Evaluation of communication reliability of a test-bed networked to the home appliances with PLC modems for the Internet accessed home automation

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Abstract: *This paper presents a systematic method of probing channel characteristics and communication reliabilities of home power line communication network applied to the Internet accessed control of home appliances. The effects of the three performance deteriorating factors, i.e., additive noise, channel attenuation, and intersymbol interference, can be systematically measured by applying the channel probing waveform in the frequency range from 100kHz to 450kHz. Probability of bit error is derived with the probed channel parameters of the signal attenuation, noise and signal-to-interference ratio read in the frequency domain. The agreement between the derived probability of bit error and the measured probability of bit error supports the validity of the proposed approach of probing home power line channel characteristics. The experimental results performed with the constructed test-bed applying the proposed channel probing method and the operation reliability measurement of the overall networked system also support the feasibility of commercially deploying the PLC modem installed home appliances and their services for the Internet accessed home automation in densely populated residential apartment complexes.*

1. Introduction

Home power line network has been considered as one of the feasible means of providing communication networks for Internet accessed home automation [1][2]. However, the widely varying unstable channel characteristics of the home power line network, that results from the direct coupling of the diverse home appliances to the network, is one of the major prohibitive factor in commercially deploying PLC (power line communication) modem installed home appliances [1][2][3].

The purpose of this research is to present a new systematic method of probing channel characteristics and communication reliability of home power line network. The proposed technique is also applied to a test-bed, which is constructed with the local area networked 100 apartment houses selected from the 1,000 unit comprised apartment complex located in Yong-In, Korea, to assess the feasibility of commercially deploying the PLC modem installed home appliances and servicing the densely populated residential site with the Internet accessed home automation.

The experiment results to assess the channel communication reliability are presented together with those to assess the operation reliability of the overall networked system.

2. PLC Channel Probing Method

The probability of bit error is approximated with the analytic expression incorporating the three deteriorating factors for communication performance, i.e., additive noise(σ_η^2), channel attenuation(I^2), and intersymbol interference(D_{ms}) as given in equation (1).

$$P_{BER} = \frac{1}{2} erfc\left(\sqrt{\frac{1}{2 \cdot (D_{ms} + \frac{\sigma_\eta^2}{I^2})}} \right) \quad (1)$$

The three channel parameters can be systematically measured by applying the channel probing waveform shown in figure 1. The measurement setup to cover the frequency range from 100kHz to 450kHz is shown in figure 2.

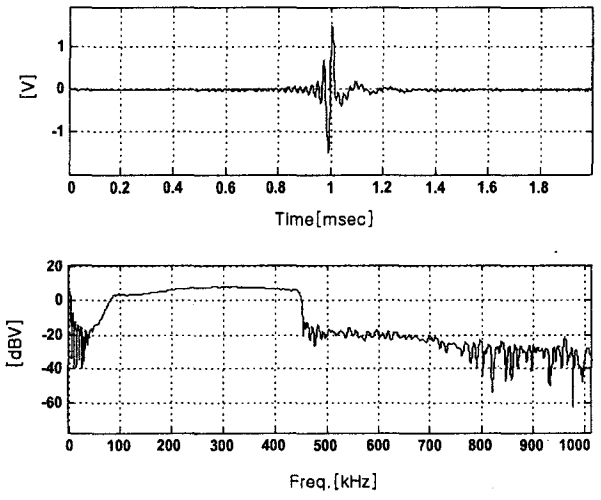

Figure 1. The channel probing waveform and its spectrum.

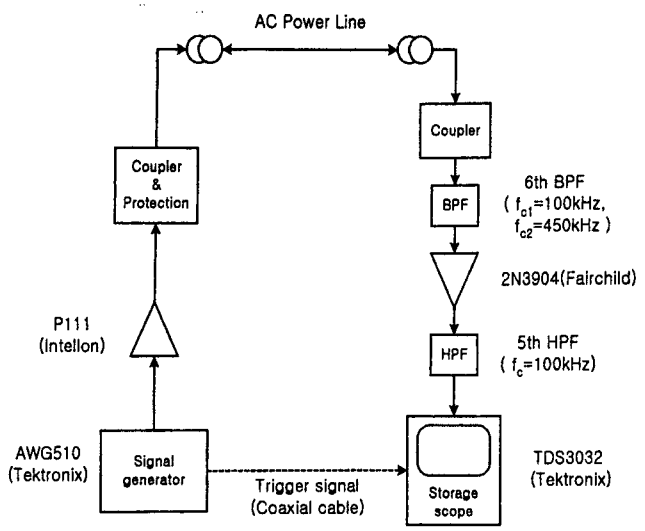

Figure 2. Measurement setup for probing channel characteristics.

Signal attenuation is derived in the frequency domain by measuring the area of the Nyquist band from the spectrum of the received probing waveform. The signal-to-interference ratio can be derived in the frequency domain as given in equation (2),

$$D_{ms}=\frac{\xi^2}{I^2}=\frac{\int_{-\frac{1}{2}}^{\frac{1}{2}}\left|\sum_k S_R(j\frac{2\pi}{T_b}(f'-k))\right|^2 df'}{\left(\int_{-\frac{1}{2}}^{\frac{1}{2}}\sum_k S_R(j\frac{2\pi}{T_b}(f'-k))\,df'\right)^2}-1 \quad (2)$$

where, S_R represent the magnitude spectrum of the received waveform, and T_b represent the bit interval.

Measurements are carried for the 88 paired combinations of electric power consents of the four bedroom apartment house where most of the home appliances are kept in running state to reflect the worst case statistics of the communication reliability. The reference bit rate used in the experiment is 5 kbps and the channel probing is performed for the Nyquist channel band. Probability of bit error is derived using equation (1) with the probed channel parameters of the signal attenuation and signal-to-interference ratio read in the frequency domain as given in equation (2). The derived probability of bit error of equation (1) are compared with the directly measured probability of bit error using the commercially available measurement device [6] as shown in figure 3, where only the paired paths that yield the probability of bit error poorer than 10^{-3} are shown for the comparison. As shown in the figure, the agreement between the derived probability of bit error and the measured probability of bit error supports the validity of the proposed approach of probing home power line channel characteristics.

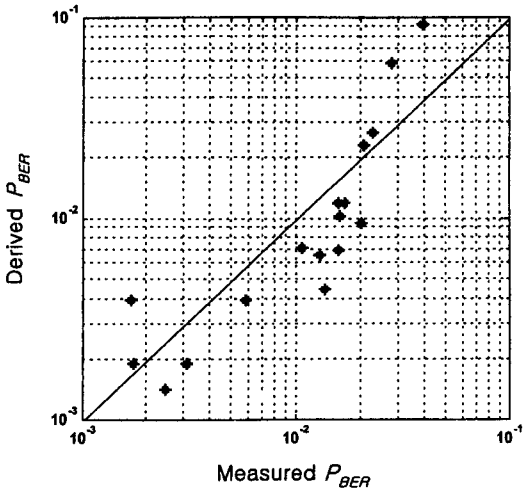

Figure 3. Derived probability of bit error verses directly measured probability of bit error.

3. Experiment to assess the channel reliability

Practical power line modems generally utilize a wider range of bandwidth or multiple Nyquist bands and/or multiple transmission trials to combat with the channel variability [5][6]. The table 1 shows the summary of the experimental results to assess the communication reliability of practical home power line network, where the figures of the reliability reflect the usage of the dual band with up to four times of multiple transmissions. The reliability factors are derived by jointly measuring the probability such that the communications using the two bands simultaneously fall into the range where the probability of bit error is poorer than the reference level of 10^{-3}. The log-normally distributed probability density functions can be obtained from the measured margin distribution of E_b/N_o with respect to the reference level of 10^{-3}.

Table 1. Summary of communication reliability measured for the practical home PLC network

Paths	Margin at 132kHz [dB]		Margin at 115kHz [dB]		Reliability [%]	Remarks
	Mean	Std.	Mean	Std.		
Paths with air-conditioner	5.9	8.5	12.3	7.0	99.9	14 paths
Paths with refrigerator	3.7	8.8	10.0	9.0	99.3	14 paths
Paths with washing-machine	-2.1	12.2	2.7	7.6	93.8	14 paths
Paths with microwave-oven	-2.5	12.4	5.1	7.3	96.5	14 paths
Other paired electric outlets	8.7	13.6	17.3	16.6	98.6	32 paths
Total	5.4	12.7	12.8	13.9	97.9	88 paths

The table 1 shows that the average communication reliability ranges from 93.6% to 99.9% for the paths including the four types of home appliances at one end of the communication path. The total average for the electric power consent coverage is 98.4%, which can be considered as a sufficiently high level of performance suitable for the commercial deployment of the PLC installed home appliances.

4. Experiment to assess the overall operation reliability

The overall operation reliability is evaluated with the test-bed which is constructed with 100 apartment houses selected from the 1,000 unit comprised apartment complex located in Yong-In, Korea.

The same models of four typical home appliances, i.e., refrigerator, washing machine, air-conditioner, and microwave oven, are installed with PLC modems and deployed to each of the selected apartment house and networked to a main server through a home gateway and the local area network as shown in figure 4. The main server allows Internet access of the home appliances and performs the data logging and system monitoring as well.

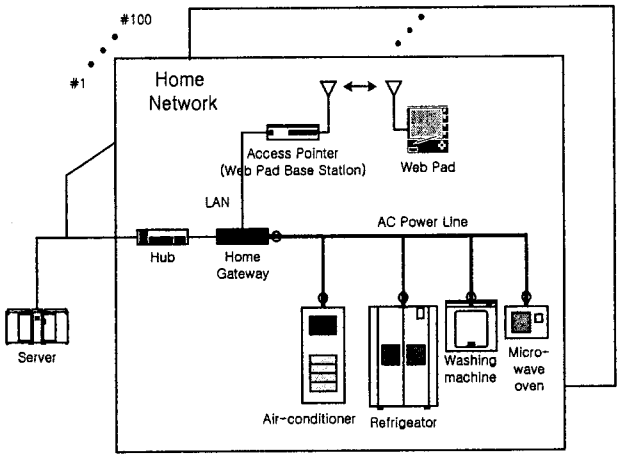

Figure 4. Construction of a test-bed which consists of the local area networked 100 apartment houses deployed with the PLC modem installed home appliances.

The PLC packet consists of 18 bytes of data to represent device IDs, packet counter, control and device status information generated at the home appliances. The home gateway attaches the side information bits to the packet data including the building number and the apartment number to make up the network frame data as shown in figure 5. The PLC frame error rate can be derived by monitoring the missing packet count number among those sent from the home appliances.

The test-bed is currently in operation with the real daily home life situations of the 100 apartment houses and its communication reliability is assessed with the logged data during the four months from September 2001 to December 2001. The figure 6 and 7 show the hourly average figures of traffic statistics and communication reliabilities of individual home appliances, respectively. It shows that the worst figure of about 90% of the reliability is observed for the operation of washing machine around ten a clock in the morning when the washing machine's network traffic is the highest during the hours of a day. The communication reliability can be considered as satisfactory in the sense that the worst level of communication reliability is around 90%.

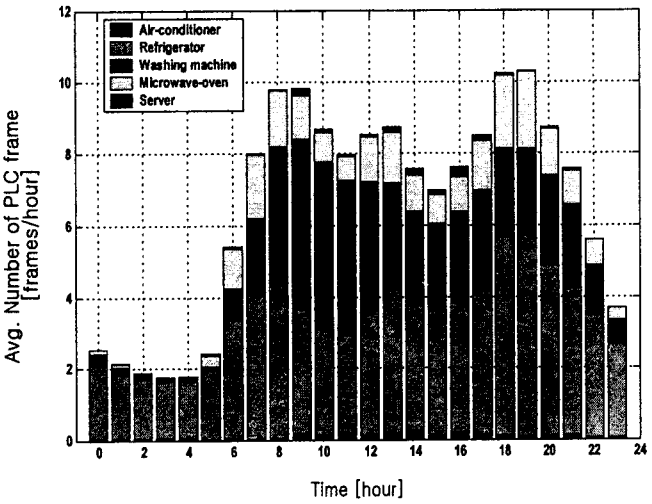

Figure 6. Hourly averages of network traffic statistics for the individual home appliances.

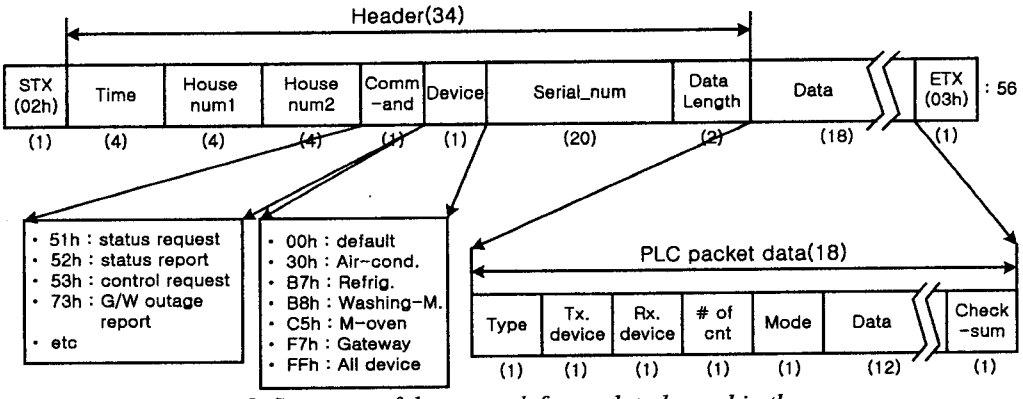

Figure 5. Structure of the network frame data logged in the server.

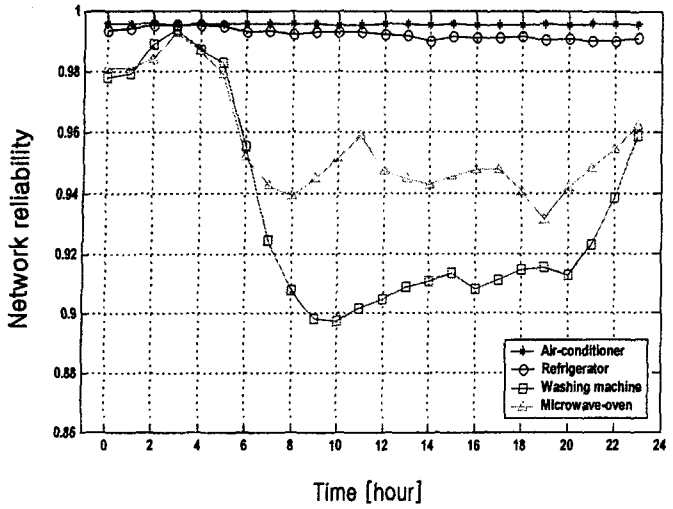

Figure 7. Hourly averages of communication reliabilities for the individual appliances measured from the test-bed of 100 apartment houses.

The averages of reliability resulting from the test-bed operation for the individual appliances are summarized in table 2.

Table 2. Summary of communication reliability evaluated during the period of four months from the operation of individual appliances in the test-bed of 100 apartment houses

Air-conditioner	Re-frigerator	Washing machine	Micro-wave oven	Total average
99.6 %	99.3 %	93.5 %	95.7 %	96.0 %

The total average of the reliability is obtained as 96.0 %, which can be considered as a high level of performance supporting the feasibility of the commercial deployment of PLC modem installed home appliances and their services for the Internet accessed home automation.

5. Conclusions

It is concluded from this research that the proposed approach of probing home PLC channel characteristics is valid and a useful method of systematically assessing the probability of bit error. The experimental results performed with the constructed test-bed applying the proposed channel probing method and the overall operation reliability measurement also support the feasibility of commercially deploying the PLC modem installed home appliances and their services for the Internet accessed home automation.

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