of fading phenomenon. To model the WiMAX system with the consideration of practical wireless scenario, the AWGN channel of the previous design discussed in section 5.2 or 5.3 should be replaced by such a channel which will characterize the actual features of the practical wireless path. As such the modeling of AWGN channel provides the analogy of addition of uniform noise over a whole transmission path if the value of SNR is constant while to check the behavior of channel under fading condition, the proper analogy can be set by the use of Rayleigh channel [26]. The most suitable option is modeling of Rayleigh channel between transmitter and receiver of the WiMAX system which describes the most prominent phenomenon of mobile radio communication system, i.e. fading. The fading is the resultant of rapid fluctuations in the amplitude, frequency or phase of the signal due to multipath propagation of radio waves. When the number of multiple delayed fading paths is large and/or the differential delay between paths is small, which is usually true for wideband systems in practice, and then a significant amount of computational effort is required in performance analysis and simulations [27]. Generally in urban areas, the line of sight path is seldom available so to model the WiMAX system in highly populated area, the Rayleigh channel modeling is the best choice for simulation.
5.4.2 Traditional WiMAX Rayleigh Channel Model

Figure 5.57 shows the basic traditional model of WiMAX system with Rayleigh channel as a virtual link between transmitter and receiver. Except the change of channel, the remaining blocks and their functions are exactly same as the previous model discussed in Figure 5.4 of section 5.2.1 where the channel has been modeled as an AWGN channel to form the base of comparative analysis of the research work.

Here again turn by turn the same leaf image with size 256x256 as well as speech with duration 2 sec would be taken as a real time input and the model is going to be analyzed.

The snapshot of WiMAX-SISO is simulated model which shows the bit by bit output at the end of each and every blocks of the model. Let’s take a brief review of the simulation.

To initiate the simulation, the input image/speech block fetches the image/speech at a time and converts it into data of dimension (280x1) which would be processed through several blocks such as randomization, FEC coding, QAM modulation and finally OFDM modulation. This OFDM modulated data with dimension (288x1) would be passed through the cascade combination of Rayleigh and AWGN channel.

![Diagram of WiMAX SISO under Rayleigh fading environment](image-url)
This is the point where the model is getting differed from the WiMAX-SISO model of section 5.2.1. Here the normal single AWGN channel has been replaced by combination of Rayleigh and AWGN channel so as to analyze the effects of practical short term and long term fading along with the effect of Gaussian noise.

The behavior of Rayleigh channel would be analyzed by evaluating the effect of its all specifications. Figure-5.58 shows the snap shot of internal structure of Rayleigh channel.

![Rayleigh channel function block](image)

Figure-5.58 Rayleigh channel function block

Basically the design of Rayleigh channel mainly depends upon three designing parameters.

1. Maximum Doppler shift (k)
2. Discrete path delay vector (Td)
3. Average path gain vector (G)

With the variations in these parameters, the performance of the channel gets differed in terms of error rate.

The Doppler shift in wireless communication solely depends on relative velocity between transmitter and receiver and is given by,

\[ k = \frac{v}{\lambda \cos \theta} \]
where, $v$ = relative velocity

$\lambda$ = wavelength of the signal

$\theta$ = angle of arrival

With the increase in Doppler shift, the phase and frequency between the input and output signal will increase which increases the BER and vice versa.

The length of discrete path delay vector defines the no. of paths taken by signal components in the multi path environment. It is given by,

$$Td = 0.7 \times 256 \times G \times (T_b/(256+256 \times G));$$

Where, $T_b=1.24756335282651 \times 10^{-5}$ & $G=40$

Finally the average path gain vector simply provides the additional gain to the transmitted signal passing through the channel. As a whole, the path gain and discrete path delay vector are kept constant and by changing the value of Doppler shift, the simulation has been performed to observe the BER and quality of output image or speech in the next section. At last the Rayleigh faded signal would be now received through receiver blocks and processed by OFDM demodulator, decoder and then converted back to the image or speech signal.

### 5.4.3 Simulation Results and Discussion

By modeling the WiMAX system under the fading constraints, with the propagation of image and speech inputs, the outputs get degraded with sudden jerk of noise at some parts rather than distributed noise as in the case of AWGN channel. The factor that decides the amount of fading is the Doppler shift.

This section of simulation results and discussion has been divided into two parts.

1. Simulation of WiMAX system with image as an input
2. Simulation of WiMAX system with speech as an input

**Case-1: For Real Time Image Transmission**

It has been already discussed that with the variation in Doppler shift of Rayleigh channel with all other parameters constant along with the SNR=29dB for cascaded AWGN channel, the system performance is changing in respect to BER. Here as an example, two
value of Doppler shift have been selected and simulation of WiMAX-SISO has been performed by passing the image of leaf with (256x256) dimension.

i. Doppler shift \( (k) = 1/1000 \) and AWGN SNR=29

Figure-5.59, 5.60 and 5.61 shows the QAM symbols variations, Output image and BER calculator respectively at high value of Doppler shift equal to 1/1000.

![Figure-5.59 QAM symbols variations](image)

![Figure-5.60 Output image](image)
The QAM symbols are quite more scattered over the space and as a result the respective output image quality is the worst which leads to the BER of 0.42 i.e. out of 526680 total no. of bits, 224037 bits are getting lost. This large value of Doppler shift of Rayleigh channel puts horrible effect of system performance in terms of BER.

By reducing the value of Doppler shift from 1/1000 to 1/3000, the significant improvement can be seen at the same constant value of SNR of AWGN channel which has been discussed further.

ii. Doppler shift (K) = 1/3000 and AWGN SNR=29

Figure-5.62, 5.63 and 5.64 depicts the QAM symbol variations, Output image and BER calculator. By reducing Doppler shift, the QAM symbols variations are becoming quite stable that leads to the improvement in the quality of output image as compare to the previous case. The BER would be improved to 0.27 that means only 145576 bits are getting lost against the transmission of same no. of total bits i.e. 526680 bits.
Here from Figure-5.63, it can be observed that the band created due to Rayleigh fading is reducing which is over a span of 150 to 250 over x-axis in the graph as compare to Figure-5.60 with Doppler frequency of 1/1000 where band of fading was on a span of 50 to 250 over x-axis.

As a whole for the larger values of the Doppler shifts, the BER would be larger for the same value of SNR as compared to that of the lower Doppler shifts. The next section analyze the effect of Rayleigh fading in the same WiMAX-SISO model for the speech signal as an input signal at constant SNR=29 dB.

Case-2: For Real Time Speech Transmission

For simulation of WiMAX-SISO under the effect of varying Doppler shift, here in this section, the same experiment has been performed by passing the speech signal through it. Again here two values of Doppler shift would be considered.
i. Doppler shift (k) = 1/1000 and AWGN SNR = 29

Figure-5.65, 5.66 and 5.67 presents the QAM symbol variations, input/output speech and BER calculator, respectively. As Doppler shift of channel is possessing higher value, so the fluctuations in phase and frequency of output speech would be more as compared to input speech which leads to poorer quality of output speech comparing input speech same as the case with image. Out of 280280 bits, 90565 bits are lost leading to the BER of 0.32. This can be improved by reducing the Doppler shift which has been proved further.
ii. Doppler shift (K) = 1/3000 and AWGN SNR=29

**Figure-5.67 BER calculator**

**Figure-5.68 QAM symbols variations**

**Figure-5.69 Input/output Speech**
The performance of WiMAX-SISO model under Rayleigh fading environment with smaller value of Doppler shift has been illustrated by Figure-5.68, 5.69 and 5.70 which represents QAM symbol variations, input/output speech and BER calculator, respectively.

Here the QAM symbols are much more concentrated as compare to first case which leads to the much better quality of output speech signal. The output image is faded in the range of 0 to 0.5x10^4 only whereas with larger Doppler shift the fading is over the range of 1.5 x10^4 to 3x10^4. Out of same no. of transmitted bits i.e. 280280, only 14182 bits are getting lost leading to the improvement in BER to 0.05.

Now it has been observed from the simulation results of WiMAX-SISO model under Rayleigh fading conditions by passing the image or speech signal that the BER can be improved or the good quality of output image/speech can be obtained only when the Doppler shift is having the lower value. But it’s not at all possible to control the Doppler shift unless and until the relative movement can be controlled. It’s not advisable to reduce the relative velocity or speed of communication to reduce the Doppler shift. So again the best solution is application of antenna diversity technique. In the first half of this chapter i.e. in section 5.2 and 5.3, the effectiveness of MIMO system has already discussed in the WiMAX system to improve the BER. Here in the next section, the same phenomenon has been discussed with Rayleigh fading environment.

5.4.4 WiMAX MIMO Modeling in Rayleigh Fading Environment

Figure-5.71 shows the snap shot of WiMAX-MIMO simulated model with Rayleigh channel. The model has been simulated by passing same image/speech signal. Also the same sequence of transmission and reception hierarchy would be followed which has been already discussed in section 5.2.7 and 5.3.7.
By applying diversity within the Rayleigh channel, the performance can be improved due to the important features of averaging of noise at the receiver side and applying Alamouti coding at transmitter side. Again same image of leaf with dimension (256x256) or speech of 2sec would be initially converted into bit stream of (280x1) dimension and identical processes of encoding/decoding, modulation/demodulation, framing/ de-framing and Alamouti encoding / decoding would take place and finally the output image/speech would be retrieved. Here the limitation caused by larger value of Doppler shift would be overcome by diversity phenomenon. With diversity much improved result can be obtained as compared to WiMAX-SISO at the same high Doppler shift of 1/1000. This has been proved in the next section of simulation results and discussion. Again it has been divided into two sub section of simulation with image and simulation with speech as an input signal.
5.4.5 Simulation Results and Discussion

Case-1: For Real Time Image Transmission

The simulation of WiMAX-MIMO has been performed by considering the same SNR and Doppler shift provided by two AWGN and two Rayleigh channels, respectively. Here the model has been analyzed by passing image signal of size (256x256).

Doppler shift (k) =1/1000 and AWGN SNR=29

Figure-5.72, 5.73 and 5.74 depict the QAM symbol variations, output image and BER calculator. The simulation has been performed by taking larger value of Doppler shift due to which the performance has degraded in previous case but here the effects are not at all severe due to advantages exposed by MIMO system.

As can be seen from Figure-5.72 that the QAM symbols are quite concentrated in their positions in spite of larger values of Doppler shift which leads to the better quality of output image and BER of just 0.0001 with the loss of only 563 bits out of 526680 bits.

The same scenario can be observed if the speech is made to pass through the model with the same value of Doppler shift.

Figure-5.72 QAM symbols variations
As can be seen from Figure-5.72 that the QAM symbols are quite concentrated in their positions in spite of larger values of Doppler shift which leads to the better quality of output image and BER of just 0.001 with the loss of only 563 bits out of 526680 bits. While at this larger value of Doppler shift, the BER was 0.425 with loss of 224037 bits in WiMAX- SISO model. The same scenario can be observed if the speech is made to pass through the model with the same value of Doppler shift.

**Case-2: For Real Time Speech Transmission**

To initiate the simulation, the speech signal would be fetched and relatively the effect of Doppler shift would be analyzed.

**Doppler shift (k) = 1/1000 and AWGN SNR=29**

It has been clearly observed from Figure-5.75, 5.76 and 5.77 that the concentration of QAM symbols is much regular, the quality of speech is more or less up to the marks i.e. almost same as an input speech and the BER would be very appreciable of 0.001 with
just 350 bits are getting corrupted out of 280280 bits despite of larger value of Doppler shift equal to 1/1000. At a comparative level, in traditional WiMAX system, the BER was 0.323 with a loss of 90565 bits.

**Figure-5.75 QAM symbols variations**

**Figure-5.76 Input/output speech**
From the above discussions of WiMAX-SISO and WiMAX-MIMO models with Rayleigh environment, it can be clearly concluded that the BER of the system would be directly affected by the Doppler shift parameter of Rayleigh fading channel. But through the implementation of antenna diversity technique in real time situations, the amount of degradation in BER due to larger Doppler shift would be certainly minimized to a greatest extent and that has been proved by the qualities of output image and speech of WiMAX-MIMO system.

The next section describes the realization of another fading channel named as a Rician channel in WiMAX-SISO and WiMAX-MIMO model. For sub urban areas where there would be the possibility of realizing the line of sight path along with multipath structure, the wireless channel should be modeled as the Rician channel which is again the real time realization of fading phenomenon of the wireless systems.

**5.4.6 Modeling and Experimentation of WiMAX System in Rician Fading Environment**

In the real time multi path environment, due to slight improvement in the structure characteristic if there would be the chances of line of sight direct path between transmitter and receiver along with multiple no. of faded paths, the behavior of Rayleigh channel changes a bit and now its transformed as a Rician channel. In the modeling of Rician channel the multipath variations of the signal are superimposed over the line of sight component which increases the overall strength of the whole information at the receiver. Figure-5.78(a) shows the snap shot of simulated traditional WiMAX model with the cascaded combination of one Rician and one AWGN channel.
5.4.7 Traditional WiMAX Rician Channel Model

The model of WiMAX shown in Figure-5.78 is the traditional model with SISO technology which has been thoroughly discussed in section 5.2.1 and 5.3.1 with image and speech transmissions. Here the main change is the presence of Rician channel which offers Rician fading.

Rician fading is characterized by a factor, which is expressed as the power ratio of the secular (los or dominant path) component to the diffused component. This ratio, $K$, defines how near to Rayleigh statistics the channel is. In fact when $K=\infty$, there is no fading at all and when $K=0$, this means to have Rayleigh fading. The ratio is expressed linearly, not in decibels. While the Average path gain vector parameter controls the overall gain through the channel, the $K$-factor parameter controls the gain’s partition into line-of-sight and diffuses components. The other blocks and properties of WiMAX model will remain the same.
Here image of same leaf with (256x256) size or speech with 2 sec duration is taken as an input and at the end of reception; the distortion due to Rician fading would be analyzed. The simulated results have been explained thoroughly in the next section by varying the value of K factor as shown in Figure-5.78 (b)

5.4.8 Simulation Results and Discussion

By modeling the WiMAX system under the fading constraints, with the propagation of image and speech inputs, the outputs get degraded with sudden jerk of noise at some parts rather than distributed noise as in the case of AWGN channel. But the span of this fading can be reduced in this channel as compared to that in the Rayleigh channel because of the presence of LOS component. The factor that decides the amount of fading is the gain factor of the line of sight path.

This section of simulation results and discussion has been divided into two parts.

3. Simulation of WiMAX system with image as an input
4. Simulation of WiMAX system with speech as an input
**Case-1: For Real Time Image Transmission**

Practically the Rician channel is more or less same as the Rayleigh channel except the presence of line of sight component along with multi path structure. In this case also the AWGN channel SNR is taken as constant 29 dB. The gain factor of the line of sight path would be varied which leads to the variation in the BER of the system.

**Gain K=2 AWGN SNR = 29dB**

![Scatter Plot](image1.png)

**Figure-5.79 QAM symbol variations**

![Output Image](image2.png)

**Figure-5.80 Output image**
Figure-5.79, 5.80 and 5.81 illustrate the performance of WiMAX-SISO system under Rician fading in terms of QAM symbol variations, Output image and BER calculator, respectively. Here the value of gain factor as an example have been chosen to be $K=2$ at the constant SNR of 29 dB.

Due to presence of line of sight path between transmitter and receiver with comparatively small strength, the quality of output image can be improved little bit as compare to that of the Rayleigh fading. This can be very well understood by looking towards the fading over the image which was continuous in Rayleigh channel from 50 to 250 over x-axis while over here lesser degradation as compared to that of the Rayleigh channel because of the presence of LOS path between transmitter and receiver of the WiMAX system. Out of 526680 bits, 13553 are corrupted leading to the BER of 0.257. This can be improved by still increasing the value of k factor from 2 to 10.

**Gain K=10 AWGN SNR = 29dB**

In this case the strength of the existing line of sight path is getting improved by increasing $K$ from 2 to 10 at the same SNR of 29 dB only as compared to the model with $K=2$. The QAM symbols are very nicely arranged in the scattering diagram shown by Figure-5.82. Due to strong LOS component the average effect of multipath fading can be reduced and it can be very well reflected from the quality of image with BER=0.02 i.e. only 14337 bits are getting lost out of 526680 bits as shown in Figure-5.83 and 5.84, respectively as compared to BER=0.25 i.e. loss of 135532 bits out of 280280 in model with $K=2$. 
The same mechanism of variation in path gain factor K would be observed for transmission of speech signal at the same value of AWGN channel SNR=29dB for the
Case-2: For Real Time Speech Transmission

Here the path gain factor is chosen initially to be low i.e. the strength of the line of sight path among the multiple faded paths is assumed to be lower. For that K=2, the simulation would be performed by passing the speech signal of 2sec duration and the output would be compared with input to derive the measurement of system performance in terms of quality of output speech as well as BER.

Gain K=2 and AWGN SNR = 29dB

Figure-5.85, 5.86 and 5.87 describe the QAM symbols variations, input/output speech and BER calculator at AWGN SNR=29dB and Rician path gain factor = 2. As the strength of LOS path is lower, the output speech gets degraded to a noticeable amount as compare to input speech which leads to the BER of 0.35 with bit loss of 100588 bits out of 280280 bits. The BER can be improved by increasing the value of K from 2 to 10 that means increasing the strength of LOS path. This has been proved in the following section.

![Figure-5.85 QAM symbol variation](image-url)
Gain $K=10$ and AWGN $SNR = 29dB$

Figure-5.88, 5.89 and 5.90 show the QAM symbol variations, input/output speech and BER calculator, respectively at larger value of K factor. Here the movement of QAM symbols becomes more and more regular which leads to the improvement in speech quality as compare to first case. The improved speech quality can also be justified by the reading of BER calculator which shows BER of just 0.045 with a loss of only 12768 bits out of 280280 bits and the same was 0.358 with a loss of 100588 bits out of 280280 bits in case of $K=2$. 

Figure-5.86 Input/output Speech

Figure-5.87 BER calculator
Figure 5.88 QAM symbol variations

Figure 5.89 Input/output speech

Figure 5.90 BER calculator
Further it can be clearly mentioned that the behavior of Rician channel can be made better by increasing the value of path gain factor that is the strength of the line of sight component present along with multiple faded components. But again it can’t be controlled at transmitter or receiver side because it’s sole property of wireless channel. So to achieve high quality of output with the same lower value of K factor equal to 2, again the antenna diversity specifically speaking MIMO plays the key role in it which has been elaborated and proved in the next section.

5.4.9 WiMAX MIMO Modeling in Rician Fading Environment

Figure-5.91 shows the model of WiMAX-MIMO with the cascaded combination of two Rician and two AWGN channels for creating the virtual link between transmitter and receiver. Except channel type, the rest of the other blocks and their functions are exactly same as that of the WiMAX-MIMO model with AWGN channel discussed in sections 5.2.7 and 5.3.7.
The main goal to develop this model is to check the influence of Rician channel as a real time fading channel with the possibility of at least one LOS path in the WiMAX system with transmission of real time image and speech signals. Here by taking the lowest value of gain factor, the simulation would be performed at the constant $\text{SNR}=29 \text{ dB}$ and still the improvement in BER would be observed as compare to WiMAX-SISO model.

### 5.4.10 Simulation Results and Discussion

**Case-1: For Real Time Image Transmission**

The simulation has been performed for the lower value of path gain factor $K=2$ by passing the leaf image of dimension $256 \times 256$ and the improved BER performance i.e. improved output image quality can be obtained as compare to WiMAX-SISO model anticipating the advantages of antenna diversity.

**Gain $K=2$ and AWGN SNR = 29dB**

Figure-5.92, 5.93 and 5.94 show the QAM symbol variations, output image and BER calculator, respectively. Here despite of low value of $K=2$, the image quality is improving drastically leading to BER of just $0.0012$ with loss of only $654$ bits out of $526680$ bits as compare to WiMAX-SISO with Rician which has possessed BER of $0.25$ with loss of $135532$ bits out of $526680$ bits.

![Figure-5.92 QAM symbols variations](image-url)
This happens just because of existence of antenna diversity phenomenon provided by MIMO technique. The next section describes the same thing for speech as an input signal.

**Case-2: For Real Time Speech Transmission**

Here again the real time speech signal of duration 2 sec is allowed to pass through the WiMAX-MIMO model to check the performance over Rician channel with lower path gain factor.

**Gain K=2 and AWGN SNR = 29dB**

The snap shots of QAM symbol variations, input/output speech and BER calculator can be seen from Figure-5.95, 5.96 and 5.97, respectively. The symbols are much more concentrated around their positions as compare to that of the WiMAX-SISO though the value of K factor is lower equal to 2.
Figure-5.95 QAM symbols variations

Figure-5.96 Input/output Speech

Figure-5.97 BER calculator
The quality of output speech is seen to be much better in this case as compare to that of WiMAX-SISO shown by Figure-5.86 and the value of BER is drastically improving to only 0.002 as compare to that in WiMAX-SISO which was about 0.358. So it can be concluded that implementation of MIMO in WiMAX under Rician fading environment solves the problem of low value of line of sight path gain.

As a whole, from these discussions of research work, one most important observation can be derived that the forth coming future generation networking system WiMAX can process on every kind of input signals such as random data, user defined data, real time image as well as speech signal under any kind of environment that fading or non fading. The other most important deduction is that with the implementation of various antenna diversity schemes along with Alamouti coding technique, more specifically with MIMO, the performance of the WiMAX system will be improved tremendously under AWGN or Rayleigh or Rician channel consideration.