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Analysis of Co-channel Interference in Rayleigh and Rician fading channel for BPSK Communication using DPLL

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Abstract---We have studied and analyzed the performance of Binary Phase Shift Keying signal over Rayleigh and Rician faded channel. Specifically we have introduced an adjacent channel interference caused by a tone processed with a cubic non linearity by raising an adjacent channel tone to the third power and experimented the performance variation of the DPLL based receiver structure of different order. A bit error rate performance is evaluated for two different types of channel with band limitted BPSK signal corrupted by arbitrary number of asynchronous Rayleigh and Rician-faded signals in presence of co-channel interfering signals.or the special case, performance analysis have been made for the proposed system for dealing with Rayleigh and Rician fading for different numbers of paths interfering signals in an interference limited environment. Bit error analysis based on the experimental results reveals that fading in co-channel interfering signals can have different impact on desired error rate performance. With the increase of order of DPLL the error rate performance of the system improves significantly.

Keywords—bit error rate; binary phase shift keying ; co-channel interference; digital phase lock loop; Rayleigh fading; Rician-fading

I. INTRODUCTION

The purpose of a PLL based receiver is to adaptively track and remove frequency/phase offsets that may exist between transmitter and receiver [1]. Multipath fading is the phenomena which is the root cause of creating the frequency/phase offsets between transmitted and received signal. Both small-scale fading and co-channel interference (CCI) limit the performances of wireless cellular systems. Multipath propagation leads to small-scale fading and frequency reuse causes co-channel interference. The Rayleigh fading model has been used extensively for describing the fading channel experienced by co-channel interfering signals [2] - [5]. BER performance improves as the fading of the interfering signal decreases[6]-[7]. Therefore, it is of interest to study the error rate of a system with Rician-faded co-channel interfering signals. However, the impact of the Rice factor of the co-channel user on the desired user's BER performance was not investigated. Recently, Giogetti and Chiani [5] studied the influence of fading on the Gaussian approximation for BPSK and QPSK with asynchronous CCI. Their work focused on Rayleigh-faded interference only. Further, it was noted in [4] that the simple Gaussian approximation is not suitable for studying the impacts of the fading in co-channel interference.

In this work, we have analyzed the performance of a DPLL based receiver structure of different orders in Rayleigh and Rician-faded co-channel interference in terms of Bit Error performance. In Section II of this paper a brief mathematical description of the system model have been made. Section III, describes the proposed structures of the DPLL based systems. Section IV is dedicated for experimental consideration, Results of simulation have been discussed in Section V. Finally conclusions have been made in Section VI.

II. BACKGROUND CONSIDERATION

We consider a band-limited binary phase keying (BPSK) signal corrupted by L-synchronous interfering signals that have the same modulation format as the desired user. The transmitted signal of the desired user is:

$$S_d(t) = \sqrt{2P_S T}\, s_d(t)\cos(\omega_c t) \tag{1}$$

where, ω_c is the carrier frequency, and P_S is the transmitted power, $s_d(t)$ is desired user base band signal given by:

$$S_d(t) = \sum_{k=-\infty}^{+\infty} a(k) g_T(t-kT) \tag{2}$$

Where $1/T$ is the symbol transmission rate and $g_T(t)$ is the impulse response of the transmitter pulse-shaping filter and energy is normalized to be unity i.e $\int_{-\infty}^{\infty} g_T^2(t)dt = 1$.

In BPSK modulation, $a(k)$ takes values from [+1,-1] with equal probabilities. When s_d is transmitted, it is subject to fading. A reasonable assumption is that all interfering signals have the same modulation format as the desired user signals. The ith interfering signal is:

$$S_i(t) = \sqrt{2P_i T}\, s_i(t)\cos(\omega_c t) \tag{3}$$

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Where, P_i is the transmitted power for the i^{th} interfering user signal and s_i is the i^{th} interferer baseband signal:

$$S_d(t) = \sqrt{2P_i T} s_i(t) \cos(\omega_c t) \tag{4}$$

where, b_i is the information bit of the i^{th} interferer which takes values form [+1,-1] with equal probabilities.

As the assumption above, both the desired user signal and interfering signals are transmitted over a slow fading channel. The received signal becomes:

$$R(t) = \sqrt{2P_s T} R_s s_s(t) \cos(\omega_c t + \theta_s)$$
$$+\sqrt{2P_i T} R_i s_i(t - \tau_i) \cos(\omega_c (t - \tau_i) - \theta_i) + n(t) \tag{5}$$

Where, τ_i represents the symbol asynchronism, which is the possible random misalignment of the i^{th} interfering user symbol with respect to the desired user symbol. And it is assumed to be uniform over [0, T]. In this work, we consider the synchronism. So we define that is equal to zero. *n(t)* is a zero-mean white Gaussian background noise process with two-sided power spectral density $N_0/2$; the phases and , for the desired user and the i^{th} interferer, respectively, representing the random phases introduced by the fading channels, are assumed to be mutually independent and uniformly distributed over (0, 2].

III. SYSTEM MODEL AND STRUCTURE OF THE DIGITAL PHASE LOCKED LOOP

The proposed DPLL is designed for carrier detection from noisy multipath faded signal, has four major components. Namely, IIR Band Pass filter, Phase Frequency Detector (PFD), Digital Loop Filter (DLF) and Numerically Controlled Oscillator (NCO). The block diagram of the total system is shown in the Figure 1.

A. *Infinite Impulse Response (IIR) filter*

The incoming signal is band pass filtered to ensure that high frequency components that would cause aliasing are not allowed into the system. Often this type of filter is called an anti-aliasing filter. An Infinite Impulse Response (IIR) filter was used to achieve the required band pass filtering. Often this type of filter is called an anti-aliasing filter. We have used a filter with lower stop band frequency as 800 MHz, lower pass band frequency 875 MHz, higher pass band frequency 925 MHz and, higher stop band frequency 1000 MHz. Lower stop band, pass band and higher stop band attenuation are taken as 60dB, 1 dB and 80 dB respectively.

B. *Phase Detector (PD)*

A very common and easy to implement PD is the Nyquist rate PD (NRPD). The NRPD is basically a digital multiplier. The incoming signal is band pass filtered to ensure that high frequency components that would cause aliasing are not allowed into the system. Often this type of filter is called an anti-aliasing filter. The digital phase difference signal is obtained by multiplying the numerically controlled oscillator (NCO) local reference signal with the incoming filtered signal. This is simply a vector multiplication of the filtered signal and the DPLL reference signal with the result being the required digital phase error. The output from the digital multiplier or the phase difference signal contain an average value. This average value is filtered out by the next stage in the DPLL, the digital filter. The NRPD was chosen as the PD to be implemented for this project.

C. *Loop Filter (LF)*

The digital LF is the next major component in the DPLL. The output from the PFD will ideally contain the difference and sum component of the input signal and the PLL reference signal. The digital filter is required to isolate the slow changing difference signal, which implies that it should be a low pass digital filter. If the difference signal is too large in terms of frequency that is the input signal and the DPLL reference signal are not reasonably close, the digital filter will reject the difference signal as well as the summation signal. A Finite Impulse Response (FIR) filter was used to achieve the required low pass filtering. FIR filters utilize a simple, non-recursive difference equation as shown below.

$$y(n) = \sum_{k=0}^{N-1} b_k x(n-k) \tag{6}$$

where, *x(n)* represents the waveform to be filtered and b_k represents filter coefficients, where the pass band is specified only in terms of samples.

The coefficients for the low pass filter is calculated by the inverse Fourier Transform (sampling method) where the pass band is specified only in terms of samples. Designing filter coefficients involves determining the frequency pass band and then calculating the inverse Fourier transform of this pass band. The inverse Fourier transform as it pertains to the frequency sampling method is as follows:

$$y(n) = \frac{1}{N} \sum_{k=-\frac{N-1}{2}}^{+\frac{N-1}{2}} H(k) e^{j\frac{2n\pi k}{N}} \tag{7}$$

It is important to note that this equation has a negative sampling range. This is because the required pass band is mirrored into negative time to allow the complex numbers to cancel as conjugates in the frequency domain. The calculated coefficients therefore have to be delayed by *(N-1)/2* when used in the FIR filter so the filter makes sense in the real world.

D. *Numerically Controlled Oscillator (NCO)*

Numerical control oscillator (NCO) takes phase-frequency difference signal as input and adjust its local reference signal's phase and frequency and outputs a new reference signal. Although a number of Numerically Controlled Oscillator algorithm have proposed, in this project work we have used a NCO for this research project which could be best described as a waveform-synthesizer NCO. A waveform-synthesizer

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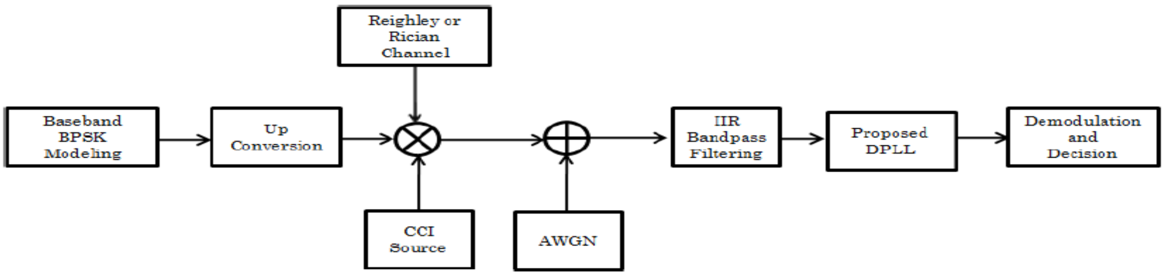

Figure 1: SISO setup in presence of CCI Source

NCO uses tables stored in read-only memory (ROM) to create cosine and/or sine waveforms. A fixed clock pulse is used to define sampled signals at a desired frequency. Signals with lower frequencies will therefore be generated with higher resolution than high frequency signals.

This algorithm accepts the filtered phase difference signal and outputs a new reference signal. The initial conditions required

for this program are a frequency value in hertz, a count of the samples in one cycle of initial frequency, and another flag that indicates whether the NCO reference signal is to be increased or decreased. The NCO should only change frequency if the input into the PLL is within a suitable range and to make sure this happens it is necessary to have a defined gain whereby signals can be rejected or accepted for calculation in the new frequency.

The new oscillator signal is calculated from the following formulas:

for a positive change in frequency:

$$freq = \left(1 + \frac{oldcount}{newcount}\right) \times freq \qquad (8)$$

for a negative change in frequency:

$$freq = \left(1 - \frac{oldcount}{newcount}\right) \times freq \qquad (9)$$

New NCO signal is generated by following question

$$newsignal = \cos\left(2 \times \pi \times freq \times clock\right) \qquad (10)$$

In the above equations ‘newcount' is the number of samples in one period of the phase difference signal and `oldcount' is the number of samples in one period of the previous oscillator signal. The `newcount' and `oldcount' values are determined by finding the difference between indexes for two sequential positive zero crossings in the relevant signal.

IV. EXPERIMENTAL CONSIDERATIONS

The experimental setup is shown in the Figure 1. We have used baseband modulators and demodulators with frequency up-conversion and down-conversion to simulate passband communication systems. In general, it is simpler and faster to model a system at complex baseband. However, there are some circumstances where it is preferable to model the system at real passband. An example of this is when an adjacent band tonal signal is processed with a nonlinearity, and causes interference in the band of interest. This experimental setup illustrates this scenario by assuming a BPSK communications system transmitting in two separate with band-limited BPSK signal corrupted by an arbitrary number of asynchronous Rayleigh and Rician-faded signals additive white Gaussian noise (AWGN) channel with interference in its passband. A tone in an adjacent channel that has been processed by a cubic nonlinearity causes this interference.

The simulation steps that we have followed are outlined below:

1. The first step of simulating a passband communication system is to modulate the random data in the baseband. We have generated random symbols and then modulate them with a BPSK modulator.
2. After modulation, we have applied pulse shaping using a square root raised cosine filter. Specified a square root raised cosine filter with a filter length of eight symbols and a rolloff factor of 0.2.
3. Then applied frequency upconversion to obtain a passband signal with a carrier frequency around 900 MHz. We have achieved this by multiplying the complex baseband signal with a complex sinusoidal and taking the real part
4. We have simulated the communication channel as a passband real Rayleigh and Rician channel in presence of AWGN with an adjacent channel interference caused by a tone processed with a cubic nonlinearity by raising an adjacent channel tone to the third power.
5. Then the signal been applied to the DPLL for phase and frequency locking purpose and demodulation.
6. And Number of Bit Error occurred is counted for different SNRs.
7. The steps are repeated for 1st order, 2nd order and 3rd order DPLL.

V. RESULTS AND DISCUSSION

We have estimated the spectrum of the signal for both before and after effects of noise channeling for two different types of channel with band-limited BPSK signal corrupted by an arbitrary number of asynchronous Rayleigh and Rician-faded signals in presence of co channel interfering signal at different

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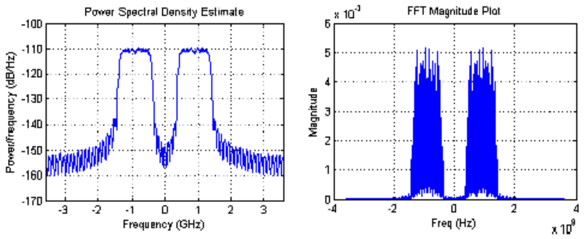
Table 1: Computational time in seconds for 10^8 numbers of symbols of Rayleigh and Rician Channel.

Computational time in seconds for 10^8 number of symbols		
DPLL Order	Rayleigh Channel	Rician Channel
1st Order	4.363875	4.359211
2nd Order	10.233521	10.232205
3rd Order	12.120036	12.200091

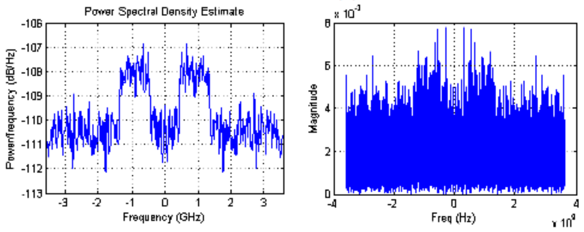
SNRs. Spectrum estimation have been made using two different tools namely, Power Spectral Density (PSD) and FFT magnitudes. The PSD, FFT of signal at various stages and constellation plot of corrupted channeled signals are shown in Figure 2 to Figure 5.

The system has been simulated for counting bit errors occurred during reception and demodulation of 10^8 numbers of transmitted bits with carrier frequency 900 MHz under uniform sampling 4.5 GHz.. We have generated channel parameters as a passband real Rayleigh and Rician channel with an adjacent channel interference caused by a tone processed with a cubic nonlinearity by raising an adjacent channel tone to the third power. Then, each of these faded signal set AWGN is added with SNR value ranging from 0dB to 14dB to produce further multiple sets of faded noisy signal sets, each representing combination of different fading conditions and different SNRs of received signal. The received signal samples are allowed to pass through the DPLL. Output of DPLL converted back to binary bits after necessary demodulation. Bit Errors occurred are counted. Figure 6 shows BER vs SNR plot in Rayleigh and Rician channel for 1st order DPLL From the plots we can conclude that 1st order DPLL is impractical to be used under fading environment.Figure 7 and 8 shows the BER vs SNR plot in Rayleigh and Rician channel using 2nd and 3rd order DPLL respectively.Comparing the plots(Fig.6,7 and 8) we can see that the receiver performance improves with the increase in the order of the DPLL.To established the fact we have generated two plots shown in the Figure 9 and Figure 10 for Rayleigh and Rician channel respectively which includes BER vs SNR plots of the different order of DPLL of interest.In the plots shown in the Figure 9 and Figure 10, we have compared our obtained results with already published results with the same communication scenarios but including their results in the same plot[8]-[9]. BER performance of the DPLL is represented by a BER VS SNR plots shown from Figure11 and Figure 12 for Rayleigh and Rician channel respectively.From the plot we can conclude that 1st order loop lacks practical importance while comparing the results obtained from 2nd and 3rd order DPLL,later provide a minimum of 3dB SNR gain over Rayleigh +CCI channel and a minimum of 0.9 dB SNR gain over Rician +CCI channel.Bit error rate analysis based on the experimental results reveals that, fading in the co-channel interfering signal can have different impacts on the desired error rate performance. With the increase of order of DPLL the error rate performance of the system improves significantly.

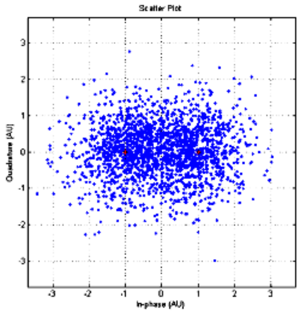
Computational time is one of the most important factors which need to be considered during design of a wireless communication system for real time applications. One must note that with the increase in the order of the DPLL, system becomes more complex and time of computation also increases sharply. We have performed our simulation using MatLab 10 under Windows 7 operating system with Intel Core i5 processor, the total Computational Time involved for 10^8 numbers of Bits for different order of DPLL and in different channel is tabulated in Table 1.. Comparing the table data,we can infer that with the increase in the order of DPLL the system performance improves but at the cost of computational time.



(a) Signal PSD before Channel (b) Signal FFT before Channel

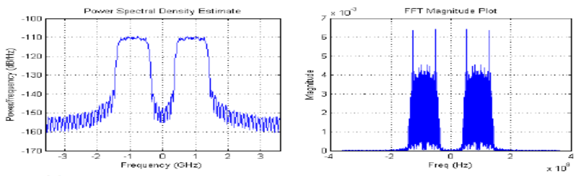


(c) Signal PSD after Channel (d) Signal FFT after Channel

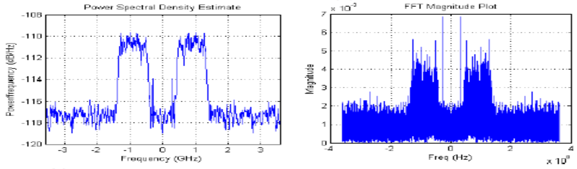


(e) Constellation of Received Signal

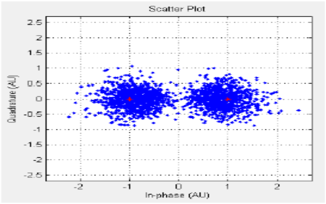
Figure 2: For Rayleigh Channel at 0dB SNR



(a) Signal PSD before Channel (b) Signal FFT before Channel

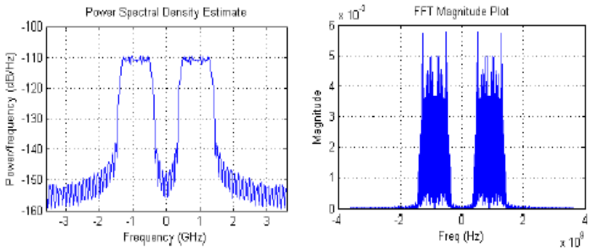


(c) Signal PSD after Channel (d) Signal FFT after Channel

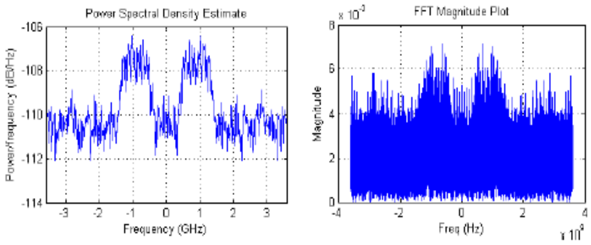


(e) Constellation of Received Signal

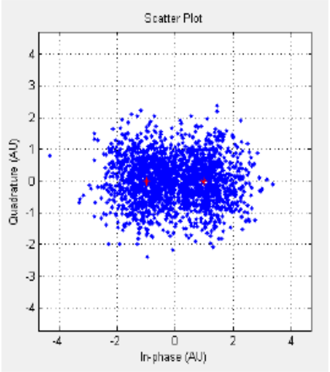
Figure 3: For Rayleigh Channel at 8dB SNR



(a) Signal PSD before Channel (b) Signal FFT before Channel

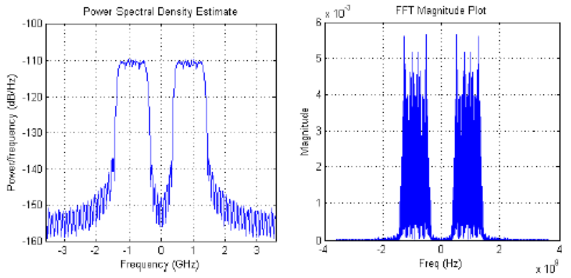


(c) Signal PSD after Channel (d) Signal FFT after Channel

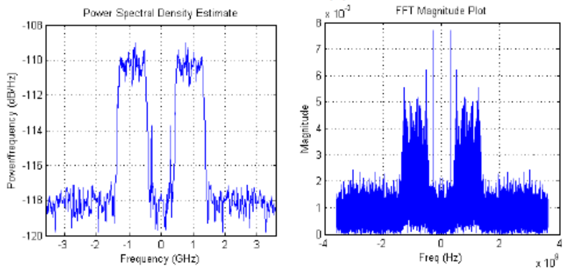


(e) Constellation of Received Signal

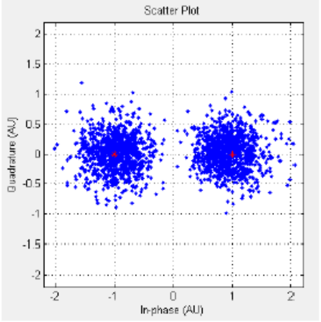
Figure 4: For Rician Channel at 0dB SNR



(a) Signal PSD before Channel (b) Signal FFT before Channel



(c) Signal PSD after Channel (d) Signal FFT after Channel



(e) Constellation of Received Signal

Figure 5: For Rician Channel at 8dB SNR

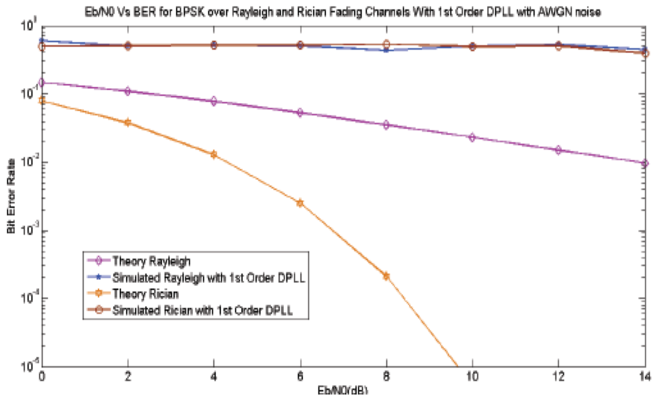


Figure 6: BER vs SNR plot in Rayleigh and Rician channel using 1st order DPLL

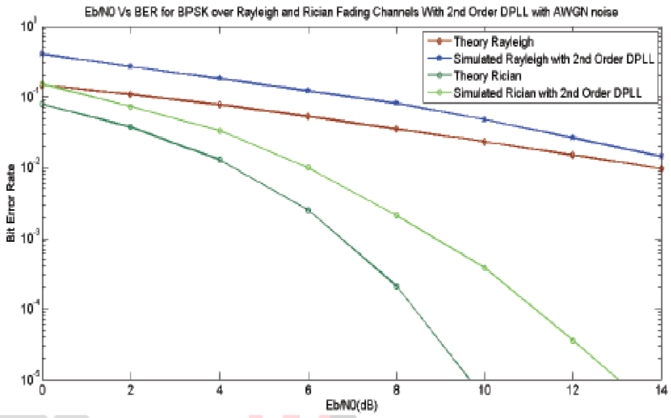


Figure 7: BER vs SNR plot in Rayleigh and Rician channel using 2nd order DPLL

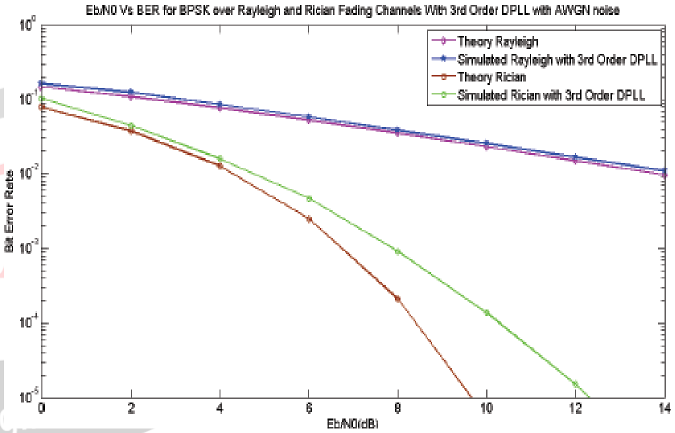


Figure 8: BER vs SNR plot in Rayleigh and Rician channel using 3rd order DPLL

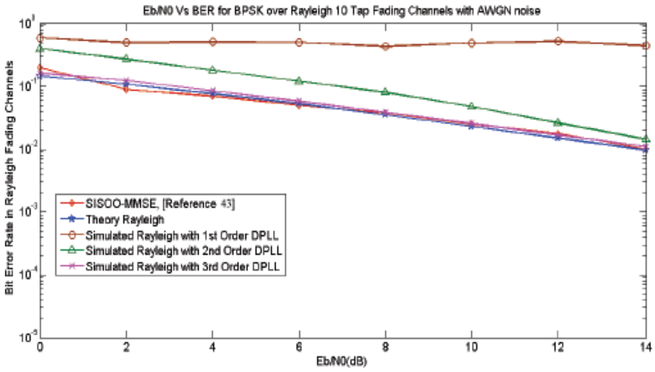


Figure 9: BER vs SNR plot in Rayleigh channel using 1st,2nd,3rd order DPLL

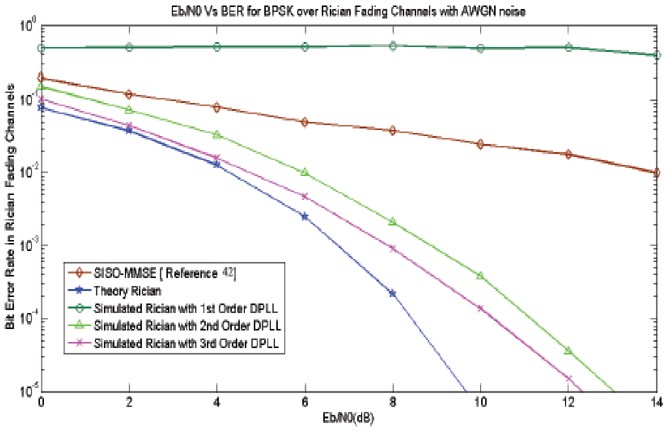


Figure 10: BER vs SNR plot in Rician channel using 1st,2nd,3rd order DPLL

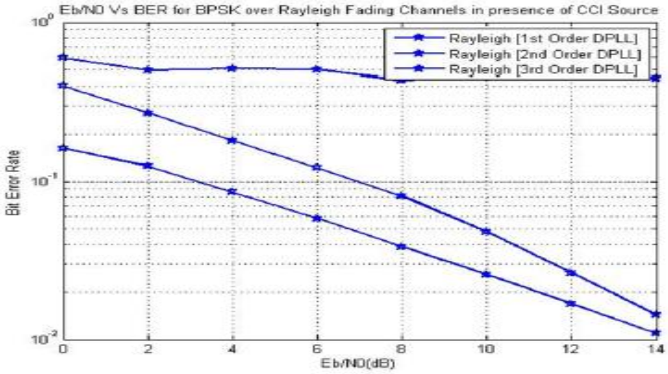


Figure 11: BER performance over Rayleigh Channel in presence of CCI Source

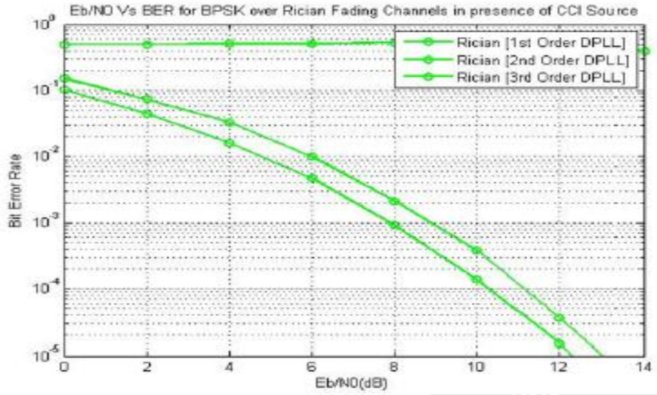


Figure 12: BER performance over Rician Channel in presence of CCI Source

VI. CONCLUSION

We have implemented DPLL based receiver structure of different order. We have analyzed the 1st ,2nd and 3rd order DPLL by varying the loop filter structure over the channel model based on Rayleigh and Rician distribution. The result of simulation of the DPLL structure shows that with the increase in the order of the DPLL, system provides better performance. We have also given a precise look at the computational time involved with DPLL of different order.We found that 1st order loop lack importance. But the 2nd and 3rd order DPLL provide acceptable result at the cost of computational time.We have also analyzed the performance of Binary Phase Shift Keying (BPSK) signal over Rayleigh and Rician-faded channel. Specifically we have introduced an adjacent channel interference caused by a tone processed with a cubic nonlinearity by rising an adjacent channel tone to the third power and experimented the performance variation of the DPLL based receiver structure of different orders. A bit error rate performance is evaluated for two different types of channel with bandlimited BPSK signal corrupted by an arbitrary number of asynchronous Rayleigh and Rician-faded signals in presence of co channel interfering signals. For the special case, performance analysis have been made for of the proposed system for dealing with Rayleigh and Rician fading for different numbers of paths interfering signal in an interference-limited environment. Bit error rate analysis based on the experimental results reveals that, fading in the cochannel interfering signal can have different impacts on the desired error rate performance. With the increase of order of DPLL the error rate performance of the system improves significantly.

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