REED-SOLOMON AND CONVOLUTIONAL CODES ON MODULATION SCHEMES FOR POWER LINE COMMUNICATION (PLC)

[1]PETER O. AIYELABOWO, [2]A. SALI, [3]SAMSUL BAHARI B. NOOR, [4]BAMIDELE ADEBISI, [5]NOR KAMARIAH NOORDIN

[1,2,3,5]Department of Computer and Communication Systems Engineering, Faculty of Engineering, Universiti Putra Malaysia, UPM Serdang, 43400, Selangor Darul Ehsan, Malaysia
[4]Department of Electrical and Electronic, School of Engineering, Manchester Metropolitan University, Room E331, John Dalton Building, Chester Street, Manchester.

Abstract- he relevance of the power line network in the transmission of broadband data for several applicatons have been identified in the smart technology. Its choice is own to is ubiquitos nature. This channel, power line, poses a huge impediment to the signal transmitted through it because its nature was not intended for broadband data. Hence the channel is characterized by multipaths and impulsive noise, which are dependent on the length and branches of the cable and the load at the far end of the line. In this paper, forward error codes is used to compensate for the noise and the multipath property of the line. Reed-Solomon and convolutional codes are used at different modulation schemes and different code rates respectively. Two channel scenarios of bad and good 150m length cable at two impulsive noise situations were considered. For all the modulation schemes/code rates considered, improvements in performance in terms of BER was achieved, terminating errors at lower SNR's. Smaller constellation sized modultion schemes were seen to offer better performance than higher order constellation sizes.

Keywords: Power line,Reed-Solomon, convolutional code, impulsive noise, multipath, attenuation.

I. INTRODUCTION

The interest of chosing of power line communication (PLC) as a broadband data provision platform for and within the home has grownowing to its ubiquitos nature, since no new installation is required as the existing electrical infrasturcture is used as its transmission medium. The characteristics of the power line channel presents some technical challenges to broadband activities because it was not intended for it, as it was originally meant for AC power distribution a 50/60 Hz respectively. Therefore high speed communication over this channel is degraded significantly by attenuation, multipath and noise [1],[2].

The power line communication has a very peculiar noise characteristics, unlike other communication systems, its noise scenario cannot be described as Additive White Gaussian Aoise (AWGN)[3]. The channel is bewitched by five (5) different types of noise.

PLC can assume two types of architecture; narrowband and broadband. Narrowband PLC frequency spectrum is from 3 KHz to 148.5 KHz in Europe and can be above 500 KHz in the US. Its data rate is in Kbps over a maximum distance of 1 Km between PLC modems[4]. Broadband PLC has a wider spectrum spanning from 1 MHz to 30 MHz [5], where 1-15 MHz is for outdoor applications and 15-30 MHz is for indoor applications. Its data rate is up to 300 Mbps [6].

Several modulation techniques has been implemented in the PLC, but the orthogonal frequency division multiplexing (OFDM) modulation scheme is recommended due to its ability to withstand selective fading multipath and all sorts of interference [7]. OFDM as a multicarrier transmission scheme, withstands well multipath and frequency selective fading as present in the power line channel. A single carrier high speed data stream is splitted into several slow data streams, carried in multiple orthogonal subcarriers. This splitting is provided by means of inverse discrete Fourier transform (IDFT), while minimizing the effect of intersymbol interference with cyclic prefix (CP).

The reliability of communication over power line channel can be improved using channel coding. Channel coding can be achieved by BCH, convolutional, Reed-Solomon and low parity density check (LPDC). To account for the bursty nature of the impulsive noise, interleaving is often required for the power line channel. Sevaral Authors has implemented one channel coding technique with or without interleaving in the power line communication [8]. In all instances, only one channel power line channel scenario and a type of modulation scheme in the OFDMwas considered, to achive some form of improvement.

In this paper the duo of Reed-Solomon and convolutional codes with bit-interleaving were implemented on the PLC channel. Two types power line channel presented by [9] were considered in the presence of awgn and impulsive noise. Three impulsive noise scenarios was simulated and implemented. Performance of the PLC was investigated under different OFDM modulation schemes (QPSK, and QAM) using different data rates. Other sections of this paper is organized as follows. Section 2 gives a description of the system model implemented. Power line communication

channel and noise were both described in sections 3 and 4 respectively. Impulsive noise is a characteristic of the the power line channel, hence section 5 was dedicated to a brief description of impulsive noise. Reed-Solomon and Convolutional codes were introduced in section 6. Section 7 has the simulation conducted while conclusion was reached in the last section.

1. System Model

The model of our system is depicted in Figure 1.On the transmitter side, the random sequence of bits passes through two series of encoding. The first uses the RS codes while the second implements convolutional codes at different code rates for different scenarios. This is done to further achieve serenity in the channel. The encoded bits were interleaved using random interleaver to achieve a combat against the bursty impulsive noise in the power line channel. Mapping was then done for both PSK and QAM as the case may be before modulation using inverse discrete fourier transform (IDFT).

In the receiver the opposite of the processes in the transmitter is carried out, namely; demodulation by means of discrete fourier transform (DFT), demapping (both PSK and QAM), de-interleaving, viterbi decoding and RS decoding.

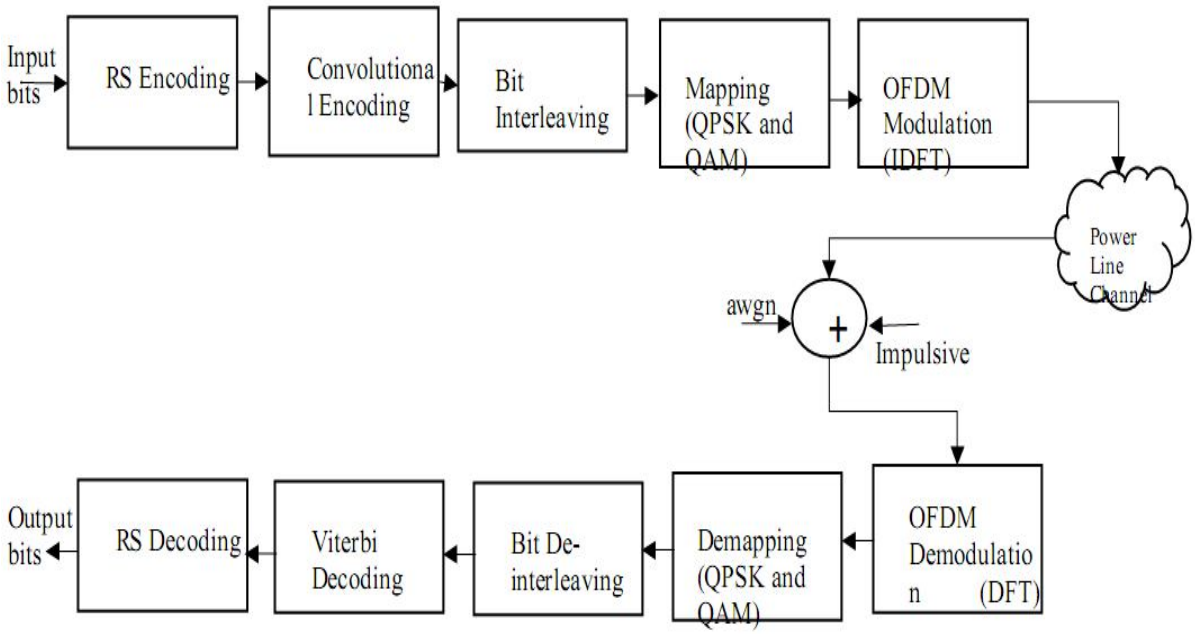


Figure 1: System model

2. PLC Channel

The capacity of PLC channel to support high data rate communication has been extensively investigated by several researchers [10],[11],[12]. The bewitchment of the data transmission on the power line channel cannot be over-emphasized, this is further made severe by the topology of consumers' power distribution (star-shaped). This makes the line susceptible to complex scenario leading to frequency selective fading, signal reflections at high frequencies and frequency dependent attenuations. Sequel to the nature of the power line channel, it presents unfavorable channel properties characterized by noise and high data attenuation.

Two models are prominent in the Power Line (PL) channel's model, they are Philipp's echo model [13] and Zimmermann and Dostert's [14] model. In both models the transfer function of the power line channel is modeled following the top-down approach.

The obtained model's transfer function is as presented in equation 1, where g_i is a factor used for describing weight of the individual's path. It is also a product of transmission and reflection factors over a path length of d_i (i is the path's number). The knowledge of g_i and d_i is necessary for the determination of the input channel responses.

$$H(f) = \sum_{i=1}^{N} g_i \cdot e^{-(\alpha_o + \alpha_1 f^k) d_i} \cdot e^{-j2\pi f \frac{d_i}{v_p}} \quad (1)$$

The first exponential presents the attenuation factor while the second exponential is a description of the echo scenario. The factor v_p is the signal's propagation speed. Parameters α_o, α_1 and k are used to model the attenuation factor. These parameters α_o(offset attenuation), α_1 (increase of attenuation) and k (exponent of attenuation) are obtained from measurements of the magnitude of the frequency response. Channel modeling of the power line network has revealed that signals propagated over

power line are liable to distortion owing to cable losses and multipath propagations.

Several models of the power line channel were presented in [9]. The adopted models for this work is the 150m length model. Two categories of this model was considered, the bad and the good. Table 1 depicts the characteristics of the channels.

Table 1: Parameters of 150m Power Line Channel [9]

150m Bad $\alpha_{o=0}$, $\alpha_{1=2.5x10^{-9}}$ m^{-1} 15 taps		150m Good $\alpha_{o=0}$, $\alpha_{1=1.65x10^{-9}}$ m^{-1} 5 taps	
g_i	$d_{i(m)}$	g_i	$d_{i(m)}$
0.01832	113.2	0.09	100
0.00516	90.1	-0.012	130
0.00765	101.8	0.012	160
-0.01031	143	-0.012	190
-0.00800	148	0.022	300
-0.00711	200		
0.00676	261		
-0.00676	322		
0.01263	411		
-0.00622	490		
0.01156	567		
-0.00978	746		
0.00747	960		
-0.01049	1130		
0.00871	1250		

A simulation of the channels response of the two channel scenarios is as depicted in Figure 2.

3. Power Line Noise

Interference and noise is another serious challenge of digital communication, in the frequency range up to 30 MHz, over the power line network. These noises, which works against the performance of the PLC, can be classified into three categories with a further sub-classification in the category [15],[16].

These noises are briefly described below.

- Colored Background Noise: These are various sources of white noise with different amplitudes at different portions of the frequency band which does not belong to the other identified classes of noise. They are usually characterized by relatively low power spectral density (PSD) which is inversely proportional to frequency [17].
- Narrowband Noise: This noise occurs at narrow fractions of the frequency band with high Power Spectral Density (PSD). It is a partial overlay to the background noise. Its source is mainly from broadcaster's signals at short, medium and long waves as well as the amateur radio and it appears in the frequency domain as sharp peaks of noise amplitudes. This noise can also appear at low frequencies, its occurrence is traceable to the switching of electrical devices such as television sets, power supply fluorescent lamps or computer screens.
- Periodic Impulsive Noise Asynchronous to the Mains Frequency: This noise occurs for only a short duration with relatively low amplitude, hence, they are usually considered as background noise. Its repetition rate is between 50 KHz to 200 KHz. It is often caused by switching power supplies.
- Periodic Impulsive Noise Synchronous to the Mains Frequency: This is of short duration, having its PSD varying inversely as frequency. Its repetition rate is of 50 Hz or 100 Hz. The power supplies which operates concurrently with the mains cycle is responsible for this noise. This is inherent in power converters found in dimmers and rectifiers using diodes.
- Asynchronous impulsive noise: This impulsive noise duration is from some microseconds upwards to a few milliseconds and they arrive randomly, they are often referred to as 'burst noise'. Its PSD can sometimes be about 50 dB above the background noise. All kinds of switching operations such as household appliances, electric motors etc., are responsible for this noise. This noise differs from its periodic counterpart in its time of occurrence and its duration.

The first three are cyclostationary, that is stationary at over long period of time, they are all considered as background noise [8], which is often represented as additive white gaussian noise (awgn). The last two types, being time-varying are called impulsive noise. According to [18], the spectral density (PSD) of impulsive noise exceeds the PSD of the background noise by a mimimum of 10 -15 dB and sometimes may approach 50 dB.

1. Impulsive Noise

Noise in PLC can be modeled by using Middleton's class A noise model. Two types of noise, background and impulsive noises are visible in this model. The background noise follows Gaussian distribution, while the impulsive noise is a noise that arrived according to Poisson distributed random sequence. Analysis of the effects from these noises on OFDM-based PLC system shows that the background noise can be modeled as AWGN with zero mean and variance σ_w^2, and the impulsive noise (i_k) is given by [17]:

$$i_k = b_k g_k \qquad (1)$$

where b_k is the Poisson process designating the arrival of impulsive noise and g_k is the white Gaussian process with zero mean and variance, σ_w^2. Impulsive noise are transient characterized uniformly

distributed disturbances over the useful transmission system passband. They can be caused by voltage spikes in equipment, voltage changes on adjacent pairs in a copper cable, tones generated for network signaling, maintenance and test procedures, lightning flashes during thunderstorms, and a wide variety of other phenomena. As impulse noise is short in duration, it has little effect on voice communications, but can cause bit errors in a data transmission.Three parameters defines the characteristics of the impulsive, which include; impulse duration, its amplitude and its inter-arrival time (time in-between two successive impulses). Impulsive noise duration is random and varies from some tens to hundreds of micro seconds, while its amplitude follows an exponential function.

The impulsive noise scenario implemented in this work are described by two basic parameters; the impulsive amplitude and the impulse impact.The impulse impact describes the intensity of the number of impulsive noise arriving over a given time period. The amplitude is maintained at unity (1) while the impulse impact considered were of two categories; the heavy impulsive and and weak impulsive.

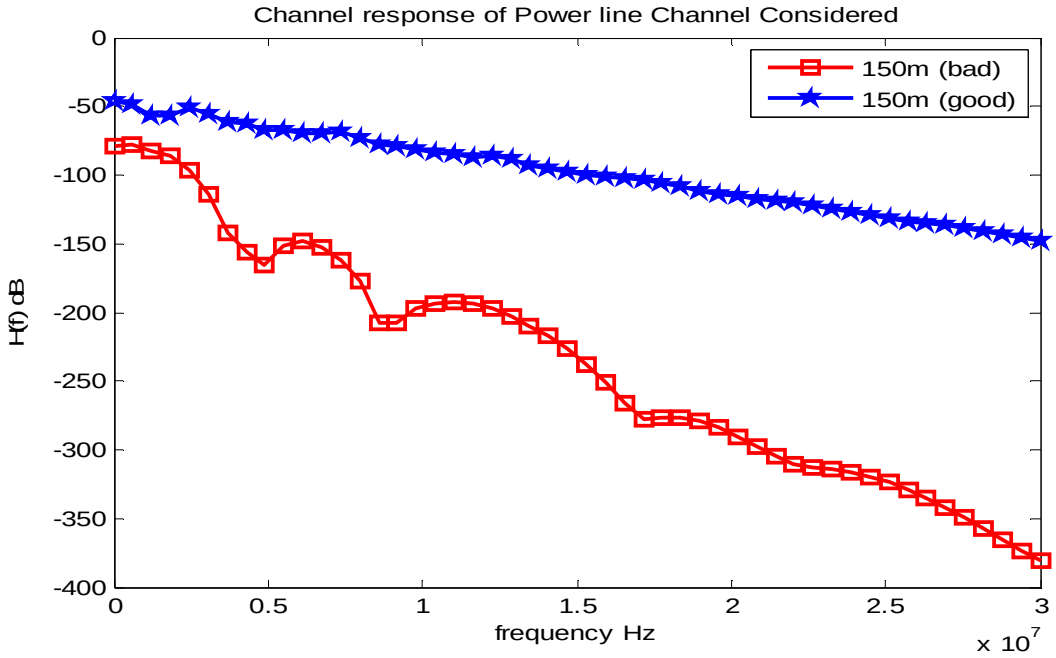


Figure 2: Channel response of investigated Power Line Channels

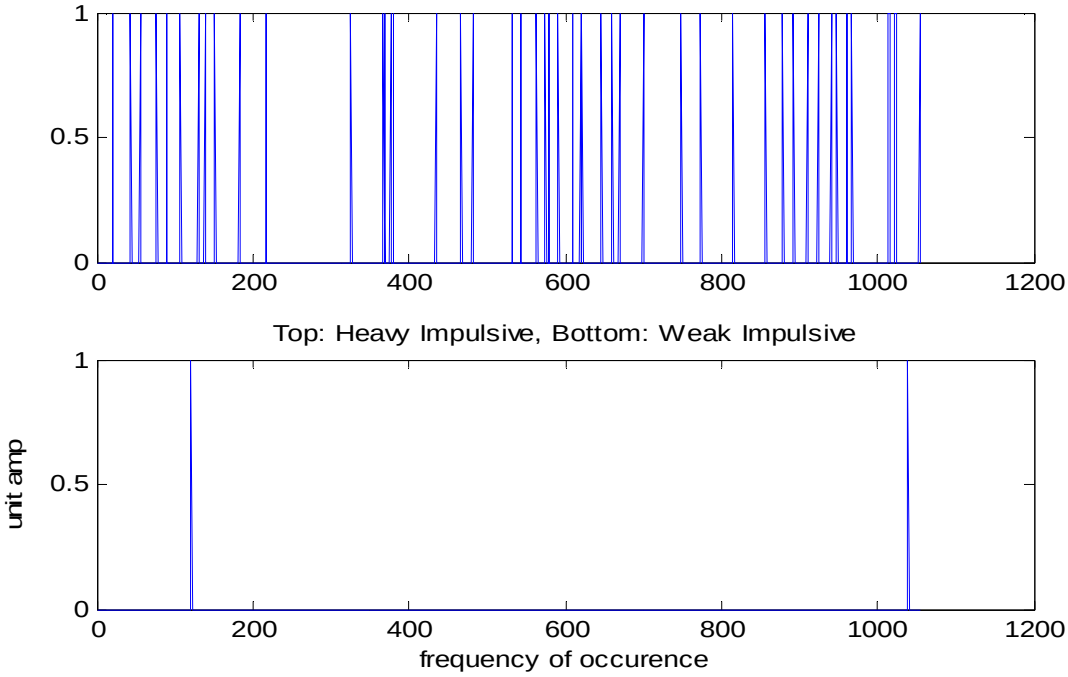


Figure 3: Simulated Impulsive Noise

Heavy describes many occurrence of impulsive noise over the space of time of description while weak depicts few impulsive noise occuring. The simulation of the two categories of impulsive noise implemented are shown in Figure 3.

2. Reed-Solomon and Convolutional Codes

The Reed-Solomon (RS) codes are subsets of BCH codes and are linear block codes. Its encoder takes a block of digital data and adds extra redundant bits. That is, it takesa *k* data symbols of 8 bits each and adds parity symbols to make an n symbol codewords[19]. The RS decoder processes each block and attempts to correct errors or recover the original data. Error control in both digital and storage systems has widely used RS codes.

Convolutional Codes consists of correction codes with simple decoding and good performances. In convolutional coding, the encoder delivers a block of N binary symbols at every moment k, giving;

$$c_k = \left(c_{k,1}, c_{k,2}, c_{k,3} \ldots\ldots\ldots\ldots\ldots, c_{k,N}\right) \qquad (4)$$

When $d_k = \left(d_{k,1}, d_{k,2}, d_{k,3} \ldots\ldots\ldots\ldots\ldots, d_{k,K}\right)$, a function of block K information is present at the imput along *m* preceeding blocks. Thus, convolutional codes introduces a memory order of *m*. A convolutional encoder associates a unique sequence with each information sequence[20]. The decoding of convolutional code is by viterbi decoding.

3. Simulation

The system model shown in figure 1 was simulated for the study of the systems' BER performance under two different scenarios shown on Table 2 for five (5) modulation scheme/code rate situations. The impulsive noise charteristics implemented are as given in section 5 and figure 2 shows the heavy and the weak impulsive noise respectively.

Table 2Simulation Scenarios

Scenario 1	150m long Bad Channel with weak impulsive noise
	150m long Bad Channel with heavy impulsive noise
Scenario 2	150m long Good Channel with weak impulsive noise
	150m long Good Channel with heavy impulsive noise

Reed-Solomon encoding for five schemes considered was done at different rates taking different n and k values. The convolutional code rates implemented for the various modulation schemes (QPSK and QAM) are ½, 2/3 and ¾ respectively. The generator polynomials (10101011,10000101) was implemented in the encoder with a constraints of k=8. The duo of the transmitter and the receiver uses 256 subcarriers to perform IFFT anf FFT respectively with an OFDM symbol of 10. A cyclic prefix of 64 was inserted. The OFDM signal was passed through the Power line channel described by the channel response in (1), whose parameters are on Table 1, over a frequency of 0-30 MHz. It should be recollected that two channel scenarios were under consideration, bad and good 150m long cable. The bad channel had 15 taps while the good, had 5 taps and k, exponent of attenuation, was chosen to be 1. Impulsive noise is assumed to arrive in a Poisson distribution while the background noise is assumed to be awgn. Hence the total noise in the power line communication is a sum of impulsive and backgroud noise.

The OFDM in the receiver is demodulated by DFT, demapped respectively (QPSK and QAM) and de-interleaved. Afterde-interleaving, the signal was viterbi decoded at different traceback depths of 4k = 32, 5k = 40 and 12k = 96 respectively.

The BER performance of the coded system was plotted on figures 4, 5,6, 7 and 8. Each figure comprises of four charts, representing two channel scenario of weak and heavy impulsive noise conditons. Three different curves were presented on each chart of the figures; PL channel (with impulsive+awgn) coded, awgn channel only coded and PL channel (with impulsive+awgn) uncoded. An observation of the curves shows generally that the combination of the codings (RS and Covolutional) achieves a significant improvement in the performance of the system over the channel and in the face of the noise. The error terminal points for each of the modulation scheme/code rates are presented in Table 3.

Table 3 Modulation Schemes/Code rates error

	SNR (dB)			
Schemes/rates	Bad, weak (BW)	Bad,nheavy (BH)	Good, weak (GW)	Good,heavy (GH)
QPSK ¾	2	5	2	5
16-QAM ½	5	5	5	5
16-QAM ¾	7	9	7	9
64-QAM 2/3	12	12	12	12
64-QAM ¾	15	15	15	15

From Table 3, it can be seen that the combination of RS and convolutional codes reduced the BER drastically and maintained some form of serenity on the channel inspite the channel state, whether bad or good and the noise effect. In [3] convolutional codes only were used and error only terminates at 25 dB for QPSK 1/3 at heavy impulsive and 24 dB for same scheme at weak impulsive situations respectively.

Table 4: Modulation Schemes/Code rates BER vs SNR

Modulation Schemes/Code rates																				
BER	QPSK ¾ (dB)				16-QAM ½ (dB)				16-QAM ¾ (dB)				64-QAM 2/3 (dB)				64-QAM ¾ (dB)			
	BW	BH	GW	GH	BW	BH	GW	GH	BW	BH	GW	GH	BW	BH	GW	GH	BW	BH	GW	GH
10^{-1}	-	1	-	0	3	3.5	3	4	5.5	6	5.5	6.5	11	12	11	11.5	12.5	13	12.5	13
10^{-2}	1	3.8	1	3.5	4	-	-	-	-	9	-	9	-	-	-	-	14.5	-	14	14.5
10^{-3}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Furthermore, it is obvious from Table 3 that lowerconstellation of modulation schemes achieve better performance in the power line communication, Error disappears early when 16-QAM ¾, 16-QAM ½ , and QPSK ¾ schemes. Table 4 further coroborate the ascertion that lower constellation modulation schemes performs better, for 10^{-2} BER in the lower schemes such as QPSK ¾ and 16-QAM ½ , it occurs at a maximum of 4 dB for all the test scenario while it occurs at maximum point of 14.5 dB in other higher constellation (64-QAM 3/4)

CONCLUSION

The BER performance of power line communication system with Reed-Solomon and convolutional coding have been investigated in this paper. Three modulation schemes with different code rates resulting in five (5) schemes were considered. Two test scenarios of good and bad channel were considered at different impulsive noise situations. The simulation resuts obataines showed that the performance of the system was enhanced significantly, terminating error at smaller SNR. Furthermore, it was identified that lower modulation constellation schemes performs better than the higher ones.

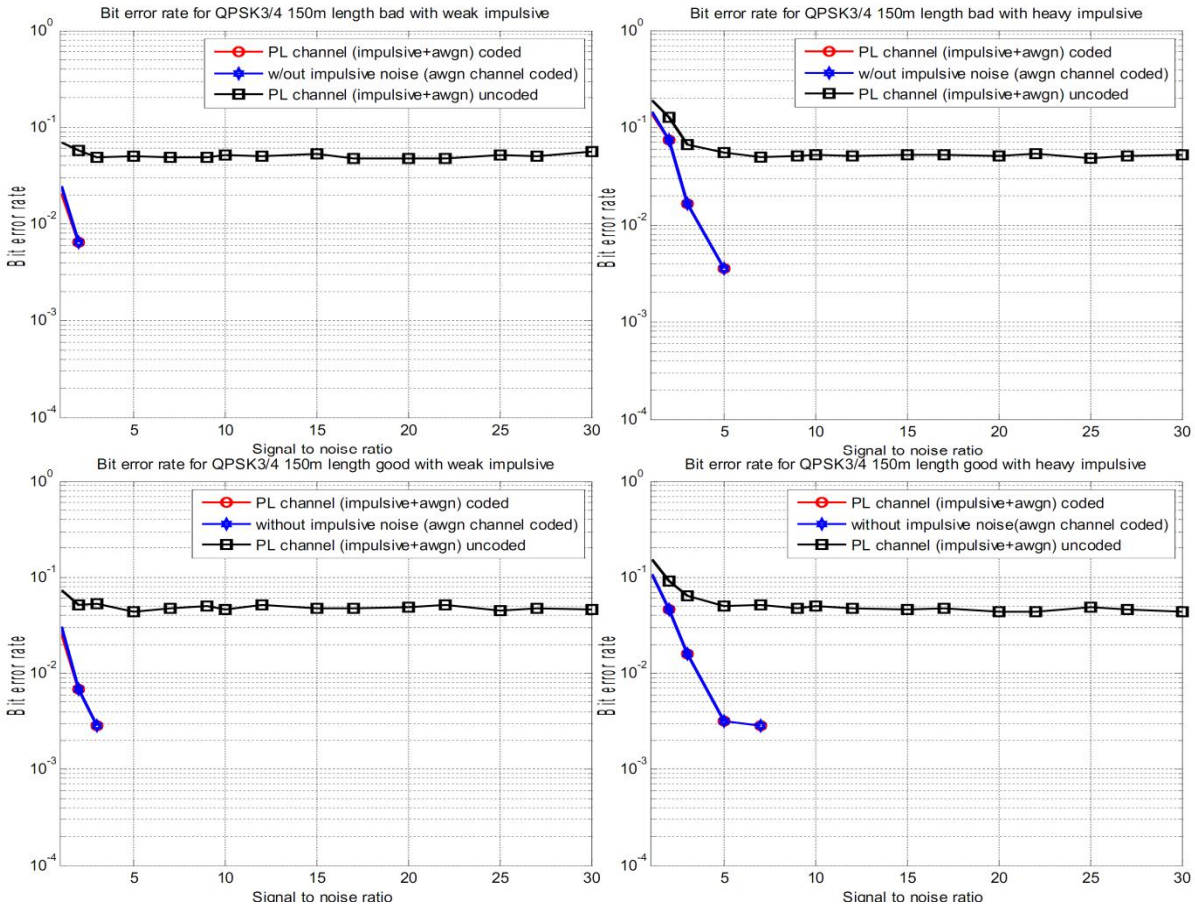


Figure 4: BER curve of QPSK, code rate = 2/3

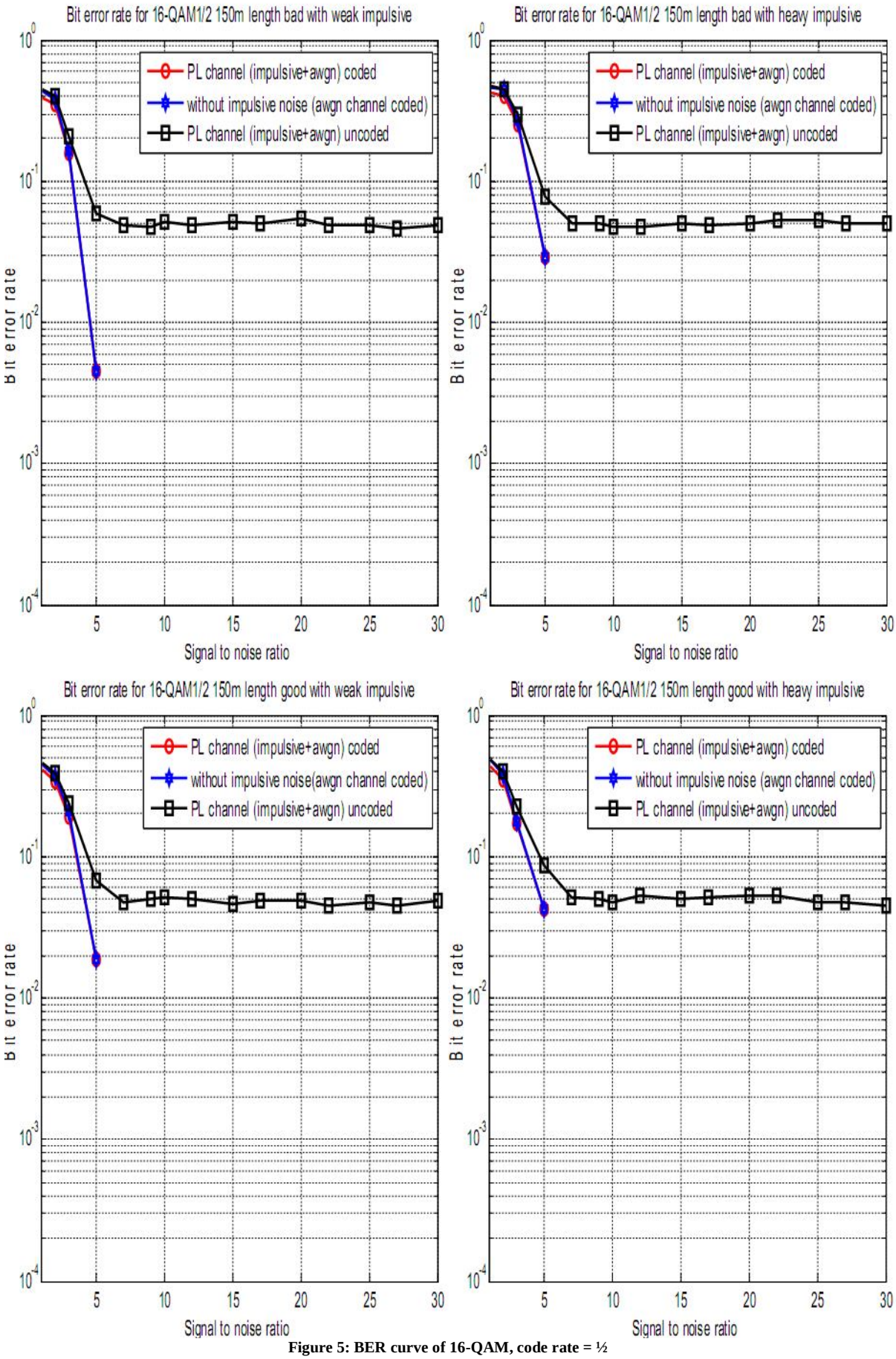


Figure 5: BER curve of 16-QAM, code rate = ½

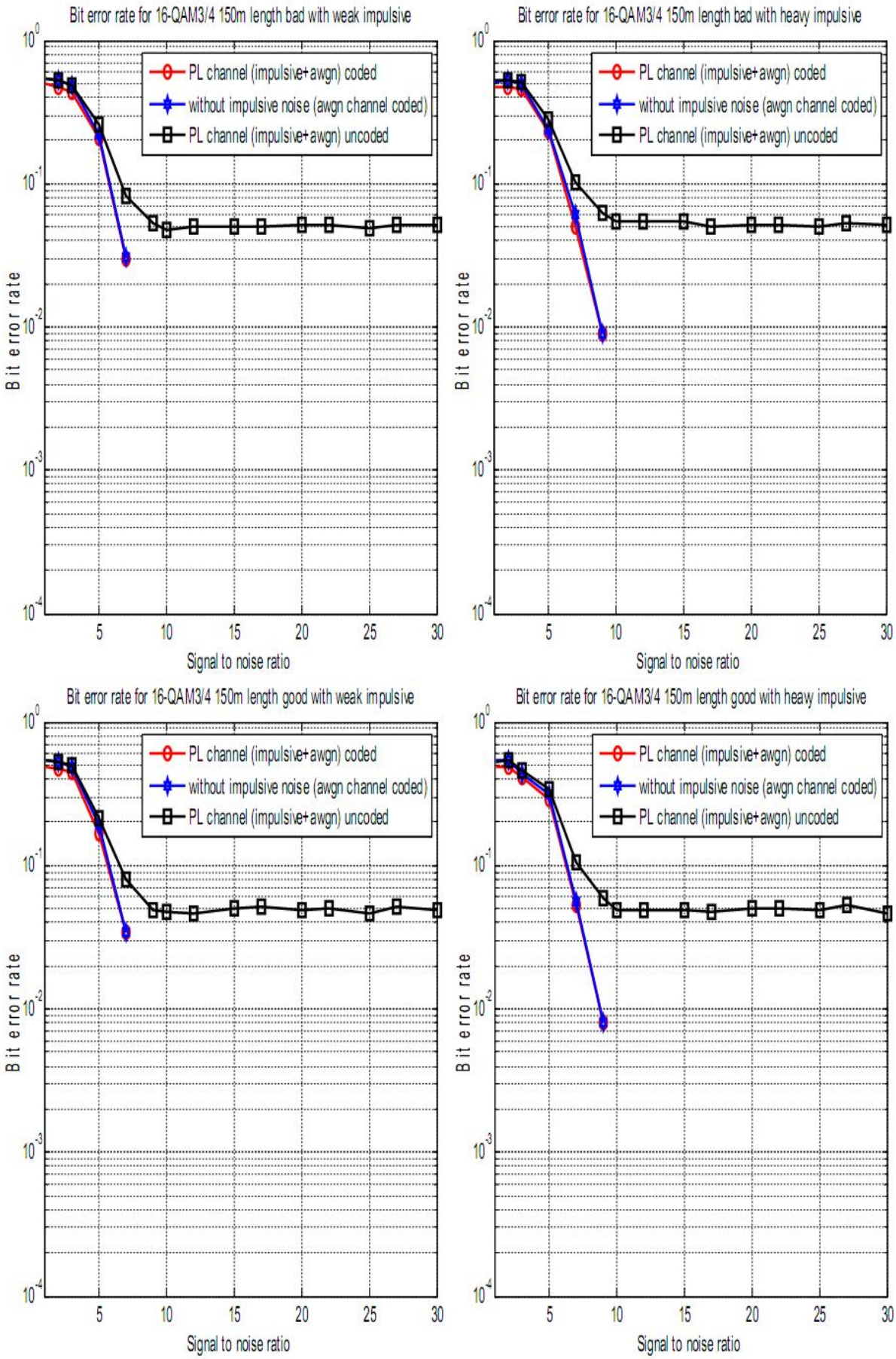


Figure 6: BER curve of 16-QAM, code rate = ¾

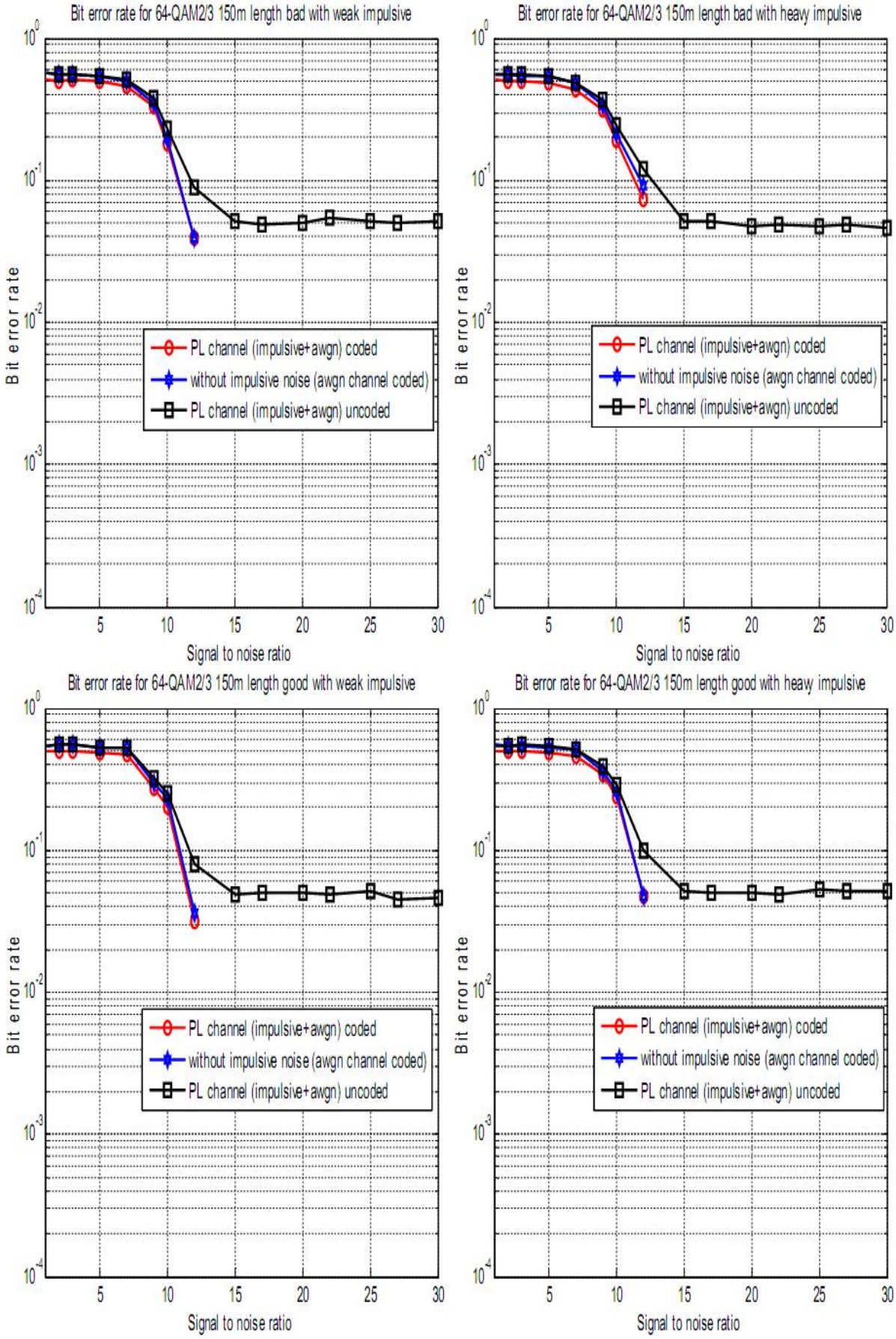


Figure 7: BER curve of 64-QAM, code rate 2/3

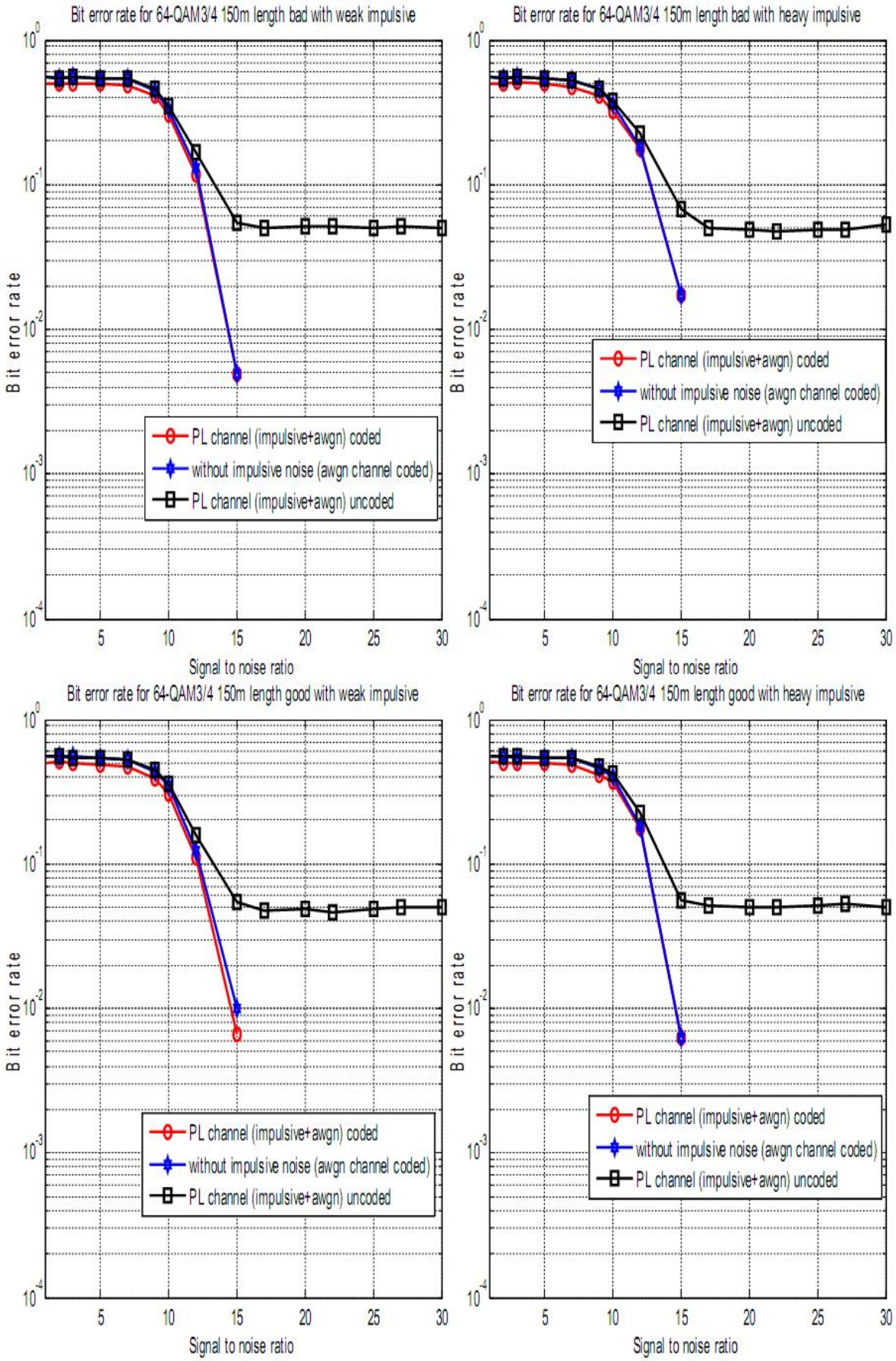


Figure 8: BER curve of 64-QAM, code rate ¾

REFERENCES

[1]. M. S. Yousuf, S. Z. Rizvi, S. Arabia, and M. El-shafei, "Power Line Communications: An Overview – Part II," 4th International Conference on Innovations in Information Technology (IIT), 2007; pp. 218 – 222.

[2]. M. Katayama, T. Yamazato, and H. Okada, "A Mathematical Model of Noise in Narrowband Power Line Communication Systems," IEEE Journal on Selected Areas in Communication, 2006; 24(7), pp. 1267–1276.

[3]. K. S. Al-Mawali and Z. M. Hussain, "Performance of bit-interleaved coded OFDM in power line communications with impulsive noise," 2009 International Conference on Advance Technologyin Communication, pp. 49–53, Oct. 2009.

[4]. H. Hrasnica, A. Haidine, and R. Lehnert, Broadband Powerline Communications: Network Design. 2005.

[5]. M. Korki, N. Hosseinzadeh, H. L. Vu, T. Moazzeni, and C. H. Foh, "Impulsive noise reduction of a narrowband power line communication using optimal nonlinearity technique," 2011 Australasian Telecommunication Networks and Applications Conference (ATNAC), pp. 1–4 Nov. 2011.

[6]. H. Latchman, S. Katar, L. Yonge, and S. Gavette, Homeplug AV and IEEE 1901: A Handbook for PLC Designers and Users. IEEE Press, 445 Hoes Lane Piscataway, NJ 08854, 2013, p. 4.

[7]. S. I. Tsakiris, A. D. Salis, and N. K. Uzunoglu, "Performance of OFDM Systems for Broadband Power Line Communications Under Low Signal Strength," Microwave Review, vol. 9, no. 2, pp. 41–46, 2009.

[8]. A.Peter, C. Ng, and N. Noordin, "Power Line Communication (PLC) Impulsive Noise Mitigation: A Review," Journal of Information Engineering and Applications, vol. 4, no. 10, pp. 1–15, 2014.

[9]. H. C. Ferreira, J. Newbury, and T. G. Swart, Power Line Communications:Theory and Applications for Narrowband and Broadband Communications over Power Lines. A John Willey and Sons Ltd. Publications, The Artium, SOuthern Gate, Chichester, West Sussex, PO198SQ, United Kingdom, 2010, pp. 120 – 140.

[10]. R. Hashmat, P. Pagani, A. Zeddam, and T. Chonavel, "MIMO communications for inhome PLC networks: Measurements and results up to 100 MHz," IEEE International Symposium on Power Line Communications and Its Applications, ISPLC, no. 1, pp. 120–124, 2010.

[11]. A. Schwager, "Powerline Communications: Significant Technologies to become ready for Integration," PhD Thesis, University Duisburg-Essen, 2010.

[12]. P. An, X. Chen, J. Wang, S. Zhou, and X. Shan, "Analysis on Application of Repeater Technology in Powerline Communications Networks,"IEEE International Symposium on Power Line Communications and Its Applications, ISPLC, pp. 273–277, 2007.

[13]. H. Philipps, "Modelling of powerline communication channels," Proceedings of 3rd International Symposium on Power Line Communications and Its Applications, ISPLC, pp. 2–9, 1999.

[14]. M. Zimmerman and K. Dostert, "A multi-path signal propagation model for the power line channel in the high frequency range," Proceedings of 3rd International Symposium on Power Line Communications and Its Applications, ISPLC, 1999.

[15]. A.Cort, D. Luis, and F. J. Ca, "Analysis of the Periodic Impulsive Noise Asynchronous with the Mains in Indoor PLC Channels," Proceedings of 3rd International Symposium on Power Line Communications and Its Applications, ISPLC, pp. 26 – 30, 2009.

[16]. V. Guillet, G. Lamarque, and P. Ravier, "Improving the power line communication signal-to-noise ratio during a resistive load commutation," Journal of Communication, vol. 4, no. 2, pp. 126–132, 2009.

[17]. K. S. Al-mawali, A. Z. Sadik, Z. M. Hussain, and A. O. System, "Time-Domain Techniques for Impulsive Noise Reduction in OFDM-Based Power Line Communications: A Comparative Study," Proc. 2009 Int. Conf. Commun. Comput. Power, pp. 1 – 5, 2009.

[18]. K. Al-mawali, A. Z. Sadik, Z. M. Hussain, and A. O. System, "Joint Time-domain / Frequency-domain Impulsive Noise Reduction in OFDM-based Power Line Communications," Australasian Telecommunication Networks and Applications Conference (ATNAC), pp. 138–142, 2008.

[19]. C. D. J. Lin Shu, Error Control Coding: Fundamentals and Applications. Pearson education Inc., Pearson Prentice Hall, Pearson Education Inc, Upper Saddle River, NJ. 07458, New Jersy, pp. 237 – 241, 2004.

[20]. A.Glavieux, Ed., Channel Coding in Communication Networks: From Theory to Turbocodes. London, UK: Iste, 6 Fitzroy Square, London W1T 5DX, UK, 2007, pp. 129 – 179.

★★★