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MITIGATION OF FADING EFFECTS IN MULTIPATH CHANNELS

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KeyWords
Coding, Concatenation, Diversity, Doppler shift, Fading, mitigation, Multipath, orthogonal, Rayleigh, Rician, spatial.

ABSTRACT

In wireless communication fading of channels cause severe degradation to the strength and quality of received signal. To minimize the impacts of fading and improve the quality of the transmitted signal, several mitigation techniques are applied. In this paper, the throughput of independent channel coding and diversity is compared with the performance of their concatenation for both Rician and Rayleigh multipath fading channels. The simulation results showed that while diversity scheme performs better than coding in Rayleigh channel, coding technique outperforms diversity scheme in Rician channel. However, the combination of the two schemes performs better than either of the independent schemes in both Rayleigh and Rician channel. Hence, OSTBC offers spatial diversity gain while TCM offers coding gain, the duo make the concatenation an excellent scheme over independent diversity or coding technique in combating effects of fading.

1. INTRODUCTION

The wireless communication channel is usually dynamic due to multipath fading and Doppler spread. Multipath channels experience several impairments such as slow fading (shadowing), fast fading and path loss. These phenomena can impact negatively on the quality of received signal and the overall performance of wireless communication networks if not mitigated. For better performance of wireless communication systems, there is need to apply appropriate mitigation scheme, depending on the system requirements and propagation environment in order to minimize the effects of these impairments.

The mitigation techniques proposed in literature are diversity, equalization and error correction coding. However, the exact mitigation to apply to a particular fading model remains a challenge. The performance analysis of diversity and coding schemes as well as their concatenation to combat multipath fading in both Rayleigh and Rician channels is the focus of this work. While diversity compensates for fast fading and not adequate to combat frequency selective fading, equalization deals with frequency selective fading to correct inter-symbol interference only. Coding, compensate for deep fade but error coding such as interleaving increases total delay since the entire interleaved block must be received before the packet can be decoded while automatic repeat request is not adequate for real-time transmission of information. It is hoped that the combination of these two schemes; diversity (MIMO channel) and error coding (convolutional coding) will utilize the advantages of the two schemes to enhance the quality of received signal and improve the overall performance of wireless communication systems in a multipath fading environment.

1.1 AIM AND OBJECTIVES OF THE STUDY

The main objective of this study is to mitigate multipath fading effects by simulating spatial diversity and coding mitigation techniques, and compare their individual performances with the performance of their combination in terms of quality of received signal and frame-error-rate (FER) in both fading channels of Rayleigh and Rician.

2 BACKGROUND TO THE STUDY

The effectiveness of wireless communication networks rely enormously on the attributes of the wireless channel, which is often unstable and dynamic due to multipath propagation. The propagation of radio signal through multipath wireless channel is a complicated process often characterized by various impairments including multipath fading, path loss and shadowing (Sanjeet and Panwar, 2012, Sudhir and Sambasiva, 2011), which degrades the quality of transmitted signal. Each of these phenomena is caused by a different underlying physical principle and must be considered when designing and evaluating how a wireless communication network performs. Multipath fading imposes this basic limitation on the performance of wireless communication systems since the transmitter to the receiver path changes drastically from simple LOS to multiple paths due to reflection, diffraction and scattering from high-rise buildings, trees, foliage, moving objects and mountains.

The fading induced by propagation through many paths in radio channel can be modelled with Rayleigh distribution, if there were no clear path between the transmitter and receiver. If a dominant line-of-sight exists among the several paths, Rice distribution is appropriate in modelling such fading (Wunderlich et al, 2014).

The adverse effects of fading can be combated by using diversity to transmit the signal over multiple paths that experience independent fading and then combining the signals coherently at the receiving antenna. Diversity scheme can be achieved in time, frequency or space (Nitika and Deepak, 2012). Other techniques used to reduce fading effects include equalization, MIMO-OFDM, Alamouti codes (space-time codes) and Rake receivers.

2.1 MULTIPATH

The objects situated around the way of the wireless signal reflect the signal. Some of these reflected waves are additionally gotten at the receiver. Since each of these reflected signals takes an alternate path; it has an alternate amplitude and phase. Multipath fading is one of the huge elements that influence the performance of a wireless communications link.

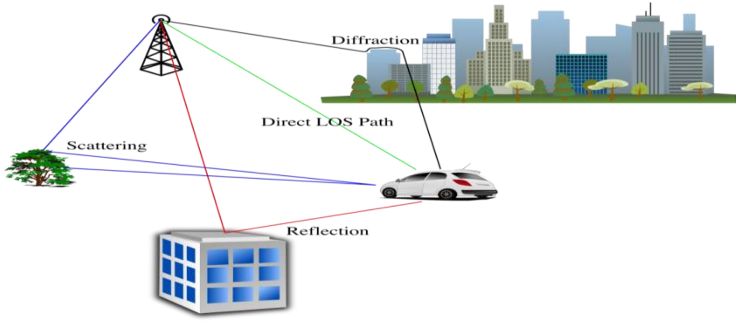

Fig 2.1 Multipath Propagation scenario

2.2 CLASSIFICATIONS OF FADING

2.2.1 LARGE SCALE FADING

Large-scale fading refers the path loss of a signal affected by large objects, such as hills, forests, buildings, between a transmitter and receiver. It occurs when a mobile transmitter and/or receiver moves over long a distance, resulting in rapid variations in the received signal's envelope. In mobile communications, large-scale fading occurs in urban, outdoor-to-indoor and indoor environments.

2.2.2 SMALL SCALE FADING

Small-scale fading refers to large changes in the amplitude and phase of a signal caused by a small change in the position of the transmitter or receiver. This effect is due to constructive and destructive interferences of the transmitted signal that occurs at very high carrier frequencies (in the range 900 MHz - 1.9 GHz). Small-scale fading includes two phenomena: time spreading due to multipath delay and time variance due to Doppler spread, both phenomena are analyzed in both time and frequency domain.

2.2.3 FREQUENCY SELECTIVE FADING

The transmitted signal reaching the receiver through multiple propagation paths, having a different relative delay and amplitude. This is called multipath propagation and causes different parts of the transmitted signal spectrum to be attenuated differently, which is known as frequency-selective fading. In this case, the channel spectral response is not flat. It has dips or fades in the response due to reflections causing cancellation of certain frequencies at the receiver.

2.2.4 FREQUENCY NON-SELECTIVE FADING

This is when all the frequency components of the signal roughly undergo the same degree of fading; the channel is then classified as frequency non-selective or flat fading.

2.2.5 FAST FADING

Fast fading is the short term component associated with multipath propagation. It is influenced by the speed of the mobile terminal and the transmission bandwidth of the signal.

2.2.6 SLOW FADING

Slow fading is a long-term fading effect changing the mean value of the received signal. Slow fading is usually associated with moving away from the transmitter and experiencing the expected reduction in signal strength. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver

2.3 DOPPLER SHIFT

The Doppler Shift is change/move in the recurrence of the received signal when the transmitter and the receiver move relatively to each other. In the event that they are advancing toward each other, at that point the recurrence of the received signal will be higher than that of the transmitted flag, and in the event that they are moving away from each other, the flag recurrence at the receiver will not exactly the transmitter's signal frequency.

2.4 PATH LOSS

The least complex channel is the free space observable pathway channel without any items between the receiver and the transmitter or around the way between them. In this basic case, the signal transmitted lessens the transmit power roundly of the transmitting reception apparatus. For this viewable pathway (LOS) channel, the received power is expressed in the Friis' free space equation:

$$\mathrm{Pr} = PtGtGr\left(\frac{\lambda}{4\pi d}\right)^{2} \text{--} (2.1)$$

Where, Pt = the transmitted power, Gt = the gain of the transmit antenna, Gr = the gain of receive antenna field radiation patterns, λ= the wavelength, and d = the distance between transmitting and receiving antennas.
In theory, the power falls off in extent to the square of the separation. However, in reality, the power falls off more rapidly, commonly third or fourth power of separation distance (Padmaja & Malleswari, 2014). The nearness of ground makes a portion of the waves reflect and reach the transmitter. These reflected waves may at some point have a phase shift of 180°and so may diminish the received power. A straightforward two-ray path loss can be shown to be:

$$\mathrm{Pr} = \frac{PtGtGr\, h_t^2 h_r^2}{d^4} \qquad (2.2)$$

Here, ht and hr are the antenna heights of the transmitter and receiver, respectively.

2.5 RAYLEIGH FADING

A fading channel has Rayleigh distribution, if there is no dominant LOS path between the transmitter and the receiver. In this case, the signal getting to the receiver comprises of reflected, diffracted and scattered waves. These signals have different amplitudes, path lengths and phases, which make the instantaneous received power a random variable. For an un-modulated carrier, the transmitted signal of frequency ωc will reach the receiver through several paths, ith with amplitude ai and phaseof ϕi.
Without an overwhelming dominant LOS, the received signal s(t) is presented as:

$$s(t) = \sum_{i=1}^{N} a_i \cos(\omega_C t + \phi_i) \qquad (2.3)$$

Where N is the number of paths. The phase is dependent upon the varying lengths, and it changes by 2π if the path length varies by a wavelength. If a relative motion exists between the transmitter and receiver equation above is modified to account for the effects of motion induced frequency and phase shifts. The Doppler shift is stated as:

$$\omega_{di} = \frac{\omega_c}{c} V \cos \psi_i \qquad (2.4)$$

ψ_i is the angle of arrival of the wave relative to the direction of antenna movement, v = velocity of mobile and c = velocity of light. The received signal is:

$$s(t) = \sum_{i=1}^{N} a_i \cos(\omega_C t + \omega_{di} t + \phi_i) \qquad (2.5)$$

And the signal expressed in phase and quadrature forms, equation (2.3) becomes:

$$s(t) = I(t)\cos \omega_C t - Q(t) \sin \omega_C t \qquad (2.6)$$

Where, the in phase and quadrature components are respectively expressed as:

$$I(t) = \sum_{i=1}^{N} a_i \cos(\omega_{di} t + \phi_i) \qquad (2.7)$$

$$Q(t) = \sum_{i=1}^{N} a_i \sin(\omega_{di} t + \phi_i) \qquad (2.8)$$

The signal envelope, R, is given by:

$$R = \sqrt{\left(I_t^2 + Q_t^2 \right)} \qquad (2.9)$$

In addition, when N is very large, the in phase and quadrature components become Gaussian [21].
The probability density function (pdf) of the received signal envelope (Pr) is Rayleigh, and is given by:

$$P(r) = \frac{r}{\sigma^2} \exp\left(\frac{-r^2}{2\sigma^2}\right), \mathrm{r} \geq 0 \qquad (2.10)$$

Where r, is the envelope of fading signal, σ is the RMS value of the received voltage signal and σ2 is the average power at the envelope detector.

2.6 RICIAN FADING

At the point when there is a dominant direct LOS between the transmitter and the receiver in addition to the diffuse components, the distribution is described as Rician. For this type of the distribution, the transmitted signal described in equation (2.5) can be written as

$$s(t)=\sum_{i=1}^{N-1}a_i\cos(\omega_C t+\omega_{di}t+\phi_i)+A\cos(\omega_C t+\omega_d t)------------------------(2.11)$$

Where the consistent constant A represents the peak amplitude of the direct LOS component, ωd is the Doppler shift along the LOS path, and ωdi are the Doppler shifts along the NLOS ways given by given by equation (2.4). The envelope for this situation has a Rician density function given by [11]

$$P(r)=\frac{r}{\sigma^2}\exp(-\frac{r^2+A^2}{2\sigma^2})I_o(\frac{Ar}{\sigma^2}),r\geq 0,----------------------------(2.12)$$

Where Io(,) is the changed Bessel capacity of the main kind and zeroth request.
The cumulative distribution of the Rician random variable stated as

$$P(r)=1-Q(\frac{A}{\sigma},\frac{r}{\sigma}),r\geq 0,-----------------------------------(2.13)$$

Where Q(,) is the Marcum’s Q function (Sanjeet & Panwar).The Rician distribution is generally depicted as far as the Rician factor K, which is characterized as the proportion between the deterministic signal power (from the direct path) and the diffuse signal from the aberrant ways). K is normally expressed in decibels as:

$$K(dB)=10\log_{10}(\frac{A^2}{2\sigma^2})-------------------------------------(2.14)$$

In the above equation, if A >>0, $\frac{A^2}{2\sigma^2}\langle\langle\frac{r^2}{2\sigma^2}$, the direct path is eliminated and the envelope distribution equals Rayleigh while K(dB) goes to $-\infty$.

3 METHODOLOGY

This work is realized by block modelling and simulation with Mathworks’ Simulink as the simulation tool. To obtain the details of the signal received from the transmitted signal, it requires a model of the link between them. Generally, the received signal power is computed from the convolution of the power profile of the transmitted signal and the impulse response of the channel.

Hence, given the transmitted flag x, subsequent to engendering through the channel H, progresses toward becoming y, where,
y(f) = H(f)x(f) + n(f) --- (3.1)
Where H (f) = channel response and n(f) is the channel noise.

3.1 SIMULATION BLOCK AND DESCRIPTION

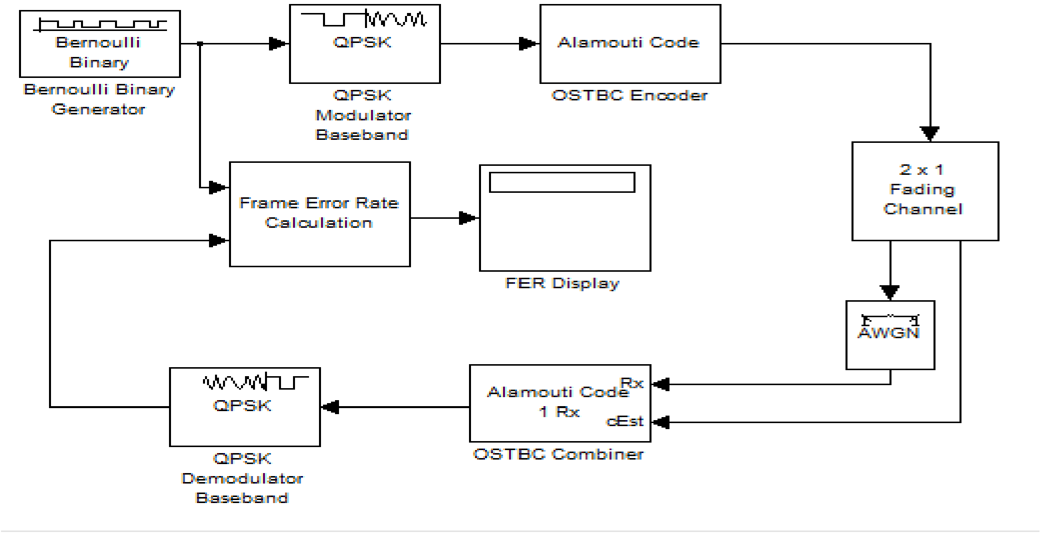

Fig 3.1 Diversity Mitigation Model

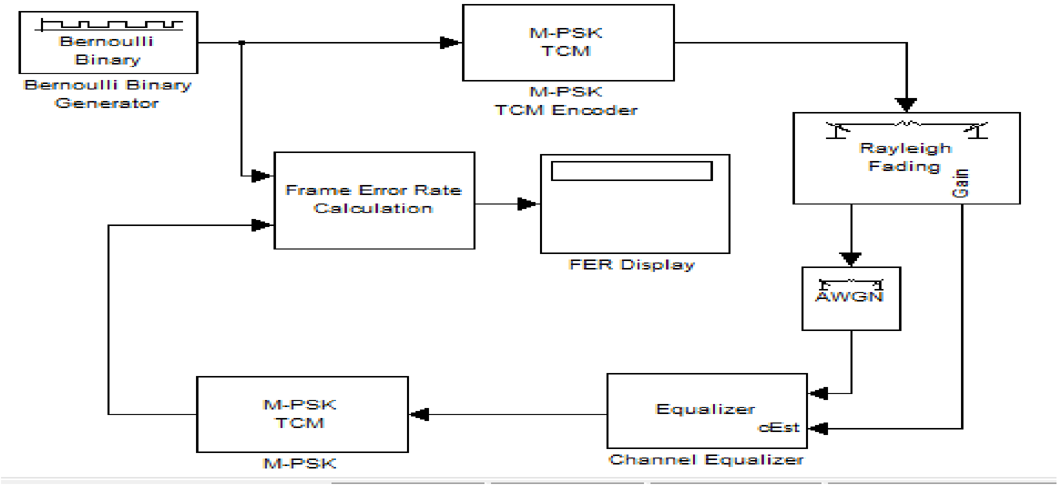

Fig 3.2 Coding Mitigation Model

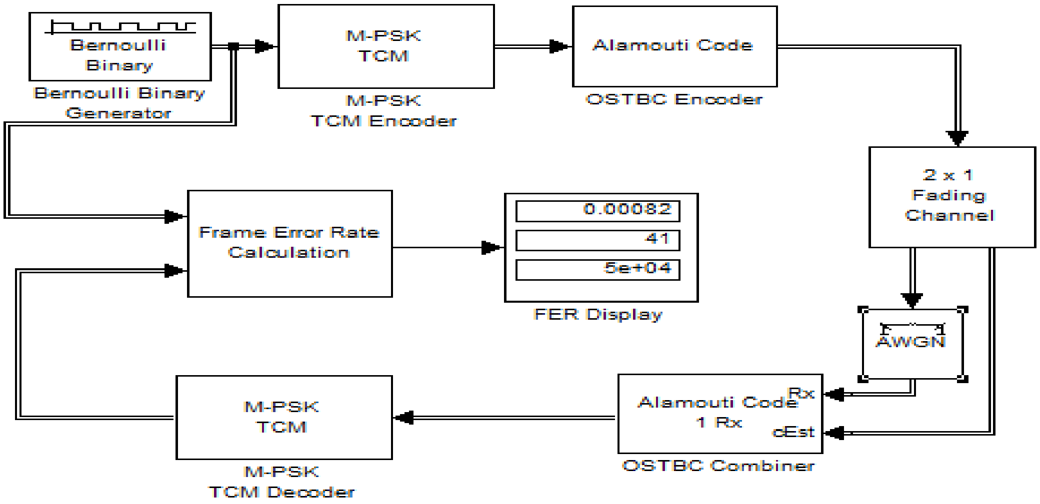

Fig 3.3 Combination of Diversity and Coding Model

BLOCK DESCRIPTION

Bernoulli Binary Generator Block represents the signal source. It creates irregular paired numbers utilizing Bernoulli distribution and the output signal is set to frame-based matrix.

M-PSK TCM Encoder Block implements trellis-coded modulations scheme. It uses convolution coding to encode the binary input signal and then maps its output to an M-PSK signal constellation.

The OSTBC Encoder Block encodes the input symbol sequence with orthogonal space-time block code. It encodes the information symbol from TCM encoder using Alamouti code.

The Frame Error Rate (FER) subsystem compares the decoded bits with the original source bits per frame to detect errors and dynamically updates the FER during simulation.

The display unit shows the output of the frame error rate block. It consists of the FER, the number of error frames and the total number of frames processed. The multipath Rayleigh Fading Channel block implements a baseband simulation of Rayleigh fading propagation channel. The initial seed parameters of the two Rayleigh Fading Channels are set to different values in order to simulate two independent fading sub channels.

The multipath Rician Fading Channel block implements a baseband simulation of a multipath Rician fading propagation channel. The two channels have different K-factors and initial seeds.
The AWGN Channel block introduces Additive white Gaussian noise to the binary input signal. The mode parameter was chosen as SNR mode.

The M-PSK TCM decoder block uses Viterbi calculation to decipher a TCM signal that initially was modulated with PSK signal constellation. The parameter of M-ary number which represents the number of points in the signal constellation is set to 8.

The OSTBC combiner block combines the received signal and channel estimate inputs according to the structure of orthogonal space-time block code, which is set to rate 1 for 2 transmit antennas.

DPSK Modulator Baseband: This block modulates the information signal utilizing the differential phase keying procedure.

DPSK Demodulator Baseband: This block detects the signal modulated by DPSK modulator.

The Channel Equalizer Block compensates channel-fading effects at the receiving end. Its output is fed into M-PSKTCM decoder block for decoding.

Scatter Plot: A scatter scope or constellation diagram is used to visualize the constellation of a digitally modulated signal.

Eye Diagram Scope: this block provides a visual indication of how much noise has affected the system performance.

Signal Trajectory: the discrete-time Signal direction degree is utilized to show a modulated signal constellation of stars in its signal space is a plot of the in phase part against the quadrature segment

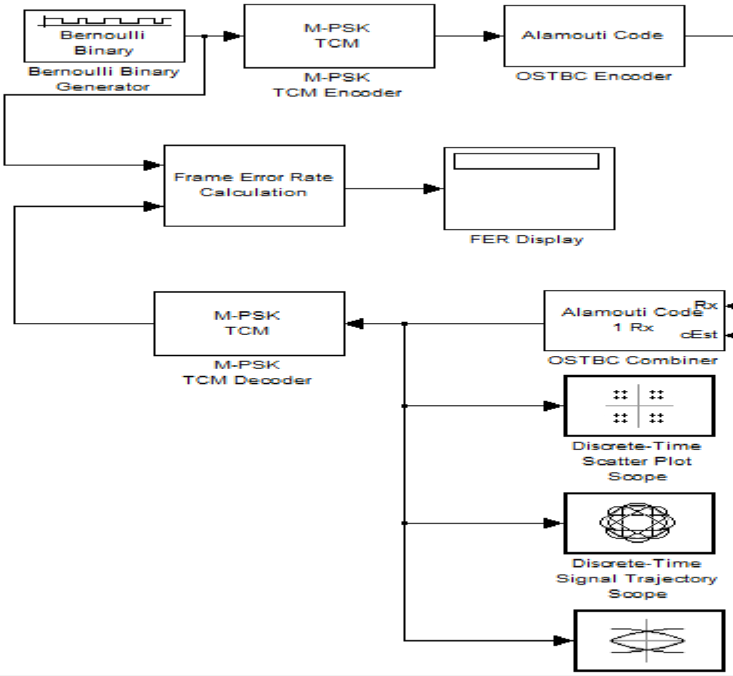

Fig 3.4 Diversity plus Coding Model with visualization blocks

4 RESULT AND DISCUSSIONS

This section presents the simulation result and its analysis. The simulation was performed over 2x1 flat Rayleigh and Rician fading channels for each of diversity and coding schemes as well as their combination as shown in tables 4.1 and 4.2 respectively. The AWGN Channel block's mode parameter chosen as SNR with the 1-ohm (watts) set to 2, while the initial seed parameter is set to 67. The Initial seed parameters of the two Multipath Rayleigh Fading Channel blocks are set to different values in order to simulate two independent fading sub channels. Similarly, the two multipath Rician Fading Channel blocks have different initial seed parameters and K-factors. The maximum Doppler shift is set to 40 for both Rayleigh and Rician channels. The following parameters are used for the Bernoulli Binary Generator block; sample per frame is set to 100, initial seed of 71, sample time of 1 microseconds and the output data type parameter is set to double. Number of transmit antenna is set to 2 for the OSTBC Encoder while the OSTBC combiner is set to 2-transmit antenna and 1- receive antenna. The simulation results are presented in tabular and graphical forms for easy analysis and comparison as shown below.

Table 4.1 : Simulation Results for Different Mitigation Techniques in Rayleigh Fading Channel

SNR dB	FER IN RAYLEIGH FADING CHANNEL		
	CODING	DIVERSITY	DIVERSITY & CODING
16	0.09330	0.05008	0.02624
18	0.05694	0.02410	0.01272
20	0.03624	0.0114	0.00494
22	0.02378	0.00468	0.00194
24	0.01598	0.00170	0.00082

Table 4.2 : Simulation Results for Different Mitigation Techniques in Rician Fading Channel

SNR dB	FER IN RICIAN FADING CHANNEL		
	CODING	DIVERSITY	DIVERSITY & CODING
16	0.01556	0.03384	0.01212
18	0.00804	0.01452	0.00766
20	0.00416	0.00678	0.00374
22	0.00234	0.00328	0.00180
24	0.00116	0.00158	0.00082

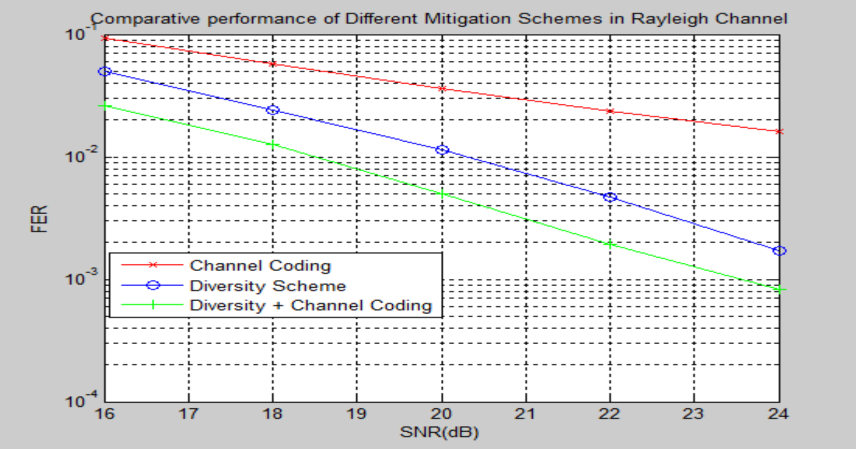

Figure 4.1: FER Performance of Different Mitigations in Rayleigh Channel.

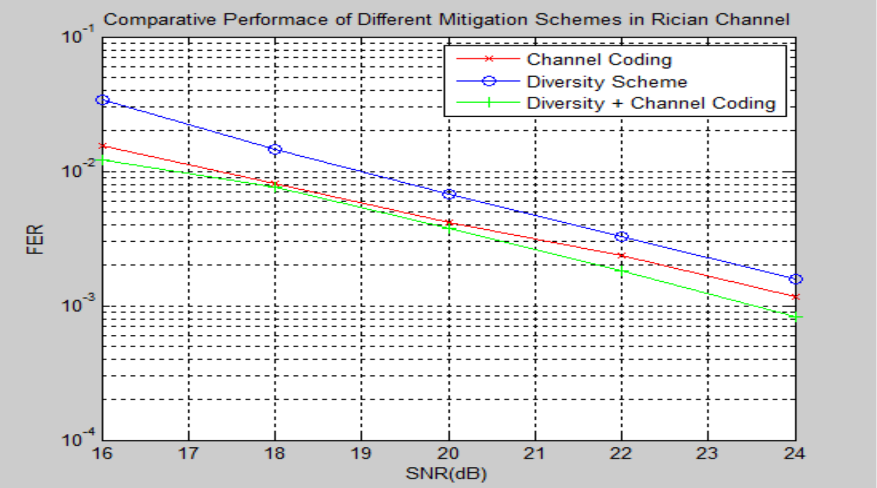

Figure 4.2: FER Performance of Different Mitigations in Rician Channel.

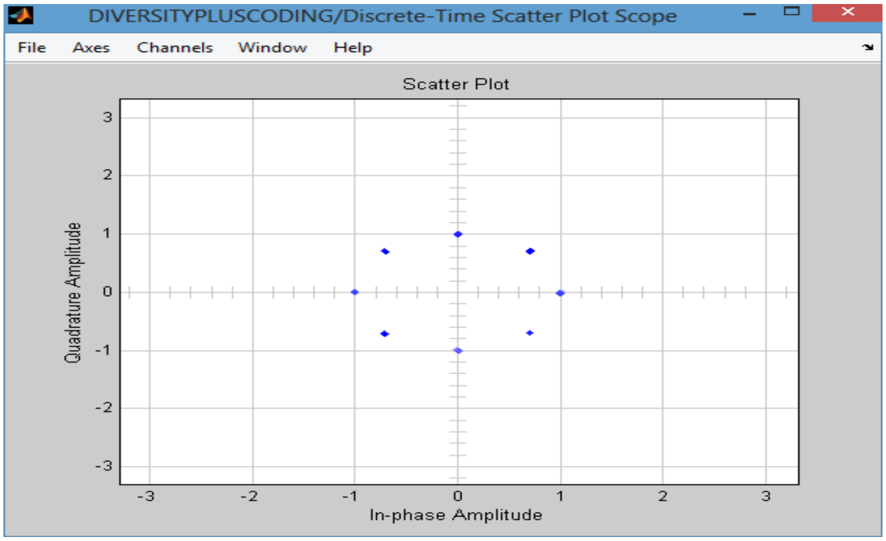

Figure 4.3: Scatter Plot for Performance Analysis Diversity/Coding Mitigation scheme.

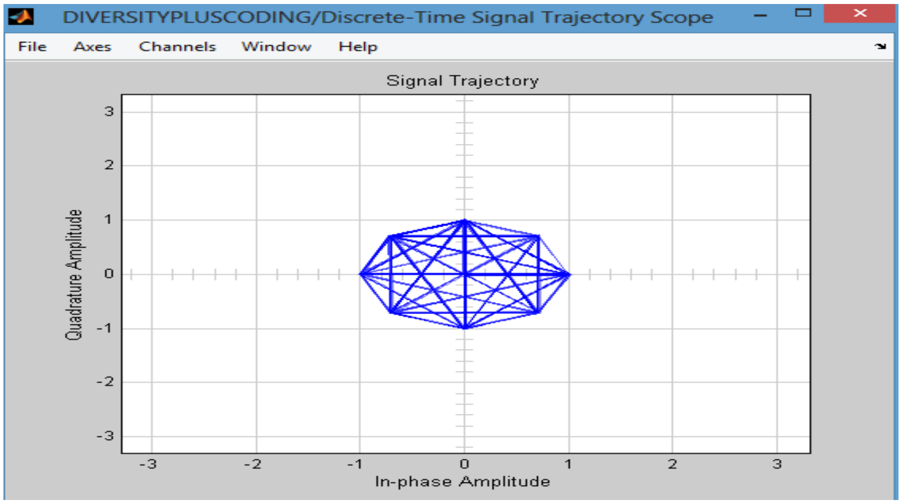

Figure 4.4: Signal Trajectory for Performance Analysis Diversity/Coding Mitigation scheme.

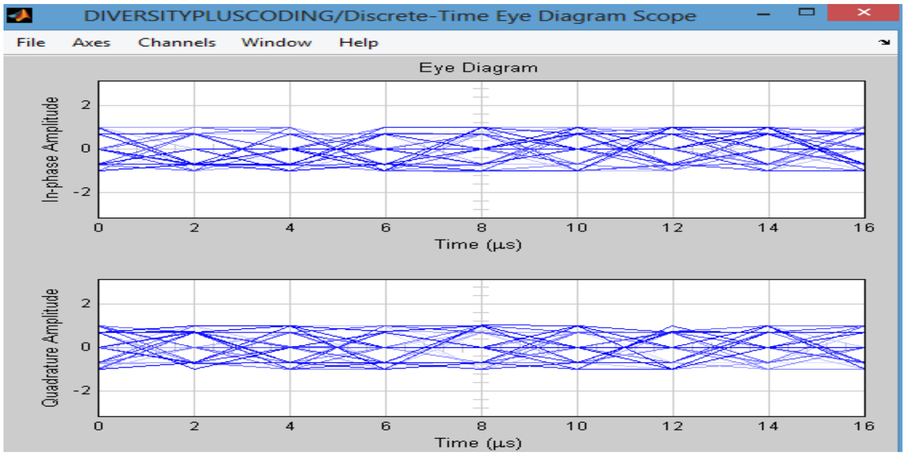

Figure 4.5: Eye Diagram for Performance Analysis of Diversity/Coding Mitigation scheme.

4.1 PERFORMANCE ANALYSIS

In fig 4.1, a FER rate of 10^{-2} require SNR of 18.5dB for the concatenation of diversity and coding but 20.4dB for independent diversity scheme and more than 24 dB for coding scheme. This shows that the combination of two schemes produce a gain of approximately 2 dB over diversity scheme and more than 6 dB over coding technique. It can also be inferred from the plot that diversity scheme performs better than coding in a multipath Rayleigh channel.

Similarly, in fig 4.2, frame error rate (FER) of 10^{-2} requires SNR of 17 dB for the combined scheme and about 17.7 dB for coding only while the diversity scheme takes 19 dB to produce same FER in Rician channel. Fig. 4.2 showed that coding mitigation technique outperforms diversity scheme in Rician multipath fading channel. Also, a comparison of fig. 4.1 and fig. 4.2 shows that the concatenation of the two schemes is better in Rician channel than Rayleigh channel which affirmed the fact that Rayleigh fading channel has no predominant LOS among the several paths and hence the worst case fading scenario.

The signal's trajectory, plot of scatters and eye diagram scopes of the simulation are also provide for visual analysis of performance of the concatenation scheme. The Discrete-Time scatter plot and Signal Trajectory scopes displayed the modulated signal constellation in its signal space by plotting the in-phase component against the quadrature component.

Figures 4.3 and 4.4 showed 8-constellation points which correspond to the M-ary number of the M-PSK/TCM modulation scheme. The 8 constellation points are equally spaced around a circle which shows minimal distortions and higher immunity to channel corruption.

5 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Multipath fading occurs in any propagation environment with the possibility of transmitted signal taking several paths and/or with relative motion among the receiver and the transmitter. The overall signal at the receiver is the summation of the various copies of the transmitted signal. As they all have different path lengths, they may add or subtract from the total received signal depending on their relative phases. This can cause problems of distortion and intersymbol interference during data transmissions. The performance of wireless mobile communication systems can be improved by mitigating fading with diversity, equalization, and channel coding techniques. Other forms of diversity include time diversity as seen in the rake receiver used in CDMA, frequency diversity, polarization diversity and pattern diversity. A diversity reception finds practical application in wireless microphone, which switches between antennas in few microseconds when one of the antennas encounters noise. Mobile phone antennas also use diversity to improve signal reception. When diversity scheme is applied at both ends of the channel, it is termed space-time coding.

From the simulation results, I was able to compare the performances of two independent mitigation schemes as well as their concatenation and discovered that independent diversity scheme performs better in a multipath Rayleigh fading channel than channel coding but in the case a Rician channel, channel-coding technique outperforms diversity mitigation technique. The concatenation of spatial diversity and channel coding combines the diversity gain of orthogonal space-time block codes (OSTBC) and the coding gain of trellis-coded modulation (TCM) for performance improvement as seen from the results of the simulation. One advantage of this concatenation over OFDM is the use of M-PSKTCM, which combines coding, and modulation to provide a large gain and make efficient use of bandwidth. The proposed concatenation produced a gain of 5dB over OFDM-BPSK, which takes an SNR, of 22dB to obtain a bit error rate of 10-4 that was attained with a lesser value of 17dB with this concatenation. Similarly, the concatenated space-time block coding requires more than 18dB to give a FER of 10^{-2}, which takes a minimum of 17.6dB to achieve here. The spatial diversity gain offered by OSTBC and the coding gain offered by TCM makes the combination an excellent fading mitigation scheme refer to results of this study.

5.2 RECOMMENDATIONS

I recommend that further research into concatenation of two schemes such as coding/equalization and diversity/equalization should done to determine the most efficient and cost effective combination scheme for practical implementation. It is also recommended that when designing a wireless channel to withstand fading degradation, it is necessary to determine the nature of fading prevalent in channel since the performance of a particular mitigation scheme depends on the type of fading in the channel as shown by the simulation results.

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