CHAPTER 2: Diversity Analysis in CDMA and LDPC systems

This chapter validates the benefits of Combinational Transmit Diversity techniques in various broadband wireless systems. The first two segments focus on diversity techniques in CDMA transmitter and CDMA receiver and the last section debates on solutions to improve the channel performance and fade mitigation with LDPC codes intertwined with diversity scheme. This session begins with an overview to diversity techniques.

2.1. Introduction to Diversity Techniques

In telecommunication systems the elementary concept of diversity is to transmit the signal via several independent diversity branches, to get independent signal replicas via radio frequency (RF) combining technique. Diversity techniques operate on the premise that the receiver will be able to decode the signal efficiently, in case of more than one independent copy of the transmitted signal [34,86]. Diversity is employed to reduce the depth and duration of the fades experienced by a receiver in a local area on account of motion. These techniques are adopted by base stations as well as the mobile receivers. The random phase and amplitudes of the different multipath components cause fluctuations in signal strength, thereby inducing either small-scale fading or signal distortion or at times both. Multipath propagation often extends the time required for the baseband portion of the signal to reach the receiver that can cause ‘Signal Smearing’ owing to inter symbol interference. The attenuation coefficients corresponding to different paths are assumed to be independent and identically distributed.
Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low costs. Unlike equalization, diversity requires no training overhead since there is no need for a training sequence by the transmitter[1]. Diversity exploits the random nature of radio propagation by finding independent to at least highly uncorrelated signal paths for communication. In the context of diversity decisions, in all most all applications the role is relegated to the receiver, while the transmitter plays a just placid role.

Diversity techniques may be classified as under:

- Time diversity
- Frequency diversity
- Spatial diversity
- Polarization diversity

2.1.1. Time Diversity

Time diversity repeatedly transmits information at time intervals exceeding the coherence time of the channel. This is to ensure that multiple repetitions of the signal can be received with independent fading conditions, thereby providing for diversity. One modern implementation of time diversity involves the use of the RAKE receiver for spread spectrum CDMA[87], where the multipath channel provides redundancy in the transmitted message. By demodulating several replicas of the transmitted CDMA signal, the RAKE receiver should be able to align the replicas in time to achieve a better estimate of the original signal at the receiver, while each of these replicas experiences a particular multipath delay.
2.1.2. Frequency Diversity

Frequency diversity is implemented by transmitting information on more than one carrier frequency. The rationale behind this technique is that frequencies separated by more than the coherence bandwidth of the channel will be uncorrelated and will not experience the same fades[88]. One fine technique to scatter signal from the transmitter in frequency domain is Orthogonal Frequency Division Multiplexing (OFDM).

2.1.3. Polarization Diversity

Polarization diversity is achieved by combining pairs of antennae with orthogonal polarizations (i.e. horizontal/vertical, ± slant 45°, Left-hand/Right-hand CP etc.). Reflected signals are likely to be subjected to polarization changes depending on the medium through which they travel. A polarization difference of 90° will result in an attenuation factor of up to 34dB in signal strength [89]. Pairing of two complimentary polarizations can immunize a system from polarization mismatches which could otherwise cause signal fade. Additionally, such diversity has proven valuable to radio and mobile communication base stations, since it is less susceptible to the near random orientations of transmitting antennae.

2.1.4. Spatial Diversity or Antenna Diversity

In Spatial diversity, multiple antennae are spaced and connected to a common receiving system. In the multiple antennae scenario, while one antenna may record a signal null, another may record the signal peak. Irrespective of this, the receiver at any given point of time is adept at picking the right antenna with the best signal[90], making
this diversity ideal for base stations for which space is inconsequential. The various antenna configurations for Space Time (ST) wireless systems are SISO, SIMO, MISO and MIMO

➢ **Single Input Single Output (SISO) Techniques**

SISO scheme has only one antenna both at the transmitter and receiver end. The transmitted signal takes different paths for propagation through the channel and these multipath signals vary in their phase and amplitude. As shown in Fig.2.1 the receiver side with a single antenna combined with multipath signals will result in destructive interference accounting for fading to a large extent. Thus the SISO scheme is therefore associated with a major constraint in the form of fading.

![SISO Scheme](image)

*Fig.2.1. Schematic diagram of SISO scheme*

➢ **Single Input Multiple Output(SIMO) System**

SISO may also be referred to as the ‘Receive Diversity Technique’ is shown in Fig.2.2, where ‘n’ antennae units are used in the receiving end compared to only a single unit at the transmitter end. To achieve such scheme it initiates the use of RAKE receivers[87].
Multiple Input Single Output (MISO) Diversity Technique

MISO otherwise known as Transmit Diversity is shown in Fig.2.3, is accomplished using multiple antennae, by the side of transmitter with the means of space-time coding (STC) [36]. The objective of this scheme is to heighten the error rate performance of the system. An increase in error rate performance facilitates the use of higher modulation schemes, which in turn implies that each symbol can carry higher amounts of data thereby leading to improved capacity.
Due to independent fading in multipath environment, replicas of the same signal transmitted at different time intervals undergo different fading, which leads to the possibility of a few versions of the transmitted signal experiencing least fading. When these received signals are combined at the receiver side, the least faded versions accounts for improved SNR associated with MISO schemes. The detailed study on MISO coding schemes are dealt in the subsequent section.

- **Multiple Input Multiple Output (MIMO) diversity technique**

MIMO system explores both transmit and receive diversity techniques and in turn leverages the best of both the techniques. The schematic diagram of MIMO scheme is shown in Fig.2.4. MIMO technique involves a minimum of two transmit and receive antenna that dramatically increase the capacity of wireless channels and system throughput.

![Fig.2.4. Schematic diagram of MIMO scheme](image)

If two independent signals are transmitted simultaneously, then each of them will traverse in two independent paths. When multiple antennae are used at the receiver side, one antenna may record a signal null, while the other may record the signal peak, thus
there is always a definitive possibility of achieving highest possible SNR at the receiver side which subdues the effect of fading.

### 2.1.5. Transmit Diversity

Transmit Diversity of a SIMO system is achieved with the use of multiple antennae at the transmitter side. Transmit diversity is easy to achieve, provided the sacrifice in information rate is acceptable. Based on channel information, transmit diversity can be implemented in two ways. Beam forming methods are employed when channel information is available at the transmitter. In the case of an unknown channel Space Time Code (STC) can be applied.

- **Beamforming Method and its Benefits**

  The standards-compatible technique can be used to improvise or surge the range of data rates using transmit and receive beamforming. The merits of beam forming can be enumerated as follows: reduction of transmit interference, enhanced receive interference tolerance, increased total output power, high antenna gain, reduced co-channel inter-cell interference, combat fading effects and multipath mitigation.

- **Space Time Coding**

  Channel knowledge at the transmitter is essential to achieve diversity. Space time coding works on the fundamental principle of use of multiple time intervals for transmission which interprets to gain in diversity. This is the basic principle for space time coding. Space time coding is performed by adding properly designed redundancy in both spatial and temporal domains which introduces correlation into the transmitted signal.
A block of m binary symbols is fed into the space time encoder. The space time encoder maps the block of m binary symbols into n modulation symbols from a signal set of $M=2^m$ points. The resulting parallel outputs are transmitted simultaneously by different antennae. The channel matrix can be written as

$$H = \begin{bmatrix}
h_{i,1}^t & h_{i,2}^t & \ldots & h_{i,nt}^t \\
h_{2,1}^t & h_{2,2}^t & \ldots & h_{2,nt}^t \\
\vdots & \vdots & \ddots & \vdots \\
\vdots & \vdots & \ddots & \vdots \\
h_{nr,1}^t & h_{nr,2}^t & \ldots & h_{nr,nt}^t
\end{bmatrix}$$

2.5

$$r_i^t = \sum_{j=1}^{m} h_{ij}^t x_j^t + n_i^t$$

2.6

The received signal vector

$$r_i = (r_1^t, r_2^t, \ldots, r_{nt}^t)$$

$$r_i = H_i x_i + n_i$$

2.7

Space time codes are of two types namely Space Time Block Code (STBC) and Space Time Trellis code (STTC).

2.1.6. Space Time Block Code

Space Time Block Coding for flat fading channels was first proposed by Alamouti as they were found to be an effective technique for transmit diversity[38]. In the ideal case of the channel being static in the duration of the space time codeword, STBC can obtain full diversity advantage by utilizing the Simple Maximum Likelihood (SML) detector. A Space time code is defined by an $m \times N_t$ transmission matrix, where $N_t$ is the
number of Tx antennae and \(m\) is the number of time periods for transmission of one block of coded symbols. As the space time block code can be defined or represented by a Non-Square transmission matrix, the Orthogonality is present only in the temporal sense. One of the features of Space time block code is its association with a simple ML decoding algorithm that is based only on linear processing in the receiver. The schematic diagram of STBC Transceiver is shown in Fig.2.5.

![Fig.2.5. STBC Transceiver](image)

Higher order modulation schemes are highly susceptible to noise and as the error rate performance of the system improves, it gets viable to use a higher order modulation scheme, which implies that each symbol carries more bits of data that may result in modest increase in system capacity. Two antennae transmitting two symbols in two time periods are categorized as rate 1 code.
2.1.7. Alamouti Code

Alamouti code is the only orthogonal space time block code that can be generalized to an arbitrary number of antennae. Diversity gain is achieved without any loss in bandwidth efficiency. Alamouti coding rule is shown in Table 2.1.

Table 2.1. Alamouti coding scheme

<table>
<thead>
<tr>
<th></th>
<th>Antenna 0</th>
<th>Antenna 1</th>
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<tbody>
<tr>
<td>Symbol Period 0</td>
<td>s₁</td>
<td>s₂*</td>
</tr>
<tr>
<td>Symbol Period 1</td>
<td>s₂</td>
<td>-s₁*</td>
</tr>
</tbody>
</table>

If assumed that the ordered pair \((s₁, s₂)\) represent a group of two consecutive symbols in the input stream to have to be transmitted. In the first symbol period t₁, if transmit antenna Tx₁ transmit symbol \(s₁\) and Tx₂ transmit symbol \(s₂\). In the next symbol period t₂, if Tx₁ transmit symbol \(s₂^*\) and Tx₂ transmit symbol \(-s₁^*\). If \(h₁\) be the channel response from Tx₁ to the receiver (Rx) and \(h₂\) be the channel response from Tx₂ to Rx. Then, the received signal samples corresponding to the symbol period’s t₁ and t₂ can be written as:

\[
\begin{align*}
    r₁ &= h₁s₁ + h₂s₂ + n₁ \quad 2.8 \\
    r₂ &= h₁s₂^* - h₂s₁^* + n₂ \quad 2.9
\end{align*}
\]

where, \(n₁\) and \(n₂\) are additive noise terms.
The receiver computes the following signals to estimate the symbols $s_1$ and $s_2$:

$$x_1 = h_1^* r_1 - h_2^* r_2 = (|h_1|^2 + |h_2|^2)s_1 + h_1^* n_1 - h_2^* n_2$$ \hspace{1cm} 2.10

$$x_2 = h_2^* r_1 - h_1^* r_2 = (|h_1|^2 + |h_2|^2)s_2 + h_2^* n_1 - h_1^* n_2$$ \hspace{1cm} 2.11

These expressions clearly show that $x_1$ ($x_2$) can be sent to a threshold detector to estimate symbol $s_1$ ($s_2$) without interference from the other symbol. Besides, since the useful signal coefficient is the sum of the squared modules of two independent fading channels, these estimations benefit from perfect second-order diversity, equivalent to that of receiver diversity under maximum-ratio combining. Alamouti’s transmit diversity can also be combined with MRC when two antennae are used at the receiver. In this scheme, the received signal samples corresponding for the first and second receive antenna respectively as follows:

Case 1: First receive antenna

$$r_{11} = h_{11}s_1 + h_{12}s_2 + n_{11}$$ \hspace{1cm} 2.12

$$r_{12} = h_{11}s_2^* - h_{12}s_1 + n_{12}$$ \hspace{1cm} 2.13

Case 2: Second receive antenna

$$r_{21} = h_{21}s_1 + h_{22}s_2 + n_{21}$$ \hspace{1cm} 2.14

$$r_{22} = h_{21}s_2^* - h_{22}s_1^* + n_{22}$$ \hspace{1cm} 2.15

In these expressions, subscripts $ij$ of $h$ designates the channel response from Tx$ij$ to Rx$ij$, with $i, j = 1, 2$, and $n_{ij}$ designates the noise on the corresponding channel.

Although this MIMO scheme does not offer any spatial multiplexing gain, as it portrays $4^{th}$ order diversity it can be fully recovered by a simple receiver. The receiver estimates the transmitted symbols 1’s and 2’s using the following expressions:
\[ x_1 = h_{11}^* r_{11} - h_{12}^* r_{12}^* + h_{21}^* r_{21} - h_{22} r_{22} \]

\[ = (|h_{11}|^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2) s_1 + h_{11}^* n_{11} - h_{12}^* n_{12}^* + h_{21}^* n_{21} - h_{22} n_{22}^* \quad 2.16 \]

\[ x_2 = h_{12}^* r_{11} + h_{11}^* r_{12}^* + h_{22}^* r_{21} + h_{21} r_{22} \]

\[ = (|h_{11}|^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2) s_1 + h_{12}^* n_{11} - h_{11} n_{12}^* + h_{22}^* n_{21} - h_{21} n_{22}^* \quad 2.17 \]

### 2.1.8. Diversity Reception Methods

Space diversity reception can be classified into four categories\[91\] as listed below,

1. **Selection diversity**
2. **Feedback diversity**
3. **Maximal Ratio Combining diversity**
4. **Equal gain diversity**

- **Selection Diversity**

Selection diversity shown in Fig.2.6 is the simplest diversity technique which employs ‘m’ demodulators to provide ‘m’ diversity branches whose gains are adjusted to provide the same SNR for each branch as depicted in the block diagram. Generally, the receiver branch recording the highest instantaneous SNR is connected to the demodulator, but since it is difficult to measure SNR alone, in practice the branch with the largest \((S+N)/N\) is used. In reality, selection diversity cannot be designed solely on instantaneous SNR, but must be well designed to ensure that the internal time constants of the selection circuitry are shorter than the reciprocal of the signal fading rate.
Feedback or Scanning diversity

Feedback diversity is much similar to that of selection diversity, but differs mainly in the mode of signal selection. The diagrammatic representation of feedback diversity is shown in Fig. 2.7. Instead of always using the best of M signals, the M signals are scanned in a fixed sequence until there is an emergence of a signal that exceeds the predetermined threshold.

Fig. 2.6. Selection diversity combining technique

Fig. 2.7. Feedback combining technique
The resultant signal is processed till it falls below the threshold value and scanning is initiated again. Here the resulting fading statistics are to some extent inferior to those obtained by other methods, however the advantage of this method is that it is very simple to implement as there is a requirement for only one receiver.

- **Maximal Ratio Combining (MRC)**

  A well-known technique which can be used to process the signals received at a number of antennae is maximal ratio combining. The received signals are co-phased and weighted so as to maximize the (SNR).

  ![Fig.2.8. Maximum Ratio Combining technique](image)

  In the scenario where none of the individual signals are themselves acceptable, MRC produces an output with an acceptable SNR. For any known linear diversity combiner[91], MRC technique offers the best statistical reduction of fading. Practical
applications of MRC’s optimal form of diversity can be identified in modern DSP techniques and digital receivers. The maximum ratio transmission (MRT) scheme[92] can be applied to an arbitrary number of transmit and receive antennae even though feedback is required from the receiver, to estimate the channel. Certain constraints on the MRT receiver combining weights result in performance degradation. A new transmit and receive diversity scheme called maximum ration transmission and combining (MRTE)[93] uses optimum transmit and receive weights so as to maximize the output SNR.

➤ Equal Gain Combining

In some instances, it is not very convenient to provide for the variable weighting capability required for true maximal ratio combining. In such settings, the branch weights are set to unity, but the signals from each branch are co-phased to provide equal gain combing diversity. This consents the receiver to exploit signals that are simultaneously received on each branch and ensures to retain the possibility of producing an acceptable signal from a number of unacceptable inputs and performance is only marginally inferior to maximal ratio combining and superior to selection diversity.

In conclusion, it can be observed that with spatial multiplexing, two or more data streams can be resolved either by a single user or by multiple users, enhancing system capacity and spectral efficiency. Other types of diversity techniques utilized in this work are code diversity through spread spectrum and temporal diversity with interleaving.

2.1.9. Code Diversity with Spread Spectrum

The direct sequence spread spectrum(DSSS) caters to a wide scope of features that include resistance to jamming, eavesdropping, fading and multiple access
DSSS technique involves spreading of the message signal over larger bandwidth using a direct sequence. To realize the claims made for spread spectrum, it becomes imperative for the bandwidth over which the message is spread to be much greater than the bandwidth of the message itself. This capacitates the transmitted signal with increased data rate and bandwidth which in comparison is greater than the information signal that is being modulated. This is achieved by directly coding the digital data at a much high frequency. The DSSS process shown in Fig.2.9, is performed by XOR-ing, input sequence with Pseudo-Noise (PN) digital signal sequence, that satisfies certain mathematical properties like Run length and Correlation.

The process of spreading causes to replace the message signal by a very wide bandwidth signal, provided by PN code that allows the signal power to drop below the noise threshold without any loss of any information.
A de-spreading operation shown in Fig.2.10, is responsible for reconstituting the information into its original bandwidth.

2.1.10.Temporal Diversity with Interleaver

In the context of mobile transmissions, data is always transmitted in the form of packets. During the process of transmission due to multipath fading and interference of signals, there is likelihood of losing one or more packets of data. To prevent the loss of this data, techniques like interleaving and deinterleaving are helpful. An interleaver is used to attain time diversity in a digital communication system without adding any overhead and also to protect the source bit from errors\cite{1,2,3}. An interleaver formats the encoded data into a rectangular array of ‘m’ rows and ‘n’ columns to interleave ‘mn’ bits at a time. An interleaver of degree ‘m’ consists of ‘m’ rows where each row represents a word of a source data having ‘n’ bits. When the original data is transmitted, the bits in the data packets are shuffled and rearranged into a different form, while the source bits are entered sequentially column wise, they are read out row-wise and transmitted over the channel. The shuffled message bits are channeled into the mobile environment only after subjecting them to an interleaving process.

The advantage gained here is that even if a few packets of data are lost, the original message bits can be recovered from the other data bits in the packet. At the receiver end the de-interleaver stores the received data by sequentially increasing the row number of each successive bit and it is finally clocked out row-wise, one row at a time. This way it is possible to recover the originally transmitted bits of data with zero or minimum loss of bits instead of an entire packet of information. To put it simply with the
help of received data bits, the original information that was lost can be successfully recovered.

The next section deals with superiority of the combinational schemes in the CDMA transmitter. This detailed introductory segments laid out foundation for the implementation modules. In the proposed work various diversity schemes are introduced in CDMA, Wi-Fi and WiMAX systems.

2.2. Transmit Diversity in CDMA system

Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) are two approaches that have contributed to appreciable advancement in the telecommunications industry. However, the widespread success of these communications systems has led to the development of newer and higher technological techniques and standards in order to facilitate high-speed communications for multimedia, data and video in addition to voice transmissions. Code Division Multiple Access (CDMA) is today’s dominant technology for the evolution of third generation (3G) mobile communications systems with the development of two major schemes: Wideband CDMA (W-CDMA) and CDMA2000.

Code Division Multiple Access systems use the spread spectrum technology and the RAKE receiver concept to minimize communications error resulting from multipath effects. Every Channel uses the full available spectrum and individual conversations are encoded with a pseudo random digital sequence. CDMA technology with its superior characteristics like increased cellular communications security, simultaneous
conversations, increased efficiency (the carrier capable of serving more subscribers), low power requirements and minimal cell-to-cell coordination required by the operators has made it the most preferred multiple access scheme. Relative to 3G mobile systems factors like bandwidth efficiency, capacity of the system and interference have been the major concerns for technologies like TDMA and FDMA. Thus, Code Division Multiple Access (CDMA) with its enviable list of advantages has defaulted to being the most suitable multiple access technique for the 3G mobile technology.

2.2.1. System Description

In the proposed system to provide spatial diversity and to reduce fade margin, transmit diversity by Alamouti code[38] is implemented. Space time block codes try to exploit the presence of independent multipath propagation to improve the reliability of propagation. The MRC receiver is introduced to exploit the features of the receiver diversity and the performance is analyzed in unknown time-varying Rayleigh multipath channels. For high quality communications, this must be achieved without causing severe degradation in the performance of the system. Thus, diversity schemes essentially imply methods of improving the reliability of the message signal, by utilizing two or more communication routes with different characteristics. In this work diversity is exploited in the transmitter and receiver and the performance comparison is done. Binary Phase Shift Keying (BPSK) is used to first modulate the data input or the message signal. Fig.2.11 shows the block diagram of transmitter used for the simulation.
For the BPSK modulation technique the probability of error is given by the equation

\[ P_e = Q\left(\frac{\sqrt{2E_b}}{N_o}\right) \]  \hspace{1cm} 2.18

where \( Q(x) \) is a complementary error function, \( E_b \) is energy per bit and \( N_o \) is the noise spectral density. These errors are mainly responsible for degrading the receiver performance and can be attributed to multipath delays and channel interferences. The modulated signal is then modulated with a larger bandwidth signal using the scalar dot product rule. This technique also introduces temporal diversity for the codes that are entered. The space time block coder is introduced to exploit the transmit diversity and is shown in shaded block to demonstrate the difference with the conventional model. In the transmitter model, CTD is introduced with a capsule of code, time and space diversity schemes. The transmit diversity scheme was originally formulated in a coding framework.
and later developments in Trellis based Space-Time codes to help achieve both coding and full diversity gain. Alamouti invented a simple Space-Time block codes over two symbols that achieve full diversity gain[38]. Unlike the Space Time Trellis coding[44,46], which codes sequence of symbols according to a specified Trellis signal constellation, space time block coding codes the disjoint blocks of symbols according to a predefined coding rule. The encoder codes pairs of symbols across two antennae in accordance to the rule specified in Table 2.1. And the detailed coding and decoding procedure is presented in section 2.1.8. At the receiver, the appropriate signals are received after de-spreading, which involves reconstituting the wide bandwidth signal to a narrower bandwidth and provide code diversity.

The classical space time coding for narrow band flat fading channels can be extended to broadband time-variant and frequency selective channels as space frequency coding[49]. Spatial Multiplexing[36] which involves transmission of multiple streams over multiple antennae is used to gain advantage of higher peak rates and increased throughput. With multiple ss at the receiver the different streams can be separated to achieve higher throughput compared to the single antenna systems. Multi carrier code division multiple access (MC-CDMA) and smart antenna array has made simultaneous transmit and frequency diversity a possibility. Some of the works that have exhibited combined diversity have emerged in support of this[95]. For demonstrations, different configurations of Tx and Rx are adopted. With receive diversity, MRC is brought in where the signals from all the branches are weighed according to their individual signal voltage to noise power ratios before being aggregated. The objective of MRC is to weigh
individual diversity branches so as to maximize the output signal to noise ratio. This technique gives the best statistical reduction of fading of any known linear diversity combiner and thus is the best diversity combining technique in terms of link performance. Modern DSP techniques and digital receivers have successfully embraced this optimal form of diversity. By summing the weighted correlated outputs it is possible to make an estimate of the signal. The spreading codes with a small autocorrelation value for any non-zero time offset is chosen to avoid the interference between the adjacent branches.

2.2.2. Results of CDMA Transmit Diversity Analysis

System performance is evaluated based on the assumption that the offset codes are orthogonal. Direct-sequence code-division multiple-access mobile communication systems, such as wideband CDMA are limited in performance by interference.

![Fig.2.12. Performance of CDMA Receive diversity technique](image-url)
By suppressing interference, linear equalization techniques such as rake receivers and transversal chip equalizers, offer remarkable gains in performance. It is evident from the Fig.2.12 that, multipath fading has been substantially reduced by diversity transmission and reception, facilitating the CDMA technology to prevail successfully over the other systems.

![Comparison of CDMA system with and without diversity schemes](image)

**Fig.2.13.** Comparison of CDMA system with and without diversity schemes

By studying the graph in Fig.2.13, it can be observed that while BER for the CDMA system with one transmitter and receiver is only $10^{-3}$ for maximum Eb/No, it is about $10^{-5}$ for the Maximum Ratio Combiner. This demonstrates the superiority of diversity reception over the single receiver system. In comparison to the SISO system,
the transmitter diversity using Alamouti code offers improvement in BER with an observed value of $10^{-5}$ when Eb/No is 20dB.

Thus, the diversity CDMA system with multiple antennae at the transmitter and receiver results in the improvement in SNR and reduction in the multipath fading and interference. The Space Time Coded Transmitter and MRC combiner proves effective over the (SISO) antenna system.

2.3. Receive Diversity in CDMA System

Multipath can result in frequency selective or in some instances non-selective i.e. flat fading depending on the characteristics of the channel. Compensation of this multipath is possible with the use of rake receiver that employs several baseband correlators to coherently process the multipath components in addition to exploiting the diversity advantages. In the presence of fading, the performance can be improved by the appropriate rake finger. For accurate modeling of the entire delay path in the channel, rake receivers can be implemented either as tapped delay lines or as FIR filter like the structures. For instance, in a 3G UMTS, the delay spread can be upto 75 chips in a 3.84 Megachips per second (Mpcs) chip rate system. Thus, the rake receiver clocks a delay of 75 delay paths. However, several distinct paths dominate the channel, but only a few taps are necessary to capture the most signal energy. If in an event where all taps are used, most of them may not correspond to the actual signal path as the channel noise would ensure linear estimate of tap weights would produce non zero weights. This not only leads to complexity but also to reduced system performance. Thus by discarding the taps
that do not contribute significantly to the channel model not only reduces complexity but also serves to increase the system performance.

The proposed model has a two pronged objective. The first objective is to simulate CDMA receiver along with rake receiver by applying time diversity. The second intent is to use BER to compare the improvement in performance of these systems. The ideal approach however would be to match the number of multipath signals with the number of correlators. Rake receivers used in CDMA systems restrict multipath fading and provide efficient reception by providing the strongest estimate of the original signal[87].

2.3.1. System Description

![CDMA Transmitter diagram]

The output of the BPSK modulation is superimposed with the PN sequence in order to provide signal security. Once the message is code modulated, for the retrieval of
message it is imperative that the receiver knows the exact PN sequenced code word used in the transmitter. This enables multiple users to transmit secure message or data simultaneously in a single channel. The choice of PN sequence for code modulation is subjected to fulfillment of some vital properties and must be orthogonal with other PN sequences. Convolutional encoder is used to map a continuous sequence of information bits into a continuous sequence of encoder output bits. As this mapping is highly structured it enables a different decoding method. The message bits are passed through a series of shift registers and followed by XOR operation to provide obtain the encoded bits. In CDMA systems since we normally deal with blocks of codes rather than bytes, it is essential to interleave the signals in order to protect it from being corrupted by noise. Thus, if one block of code gets corrupted by noise, it is still possible to retrieve message from the other blocks which reflects the benefit of temporal diversity Fig.2.14 represents a sample transmitter model considered in the simulation of the system.

2.3.2 Diversity Reception with different Rake configuration

CDMA systems suffer from multiple access interference (MAI) and multipath interference (MPI) or multipath fading. Diversity reception technique optimizes the working of the CDMA systems to attain the expected levels of efficiency. Diversity scheme refers to the technique of improving the reliability of the message signal, utilizing two or more communication channels with different characteristics. In this work different configurations of rake receiver is proposed as part of the receiver block.
A. Multiple Antenna Single Rake (MASR) finger receiver structure

The signal that is transmitted by the antenna undergoes multipath fading and arrives at the receiver. Fig. 2.15 shows the multiple antenna single Rake finger receiver structure. In this receiver model, the various time delayed versions of the message signals are detected by multiple sets of antenna. Each antenna detects a multipath component. The receiver combines the signals obtained from different antenna into a single stream which provides a better estimate, as the stronger signal at different time intervals is taken into consideration from these antennae.

![Diagram](https://example.com/diagram.png)

Fig. 2.15. Multiple Antenna Single Rake finger receiver structure

The estimate of the original message is produced by combining all the signals using various combining techniques. In this thesis, to achieve simulation, signals from various antennae are compounded to obtain the strong received signal. The output is then processed by the rake finger to produce the code-demodulated signal by decorrelating the
signal with the corresponding PN sequence. This signal is then processed by rest of the receiver blocks to provide the required data output.

**B. Single Antenna Multiple Rake (SAMR) Finger Receiver Structure**

The next kind of the receiver structure is the single antenna multiple rake finger receiver structure. In this model the signal that is transmitted from the antenna is received by a single antenna wherein the delayed versions are produced by tapped delay lines. The various time delayed versions of the signal are then decorrelated using the corresponding PN sequence before combining them to get the strong estimate of the original signal. Fig.2.16 illustrates the structure of the Rake receive model.

![Single Antenna Multiple Rake (SAMR) Finger Receiver Structure](image)

Unlike in the previous model, here in this structure just a single antenna is used to produce the signal estimate. As multiple rake fingers decorrelate the delayed version of the signal immediately with the PN sequence, it translates to an advantage, since the
hardware requirement is reduced and efficiency is improved to a reasonable extent. As
the received signal is already code demodulated, it is further processed by other receiver
blocks to obtain the original message signal that was earlier transmitted by the antenna.

C. Multiple Antennae Multiple Rake(MAMR) finger receiver structure

The third and perhaps the most efficient receiver structure is the Multiple
Antenna Multiple Rake Finger Model. Fig.2.17, illustrates the structure of this receiver
model. In this structure several Rake fingers are responsible for code demodulation
unlike in the first case where only one finger is used to decorrelate the signal. As each
antenna collects a multipath component, a corresponding rake finger is assigned in order
to code demodulate the signal. There can be ‘n’ delay antenna and the signals from these
entire antennae are summed up to produce a strong estimate of the signal.

Fig.2.17. Multiple Antennae Multi Rake(MAMR) finger receiver structure
This structure is considered to be far more superior in comparison to the other two structures as it produces accurate and efficient results. Although all the three cases considered are essentially rake receivers, yet they differ from each other in terms of their performance characteristics and therefore form the basis for comparison of these structures which will be presented in the forthcoming section.

2.3.3. Receiver Model

The receiver block considered in the simulation of the system is shown in the Fig.2.18. The receiver block used here consists of a de-interleaver, Viterbi decoder and BPSK demodulator. After the signal reception, the signals are combined using maximum ratio combining technique to produce the signal estimate.

Fig.2.18. CDMA Receiver

Viterbi algorithm is used to perform Maximum Likelihood Decoding of convolutional codes. Thus, Viterbi decoder is used to estimate the path through the trellis
that was followed by the encoder. Finally the signal is BPSK demodulated and the original message is retrieved.

2.3.4. Results of CDMA Receive Diversity Analysis

From the graph shown above, we can compare how the three methods prescribed here fights these loss to decrease the bit errors. When the number of antennae is increased, the receiver simultaneously receives the reflected wave from various paths. This sort of reception is best suited for the urban and suburban areas that face many obstacles on account of their topography.

Fig.2.19 shows the BER comparison graph of the cases A, B and C and all the other cases respectively. Considering the second case where the single antenna has multiple rake fingers, the single delayed signal received at any instant is correlated simultaneously with multiple delayed components to obtain maximum correlated signal which in fact works well for high delay path. UWB systems were able to provide an optimized performance while maintaining a low system complexity [96,97]. In the case of UWB systems, very small reflections cause high delay. Hence UWB systems will benefit greatly from this kind of reception.

For the Max Eb/No at 35 dB, SAMR provides BER between $10^{-3}$ and $10^{-4}$, MAMR gives BER around $10^{-11}$. When exploiting the signal in time domain at the receiver with various rake pattern, it is observed that multiple rake multiple antenna system benefits the greater reduction in BER.
Fig. 2.19. Comparison of SAMR, MASR and MAMR

The multiple antennae multiple Rake combines the best of features from both the systems, thus offering least BER. It can thus be concluded that this system is very versatile and can exhibit optimum performance in the multipath scenario.

The capacity to resolve multipath faded signal components renders dominancy to the CDMA system. The unique code sequence provides high security to the users in the CDMA system. The multipath fading has been substantially reduced by diversity reception technique. The non correlation of signals after spatial combining process delivers a better estimate of the signal at the output. From the BER graphs, it can be inferred that multiple antenna multiple rake fingers receiver structure is the best amongst the three as it offers low error rate with an increase to the number of users in the system. However for minimum number of users the justified case may not produce a larger
efficiency. By using channel coding the error on the digital data is minimized. Since, the code words generated are orthogonal to each other it can be concluded that, unless the receiver has knowledge about the code word used by the transmitter, decoding is highly impossible. Also some disadvantages associated with the system like the near far problems, jamming, ISI, adjacent channel and co-channel interference, are likely the issues to be dealt with. Though diversity reception reduces the multipath fading, it has been found that with the increase in the number of users using the system, there has been an increase in co-channel and adjacent channel interference. The BER performance graphs shown above clearly indicate that a multiple antenna multiple rake finger receiver structure provides increased SNR and lowest BER apt for efficient communication.

It is clearly seen that multipath fading has been substantially reduced by diversity reception, facilitating CDMA technology to prevail over other systems. The next section investigates the performance of LDPC system augmented with diversity techniques

2.4. Suitability of LDPC with Diversity schemes

This module report lays out the idea of introducing LPDC codes in tandem with the spreading sequence, to improve noise immunity pertaining to the signals traversing in wireless environment. Spread spectrum has become instrumental in making communication techniques more efficient and reliable with its various added advantages. Since 1948, many researchers have attempted to make a breakthrough in the world of error correcting codes, and surprisingly some remarkable discoveries have been made. One such breakthrough came in early 1960’s[98], when Gallager found codes that were capable of reaching the proximity region of the Shannon limit. Low Density Parity Check
is in the limelight since the last few years. Comprising of relatively faster encoding and decoding techniques, LDPC codes are capable of recovering the original message in the cases of any larger parts of the messages being corrupted. Spread spectrum concept used along with LDPC codes, can accomplish lesser BER. In this work, the signal was first made to spread and then the encoding and decoding algorithms were subsequently employed. The original message is finally recovered after de-spreading the signal. Features such as Approaching Shannon capacity, good block error correcting performance, and low error floor can be exploited by means of this technique. The presented idea is viable to be applied to broadband wireless systems for instance WiFi and WiMAX[99] This effort demonstrates the suitability of LDPC along with spread spectrum technique in broadband wireless systems.

With the evolvement of the new error-correcting code there has always been the possibility of being linked to an interesting technology called OFDM. David Benmayor et al., developed LPDC-COFDM systems with QPSK as a modulation technique and showed that the effectiveness of the combination remained unmatched when compared to other systems[100]. The same was later encouraged by the use of multiple encoders, each sliced in a different 3-D layered architecture of time-space-frequency for an OFDM-MIMO system to facilitate high speed data transmission over a frequency selective fading channel as in[101]. LDPC’s application in CDMA systems as overloaded LDPC-Coded CDMA system[102] showed that when combined with multi-user detector, there could be an increase in the number of users simultaneously accessing the channel without degrading the performance of the system.
2.4.1. System Description

Fig. 2.20 gives a sight into the LDPC transceiver, with spreading and despreading at the Tx and Rx respectively. The transmitter gets a block of message to send over, to which the chipping sequence is applied for spreading.

When the chipping sequence is used appropriately, it appears as random noise. During the transmission, the narrow band and the broadband interference get accumulated with the signal. The received signal now has the original signal clubbed with the interference. The block Spreading is responsible for spreading the signal.

The signal received is de-spread by the de-spread block which has knowledge about the chipping sequence. Thus, the receiver converts the user signal into a narrowband signal. The narrow band interference is spread in the same way while the broadband interference is left untouched. To segregate the frequencies that are to the right and left of the narrowband signal the receiver uses a band-pass filter. The chipping sequence can be of any length and must be a pseudo-noise sequence. The supposition
being that the power level of the signal can be much lower than the original narrowband signal without incurring any loss of data. Thus, the power level of the user message signal can be as low as background noise depending on the generation and reception of the spread signal.

The block LDPC encoder makes use of the generator matrix derived from parity-check matrix to encode the output of the spreading block and the resultant output is then passed to the BPSK block. In the BPSK block all the ‘0’ s are transposed by ‘-1’ s leaving the 1’s unchanged. Two channel models, AWGN Channel and Rayleigh Channel, have been used for noise simulation. At the receiver’s end BPSK demodulation is applied to the received codeword. Finally the decoder block corrects the erroneous codeword which is then fed to the de-spreading block to extract the final user message. The decoding algorithm is based on ‘Likelihood Difference’. It works on the principle that ‘the received codeword will be decoded to the nearest codeword available’.

A. Iterative Decoding Algorithm based on Likelihood Difference

![Tanner Graph representation of a parity-check matrix H](image)

Fig.2.21. Tanner Graph representation of a parity-check matrix H
From the Tanner graph shown in Fig. 2.21, following are derived,

- \( N(i) \{ j : h_{ij} = 1, 1 \leq j \leq n \} \) is the set of codeword bits (\( v_j \) in Fig. 2.21) that take part in parity check. \( i, n \) is denotes the codeword length.

- \( M(j) \{ i : h_{ij} = 1, 1 \leq i \leq J \} \) is the set of parity checks (\( c_i \) in Fig. 2.21) that check the codeword bit \( j \). \( j \) are the number of parity checks and also the number of rows in parity-check matrix.

- \( N(i) \setminus j \) is the set of codeword bits taking part in the parity check \( i \), excluding the message bit \( j \).

- \( M(j) \setminus i \) is the set of parity checks that check the codeword bit \( j \), excluding parity check \( i \).

- \( \Psi^a_\theta \) is the probability that code bit \( j \) gets the value \( a \), given the information from all the parity checks excluding check \( i \).

- \( \Omega^a_\theta \) is the probability that parity check \( i \) is satisfied if code bit \( v_j = a \) and the probability for the other codeword bits to get their values are given by

\[ \{ \Psi^a_{\theta^i} : j' \in N(i) \setminus j, a=0,1 \} \]

- Initially, the \textit{a posteriori} probabilities of the codeword bits can be initialized at \( p(r_{j+1}) \) and \( p(r_{j-1}) \).

The probabilities of the channel outputs for the given transmitted symbols is given by the equation

\[ p(r_j | -1) = \frac{1}{1 + e^{-2\sigma^2}} \text{ and } p(r_j | +1) = 1 - p(r_j | -1) \]

2.19
To begin with, $\Psi_{ij}^0$ and $\Psi_{ij}^1$ are initialized at $p(r_j|x_j=-1)$ and $p(r_j|x_j=1)$, respectively. For the given matrices $\Psi_{ij}^0$ and $\Psi_{ij}^1$, the messages sent by the variable node to all the parity checks connected to it are the same and equal to $p(r_j|x_j=-1)$ and $p(r_j|x_j=1)$.

**B. Iterative Decoding**

(a) **Horizontal step**: The difference can be defined by the equation $\delta\Psi_{ij} = \Psi_{ij}^0 - \Psi_{ij}^1$. For each pair $(i, j)$ with $a = 0$ and $a = 1$, $\Omega$ messages from the check nodes to the variable nodes are updated using the equations 2.20 and 2.21

$$\delta\Omega_{ij} = \prod_{j' \in N(i), j} \delta\Psi_{ij'}.$$  

$$\Omega_{ij}^a = \frac{1}{2} \left[ 1 + (-1)^a \delta\Omega_{ij} \right].$$

(b) **Vertical step**: For every pair $(i, j)$, with $a = 0$ and $1$. The $\Psi$ messages from the variable nodes to the check nodes are updated using the equation 2.22

$$\Psi_{ij}^a = \alpha_{ij} p(r_j | x_j = 2a - 1) \prod_{i \in M(j) \cap j} \Omega_{ij}^a.$$  

$\alpha_{ij}$ is the normalizing constant chosen to satisfy/obtain the equation $\Psi_{ij}^0 + \Psi_{ij}^1 = 1$. For each $(j, a) = (0, 1)$ the “pseudo a posteriori probabilities”, $\Psi_j^0$ and $\Psi_j^1$ are updated using equation 2.23. Here $\alpha_j$ is taken as the normalizing constant to satisfy/obtain the equation $\Psi_j^0 + \Psi_j^1 = 1$

$$\Psi_j^a = \alpha_j p(r_j | x_j = 2a - 1) \prod_{i \in M(j)} \Omega_{ij}^a.$$
C. Evaluation

A bit-by-bit decoded value $\hat{x_j}$ is chosen using the rule: If $\Psi_j > 0.5$, $\hat{x_j} = 1$, if $\Psi_j \leq 0.5$, $\hat{x_j} = 0$. If $x^H H^T = 0$ (H being the parity-check matrix) then $\hat{x}$ is a valid codeword and the algorithm ends successfully.

Else if maximum number of iterations have been reached, then a failure is recorded and the algorithm stops.

Else: Go back to the beginning of Iterative Decoding.

2.4.2. Results of LDPC Diversity Analysis

The graph in Fig.2.22 is obtained after simulation of the channel for different code rates. It can be observed that a pull down occurs in the bit-error rate as the rate decreases. This happens because of the fact that the number of redundant bits is more than the user or message bit/s.

Fig.2.22. Performance of LDPC system with different code rate
To increase it further, the same can be extended for specific channels like AWGN and Rayleigh. For AWGN at 2dB, comparing the values of rate at $\frac{1}{4}$ and $\frac{1}{2}$, a gain of more than 2dB is observed for rate = $\frac{1}{4}$. Gain is also achieved in the Rayleigh channel which is not very significant.

The graph plotted by comparing two different error codes is represented in Fig.2.23. From the graph it can be inferred that the performance of the conventional convolutional codes is lower in comparison to the LDPC codes which exhibits a performance gain of almost 3dB at 2dB of SNR.
Referring to Fig. 2.24 which represents the spreading in the error-rate, though the difference is considerably high, the gain is 3dB. The length of the chipping sequence has a direct bearing on the bit-error rate. Thus, as the length of the chipping sequence increases, a dip in the bit-error rate can be noticed. However, the trade-off gained is an increase in the length of the chipping sequence as the decoding time increases every time.

![Performance of LDPC system in AWGN Channel](image)

Fig. 2.24. Comparison of LDPC scheme with and without spreading techniques

### 2.4.3. Conclusion

Recapitulating the study in this chapter, it has been observed that spreading which involves processing of extra bits at the decoder’s is associated with an undesirable overhead. To reduce the overhead of processing on the decoder side, the need of the hour is the designing of a faster decoding algorithm which can be combined with spread
spectrum to obtain a positive synergistic effect. Summarizing, it can be concluded that LDPC which has an edge over other codes has to be evaluated to assess its feasibility as an emerging technology along with spread spectrum for the next generation communication systems. For a more profound impact the proposed scheme can be combined with STBC.

The exhaustive analysis conducted in this session further reiterates the superiority of diversity and encoding schemes in successfully containing propagation of errors leading to better and efficient transmission of information. To reaffirm and substantiate the benefits of the proposed combinational diversity scheme the next chapter on WLAN and WMAN seeks to dissect and scrutinize the proposed scheme in the realm of wireless networks.