Measurement, Modeling and Simulation of Power Line Channel for Indoor High-speed Data Communications

Jong-ho Lee, Ji-hoon Park†, Hyun-Suk Lee, Gi-Won Lee†† and Seong-cheol Kim
School of Electrical and Computer Engineering, Seoul National University
†Wireless Media Communication Dept. Advanced Communication Lab. LG Electronics
††Keyin Telecom
Phone : +82-02-880-1822 , E-mail : sckim@maxwell.snu.ac.kr

Abstract – The empirical channel model of power line is obtained through impulse response measurements using the *pseudo-noise* (PN) correlation method. The BER performance for QPSK is also reported as a result of computer simulation with the proposed channel model. Simulation results show that effective mitigation methods are required to support high speed data communication over power line with the acceptable BER.

Keyword – power line channel measurement, empirical channel model of power line

1. Introduction

For last few years, the number of households and small business offices having multiple PCs and subscribing to high speed data communication service via LMDS, ADSL, Cable modem, etc. increases explosively. It is expected that many of those homes and offices come to connect their multiple PCs through in-home distribution network in order to share not only files and peripherals but also access to Internet service provider.

Some proposed technologies for in-home distribution network are HomePNA based on existing phone line, Power Line Communication (PLC) through power distribution line, and wireless solutions such as wireless LAN, HomeRF and Bluetooth. The PLC technology is believed as an attractive solution for in-home distribution network since it does not require installation of a new wire and provides ubiquitous access to network through many existing power outlets at home although there are some barriers such as impulse noise, dynamic change of input impedance, etc. obstructing reliable data communication service [1,2,3].

In this paper, the wideband channel properties of power line in the frequency bands from 10MHz to 30MHz are characterized through impulse response measurements using the PN correlation method. From the measured data, the empirical multipath channel model of power line is proposed. The BER performance is obtained using computer simulation with the proposed channel model. Simulation results show that the effective mitigation methods for the channel impairment are necessary to support high speed data communications over power line channel with acceptable BER.

2. Measurement systems

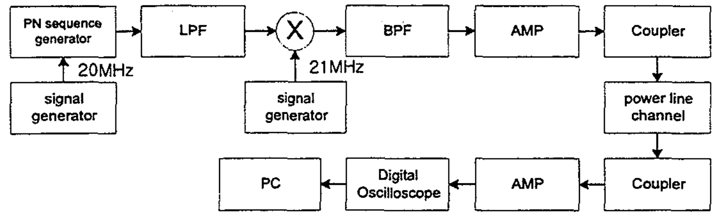
Impulse responses of power line channel are obtained using the PN correlation method [4]. The measurement system for obtaining the impulse response is shown in Fig. 1.

In Fig. 1(a), PN sequences are generated with the chip rate of 20 Mhz and 21 Mhz carrier is modulated with the generated PN sequences. The modulated signals are amplified and injected into the power line through the coupler. The received signals through power line channel are amplified and sampled at the rate of 100 MS/s by the digital oscilloscope. The amplitude a and phase p can be expressed by the following equations,

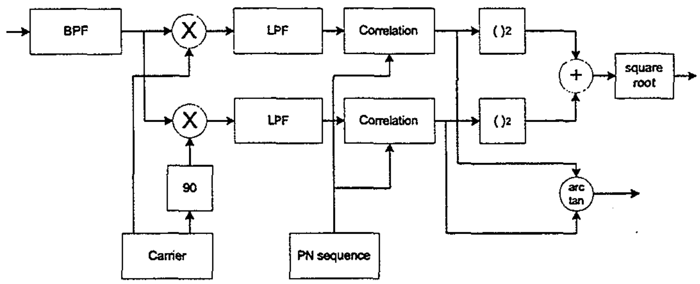
$$a(n) = \sqrt{h_i(n)^2 + h_q(n)^2} \qquad p(n) = \tan^{-1}\left(\frac{h_i(n)}{h_q(n)}\right) \tag{1}$$

where h_i and h_q represent in-phase and quadrature-phase components of the correlation output, respectively in Fig. 1(b). The resolution of the measurement system is 0.05 μs that is the same as the chip duration of PN sequence and impulse responses are measured every 1.73 sec.

This work was supported by Brain Korea 21 project, Keyin Telecom and SNU Development Foundation



(a) Hardware system



(b) Software system

Fig. 1 Block diagrams of power line channel impulse response measurement system.

3. Impulse response measurements

Measurements were carried out in the laboratory environment as shown in Fig. 2. The transmitter was fixed at outlet F, and the receiver was located at each outlet (outlet A, B, C, D, E). Two hundred impulse responses were measured at each outlet at midnight (AM 1:00), in the afternoon (PM 3:00) and in the evening (PM 8:00). In case of measurements in the afternoon, typical electric appliances such as PCs, television, refrigerator, mechanical fan and humidifier were connected throughout and switched on. In the evening, only PCs and television were switched on. All appliances were disconnected for measurements at midnight. The distance between each outlet was 2 m.

Fig. 3 and 4 show impulse responses measured at outlet A and outlet D. When the receiver is located at outlet D, there is no junction between the transmitter and the receiver. On the other hand, the transmitted signal at outlet F must pass through the junction to reach at outlet A. The normalized amplitude in Fig. 3 ranges from 0 to 0.1 while those in Fig. 4 does from 0 to 1. Therefore, it is observed that the radio signal in the frequency bands between 10Mhz and 30Mhz attenuates more than 20 dB to cross over the junction.

4. Empirical channel model and discussion

Based on measured data, the empirical multipath channel model for power line [5,6,7] is proposed. The propagation loss model for the first path at each outlet can be obtained from Fig. 5.

In Fig. 5(a), the slope of the attenuation curve for outlets without a junction between the transmitter and the receiver is about 0.75 dB/m and the initial attenuation that is conjectured as the coupling loss is 4.4 dB. At outlet E and D for which there is no junction between the transmitter and the receiver, the additional propagation loss of 5.7 dB is observed in the afternoon and in the evening compared to the propagation loss at midnight. On the other hand, propagation loss curves for the other group of outlets having a junction in Fig. 5(b) show that the initial loss, which is believed to include the junction loss in addition to the coupling loss, is 23.55 dB. Furthermore, we cannot tell the difference among the propagation loss in the afternoon, in the evening and at midnight. The slope of the attenuation curve is maintained at 0.75 dB/m, regardless of the time of measurements.

Analyzing measured impulse responses, there exist three multipath components within 1 μs for most of measurements on the average. The propagation loss of each path calculated from the time averaged impulse response curve is shown in Fig. 6. The propagation loss increases constantly with multipaths at the rate of 6.1 dB for outlets having a junction between the transmitter and the receiver and at the rate of 10.5 dB for outlets having no junction between the transmitter and the receiver.

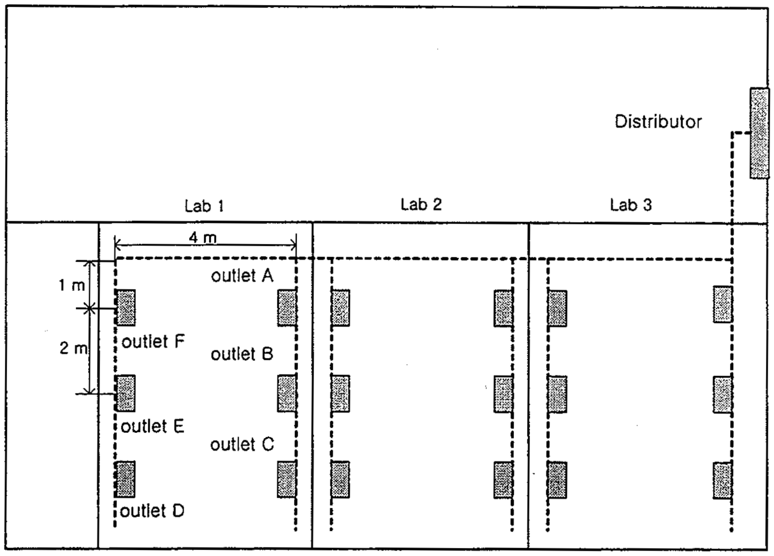
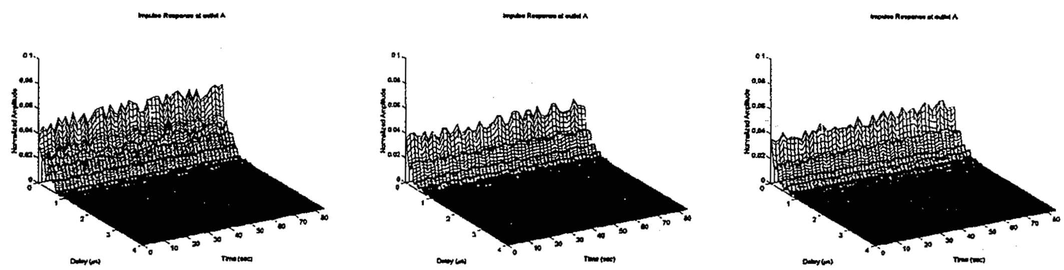
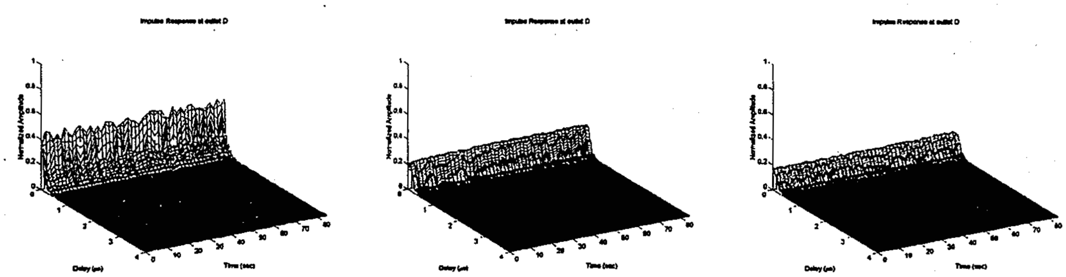


Fig. 2 Floor plan and layout of power outlets.



(a) at midnight (b) in the afternoon (c) in the evening

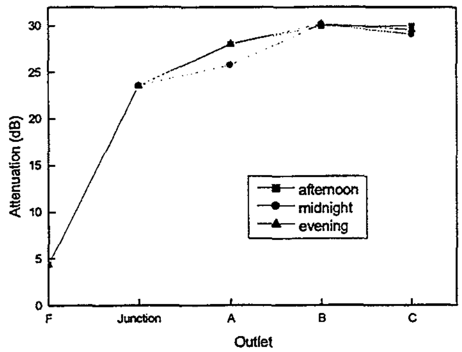
Fig. 3 Impulse responses measured at outlet A.

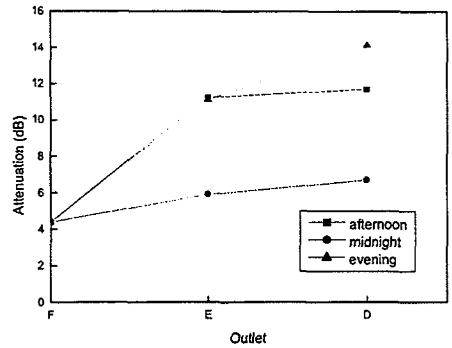


(a) at midnight (b) in the afternoon (c) in the evening

Fig. 4 Impulse responses measured at outlet D.

The statistical properties of the amplitude and phase variations as well as the interval variation between each path are obtained from measured impulse responses. The analysis reveals that the statistics of the amplitudes normalized by the time averaged value follows the Rician distribution curve with mean=1 and K=20 for the first and second paths and the Rician distribution curve with mean=1 and K=5 for the third path in case of outlets having no junction between the transmitter and the receiver. For the other outlets having a junction, the distribution curve follows the Rician curve with mean=1 and K=20 for the first path and the Rayleigh curve with mean=1 for the second and third path. The phases are uniformly distributed from 0 to 2π. The interval between the first and second path is uniformly distributed between 0.1 μs and 0.24 μs and the distribution of the interval between the second and third path follows the uniform distribution between 0.1 μs and 0.27 μs. The power line channel can be statistically simulated by the following procedures.





(a) outlets having a junction

(b) outlets having no junction

Fig. 5 Attenuation curve of the first path at each outlet.

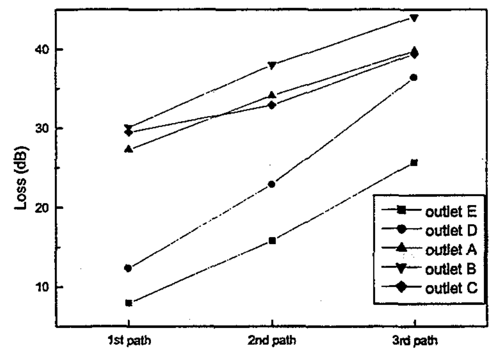


Fig. 6 Comparison of propagation loss of each path.

First, determine the attenuation of the first path PL_1 depending on the location of the receiver. Assuming the distance between the transmitter and the receiver is r m, the path loss can be obtained from the following equation

$$PL_{1(dB)} = 23.55_{(dB)} + 0.75_{(dB/m)} \times r_{(m)} \tag{2}$$

for outlets having a junction between the transmitter and the receiver.

$$PL_{1(dB)} = 4.4_{(dB)} + 0.75_{(dB/m)} \times r_{(m)} + AAF_{(dB)} \tag{3}$$

for outlets having no junction between the transmitter and the receiver. Additional attenuation factor (AAF) is 5.7 dB for outlets having no junction between the transmitter and the receiver in the afternoon and in the evening. With the calculated PL_1, the amplitude of the first path A_1 can be obtained by

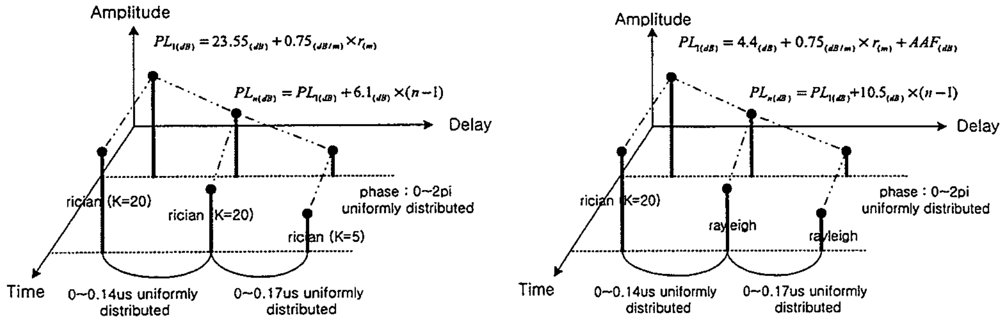
$$A_1 = 10^{-\frac{PL_1}{20}} \cdot R \tag{4}$$

where R is a Rician random variable with mean=1 and K=20.

Second, determine the phase of the first path P_1 from the uniform distribution from 0 to 2π.

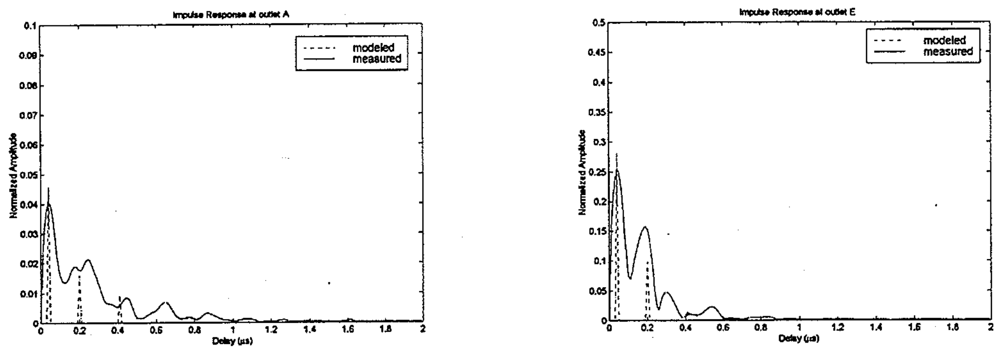
Third, determine the attenuation of the second and third path PL_2, PL_3. In case of 'with the junction',

$$PL_{n(dB)} = PL_{1(dB)} + 6.1_{(dB)} \times (n-1) \qquad n = 2,3 \tag{5}$$



(a) the case with the junction (b) the case without the junction

Fig. 7 Empirical multipath channel model of power line.



(a) Outlet A (b) Outlet E

Fig. 8 Comparison of simulated and measured impulse responses

where n means the path index. The amplitude of the second path A_2 is determined from PL_2 and Rician random variable with mean = 1 and K = 20 with the same equation to determine A_1. The amplitude of the third path A_3 is also obtained from PL_3 and Rician random variable with mean=1 and K=5. In case of 'without the junction',

$$PL_{n(dB)} = PL_{1(dB)} + 10.5_{(dB)} \times (n-1) \qquad n = 2,3. \qquad (6)$$

A_2 and A_3 are determined from PL_2, PL_3 and the Rayleigh random variable with mean=1.

Fourth, determine the phase of the second and third path P_2 and P_3, which follow the uniform distribution from 0 to 2π.

Fifth, the interval between the first and second path d_{12} is determined from the uniform distribution between 0.1 μs and 0.24 μs. The interval between the second and third path d_{23} is also obtained to be uniformly distributed between 0.1 μs and 0.27 μs.

The channel modeling procedures are summarized in Fig. 7. The empirical multipath channel model of power line is given by

$$h(t) = A_1 e^{jP_1}\delta(t) + A_2 e^{jP_2}\delta(t-d_{12}) + A_3 e^{jP_3}\delta(t-d_{23}). \qquad (7)$$

The simulated impulse response is compared with the measured impulse response in Fig. 8.

The BER performance for QPSK with the proposed channel model is obtained using computer simulation [8,9]. For QPSK, BER vs E_b/N_0 performances are simulated in case of 'with the junction' and 'without the junction' as shown in Fig. 10.

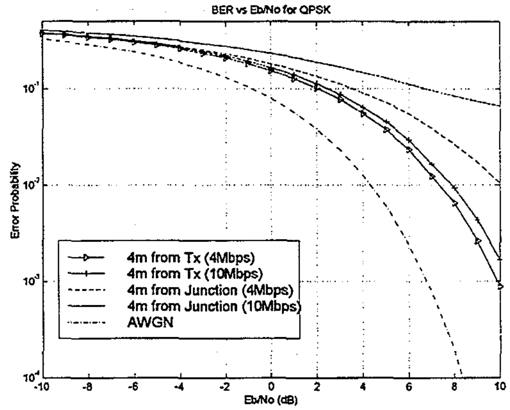


Fig. 9 Performance curves for QPSK in the power line channel.

6. Conclusion

In this paper, the channel properties of power line are characterized through impulse response measurements. The empirical multipath channel model is proposed from measured data. The number of multipath components is 3 within 1 μs on the average. The statistics of the amplitudes normalized by the time averaged value at each path follow the Rician or Rayleigh distribution curve. The phases are uniformly distributed between 0 and 2π. The distribution of the interval between each path follows the uniform distribution during about 0.2 μs.

The BER performances for QPSK are simulated with the proposed channel model. From simulation results, we conclude that the effective mitigation methods are necessary to high speed data communications over power line with the acceptable BER.

References

[1] H. Philopps, "Performance measurements of powerline channels at high frequencies," *Proc.* ISPLC'98, Tokyo, pp. 229-237, Mar. 1998.

[2] C. Hensen, "Characterization, measurement and modeling of medium voltage powerline cables for high data rate communication," *Proc.* ISPLC'99, Essen, pp. 37-44, Mar. 1999.

[3] D. Liu, E. Flint, B. Gaucher, and Y. Kwark, "Wide band AC power line characterization," *IEEE Trans. Consumer Electronics.*, vol. 45 4, pp. 1087-1097, Nov. 1999.

[4] J. D. Parsons, "The mobile radio propagation channel," *John wiley & sons*, 1992.

[5] A. A. M. Saleh and R. A. Valenzuela, "A statistical model for indoor multipath propagation," *IEEE J. Select. Areas Commun.*, vol. SAC-5, no. 2, pp. 138-146, Feb. 1987.

[6] S. C. Kim, H. L. Bertoni and M. Stern, "Pulse propagation characteristics at 2.4Ghz inside buildings," *IEEE Trans. Veh. Technol.*, Vol. 45, no. 3, pp. 579-592, Aug. 1996.

[7] T. S. Rappaport, S. C. scott and K. Koichiro, "Statistical channel impulse response models for factory and open plan building radio communication system design," *IEEE Trans. Commun.*, vol. 39. no. 5, pp. 794-807, May 1991.

[8] J. G. Proakis, "Digital communications," *McGrow-Hill*, 1995.

[9] M. C. Jeruchim, "Simulation of communication systems," *Plenum*, 1994.