SCIREA Journal of Electrical Engineering

http://www.scirea.org/journal/DEE

April 6, 2019

Volume 4, Issue 1, February 2019

BER Performance Degradation of a Powerline Communication System due to Power Transformer and Performance Improvement by Diversity Reception Technique

M Mahbubur Rahman[1], S P Majumder[2]

[1]Dept of EECE,Military Institute of Science and Technology,Naval Academy Campus, Bangladesh

e-mail: mmrahman549@gmail.com

[2]Dept of EEE, BUET, Dhaka-1000, Bangladesh

e-mail: spmajumder@eee.buet.ac.bd

Abstract

In powerline communication, both the RF data and low frequency electric power flow through the same line. Where the power-line is actually designed for the transmission and distribution of electrical power. Therefore, the cables/wires are so chosen as suitable for the use of high voltages at low frequencies. But RF transmission requirement is low voltages at higher frequencies. So, the transmission channel for RF signal finds some unfavourable factors in the channel such as, high attenuation, isolation of transformer, varying impedance, noise, etc. These factors lead to low data rates, which tend to limit its performance for applications like home automation or monitoring. A power transformer used in a PLC line intended to handle the power transformation

of the power line of very low frequency. But when a RF PLC signal is applied to the line its behavior and response to RF frequencies will be different from its response to power frequencies. At the power frequency, all power lines are electrically short in terms of wavelength. At RF carrier frequencies, however, most lines are many wavelengths long because of the much shorter wavelength. In this paper, an analytical approach made to investigate the behavior of a power transformer used in a PLC system and find out the losses of RF signal due to the presence of a transformer, and mitigate the same using diversity reception.

keywords: OFDM, Diversity reception, Transfer function

I. INTRODUCTION

The public power line network is designed for transmission of AC power at typical frequencies of 50 or 60Hz. It has only a limited capability to carry higher frequencies [3-4]. Now a day, higher frequency signals are superimposed to the signal of the power wave for communication purpose. In order to ensure that the power wave does not interfere with the data signal, the frequency range used for communication is very far from the one used for the power wave (50 Hz in Europe and 60 Hz in the U.S). The frequency range used for PLC narrowband applications is 3 kHz to 500 kHz and from 1 MHz to 30 MHz for broadband applications [5].

One of the major causes of high frequency attenuation in a power line communication channel is attenuation due to reflections from abrupt discontinuities and mismatched impedances (e.g., underground to overhead risers, taps, transformers and capacitors) that occur along the power line. These reflections cause part of the signal to be diverted away from the receiver and absorbed in other parts of the system [6].

The low voltage power line grid connects the subscribers of a PLC network with the medium/low voltage transformer where probably the first level nodes of such a communication network will be placed. Because of the fact that telecommunication signals suffer large attenuation when passing through this transformer [7], and it can be regarded as a physical boundary.

Since users are supplied through a LV transformer, one needs to know the behaviour of LV transformers, as they will have a significant effect on the PLC signals. If the PLC signals are to be generated at MV or HV substations, then the PLC signals must pass through the LV transformers, just like the ripple control signals do at present. If the PLC signals are coupled directly onto the LV lines, then the impedance of the transformer may be such that most of the PLC signals are lost in the transformer and do not reach the consumer [8].

Generally power transformers are accepted as being a high shunt impedance at the carrier frequencies. Depending on their location in the carrier channel, their effect may or may not affect carrier channel performance. It is also commonly accepted that a power transformer connecting two transmission lines of different voltages constitutes a broad band high-frequency blocking device, preventing carrier on one line from reaching the other. Thus when a power transformer is at the terminal location of a carrier channel it will probably appear to the carrier signal as a trap.

Experimentally it is proved that delta connected windings are more capacitive than wye-connected ones. This high capacitance produces lower impedance to ground than might be expected. If the transformer impedance is low, then the impedance at the tap point will be high and the tap will have little effect. On the other hand, if the transformer impedance is high, then the impedance at the tap point will be low and the tap will have a significant effect on the carrier channel. In the case of taps at even quarter wavelengths, the high terminating impedance will be reflected as a high impedance with little effect on the channel and the low terminating impedance is reflected as a low impedance with a large effect.

The shunt capacitance component present in a transformer will offer a short circuit to the high frequency signals. However, this capacitance is in parallel with inductances and thus may resonate and present high impedances at least for certain frequencies. Ultimately, the transmissions of signals through a transformer become a very strong function of frequency.

For radio frequency use, transformers are sometimes made from configurations of transmission line, sometimes bifilar or coaxial cable, wound around ferrite or other types of core. This style of transformer gives an extremely wide bandwidth but only a limited number of ratios (such as 1:9, 1:4 or 1:2) can be achieved with this technique. The core material increases the inductance dramatically, thereby raising its Q factor. The cores of such transformers help to improve performance at the lower frequency end of the band. RF transformers sometimes use a third coil (called a tickler winding) to inject feedback into an earlier (detector) stage in antique regenerative radio receivers.

In RF and microwave systems, a quarter-wave impedance transformer provides a way of matching impedances between circuits over a limited range of frequencies, using only a length of transmission line. The line may be coaxial cable, waveguide, stripline or microstripline.

II. SYSTEM BLOCK DIAGRAM

The block diagram of a power line communication channel using normal power transformer considered for this analysis is shown in fig 1. The system consists of a transmitter, powerline channel and a receiver. In the transmitter, the radio signal is initially processed and then suitably modulated to get carrier signal. At the receiving end signal is received through demodulation process.

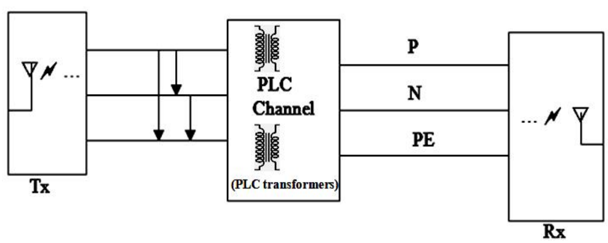

Fig 1: PLC with transformer block diagram

III. POWERLINE CHANNEL MODEL

A. BER analysis of a PLC system

In a PLC system the signal is transmitted through the powerline cables where orthogonal frequency division multiplexing (OFDM) found to be more suitable [9]. When the power cable in a PLC system is exposed in the open weather, the whole cable acts as an antenna for high frequencies. The noise it picks up from the atmosphere in mainly impulsive. So, for BER analysis only impulsive noise will be considered.

Considering OFDM modulation, the signal transmitted in a PLC channel can be expressed as

$$S(t) = \sum_{k=1}^{N} s_k(t) \quad (1)$$

And the received signal is given by,

$$r(t) = s(t) \otimes h(t) \quad (2)$$

Where, the impulse function h(t) is given by

$$h(t) = FT\ [H(f)] \quad (3)$$

B. Formulation of Transfer Function and BER without considering the Presence of Transformer

In powerline communication, the transfer function model for power line in the radio frequency range (1-30MHz) is given by [10]

$$H(f) = \sum_{i=1}^{N} g_i\, e^{-(a_0 + a_1 f^k) d_i}\ e^{-2\pi j f \tau_i} \quad (4)$$

here, g_i = weighting factor for path i

a_0 and a_1 = attenuation parameters

f = frequency

k = exponent of attenuation factor (0.5…1)

d_i = length of the path and the delay is τ_i

For orthogonal frequency division multiplexing (OFDM), if the PSD (power spectral density) of the overall noise be Nm; where Nm is given by

$$N_m = N_0 + P_i N_i \quad (5)$$

Considering additive white Gaussian noise (AWGN) noise power is N_0 and impulsive noise power is Ni, then we define

$$\mu = Ni/N_0$$

and, BER under AWGN and impulsive noise is

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_m}}\right) \qquad (6)$$

$$P_b = Q\left(\sqrt{2\frac{E_b/N_0}{1+\mu\lambda\ Tnoise}}\right) \qquad (7)$$

$$P_b = 0.5\ erfc\left(\sqrt{\frac{E_b/N_0}{1+\mu\lambda\ Tnoise}}\right) \qquad (8)$$

So, the BER under AWGN and impulsive noise in OFDM is given by [11]

$$BER = \frac{1}{N}\sum_{i=1}^{N} 0.5\ erfc\left(\sqrt{\frac{E_b/N_0}{1+\mu\lambda\ Tnoise}\left|H(f)\right|^2}\right) \qquad (9)$$

Considering m=Rb/B,

$$BER = \frac{1}{N}\sum_{i=1}^{N} 0.5\ erfc\left(\sqrt{\frac{m\cdot E_b/N_0}{1+\mu\lambda\ Tnoise}\left|H(f)\right|^2}\right) \qquad (10)$$

C. Formulation of Transfer Function and BER in the Presence of Transformer

The impulse response of the powerline is given by h(t) = F^{-1}[H(f)]

so from equation (4), we get

So,

$$h_1(t) = \sum_{i=1}^{N} g_i\, e^{-(a_0+a_1f^k)d_i}\,\delta(t-\tau_i) \qquad (11)$$

To formulate of the transfer function, let,

$$H_1(f) = \Im\{h_1(t)\} \qquad (12)$$

so, H_1(f) can be calculated as follows,

$$H_1(f) = \left[\sum_{i=1}^{N} g_i\, e^{-(a_0+a_1f^k)d_i}\, e^{-2\pi f\tau_i}\right] \qquad (13)$$

For an outdoor network, the powerline consists of the channel having number of transformers that exhibit this periodic time-varying behavior in different frequencies. A simple approximation for modeling the periodic channel of the transformer, the impulse function is given by [12]

$$\begin{aligned} h_2(t) &= \alpha \left[Sin \ \frac{4\pi}{T_{AC}} t + \beta \right] h_c(t) \\ &= \alpha \ h_c(t) \ Sin \ \frac{4\pi}{T_{AC}} t + \alpha \ \beta \ h_c(t) \end{aligned} \tag{14}$$

And

$$H_2(f) = \Im \ \{ \ h_2(t) \} \tag{15}$$

Now the total impulse function of the outdoor channel is given by

$$h(t) = h_1(t) \otimes h_2(t)$$

$$\begin{aligned} h(t) = &\left\{ \sum_{i=1}^{N} g_i \, e^{-(a_0 + a_1 f^k) d_i} \delta(t - \tau_i) \right\} \\ &\times \left\{ \alpha \left[Sin \frac{4\pi}{T_{AC}} t + \beta \right] h_c(t) \right\} \end{aligned} \tag{16}$$

Or,

$$\begin{aligned} H_2(f) &= \Im \left[\alpha \ h_c(t) \, Sin \ \frac{4\pi}{T_{AC}} t + \alpha \ \beta \ h_c(t) \right] \\ &= \int_{-\infty}^{\infty} \alpha h_c(t) \ Sin \ \frac{4\pi}{T_{AC}} t \ . \ e^{-j2\pi ft} \, dt \\ &\quad + \int_{-\infty}^{\infty} \alpha\beta \ \ h_c(t) \ \ e^{-j2\pi ft} \, dt \end{aligned} \tag{17}$$

where α is gain constant, β is positive offset, and $h_c(t)$ is a common channel response.

$$\begin{aligned} H_2(f) = \alpha h_c(t) \int_{\infty}^{\infty} Sin \ \frac{4\pi}{T_{AC}} t \ . \ e^{-j2\pi ft} \, dt \\ + \ \alpha\beta h_c(t) \int_{-\infty}^{\infty} e^{-j2\pi ft} \, dt \end{aligned}$$

$$H_2(f) = \alpha h_c(t) \frac{\frac{4\pi}{T_{AC}}}{\left(\frac{4\pi}{T_{AC}}\right)^2 + \left(j2\pi f_{ac}\right)^2} + \alpha\beta\, h_c(t) \frac{1}{j2\pi f_{ac}}$$

$$H_2(f) = \frac{\alpha\, h_c(t)}{\pi}\left[\frac{T_{AC}}{4 - T_{AC}{}^2 f_{ac}{}^2} - j\frac{\beta}{2 f_{ac}}\right] \qquad (18)$$

So, the combined transfer function of a powerline network becomes

$$H\left(f\right) = H_1(f) \cdot H_2(f) \qquad (19)$$

$$or, H(f) = \left(\sum_{i=1}^{N} g_i\, e^{-(a_0 + a_1 f^k) d_i} e^{-2\pi f \tau_i}\right) \times \left(\frac{\alpha\, h_c(t)}{\pi}\left[\frac{T_{AC}}{4 - T_{AC}{}^2 f_{ac}{}^2} - j\frac{\beta}{2 f_{ac}}\right]\right)$$

$$P_{bk} = \frac{1}{N}\sum_{i=0}^{N} Q\left(\sqrt{\frac{2\left|H\ (f\ )\right|^2 E_b}{N_0}}\right) \qquad (20)$$

So, $SNR \quad \infty \quad \left|H\ (f\ )\right|^2$; and BER is given by

$$BER = \frac{1}{N}\sum_{i=1}^{N} 0.5\, erfc\left(\sqrt{\frac{E_b}{N_0}\left|H\ (f\ )\right|^2}\right) \qquad (21)$$

$$Now, \quad SNR = \frac{E_b}{N_m}$$

$$E_b = P_s T_b$$

$$SNR = \frac{P_s}{P_n}; \quad (Pn = \sigma_n{}^2)$$

$$\begin{aligned} SNR &= \frac{E_b / T_b}{\left(N_0 / 2\right) \cdot 2B} = \left(\frac{E_b}{N_0}\right)\left(\frac{1/T_b}{B}\right) \\ &= \left(\frac{E_b}{N_0}\right)\left(\frac{R_b}{B}\right) = \left(\frac{E_b}{N_0}\right)\left(\frac{R_b}{B}\right) \\ &= \left(\frac{E_b}{N_0}\right)\left(\frac{1}{m}\right); \quad m = R_b / B = 1, 2, 3 \ldots \end{aligned} \qquad (22)$$

So, the BER equation becomes

$$BER = \frac{1}{N}\sum_{i=1}^{N} 0.5\, erfc\left(\sqrt{m\frac{E_b}{N_0}\left|H(f)\right|^2}\right) \qquad (23)$$

IV. RESULT AND DISCUSSION

In this paper, we have developed a suitable model for transfer function of powerline carrier communication network considering the presence of power transformer. Following the same, a BER equation has been derived for the PLC with OFDM in the presence of impulsive noise. The performance of the OFDM PLC channel has been evaluated by MatLab simulation with and without transformer in impulsive noise environment is shown in fig 2 to 4, which show the comparison of BER plot with and without transformer. In figs 5, the BER penalty in different channel bandwidth with the presence of Transformer is shown. These analysis show that there a loss of BER at about 10-15 dB for transformer. The BER penalty due to transformer is shown in fig 5.

The BER performance with diversity reception and performance improvement in the presence of transformer is shown in figs 6-9. The overall performance improvement in BER by using more number of receivers (upto 8 in number) in the presence of transformer is shown in fig 10.

The performance degradation due to the presence of power transformer in a PLC channel can be improved by increasing the number receivers (diversity reception), and furthermore there is additional amount of improvement of the system performance by this proposed technique. However, the optimum number of receivers and transformers can be used for best performance are not calculated, remain as future works.

A. BER Performance with and without transformer

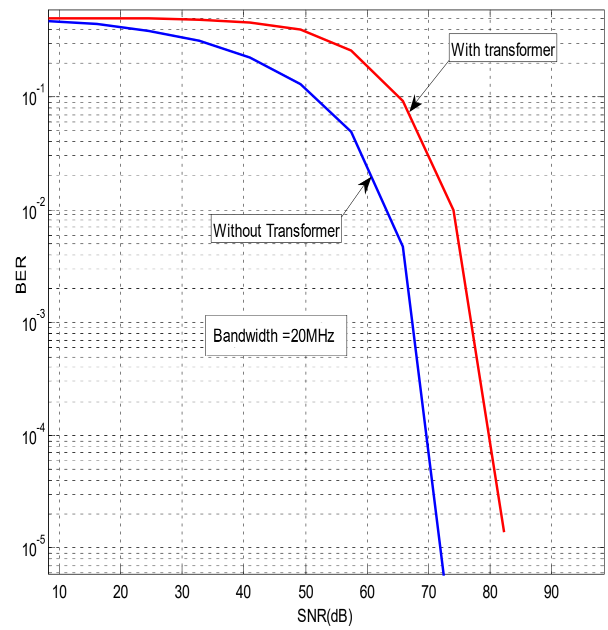

Fig 2: BER performance in 20 MHz range in the presence of transformer with impulsive noise.

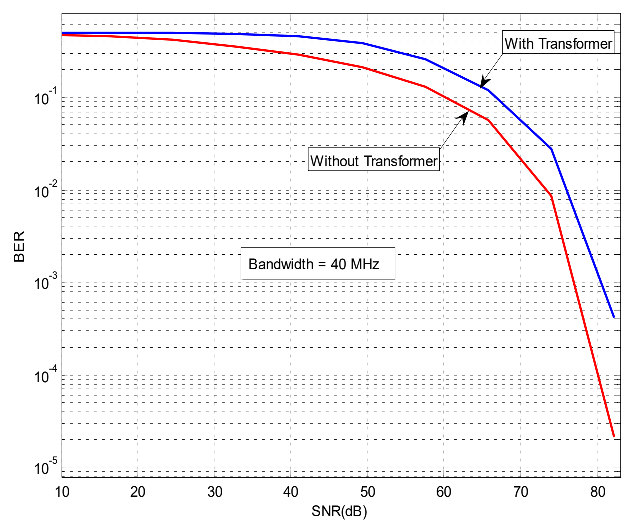

Fig 3: BER performance in 40 MHz range in the presence of transformer with impulsive noise.

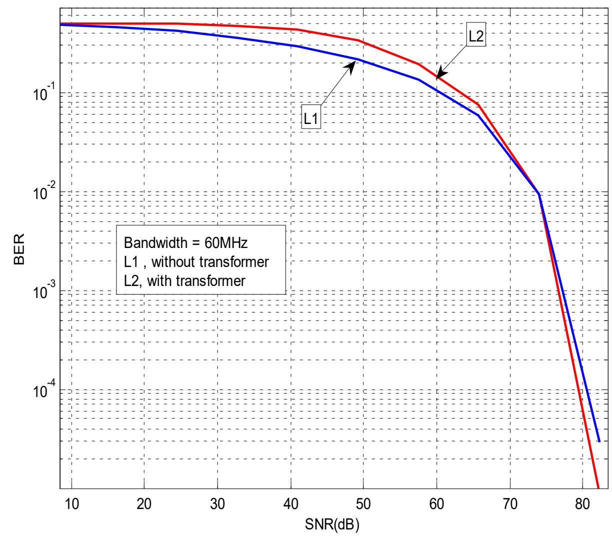

Fig 4: BER performance in 60 MHz range in the presence of transformer with impulsive noise.

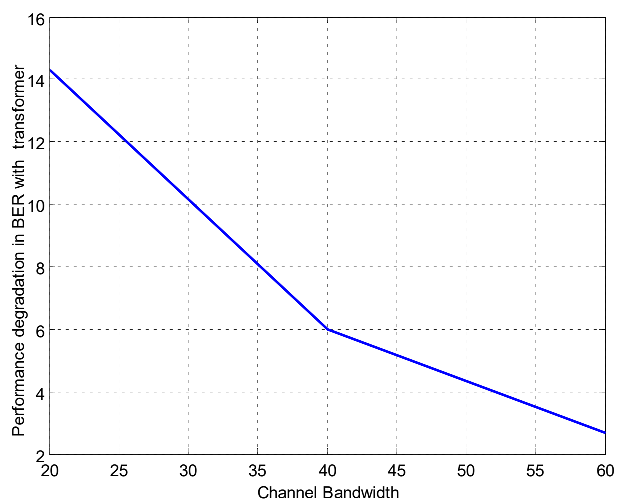

Fig 5: BER penalty with transformer in different channel bandwidth

B. BER Performance Improvement in the presence of Transformer by diversity reception

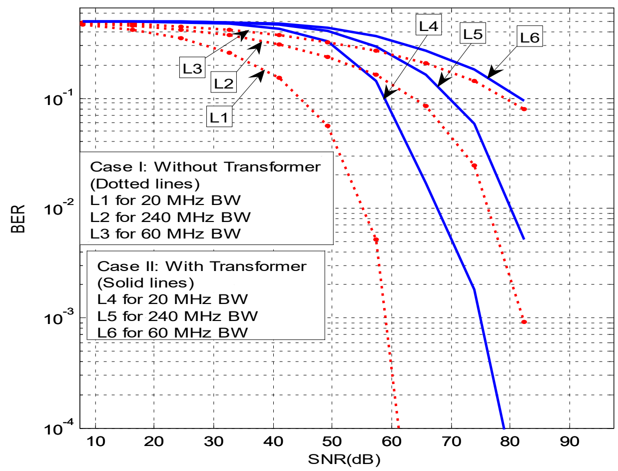

Fig 6: BER performance in 20, 40 and 60 MHz range in impulsive noise environment with and without transformer.

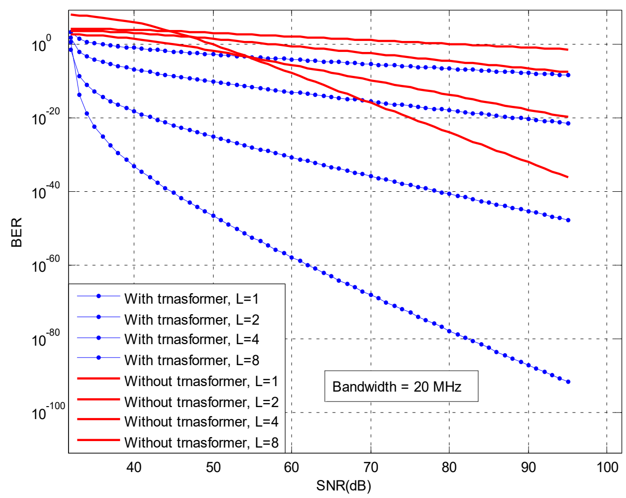

Fig 7: BER performance in 20 MHz BW with and without transformer in impulsive noise environment (with 1, 2, 4 and 8 receivers).

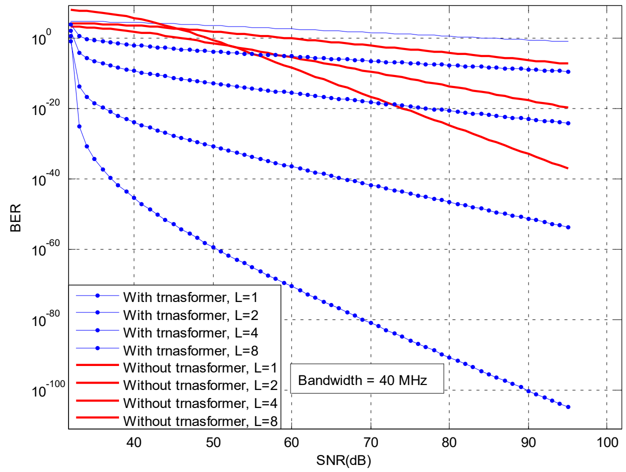

Fig 8: BER performance in 40 MHz range with and without transformer in impulsive noise environment (with 1, 2, 4 and 8 receivers).

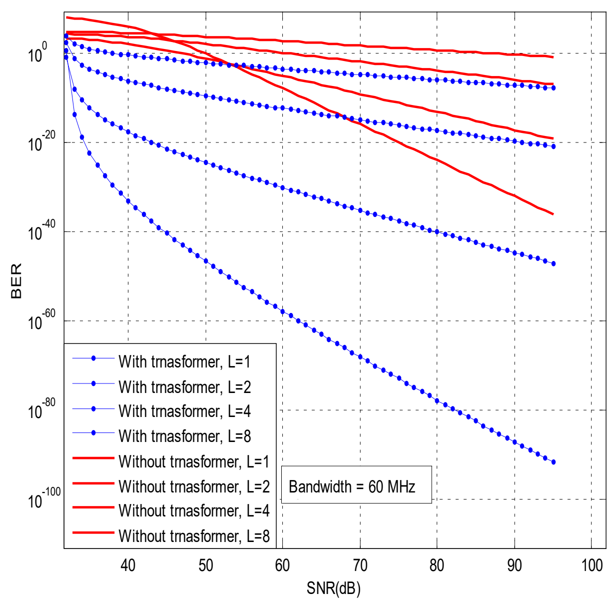

Fig 9: BER performance in 60 MHz range with and without transformer in impulsive noise environment (with 1, 2, 4 and 8 receivers).

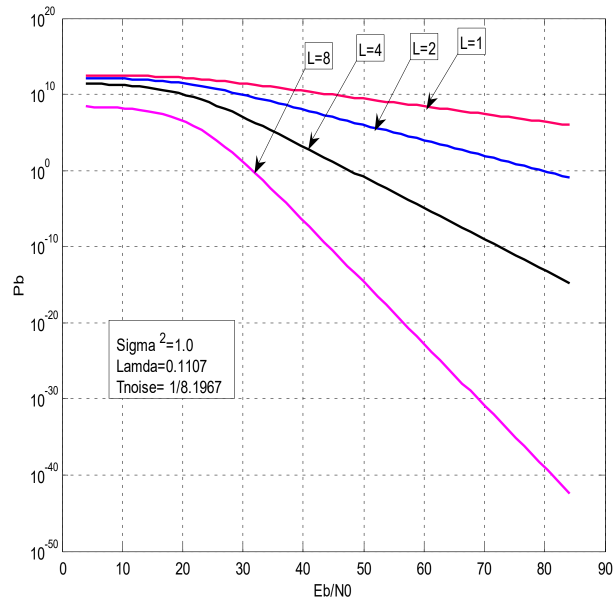

Fig 10: BER performance improvement by increasing the no of receivers (diversity reception).

REFERENCES

[1] S. Tachikawa, H. Hokari and G. Marubayashi,"Power line data transmission," IEICE Technical report, SSTA89-7, March 1989.

[2] T.V.Prasad, S.Srikanth, C.N.Krishnan, P.V.Ramakrishna, "Wideband Characterization of Low Voltage outdoor Powerline Communication Channels in India", AU-KBC Centre for Internet and Telecom Technologies Anna University, M.I.T. Campus,Chennai, India.

[3] Holger Philipps, "Performance measurements of powerline channels at high frequencies" Research paper of Institute for Communications Technology, Braunschweig Technical University, Schleinitzstrasse -22, D-38106 Braunschweig, Germany, PLC'98.

[4] Abdelali Rennane, Christophe Konaté and Mohamed Machmoum, "A Simplified Deterministic Approach to accurate Modeling of Transfer Function for the Broadband Power Line Communication" New, 2 Advanced Technologies journal, Nantes of University (Nantes), France, www.intechopen.com.

[5] Batuhan Danisman, "Analysis of conventional low voltage power line communication methods for automatic meter reading and the classification and experimental verification of

noise types for low voltage power line communication network" Thesis for master of science in electrical and electronics engineering, Graduate School of Natural and Applied Sciences, February 2009.

[6] Hasan Basri Çelebi, "Noise and multipath characteristics of power line communication channels" Thesis for master of science in Electrical Engineering Department of Electrical Engineering College of Engineering, University of South Florida, 30 March, 2010.

[7] Olaf G. Hooijenl and A.J. Han Vinck, "On the Channel Capacity of a European-style Residential Power Circuit" ' Signaal Communications, Institute for Experimental Mathematics, University of Essen, ~llernstr&se 29, 45326 Essen, Gennany.

[8] M. Zimmermann and K. Dostert, "Analysis and modeling of impulsive noise in broad-band powerline communications," *IEEE Trans. Electromagn.Compat.*, vol. EMC-44, no. 1, pp. 249–258, Feb. 2002.

[9] M. Rahman M and Majumder S. P "Analysis of a powerline communication system over a non-white additive Gaussian noise channel and performance improvement using diversity reception "Network and Communication Technologies journal Vol. 1, No. 1; June 2012.

[10] Manfred Zimmerman and Klaus Dostert "A multipath model for the powerline channel" IEEE transaction on communications, vol. 50, No. 4, April 2002.

[11] P A. JANSE VAN RENSBURG "Effective coupling for power line communications" D. Ing (Electrical and Electronics), University of Johannesburg, Jan 2008.

[12] Marcel Nassar, Jing Lin, Yousof Mortazavi, Anand Dabak. Han Kim, and Brian L. Evans, "Local Utility Powerline Communications in the 3-500 kHz Band: Channel Impairments, Noise, and Standards" IEEE SIGNAL PROCESSING MAGAZINE 1, January 20, 2012.