CHAPTER 7: ADAPTIVE MODULATION AND CODING FOR MULTIPATH FADING IN IEEE 802.11N

Signal vanishing in any wireless network is a deviance of the attenuation that a telecommunication system experiences over a specific channel. It may change with the variations in the environmental conditions, location of the transmitting and receiving antennas and the frequency used for propagation. In radio communication, fading may be mainly due multipath propagation, considered as multipath induced fading or due to the obstacles affecting the signal transmission. If the transmitted signals are reflected, then multiple paths are created. Each signal copy reaches the receiver with a different amplitude, delay and phase angle. The ultimate effect of fading can be seen at the receiving end. It may be either constructive or destructive in nature.

In most of the communication systems, multipath fading is a challenge against providing the required channel performance in terms of SNR. To improve the SNR it is highly desirable to reduce the time duration of the fade and the magnitude of the depth of fade. Using spatial diversity technique the effect of multipath fading can be minimized. It uses multiple receiving antennas at the receiver, to accept separate copies of the signal. A frequency diversity technique transmits the message on multiple carrier frequencies, separated from each other, so as to provide independent fading variations of the channel. Time diversity transmits the message in different time slots providing signal repetition. These techniques are not suitable, because they consume more bandwidth.

One of the main processes used to improve the throughput of a time varying wireless channel is Adaptive Modulation and Coding (AMC). It is designed to track the quality
of the fading channel by adapting the channel throughput to the actual channel state and maintain a predicted BER. In a high fade, i.e., when the channel state is poor, the signal constellation size is reduced in order to improve the fidelity, lowering the SNR to make the transmission more robust. Also during low fading, i.e., high SNR, the signal constellation size is increased in order to allow higher data rate modulation method, to provide lower probability of error. This improves the instantaneous SNR.

The performance of AMC is better with accurate CSI [28], at the transmitter. One of the techniques used in AMC is based on the SNR measurement at the receiver for channel quality information (CQI). The transmitter selects a particular modulation and coding method for further communication, depending on the estimate of the channel state. Threshold value for SNR is fixed in such a way that it decides the required BER. If the BER is below the target BER (BER\text{t}), defined by the system for each scheme whenever the SNR is above the SNR\text{t}. The SNR\text{t} value is obtained from the BER versus SNR characteristics of a modulation mode on AWGN channel. The receiver once evaluates the total SNR and it then converts it into BER. This value of BER is compared with the threshold bit error rate, BER\text{t}.

These details are used to provide feedback of the selected mode to the transmitter, in order to perform the adaptation. For an accurate adaptation, the feedback mechanism must be considered in a channel, which is free from all types of errors. The associated CSI is sent back to the transmitter. Transmitter then adapts its transmission rate and the particular modulation scheme. By transmitting with the adapted modulation scheme, it guarantees that the BER using this scheme is less than BER\text{t}. This helps the system to transmit data with high spectral efficiency, when the SNR is high and decrease the spectral efficiency as the SNR reduces.
7.1 ADAPTIVE MODULATION

In order to enhance the performance of a signal communicated or received by a specific antenna, it is modified to accommodate the changes in the signal quality by a mechanism called link adaptation. In this chapter an AMC for MIMO (AMC-MIMO) algorithm is proposed. It utilizes the complete benefits of MIMO technology adapted in IEEE 802.11n. Among the different modulation techniques (2 PAM, 8QAM, 16QAM or 64QAM) a particular modulation scheme is selected to meet the required SNR. Based on the channel conditions, the AMC either reduce or increases the transmission rate.

![Figure 7.1 BER versus SNR Relationship](image)

Consider a MIMO antenna system, with multiple antennas both at the transmitter and receiver side. It provides better signal quality by using space time block coding (STBC) and an increased throughput by spatial multiplexing (SM). In case of STBC mode the transmitting antenna send multiple copies of the same symbol through different antenna. The transmitted signal by this mechanism is said to be more reliable
in the receiver side. In spatial multiplexing it transmits different symbols over the multiple transmitting streams. This subsequently improves the performance of the WLAN. For a MIMO system the BER versus SNR performance for different transmission modes is shown in figure 7.1. The SNR changes as the modulation scheme changes.

**7.1.1 Adaptive Modulation and Coding (AMC)**

AMC is a collective process between the PHY and the MAC layer of a MIMO based WLAN. Its data bit stream flows between these two layers. In a most reliable mode of data transmission using BPSK, the Physical Layer Convergence Protocol (PLCP) header and PLCP preamble are being communicated. The rate at which modulation of the data bit during transmission and the demodulation while receiving, is indicated by AMC and STBC. This information is needed by the MAC layer. The AMC and the MIMO mode (in STBC or SM) are used later for the calculation of the channel allocation. IEEE 802.11n uses a high throughput control field in the MAC header. The first byte of this control field represents the link adaptation control. One bit out of this indicates whether the transmitting end needs an AMC feedback, called AMC Request (AMRQ). The other 7 bits are AMC Feed Back (AMFB). It includes the suggested AMC scheme for the requesting wireless terminal. The AMC–MIMO in coordination with the MAC and PHY layer has the following main functionalities.

- To track the wireless medium at the receiver end.
- Transfer the SNR details from the receiver end to the transmitting end for the calculation of BER.

Let Tx be the transmitting and Rx receiving antennas of a MIMO system considered as in figure 7.2. LTx and LRx are the link adaptation mechanism distributed in both
transmitting and receiving sides. In the MIMO system the transmitting antenna Tx wants to transmit signals to the stations at the receiver end. Initially the Transmitter Tx sets its LTx=1, in the AMRQ field of the control field. This is to be sent as a request to the Receiver Rx, to get AMFB. The Transmitters MAC forwards this by using a BPSK mode. The Receiver Rx receives these packets. In the receiver side the AMRQ triggers the LRx section. It gathers the CSI [28], which includes the SNR estimate from the PHY layer and the MIMO channel matrix H. The LTx of the receiver Rx uses these parameters for the assessment of throughput requirements and the modulation scheme required. This channel estimation can deliver the better throughput as in the algorithm.

![Figure 7.2 ACM-MIMO Schemes](image)

### 7.1.2 Throughput Calculation

The total time spent for the transmission of packet is:

\[
T_{\text{Total}} = T_{\text{DIFS}} + T_{\text{Back-off}} + T_{\text{Header}} + T_{\text{Data}} + T_{\text{SIFS}} + T_{\text{ACK}} \quad \cdots \quad (7.1)
\]

In equation (7.1),
$t_{Data}$ - is the time duration for the MAC payload of length D.

$t_{Total}$ Obtained from equation (7.1) is different for STBC and SM. Using $t_{Total}$ the throughput is calculated as;

$$r = \frac{D}{t_{Total}} \times (1 - b_i)^{D + l_m} \ldots \ldots (7.2)$$

Where $r$ – is the throughput, $D$ – the number of bits in a packet or the packet length, MAC header duration field provides its value and $b_i$ - is the BER for a particular modulation scheme.

$l_m$ - Number of bits in the MAC header.

Using these parameters the throughput for STBC ($r_{STBC}$) and for SM ($r_{SM}$) is calculated as below.

**For STBC**: - Let $R$ - the PHY transmission rate, the throughput for STBC is,

$$r_{STBC} = \frac{D \times R}{D + \rho} \times (1 - b_i)^{D + l_m} \ldots \ldots (7.3)$$

In equation (7.3) 

$$\rho = (t_{DIFS} + t_{Back-off} + t_{Header} + t_{Data} + t_{SIFS} + t_{ACK}) \times R$$

$$t_{Data} = D / R$$

$$r_{STBC} = \frac{R}{1 + \rho \times D^{-1}} \times (1 - b_i)^{D + l_m} \ldots \ldots (7.4)$$

**For SM**: - In SM mode the transmission time is reduced to half. The MPDU splits the signal and delivers $(D+l_m)/2$ on individual antenna. There are no more additional physical layer overheads. The successful reception of the entire data stream depends on the probability that all the packets are transferred without any error. Using SM the
probability of receiving the data streams without any error is \((1-b_i)^{D+I_m}\). The throughput of a 2x2 MIMO SM system is;

\[
r_{SM} = 2 \times \frac{\frac{D \times R}{2 \times \rho}}{2} \times (1-b_i)^{D+I_m} = \frac{R}{0.5 + \rho \times D^{-1}} \times (1-b_i)^{D+I_m} \quad \text{ ..........}(7.5)
\]

Where \(\rho = \frac{T_{in}}{2} + \frac{T_{LACK}}{2} \times R\)

Pseudo code for Maximum Throughput Allocation:

\(r_{max}\): Maximum throughput recorded
\(m\): Total number of transmission modes both in STBC and SM
\(j\): Selected mode
1. \(r_{max} = 0\);
2. \(LT_x = 1\);
3. get AMRQ;
4. BER estimate = \(b_i\);
5. For \((i = 0; i < m; i++)\)
6. If {
7. mode = STBC;
8. \(r_i = [R/(1 + \rho \times D^{-1})] \times (1-b_i)^{D+I_m}\);
9. Else
10. mode = SM;
11. \(r_i = [R/(0.5 + \rho \times D^{-1})] \times (1-b_i)^{D+I_m}\);
12. ElseIf
13. \((r_i \geq r_{max})\);
14. \(r_{max} = r_i\);
15. \(j = i\);
16. EndIf
17. }
18. send AMFB;
19. End
20. End loop,

Figure 7.3 Pseudo Code for Maximum Throughput Allocation
Once the maximum throughput is estimated the LTx of the receiver Rx selects the mode j, in the filed AMFB of the ACK or CTS packets and forwards to the transmitting station Tx. When its MAC receives this, its LRx analyzes the mode j, provided by the AMFB and maps j, to a delivery mode, by selecting suitable modulation scheme. If there is no any feedback from the receiver side, the conventional mode of modulation is used to transmit the signal.

7.2 SIMULATION MODEL

The model is implemented by using MATLAB script to generate various MIMO channel matrix H, and the NS-2 for simulation. Using this, power received at the receiving antenna Rx by each spatial stream is calculated. The SNR for each receiving antenna is measured by using the parameters provided in the Table 7.1.

Table 7.1 Physical Layer Parameters

<table>
<thead>
<tr>
<th>MIMO</th>
<th>Spatial spreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multipath fading</td>
<td>Enabled</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>5.25GHz</td>
</tr>
<tr>
<td>Signal Frequency</td>
<td>20MHz</td>
</tr>
<tr>
<td>Transmitting Power</td>
<td>50 mW</td>
</tr>
<tr>
<td>Noise</td>
<td>10dB</td>
</tr>
<tr>
<td>Data Sub-carrier</td>
<td>52</td>
</tr>
<tr>
<td>Pilots signals</td>
<td>4</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>80MHz in 20 MHz mode</td>
</tr>
</tbody>
</table>

The received power at each receiver antenna is used to estimate the SNR. The SNR is also considered as the RSSI value communicated by the physical layer to the MAC.
layer. Power at the receiver antenna Rx is used to find the SNR. It is also used for calculating the BER. For BPSK modulation the BER is:

\[ P_b = Q(\sqrt{2\gamma_b}) \] ...............................(7.6)

Where \( \gamma_b = \frac{E_b}{N_0} \) = SNR  The function \( Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{x^2}{2}} \, dx \)

For QAM the symbol probability of error is;

\[ P_s = 1 - [1 - Q(\sqrt{2\gamma_b})]^2 \] ...............................(7.7)

The BER by using Gray coding is \( P_b \), where \( P_b = P \frac{1}{\log_2 M} \) ...............................(7.8)

Where M= 4, 16, or 64. For a specific modulation and coding scheme the BER of the decoded bit is given as, \( P_\mu < \sum_{k=d_{free}}^{\infty} a_k P_k \) where, \( a_k \) is the number of error events with \( k \) bit errors.

\[ P_k \] represent the probability of an improper link at distance \( k \), being chosen by the decoder.

\( d_{free} \) - is the free distance of the convolution code.

\( P_k \) - is obtained as;

\[ P_k = \begin{cases} 
\frac{1}{2} \left( \frac{k}{2} \right) (P_b)^{k/2} (1-P_b)^{k/2} \\
\sum_{i=1}^{k} \left( \begin{array}{c}
\frac{k}{2} \\
i
\end{array} \right) P_b^i (1-P_b)^{k-i} & \text{if } k \text{ is even} \\
\sum_{i=1}^{k} \left( \begin{array}{c}
\frac{k}{2} \\
i
\end{array} \right) P_b^i (1-P_b)^{k-i} & \text{if } k \text{ is odd}
\end{cases} \] ...............................(7.9)

Using \( P_\mu \) the probability of correctly received data segment is, \( P_j = (1-P_\mu)^j \)
Here \( l \) is length of the data segment over which the SNR and the modulation coding scheme are constant. The packet error rate for a MIMO system with 1x1 antenna (or SISO) is obtained as:

\[
P_e = 1 - \prod_{j=1}^{n} P_j \quad \text{(7.10)}
\]

Where the total amount of data segments is \( n \) and \( j \) is its index. The SNR and modulation coding on each data segment is constant, whereas for the entire set of data segments in a packet it is different. In IEEE 802.11n, MIMO network with multiple transmit and receive antennas, for each spatial streams \( i \), \( P_b \) and \( P_j \) is calculated. The overall PER for \( N \) number of spatial streams is:

\[
P_e = 1 - \prod_{i=1}^{N} (1 - P_i) \quad \text{(7.11)}
\]

The SNR and RSSI value recorded from each receiving antenna is received by PLCP preamble. The AMC-MIMO scheme using these details in the MAC layer decides the required modulation and coding scheme.

### 7.3 Simulation Results

The different channel models and scenarios are applied in the simulation process to understand the channel fading mechanisms. End result shown using the AMC-MIMO for IEEE 802.11n improves the spectral efficiency and throughput. The channel modelling for the proposed mechanism, using the k-factor for Rayleigh and Rician fading channels are considered as the parameters for classification. These k-factor values chosen are 0, 5dB, and 10dB. Where, 0 corresponds to Rayleigh channel with respect to an indoor system. 5dB and 10dB are for Rician channels. When the transmitter and receivers are very close to each other, with line-of-sight mode, the rms
(root mean square) delay is assumed as 20 nanoseconds. For a hotspot with high delay spread it is 50 nanoseconds. Based on these parameters the channel models are classified Rayleigh and Rician channels.

![SNR changes with respect to Distance](image)

Figure 7.4 SNR at the Receiver at Different Distance

Figure 7.4 shows the SNR changes with respect to the distance between the transmitting and receiving antenna. Simulation result shows that the received SNR varies as the distance increases [18]. The average physical layer throughput measured at different SNR at the receiver is compared with the throughput in MIMAC as in figure 7.5. It shows that using the proposed system the throughput performance is lower compared to MIMAC system when the SNR is low. This is basically due to the lossy channel. In a lossy channel the diversity can help to minimize the BER. At high SNR the reduction in BER is a function of the diversity order. The increased throughput in AMC-MIMO scheme is due to the decreased number of signal re-transmission.
The simulation result shows that AMC-MIMO outperforms with higher throughput compared to MIMAC. Figure 7.6 shows the average physical layer throughput with respect to the distance (in Meters). It is compared with the simulation results of MIMAC.

Figure 7.7 shows the throughput variation with and without the proposed AMC-MIMO scheme for MIMO based WLAN system. The improved performance is due to the use of closed loop method for communicating CSI to the transmitter. These details
are used to select appropriate modulation and coding scheme at the transmitter for rest of the transmission.

Figure 7.7 Throughputs versus SNR

Figure 7.8 shows the variations of throughput when the packet size is increased. As the packet size increases for a specific BER, the throughput decreases. This variation of throughput clearly determines the trade-off between a small packet size for nosily channel and for large packet size, which decreases the overhead.

Figure 7.8 Throughput Variations as the BER Changes
7.4 SUMMARY

AMC is one of the performance enhancement mechanisms for WLANs. The AMC-MIMO scheme proposed in this chapter for IEEE 802.11n MIMO wireless network on a closed loop method, to enhance the spectral efficiency of MIMO system. Under different fading scenarios the proposed AMC scheme adapts different modulation and coding techniques to minimize the BER. The results obtained from the proposed system by simulation are compared with MIMAC system for calculation.