Probability Density Function Analysis of Multipath Fading with Phase Error over Rayleigh and Rician Fading Channels in Equal Gain Diversity

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Abstract:- The performance and capacity improvement of Wireless Communication (WC) are growing tremendously due to its global acceptability. However, it suffers from multipath fading, which is made worse as a result of the imperfect recovery of the carrier phase by the Phased Locked Loop (PLL) circuit, thereby, causing Phase Error (PE). The previous analyses over various channels resulted in very difficult and complex integrals. This work is an attempt to analyze the WC in Rayleigh and Rician channels corrupted by multipath fading with phase error, using PDF (Probability Density Function) in Equal Gain Combining (EGC) statistical analysis. Closed form expressions were derived over independent and identically distributed (i.i.d) channel for different schemes. BER for BPSK modulation was obtained. Numerical and simulation results for different degrees of phase error were obtained. The results show that the higher the degree of the PE, the higher the Bit Error Rate and the Outage Probability, indicating that the PE must be kept within the allowable values.

Keywords:- *Phase Error, Bit Error Rate, Outage Probability, PDF, EGC.*

I. INTRODUCTION

Wireless Communication (WC) is the transmission of information from one place to another without any physical connection. It is one of the fastest developing areas of digital communications with applications in global interconnection of computers, mobile communication and satellite communications. The increasing demands for emerging wireless systems by multiple users have led to advancement in electronic technology producing more fascinating mobile devices and life changing Information Technology (IT) products [32]. These developments allow people to operate a virtual office using a small handheld device with seamless telephone and computer communications anywhere in the world [11]. This progress has made a positive impact on the mode of communication for business, education, research and personal communication [8, 25, 29, 27, 31, 14]

The WC channel is the atmosphere which consists of both the troposphere and the ionosphere; these two environments possess challenges ranging from obstruction, absorption, scattering and so on, causing severe impairment. In the terrestrial environment, there are many tall buildings, trees, foliage and sky-scrappers either densely or scarcely populated, which may corrupt the signal or thus cause the signal to have different orientation. Therefore, the WC channel possesses very serious challenge that could affect the signal propagation in the channel [25, 13].

The characteristics of this channel cause multipath propagation which occurs as a result of the obstacles or different objects encountered by the signal in the WC channel. Therefore, the transmitted signal takes multiple paths to reach the receiver; hence, many copies of the signal are generated as if coming from different sources. These multiple signals arrived at the receiver and combine to form a resultant signal with varying amplitude and phase over a period of time. The consequence of this is rapid fluctuations of the signal amplitude and phase over a period of time and distance. This is called multipath fading and the performance of the system in the presence of this fading, therefore, becomes very poor [18, 23].

Further to the multipath fading is the imperfect recovery of the carrier phase, which leads to phase error and further degrades the system performance considerably. Physical impairments suffered by wireless communication in a multipath channel, therefore, include but not limited to multipath fading, Doppler spread, delay spread, phase error and interference from other users. These impairments cause performance degradation at the receiving end [16, 21, 26, 6]

Diversity combining has been the most common technique to ameliorate the destructive effect of multipath fading. The technique exploits the multipath propagation effects by treating each of the multiple signals as a single entity coming from a different source and thus combine the multiple signals for a better reception at the receiver. In WC, various diversity combining techniques employed to combat fading are Selection Combining (SC), Maximal Ratio Combining (MRC) and Equal Gain Combining (EGC). MRC gives an optimum performance but the complexity is high in terms of implementation. EGC performance is very close to that of MRC and it is relatively less complex in its implementation. SC is the least in performance but very simple to implement [9, 11, 24, 20].

WC channels are modelled by different distributions that describe the statistical behaviour of the channel depending on the nature of the WC environment. These include: Rayleigh, Weibull, Nakagami-m, and Rician [24, 20]. This research, therefore, is an attempt to statistical analyse EGC with phase error over Rayleigh and Rician fading channels and to investigate the adverse effect of

Phase Error (PE) on the performance of WC system using Binary Phase Shift Keying (BPSK) as a modulation technique, Bit Error Rate (BER) and Outage Probability (P_0) as performance metrics.

II. RELATED WORKS

[19]Studied the effects of phase estimation errors on RAKE receiver performance, the authors stated that the challenges posed by multipath fading and thermal noise in spread spectrum systems were resolved by diversity and coding. However, the system performance is increasingly being degraded by channel estimation error, it is therefore, appropriate to design a system, that incorporate the effects of estimation errors. Closed-form expression was obtained for a RAKE receiver operating with imperfect phase error, using error function integrals to evaluate this effect of channel estimation error. [21] studied the effect of carrier phase error on EGC receivers in correlated Nakagami-m fading channel. In the research, impairments such as noise and interference which lead to phase error were identified as a major problem confronting mobile communication channel. The MGF approach was used to model the mobile communication channel receiver with P$\acute{a}$de Approximation (PA) used to truncate the infinite series expansion of the MGF. Closed-form expressions were obtained using Amount of Fading, (AF), Outage Probability (P_o) and Average Bit Error Probability (ABEP) with dual-branch, EGC.[26] researched on the performance analysis of generalized faded coherent PSK channels with EGC and carrier phase error. The authors based the modelling on the Beaulieu series for the cumulative distribution function (CDF). This was done over Nakagami-m, Rician and Rayleigh fading channel. The closed-form expressions obtained were used to evaluate the performance of PSK modulation over EGC with phase error in a mobile wireless communication channel. [29] worked on the effect of imperfect channel estimation on the performance of MRC in the presence of Co-Channel Interference (CCI) with both equal and un-equal power interferers, over slowly varying flat Rayleigh fading channel that was also spatially independent. The work emphasizes the challenge of multipath and CCI as major impairment in mobile wireless communication systems. The author stated that, spatial combining cannot be performed optimally in practical systems due to inaccuracies in channel estimation. Therefore, it is of practical interest to examine the performance degradation caused by the phase error. The modelling of Signal to Interference Noise Ratio (SINR) and P_o of system with multiple CCI with equal or unequal power levels was the main focus of the research. [2] investigated the impact of channel estimation error on the performance of MRC system in the presence of CCI with an arbitrary Power Interference to Noise Ratio (PINR). [6] investigated Average Bit Error Rate (ABER) of EGC receiver over correlated Hoyt fading channels with phase error and co-channel interference. In the work, the challenge of phase error and co-channel interference was emphasized, closed-form expressions were obtained through the MGF series in combination with P$\acute{a}$de Approximation (PA). [7] studied the ABEP of EGC receiver over composite and non-homogenous fading channels with PE and CCI, the problem of fading caused by both PE and CCI were identified as the two major factors degrading the system performance.The authors assumed an imperfect carrier phase error over correlated Generalized Gamma (GG) distribution. [4] presented a study on performance analysis of MRC receiver with channel estimation error and CCI in Nakagami-m fading channel. [5] derived a stochastic model to study L-branch EGC combiner with carrier PE and CCI over Nakagami-m fading channel using the PDF method. [33] worked on comparative study of carrier estimation methods in dispersion-unmanaged optical transmission systems, the research studied three methods of carrier phase estimation which were one-tap normalized least-mean-square algorithm, a block-wise average algorithm and a Viterbi-Viterbi algorithm in coherent optical transmission systems. [22]developed L-MRC receiver with estimation error over Hoyt fading channels. The authors used the PDF based approach combine with the conditional BER of the Hoyt fading channel. Channel capacity and ABEP were used as performance metrics. [1] study the Moment Generating Function (MGF) analysis of spatial diversity combiner over composite Rayleigh and Rician fading channel. The authors claimed that the modelling of the wireless environment is highly challenging because of the two models involved. An approximated MGF was developed for both EGC and MRC using Taylor's series, which was generated from the expected values of the combined Rayleigh and Rician fading channel. The models developed through PA were evaluated using amount of fading (AF) and BER. [10] analyze the performance of QAM for L-MRC receiver with estimation error over independent Hoyt fading channel. The difficulty in having an ideal channel estimator which could leads to estimation error in both phase and envelope of the estimated channel information was clearly affirmed by the authors. The work derived a general expression for ABER for arbitrary branch of MRC while taking imperfect channel estimation over Hoyt fading channel.

III. THEORETICAL FORMULATION

A. *Channel Model*

The instantaneous SNR (B_e) in the presence of PE in L-branch EGC was given in[4] as

$$B_e = \left(\sum_{l=1}^{L} \sqrt{B}\cos\theta_l\right)^2 \qquad (1)$$

Where 'B' is the fading distribution considered and is the instantaneous SNR of the fading distribution. $\cos\theta_l$ is the cosine of the phase angle θ_l in each l^{th}paths. Consequently, from this equation, using the PDF based approach to find the PDF of B_{egc}, requirethe derivation of the PDF of $\sqrt{B}$, θ_l, and $\cos\theta_l$. The PDF of θ_l, which is Tikhonov distributed, $f_{\theta_l}(\theta_l)$ is given in[16] and simplified in[6] as

$$f_{\cos\theta_l}(\cos\theta_l) \cong f_{\theta_l}(\theta_l) = \frac{exp-\left(\frac{\rho_l{\theta_l}^2}{2}\right)}{\sqrt{\frac{2\pi}{\rho_l}}} = \sqrt{\frac{2\rho_l}{\pi}}\frac{exp-\left(\frac{\rho_l{\theta_l}^2}{2}\right)}{\theta_l} \qquad (2)$$

Equation (2) is valid because the value of PE must be very small for a meaningful signal reception at the receiver, and that $\sin\theta_l \cong \theta_l$ in radian when $1^0 \leq \theta \leq$

10^0.Where,ρ_l is the SNR of the Carrier Recovery Loop (CRL) and is related to σ_l, the Phase Error (PE) given by[15] as.

$$\rho_l = \frac{1}{(\sigma_l)^2} \Rightarrow \sigma_l = \sqrt{\frac{1}{\rho_l}} \qquad (3)$$

This implies that the higher the CRL, the lower the value of PE.

B. *Probability Density Function of Rayleigh Fading Channel with Phase Error*

In Rayleigh fading channel, the PDF of the fading distribution is given by [24] as

$$f_B(B) = \frac{1}{\bar{B}} \exp\left(\frac{-B}{\bar{B}}\right) \qquad (4)$$

Using the random variable transformation as given by [27], the PDF of$\sqrt{B}$is derived as

$$f_{\sqrt{B}}(\sqrt{B}) = 2\frac{B}{\bar{B}} \exp\left(\frac{-B}{\bar{B}}\right) \qquad (5)$$

From the obtained PDFs in (2) and (5) and with the random variable transformation as given by [28], using the identities in [12]and the modified Bessel function of the second kind given in[17], the PDF of the product $C = \sqrt{B} \times \cos\theta_l$ is derived as the PDF of the Rayleigh fading channel in the presence of PE is therefore, after some mathematical operations

$$f_{C_l}(C_l) = \left(\frac{1}{\bar{B}}\right)^{\frac{3}{2}} \rho_l exp\left(-2\sqrt{\frac{\rho_l}{\bar{B}}}\, C\right) \qquad (6)$$

Equation (6) is the PDF of a single Rayleigh fading channel in the presence of PE, when there are Lth multipath channels, then these can be received by L number of properly placed antennae and therefore becomes necessary to combined them using EGC, consequently, the joint PDF at the output of the EGC diversity combiner, is derive from the Characteristics Function, (CHF), which is the Fourier Transform (FT) of C.For L-branch EGC receiver with PE equation (1) is equal to the square of the summation of $C_1 \ldots\ldots C_L$. With CHF given in [28, 12], and after some mathematical analysis the PDF of $B_e$is derived as

$$f_C(C) = \frac{{\rho_l}^L C^{L-1} e^{-2\sqrt{\frac{\rho_l}{\bar{B}}}C}}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \qquad (7)$$

but substituting for C, (9) becomes

$$f_{B_e}(B_e) = \frac{{\rho_l}^L\left(\sqrt{B_e}\right)^{L-1} exp\left(-2\sqrt{\frac{\rho_l}{\bar{B}}B_e}\right)}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \qquad (8)$$

IV. SYSTEM PERFORMANCE MEASURES

A. *Outage Probability of EGC in Rayleigh Fading Channel with Phase Error*

To determine Outage Probability,(P_o) for the output of the EGC, the expression for (P_o) is given by [24] as

$$P_o = \int_0^{B_{th}} f_{B_e}(B_e)dB_e \qquad (9)$$

By substituting and simplifying of (8) in (9) with$y = \sqrt{B_e}$then,

$$P_o = \frac{2{\rho_l}^L}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \int_0^{B_{th}} y^L exp\left(-2\sqrt{\frac{\rho_l}{\bar{B}}}\, y\right) dy \qquad (10)$$

Using the table of integrals in[12] and bysimplifying, (10) is

$$P_o = \frac{2{\rho_l}^L}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \left(2\sqrt{\frac{\rho_l}{\bar{B}}}\right)^{-(L+1)} \gamma\left(L+1, 2B_{th}\sqrt{\frac{\rho_l}{\bar{B}}}\right) (11)$$

where, $\Gamma(.)$ is the complete gamma functionand $\gamma(. , .)$ is the incomplete gamma function and using the definition given by [12] for the incomplete gamma function in (11) becomes by substitution in (12) given below.Equation (12) is the P_o closed-form expression for a Rayleigh fading channel in the presence of PE.

$$P_o = \frac{L!\, {\rho_l}^{\frac{1}{2}(L-1)} (\bar{B})^{\frac{1}{2}(2L-1)}}{2^L\Gamma(L)} \times \left[1 - exp\left(-2B_{th}\sqrt{\frac{\rho_l}{\bar{B}}}\right)\left(\sum_{b=0}^{L} \frac{\left(2B_{th}\sqrt{\frac{\rho_l}{\bar{B}}}\right)^b}{b!}\right)\right] \qquad (12)$$

B. *Bit Error Rate (BER) in Rayleigh Fading*

The BER is obtained from the expression given by [24] as

$$P_E = \int_0^{\infty} Q\left(a\sqrt{2gB_e}\right) f_{B_e}(B_e)\, dB_e \qquad (13)$$

$$P_E = \int_0^{\infty} Q(a\sqrt{2gB_e}) \frac{{\rho_l}^L\left(\sqrt{B_e}\right)^{L-1} exp\left(-2\sqrt{\frac{\rho_l}{\bar{B}}B_e}\right)}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \qquad (14)$$

but $Q(x)$ is the Marcum Q function is defined by [17, 12] and$a$ and g are define for various modulation schemes in [3], therefore, the Marcum Q function as given in (15). Substituting (15) in (14) and after series of Mathematical operations using the identities in [12], the Bit Error Rate P_E is derived in (16). Using (3) the outage probability and the bit error rate in terms of PE in Rayleigh fading channel are derived as (17) and (18).

Equation (8) is the PDF of the EGC in the presence of the Phase Err

$$Q\left(a\sqrt{2gB_e}\right) = \quad \frac{1}{2} - \frac{2}{\sqrt{\pi}} \sum_{m=0}^{\infty} \frac{(-1)^m (a\sqrt{g})^{2m+1}}{m!(2m+1)} \left(\sqrt{B_e}\right)^{2m+1} \tag{15}$$

$$P_E = \frac{{\rho_l}^L}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \left[\left(\frac{1}{2}\right)^{L+1} \left(\sqrt{\frac{\bar{B}}{\rho_l}}\right)^{L+1} \Gamma(L+1) - \frac{2(a\sqrt{g})^{2m+1}}{\sqrt{\pi}} \sum_{m=0}^{\infty} \frac{(-1)^m}{m!(2m+1)} \left(\frac{1}{2}\sqrt{\frac{\bar{B}}{\rho_l}}\right)^{2m+L+2} \times \Gamma(2m+L+2) \right] \tag{16}$$

$$P_o = \frac{L!{\sigma_l}^{(1-L)}(\bar{B})^{\frac{1}{2}(2L-1)}}{2^L\Gamma(L)} \left[1 - exp\left(-\frac{2B_{th}}{\sigma_l}\sqrt{\frac{1}{\bar{B}}}\right) \times \left(\sum_{k=0}^{L} \frac{\left(\frac{2B_{th}}{\sigma_l}\sqrt{\frac{1}{\bar{B}}}\right)^k}{k!} \right) \right] \tag{17}$$

$$P_E = \frac{(\sigma_l)^{-L}}{(\bar{B})^{\frac{3}{2}L}\Gamma(L)} \left[\left(\frac{1}{2}\right)^{L+1} \left(\sigma_l\sqrt{(\bar{B})}\right)^{L+1} \Gamma(L+1) - \frac{2(a\sqrt{g})^{2m+1}}{\sqrt{\pi}} \sum_{m=0}^{\infty} \frac{(-1)^m}{m!(2m+1)} \left(\frac{\sigma_l}{2}\sqrt{(\bar{B})}\right)^{2m+L+2} \Gamma(2m+L+2) \right. \tag{18}$$

$$f_{B_e}(B_e) = \frac{[J\Gamma(P+1)]^L}{\Gamma(L(P+1))} (B_e)^{-\frac{1}{2}(L(P+1)-1)} \exp\left(-\sqrt{\frac{2\rho_l(1+K)B_e}{\bar{B}}}\right) \tag{19}$$

where $J = R\sqrt{\frac{\pi}{2}}\left(\frac{\bar{B}}{2(1+K)}\right)^{\frac{2+P}{2}} (\rho_l)^{\frac{1+P}{2}}$ for simplification

$$P_O = 2\frac{\left(L(P+1)\right)!}{\Gamma\left(L(P+1)\right)} \times \left(\frac{\bar{B}(\sigma_l)^2}{2(1+K)}\right)^{\frac{1}{2}(L(P+1)+1)} \times \left(e^{-K} \sum_{P=0}^{\infty} (-1)^P \frac{K^P(1+K)^{\frac{P}{2}}\Gamma(P+1)}{(2\bar{B})^{\frac{P}{2}}(P!)^2(\sigma_l)^{2+P}} \right)^L \times \left[1 - \exp\left(-\frac{B_{th}}{\sigma_l}\sqrt{\frac{2(1+K)}{\bar{B}}}\right) \times \sum_{b=0}^{L(P+1)} \frac{\left(\frac{B_{th}}{\sigma_l}\sqrt{\frac{2(1+K)}{\bar{B}}}\right)^b}{b!} \right]$$

(20)

$$P_E = \left(e^{-K} \sum_{P=0}^{\infty} (-1)^P \frac{K^P(1+K)^{\frac{P}{2}}}{(2\bar{B})^{\frac{P}{2}}(\sigma_l)^{2+P}(P!)^2} \right)^L \frac{\Gamma(P+1)^L}{\Gamma\left(L(P+1)\right)} \left(\frac{\bar{B}(\sigma_l)^2}{2(1+K)}\right)^{-\frac{1}{2}(L(P+1)+1)} \Gamma\left((L(P+1)+1)\right) - 2\left(e^{-K} \sum_{P=0}^{\infty} (-1)^P \frac{K^P(1+K)^{\frac{P}{2}}}{(2\bar{B})^{\frac{P}{2}}(\sigma_l)^{2+P}(P!)^2} \right)^L \frac{\Gamma(P+1)^L}{\Gamma\left(L(P+1)\right)} \times \frac{2}{\sqrt{\pi}} \sum_{m=0}^{\infty} \frac{(-1)^m (a\sqrt{g})^{2m+1}}{m!(2m+1)} \left(\frac{\bar{B}(\sigma_l)^2}{2(1+K)}\right)^{-\frac{1}{2}(2m+L(P+1)+2)} \times \Gamma((2m+L(P+1)+2)) \tag{21}$$

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Equations (8), (17) and (18) are the PDF, P_o and BER models developed at the output of the EGC with the PE in a Rayleigh fading channel. In a similar fashion, (19), (20) and (21) are the PDF, P_o and PE models developed at the output of the EGC with the PE in a Rician fading channel.

V. RESULTS AND DISCUSSION

Fig.1 and 2are the graphs of BER against SNR for two different values of PE and different number of paths. Fig.1 depicts the result in a Rayleigh fading channel, for SNR of 10 dB, and at PE of 3°, the P_E results obtained for L of 2, 4, 8 were 1.19×10^{-4}, 5.93×10^{-8} and 1.48×10^{-9}, respectively. While at 12° PE and at 10 dB SNR, 9.49×10^{-1}, 2.37×10^{-2} and 34×10^{-3} were obtained, respectively. These results confirm the earlier result that with a high PE, the received signal strength will be very low, therefore, quality of the received signal is not guaranteed. Fig. 2 shows a similar result over a Rician fading channel, where, at SNR of 10 dB, with PE of 3°, 2.71×10^{-10}, 3.76×10^{-14} and 3.63×10^{-22}, were obtained as BER results while at 12° PE, the BER results of1.78×10^{-5}, 6.35×10^{-7} and 6×10^{-9}, were obtained respectively for L of 2, 4, 8. These results also confirmed that Rician fading channel is a better channel to transmitin than Rayleigh fading channel. The results show clearly that any increase in PE more than the allowable value will have an adverse effect on the signal transmitted.

Fig. 3 and 4 show the relationship between BER and PE in Rayleigh and Rician fading channel. Fig.3 shows that in a Rayleigh fading channel with a constant SNR of 2 dB, at 10° PE, the BER result obtained for L of 2, 4, 8 were 8.84×10^{-1}, $1.11 \times 10^{-1}$and 8.3×10^{-3}, respectively. While in Fig.4 for Rician fading channel the BER results at a constant value of 2 dB SNR and 10° PE, were 3.39×10^{-8}, $1.18 \times 10^{-10}$and 7.13×10^{-16}, respectively. The results show that as the number for path increases the BER decrease, this implies that the more the number of receiving antennae the better the performance of wireless communication channels. This also reveal that the Rayleigh channel degrades the performance of WCS while the Rician channel as a result of LOS components offers an improved performance in wireless communication systems (WCS).

Fig.5 to 6 depict the performance of the Outage probability (P_o) and Phase Error (PE) at different values of SNR and threshold. Fig.5 to 6 were obtained at a threshold value of 2 dB. Fig.5 shows the outage probability over a Rician fading channel versus phase error. The P_o obtained at a PE of 2° were 1.57×10^{-4} and 3.82×10^{-23} for L of 2 and 8, respectively, while at 18° the P_o results were 7.82×10^{-4} and 2.98×10^{-18}, respectively, for L of 2 and 8. The results in a Rayleigh fading channel is given in Fig.6, again PE of 2°, the P_o obtained were respectively 4.3×10^{-2} and 2.71×10^{-10} for L of 2 and 8, respectively, while at PE of 18°1.26×10^{-2} and 1.23×10^{-5} were obtained for L of 2 and 8 respectively. Fig.5 and 6 were obtained at a threshold value of 2 dB.

Fig.7 and 8 show the graphs of outage probability versus SNR. In Rayleigh fading channel, Fig.7 shows that at a threshold value of 2 dB, with a constant PE (pha) of 3°, the $P_o$results obtained at an SNR of 2 dB, were 1.36×10^{3}, 1.36×10^{3} and 2.48×10^{-1} for L of 2, 4 and 8, respectively, while at SNR of 18 dB, 3.48×10^{-2}, $3.1 \times 10^{-2}$and 1.22×10^{-2} are the corresponding values, respectively. Fig.8 show a similar result in a Rician fading channel, at L of 2 with SNR of 2 dB and 18 dB, the $P_o$values were $7.1 \times 10^{-2}$and 6.32×10^{-3}, respectively, at L of 4 the $P_o$values were 7.1×10^{-6} and 2.88×10^{-8}, respectively, while at L of 8, 7.1×10^{-14} and 2.99×10^{-17} were obtained respectively.

These results show that Rayleigh channel can attenuate a signal completely without adequate counter measure.

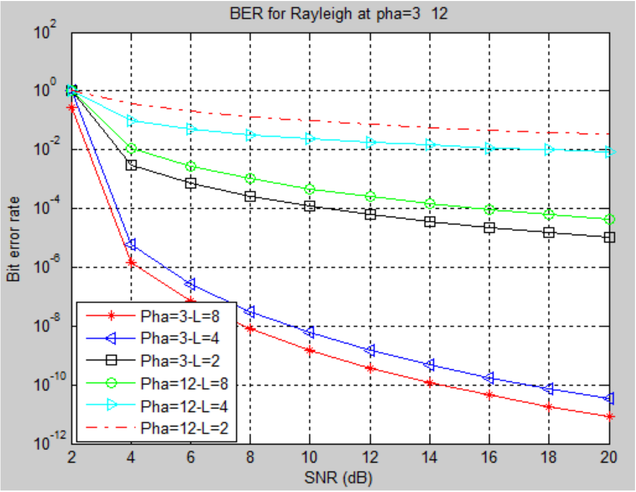

Fig. 1: Theoretical Bit Error Rate of BPSK modulated signal versus SNR at PE (pha) of 3o and 12o over Rayleigh fading channel for L of 2, 4 and 8

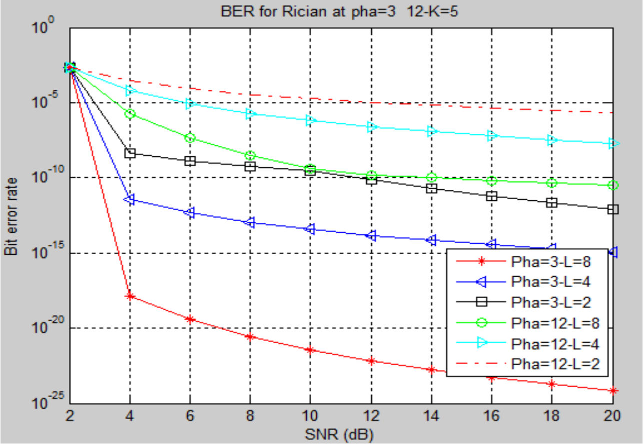

Fig. 2: Bit Error Rate of BPSK modulated signal versus SNR at PE (pha) of 3° and 12° over Rician fading channel at K of 5 and for L of 2, 4 and 8

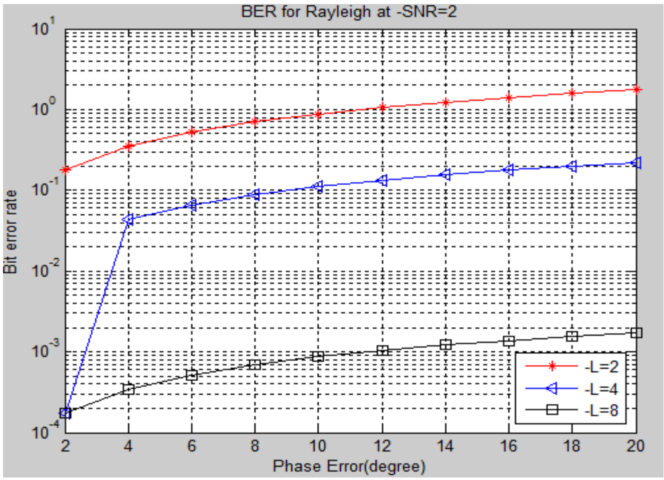

Fig. 3: Theoretical Bit Error Rate of BPSK modulated signal versus Phase Error at SNR of 2 dB over Rayleigh fading channel for L of 2, 4 and 8

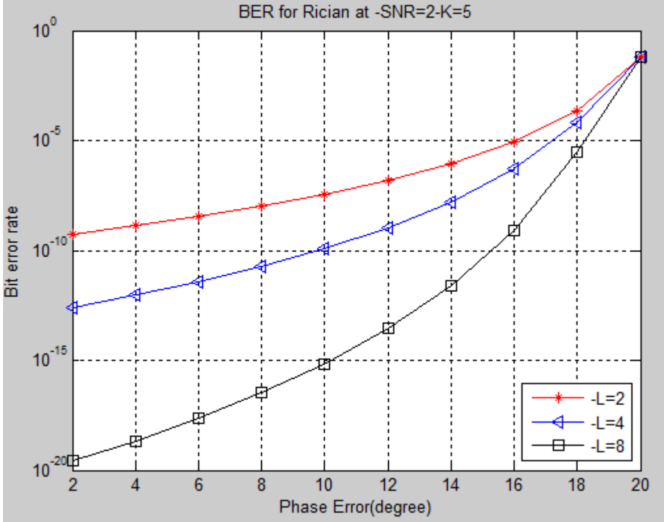

Fig. 4: Theoretical Bit Error Rate of BPSK modulated signal versus Phase Error at SNR of 2 dB over Rician fading channel at L of 2, 4 and 8

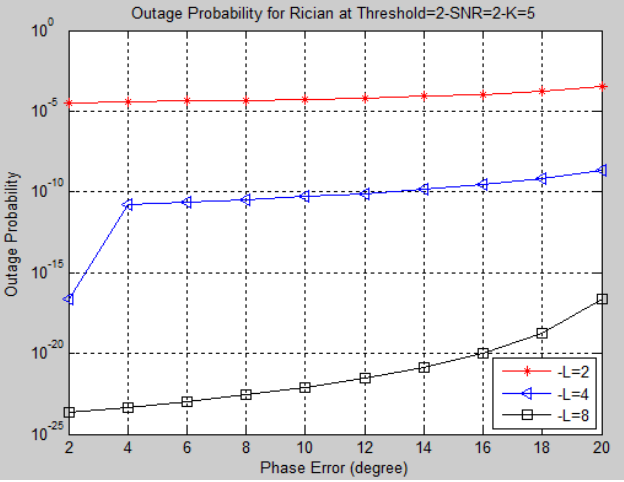

Fig. 5: Theoretical Outage Probability versus Phase Error at SNR of 2 dB and a threshold value of 2 dB over Rician fading channel at L of 2, 4 and 8

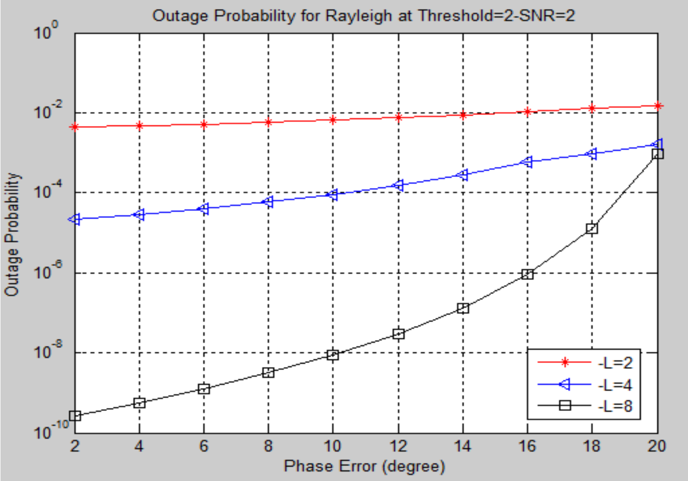

Fig. 6: Theoretical Outage Probability versus Phase Error at SNR of 2 dB and a threshold value of 2 dB over Rayleigh fading channel at L of 2, 4 and 8

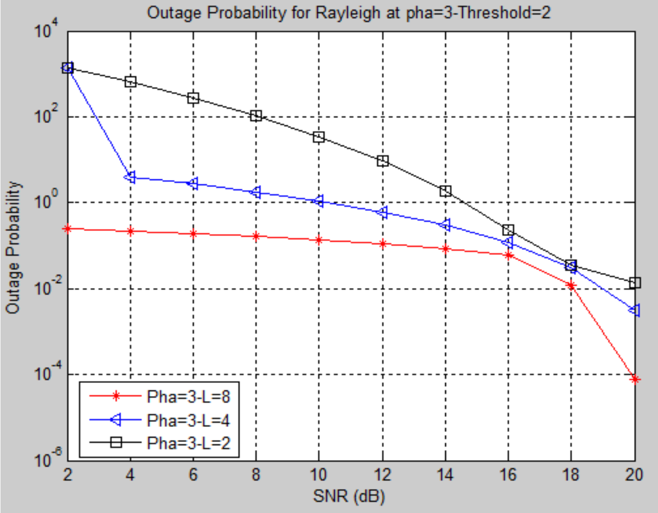

Fig. 7: Theoretical Outage Probability versus SNR at a PE (pha) of 3° and a threshold value of 2 dB over Rayleigh fading channel at L of 2, 4 and 8

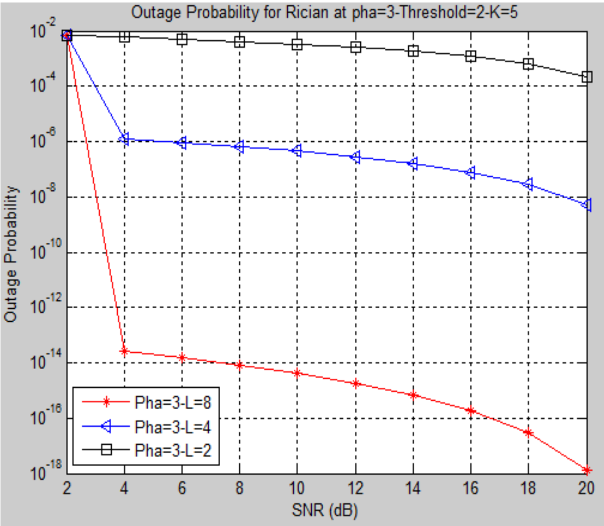

Fig. 8: Theoretical Outage Probability versus SNR at a PE (pha) of 3° and a threshold value of 2 dB over Rician fading channel with k of 5 and L of 2, 4 and 8

VI. CONCLUSION

This work has theoretically investigated the effects of phase error in fading channels; Rayleigh and Rician, the equations derived for the performance measures were in agreement with the simulation results.The results could serve as a guide for communication engineer in the design of WC systems in the presence of multipath fading and PE.

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