

# PERFORMANCE ANALYSIS OF COHERENT AND NONCOHERENT PLC SYSTEMS

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DEPARTMENT OF ELECTRICAL ENGINEERING  
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# PERFORMANCE ANALYSIS OF COHERENT AND NONCOHERENT PLC SYSTEMS

by

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# Certificate

This is to certify that the thesis entitled “**Performance analysis of coherent and noncoherent PLC systems**” being submitted by **Soumya Prakash Dash** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is the record of the bona-fide research work carried out by him under our supervision. In our opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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# Abstract

Unreliable transmission of data via power lines has been the most challenging aspect of the study of power line communication (PLC) systems. Unlike conventional wired communication systems, PLC systems encounter strong, time varying non-white and often non-Gaussian noise along with the presence of multi-path phenomenon. The additive noise in PLC is broadly classified as background and impulsive noise and its mathematical model depends on the frequency bandwidth of PLC operation. The reliability of the system is expressed in terms of the symbol error probability (SEP), and receive diversity scheme along with optimal modulation schemes are employed to achieve reliable communication via the PLC channels.

In this thesis, an  $N$ -branch diversity reception for a PLC system with binary phase-shift keying is employed to improve the reliability of data transmission. The PLC channel is subject to Rayleigh fading and is perturbed by additive Nakagami- $m$  background noise with  $m < 1$ , which is caused by multiple noise sources. The optimal receiver for this system is derived and is further simplified by approximating the noise distribution by a Hoyt distribution. A Gauss-optimal receiver is also obtained from the optimal receiver. For the optimal receiver, a closed form expression and a series expression for the SEP for even and odd  $N$ , respectively, are obtained. Furthermore, the Gauss-optimal receiver structure is utilized to derive a closed form expression for the SEP using a characteristic function approach under the condition that  $mN$  is an integer. Asymptotic expressions for the SEP at high signal-to-noise ratio (SNR) are obtained for both the receivers which further show the diversity order of the PLC system to be independent of the noise shape parameter  $m$ . Furthermore, the advantage of using multiple receive branches in terms of achieving better error performance and the effect of the shape parameter  $m$  of the background noise on the SEP of the receivers are also demonstrated using numerical results.

This thesis next considers a noncoherent PLC system employing multi-level amplitude-shift keying (ASK) modulation in the presence of Middleton Class-A impulsive noise. For the case of diversity reception along with the knowledge of the noise state at the receiver, the Hermite numerical integration technique is used iteratively to obtain the statistics of the decision variable of an asymptotically optimal receiver which is utilized to derive a series expression for the SEP. Furthermore, a single channel PLC system in the presence of Middleton Class-A impulsive noise employing multi-level ASK modulation at the transmitter and noncoherent reception at the receiver is considered. For this case, an asymptotically optimal receiver for the PLC system is obtained using a tight approximation of the noise statistics. The magnitude of the received symbol is obtained as the decision variable, whose statistics is utilized to derive a series expression for the SEP. For both the cases, the corresponding asymptotic expressions for the SEP at high SNR are utilized to find the optimal ASK constellation minimizing the SEP. Numerical optimization of the ASK levels results in the optimal solution to be close to the equally spaced ASK constellation. The asymptotic optimality of the proposed receivers is validated by the SEP variation of the systems with the impulsive index of the noise. The thesis finally proposes a few possible extensions and the future scope of this work.

# सार

विजली लाइनों के माध्यम से डेटा का अविश्वसनीय संचरण पावर लाइन संचार (पीएलसी) सिस्टम के अध्ययन में सबसे चुनौतीपूर्ण पहलू रहा है। पारंपरिक वायर्ड संचार प्रणाली के विपरीत, मल्टीपाथ की उपस्थिति में पीएलसी सिस्टम दृढ़, समय के साथ बदलने वाले गैर-सफेद और अक्सर गैर-गॉसियन नोएस का सामना करता है। पीएलसी में जुड़ने वाला नोएस व्यापक रूप से पृष्ठभूमि और आवेगपूर्ण नोएस के रूप में वर्गीकृत है और इसका गणितीय मॉडल पीएलसी ऑपरेशन के आवृत्ति बैंडविड्थ पर निर्भर करता है। प्रणाली की विश्वसनीयता को प्रतीक त्रुटि संभावना (एसईपी) के संदर्भ में व्यक्त किया जाता है और रीसिव विविधता योजना और इष्टतम मॉड्यूलेशन योजनाएं पीएलसी चैनल के माध्यम से विश्वसनीय संचार प्राप्त करने के लिए नियोजित की जाती हैं।

इस थीसिस में, पीएलसी प्रणाली के लिए एक एन-शाखा विविधता रिसेप्शन के साथ बाइनरी चरण-शिफ्ट कुंजीयन को डेटा संचरण की विश्वसनीयता में सुधार के लिए नियोजित किया गया है। पीएलसी चैनल रेलेई फेडींग के अधीन है और अनुपयोगी नाकागामी-एम पृष्ठभूमि नोएस,  $EM < 1$ , के साथ पाया जाता है, जो कई नोएस स्रोतों के कारण होता है। इस प्रणाली के लिए इष्टतम रिसीवर व्युत्पन्न किया गया है और नोएस के लिए होएत वितरण अनुमान लगाकर इसे और सरल बनाया गया है। एक गॉस-इष्टतम रिसीवर इस इष्टतम रिसीवर से भी प्राप्त किया है। इष्टतम रिसीवर के लिए, एक बंद फॉर्म एसईपी अभिव्यक्ति और श्रृंखला एसईपी अभिव्यक्ति सम और विषम एन के लिए, क्रमशः, प्राप्त किया है। इसके अलावा, गॉस-इष्टतम रिसीवर संरचना का उपयोग कर एसईपी के लिए एक बंद फॉर्म अभिव्यक्ति एक विशेषता समारोह दृष्टिकोण का उपयोग करके प्राप्त किया गया है, इस शर्त के तहत कि एमएन एक पूर्णांक है। उच्च सिग्नल-टू-नोएस अनुपात (एसएनआर) पर एसईपी पे दोनों रिसीवर के लिए असीमित अभिव्यक्तियां प्राप्त किए जाते हैं जिससे पीएलसी प्रणाली के विविधता क्रम को नोएस के आकार पैरामीटर एम से स्वतंत्र दिखाया गया है। इसके अलावा, एकाधिक प्राप्त शाखाओं का उपयोग करके बेहतर त्रुटि प्रदर्शन करने का लाभ और पृष्ठभूमि नोएस के आकार पैरामीटर एम का रिसीवर के एसईपी पर प्रभाव संख्यात्मक परिणामों का उपयोग कर प्रदर्शित किया गया है।

यह थीसिस अगले बहु-स्तर पर एक गैर-सुसंगत पीएलसी प्रणाली पर चर्चा करती है जिसमें मिडलटन क्लास-ए आवेगपूर्ण नोएस की उपस्थिति में आयाम-शिफ्ट कुंजी (एएस्के) मॉड्यूलेशन है। रिसीवर पर नोएस की स्थिति के ज्ञान के साथ विविधता रिसेप्शन के मामले के लिए हार्माट संख्यात्मक एकीकरण तकनीक असीम रूप से निर्णय चर के आंकड़े प्राप्त करने के लिए इसे क्रमशः उपयोग किया जाता है जिसका उपयोग श्रृंखला अभिव्यक्ति इष्टतम डिटेक्टर के एसईपी को प्राप्त करने के लिए किया जाता है। इसके अलावा, मिडलटन क्लास-ए आवेगपूर्ण नोएस की उपस्थिति में एक चैनल पीएलसी प्रणाली ट्रांसमीटर पर बहु-स्तर एएस्के मॉड्यूलन नियोजित और रिसीवर पर गैर-सुसंगत रिसेप्शन माना गया है। इस मामले के लिए, एक असीमित पीएलसी प्रणाली के लिए इष्टतम डिटेक्टर नोएस आंकड़ों का एक

सखत अनुमान का उपयोग करके प्राप्त किया जाता है। प्राप्त प्रतीक के परिमाण को निर्णय चर की तरह प्राप्त किया जाता है, जिसके आंकड़ों का उपयोग एसईपी के श्रृंखला अभिव्यक्ति प्राप्त करने के लिए किया जाता है।

दोनों मामलों के लिए, एसईपी से संबंधित एसिम्प्टोटिक अभिव्यक्तियों का उपयोग उच्च एसएनआर पर एसईपी को कम करने के लिए इष्टतम एएस्के नक्षत्र की प्राप्ति की जाती है। एएस्के स्तर के संख्यात्मक अनुकूलन के परिणामस्वरूप इष्टतम समाधान समान दूरी वाले एएस्के नक्षत्र के करीब होता है। प्रस्तावित रिसीवर की एसिम्प्टोटिक इष्टतमता सिस्टम के नोएस के आवेगपूर्ण सूचकांक के साथ एसईपी की भिन्नता द्वारा मान्य है। थीसिस अंततः कुछ संभावित एक्सटेंशन और इस काम के भविष्य के दायरा का प्रस्ताव करता है।

# Table of Contents

Certificate	i
Acknowledgements	ii
Abstract	iv
List of Figures	viii
List of Tables	x
<b>1 Introduction</b>	<b>1</b>
1.1 Introduction . . . . .	1
1.2 PLC Channel . . . . .	2
1.2.1 The Multipath Phenomenon . . . . .	5
1.2.2 The Additive Noise . . . . .	6
1.3 Receive Diversity Techniques . . . . .	10
1.4 Modulation Techniques . . . . .	12
1.5 Related Work . . . . .	13
1.6 Motivation . . . . .	14
1.7 Key Contributions . . . . .	16
1.8 Organization of Thesis . . . . .	17

<b>2</b>	<b>Coherent Reception in Receive Diversity PLC System Under Nakagami- <i>m</i> Noise Environment</b>	<b>19</b>
2.1	Introduction . . . . .	19
2.2	System Model . . . . .	20
2.2.1	The Gauss-Optimal Receiver . . . . .	22
2.2.2	The Optimal Receiver from Hoyt Approximation . . . . .	23
2.3	Error Analysis . . . . .	24
2.3.1	System Performance using the Gauss-Optimal Receiver . . . . .	25
2.3.2	System Performance using the Optimal Receiver . . . . .	28
2.4	Numerical Results . . . . .	33
2.5	Summary . . . . .	40
<b>3</b>	<b>Noncoherent Reception in PLC System in Impulsive Noise Envi- ronment</b>	<b>42</b>
3.1	Introduction . . . . .	42
3.2	System Model . . . . .	43
3.2.1	Receiver for SISO PLC System . . . . .	43
3.2.2	Receiver for SIMO PLC System . . . . .	46
3.3	Error Analysis . . . . .	49
3.3.1	System Performance for SISO PLC System . . . . .	49
3.3.2	System Performance for SIMO PLC System . . . . .	57
3.4	Optimization of ASK Amplitude Levels . . . . .	61
3.4.1	Optimization for SISO PLC system . . . . .	62
3.4.2	Optimization for SIMO PLC system . . . . .	63
3.5	Numerical Results . . . . .	68
3.6	Summary . . . . .	76
<b>4</b>	<b>Conclusions and Future Work</b>	<b>77</b>
4.1	Contributions of this Research . . . . .	77
4.2	Future Work . . . . .	80

# List of Figures

1.1	Factor $A^u/u!$ versus the variable $u$ . . . . .	9
1.2	Comparison of p.d.f.s $f_{n_i}(x)$ and $\hat{f}_{n_i}(x)$ for varying values of $A$ . . . . .	11
2.1	Comparison of performance of optimal and suboptimal receivers with Nakagami shape parameter $m = 2/3$ . . . . .	34
2.2	SEP versus average SNR per symbol per branch for suboptimal receiver with varying number of diversity branches $N$ and Nakagami shape parameter $m$ . . . . .	35
2.3	SEP versus average SNR per symbol per branch for optimal receiver with varying number of diversity branches $N$ and Nakagami shape parameter $m$ . . . . .	37
2.4	Variation of SEP with Nakagami shape parameter $m$ , average SNR per symbol per branch $\Gamma_{av} = 2$ dB, and number of diversity branches $N = 4, 6, 8$ for suboptimal receiver. . . . .	38
2.5	Variation of SEP with Nakagami shape parameter $m$ , average SNR per symbol per branch $\Gamma_{av} = 5$ dB, and number of diversity branches $N = 1, 2, 3, 4, 5, 6$ for optimal receiver. . . . .	39
2.6	Variation of average SNR per symbol per branch $\Gamma_{av}$ with Nakagami shape parameter $m$ to achieve SEP $P_e = 10^{-4}$ for suboptimal receiver with number of diversity branches $N = 4, 6, 8$ . . . . .	40

2.7	Variation of average SNR per symbol per branch $\Gamma_{av}$ with Nakagami shape parameter $m$ to achieve $SEP = 10^{-4}$ for optimal receiver with number of diversity branches $N = 2, 4, 6$ . . . . .	41
3.1	SEP versus average SNR per symbol for optimal and asymptotically optimal receiver with number of ASK levels $L = 4$ in A.P., impulsive index of noise $A = 0.01$ , and $T = 0.01$ . . . . .	70
3.2	SEP versus average SNR per symbol for asymptotically optimal receiver with number of ASK levels $L = 4, 8$ in A.P. and G.P., and with impulsive index of noise $A = 0.01, 0.1$ , and $T = 0.01$ . . . . .	70
3.3	SEP versus impulsive noise index $A$ for asymptotically optimal receiver with $T = 0.01$ , $L = 4, 8$ in A.P., and varying average SNR per symbol $\Gamma_{av}$ . . . . .	72
3.4	SEP versus average SNR per symbol per branch for asymptotically optimal receiver and suboptimal receiver with number of diversity branches $N = 1, 3$ , number of ASK levels $L = 4$ in A.P. and G.P., with $A = 0.01, 0.1$ , and $T = 0.01$ . . . . .	72
3.5	SEP versus impulsive noise index $A$ for asymptotically optimal receiver with number of diversity branches $N = 3$ , $T = 0.01$ , $L = 4, 8$ in A.P. and G.P., and varying average SNR per symbol per branch $\Gamma_{av}$ . . . . .	74
3.6	SEP versus average SNR per symbol per branch for asymptotically optimal receiver with $N = 1$ , $A = 0.1, 0.01$ , $T = 0.01$ , and $L = 4$ sized ASK constellation in A.P. and G.P. and FSK constellation. . . . .	74
3.7	SEP versus $N$ for asymptotically optimal receiver with $\Gamma_{av} = 5\text{dB}$ , $L = 4$ in A.P., and varying $A$ and $T$ . . . . .	75

# List of Tables

2.1	Number of enumerations of $(\ell_1, \dots, \ell_{mN-1})$ in (2.28), (2.29), and (2.31), and $(\ell_1, \dots, \ell_{M-k})$ in (2.40) . . . . .	33
2.2	Values of $\Gamma_{av}$ for optimal and suboptimal receivers for $m = 2/3$ with number of diversity branches $N = 3$ . . . . .	35
2.3	Values of suboptimal SEPs for $m = 2/3, 1$ with number of diversity branches $N = 3, 6, 9$ . . . . .	36
2.4	Values of the SEPs obtained by the optimal receiver for $m = 0.6, 0.9$ with number of diversity branches $N = 1, 2, 3, 4$ . . . . .	38
3.1	Values of $\Gamma_{i,opt}$ and $\Gamma_{i,A.P.}$ for $i = 2, 3, 4$ and the relative error in SEPs for 4 level ASK ( $L = 4$ ) and $A = 0.01$ . . . . .	63
3.2	Values of $\Gamma_{i,opt}$ and $\Gamma_{i,A.P.}$ for $i = 2, 3, 4$ and relative error in SEPs for 4 level ASK ( $L = 4$ ) and $N = 1, 3, 12, A = T = 0.01$ . . . . .	65
3.3	Values of abscissas and weight factors for Hermite integration technique for $n = 10$ . . . . .	69
3.4	Values of the SEPs obtained by the asymptotically optimal receiver for 4-level ( $L = 4$ ) and 8-level ( $L = 8$ ) ASK with $A = 0.01, 0.1$ and $T = 0.01$ . . . . .	71