Analysis of the Competitiveness of Broadband over Power Line Communication in Korea

Gicheol Jeong, Daeyoung Koh, and Jongsu Lee

This study analyzes factors affecting the competitiveness of broadband over power line communication (BPLC) and predicts demand for the service, based on quantitative information about consumer preferences drawn from a survey of Korean consumers. Findings from the estimation suggest that, although consumers value some beneficial features of BPLC, to be competitive the speed and stability of its data transmission needs to be improved. Moreover, on the basis of a market simulation, we expect BPLC to occupy only a small portion of Korea's Internet access market in the future, a finding we expect would hold true for other developed countries whose Internet access markets are already mature.

Keywords: Broadband over power line communication, conjoint analysis, rank ordered logit, demand forecasting.

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I. Introduction

Power line communication is defined as the information service which conducts data communications using power lines that were originally used for provision of electricity [1]. In the past, because of technological restrictions, the main focuses of power line communication (that is, the use of existing power lines to transmit data from one device to another) were narrowband communication and electricity consumption control. However, improvements in communication technologies have enabled the provision of broadband Internet access over power lines, called broadband over power line communication, or BPLC [2]-[8]. Recently, due to technological improvements, such as the application of orthogonal frequency division multiplexing (OFDM), BPLC has become capable of providing data transfer at speed over 10 Mbps in the moderate conditions [1]. Finally, BPLC has been heralded by the Federal Communications Commission (FCC) as the "3rd wire" to every home and has matured to the point of field trials and limited deployment [8].

Optimistically, since BPLC provides consumers with a new alternative to existing broadband Internet access services—such as xDSL (refers collectively to the family of digital subscriber line technologies, including ADSL and VDSL), cable, wireless LAN (WLAN), satellite, and so on—one might expect to see an increase in consumer welfare due to the positive effects of diversity of choice, degree of competition, and speed of innovation of the existing broadband access technologies, especially in mature broadband Internet service markets.[1)] In

1) We are mentioning the corresponding expected optimistic influence of BPLC in the general context. However, in some studies, such as [9] to [11], it is also found that an increase in competition does not always result in decreasing prices with a resultant increase in consumer surplus.

addition, because BPLC uses power lines everywhere, it offers beneficial features compared with xDSL and cable, such as fewer restrictions on where computers or TV terminals connecting to the Internet can be located and easier connection of extra terminals to the network without burdensome wires [12].

For example, those with xDSL or cable can only use Internet service at a few restricted locations where copper lines or hybrid-fiber-coaxial (HFC) lines are established in their homes. Additional long connecting lines are required (which are inconvenient and can be aesthetically disadvantageous,) if users want to use the service somewhat far from the restricted places; however, those with BPLC are able to use Internet service at almost any location in their homes thanks to the existence of electricity lines and connecting outlets in every room. Also, while those with xDSL or cable need to attach long connecting lines when they want to use more than one terminal for Internet service, those with BPLC just need to connect the extra terminal to the electricity connecting outlets. By using existing power lines, the cost of establishing the network lines for BPLC can be kept low, and it can be applied to old housing or important cultural constructions without any large-scale construction [3].

All these advantages can help reduce the degree of digital divide by providing broadband Internet service to places where extant broadband Internet services do not provide coverage for some reason, especially in developing countries with insufficient resources to establish networks for other broadband Internet services, or in regions far from high-density areas where profitability is not guaranteed for other services [8]. Finally, BPLC has very good technological conformity with many electricity-related services such as auto-metering-report (AMR) service and real-time pricing (RTP) service. For example, whereas other broadband access technologies require additional equipment to be installed for these services, BPLC can provide these services without additional equipment or additional costs. Also, those with BPLC can receive an integrated bill for electricity usage and broadband Internet services. For these reasons one might expect BPLC to increase consumer welfare and to compete well against preexisting broadband access technologies.[2)]

That having been said, significant obstacles stand in the way of BPLC's adoption by consumers. First, the provision of high-speed, stable data transmission over long distances over power lines (an important attribute to be competitive in the broadband access service market) has been hampered by the various unstable characteristics of the electric environment and electromagnetic compatibility issues [1]-[5], [14]-[16]. Additionally, in the case of high data transfer speed, wider bandwidth is required for BPLC. The frequency range occupied by BPLC (1.6 MHz to 30 MHz) may overlap or interfere in the frequency ranges of other existing wireless communications. This requires reinvestigation or relaxation of some regulations. These regulatory issues can prevent BPLC from being competitive [1], [4], [14]. Meanwhile, even with the cost advantage of BPLC, opposing opinions still exist. With the current technology level, in conflict with the expectation of groups supporting BPLC, instead of utilizing only electricity power lines to provide broadband access service among servers and users, BPLC requires additional modem equipment or connecting facilities that can amplify the weakened signals and suppress high noises to provide a sufficient speed of data transfer and quality stability [6]. All these additional required facilities and equipment add substantially to the cost in practice, which reduces its cost-side advantages over xDSL or cable broadband Internet services to a large extent [8], [17]. Most of all, in many developed countries, such as Korea, the broadband access market is almost saturated, so BPLC will have to compete with preexisting, already stable, access technologies to woo customers, who could face potentially high costs to switch services. The presence of these obstacles leads many to be pessimistic about the competitiveness and future success of BPLC. In particular, from quantitative simulation cost analysis, Tongia [8] predicted that PLC may not represent a major disruptive technology.

To sum up, BPLC can potentially offer the consumer unique advantages and increase social welfare, but, at the same time, it faces several limitations. This leads to both optimistic and pessimistic forecasts for its success, so predicting how BPLC will fare in the Internet access market would be a worthwhile, although not an easy, undertaking. Policymakers, service providers, and BPLC developers would all benefit from an examination from the perspective of the consumer regarding BPLC's ability to compete and its future demand. In one of the few previous relevant studies of which we are aware regarding quantitative analysis on competitiveness of BPLC, the author of [8] used a simulation approach to analyze the competitiveness of BPLC. He examined the technology from a techno-economic perspective, factoring in regulatory issues and network design focusing on the United States. The results

2) With respect to home networking services, [2] and [13] found that BPLC is competitive enough to take a considerable portion of the whole market. However, concepts and uses of BPLC in home networking service in [2] and [13] are confined to the services for connection among many home appliances or electronic devices such as TV, audio system, refrigerator, etc. To be more specific, they differ to a large degree in terms of technological characteristics of BPLC. For example, BPLC for connection among home appliances or electronic devices can reach 200 Mbps data transfer speed even at current technological level, while BPLC for broadband access can only reach 1 to 10 Mbps at best. Also, BPLC in home networking service here is aimed at short-distance data communication in which BPLC experiences less problems, while BPLC for broadband access is aimed at long-distance data communication with a lot more problems such as interference, etc.

Table 1. Attributes and attribute levels used in the survey.

Attribute	Attribute level	Description
Monthly cost (won [$US]) a)	20,000 [19.27], 40,000 [38.54], 60,000 [57.80]	Average monthly cost of broadband service package shown, including monthly service charge for broadband service itself and bundled services, if any, and rental fee for equipment, etc., not including discount effects of year-based long-term contract
Access technology	xDSL	Broadband access over copper wire (e.g., ADSL, VDSL, etc.)
	CABLE	Broadband access over hybrid-fiber-coaxial (HFC) line mainly used for cable TV service
	BPLC	Broadband access over power lines mainly used for electrical power
	WLAN b)	Wireless broadband access provided around the specific access point equipment and covered areas
	Satellite	Broadband access technology provided through satellite
Additional service	No	No additional service is bundled
	AMR	Service that can give information about electricity usage to the consumers automatically in real time is bundled
	VoIP	Voice over IP service is bundled
	TV service c)	Television service such as IPTV or cable TV is bundled
Quality stability	0, 2, 4	Occurrences of quality degradation in broadband service per hour
Data transfer speed (Mbps)	1, 5, 15, 30	Data transfer speed that can be maintained with stability

a) US$1 = 1,038 won, as of January 18, 2005.
b) We include wireless LAN as one of the competing broadband access technologies in our analysis since it will affect the demand of BPLC in the near future when wireless broadband Internet services have sufficiently improved. Many studies analyzing wireless broadband Internet services such as WiBro have mentioned they will affect the demand of fixed broadband Internet services [27], [28].
c) Such a television service would consist of IPTV, cable TV, or other TV-related service, depending on what access technology is used, provided in the form of a service bundle (such as part of triple play service or quadruple play service).

indicate that BPLC does not represent a major disruptive technology, especially from a price-performance perspective. However, that study focused mainly on the cost side, without treating the demand side in depth, even though the demand side is one of the important factors in determining the competitiveness of BPLC. A second limitation is that the study considered the case in the United States, where broadband access market conditions are somewhat different than in many other countries, including Korea, where xDSL technology is most popular or the market is almost saturated.

To augment that research and derive a clearer indication of the competitiveness of BPLC, especially in mature markets, we attempt to forecast future demand for BPLC and analyze under what conditions BPLC can be competitive, based on quantitative information about consumer preferences. We use a conjoint survey (an established stated preference approach) to obtain our data. To estimate consumer preferences and forecast future demand, we employ a rank-ordered logit model and a dynamic market simulation with various scenarios.

The remainder of this paper is organized as follows. Section II explains the methodologies and survey data used in our research. Section III reports the estimation results and the main findings regarding consumer preferences. Section IV recounts the demand forecasting simulations, and section V contains the conclusion and summary.

II. Methodologies

1. Survey and Data

In a conjoint survey, attributes composing a product or service of interest are combined to form hypothetical alternatives. Respondents are asked to state their preferences for each alternative card by ranking, rating, or choosing from among the hypothetical alternative cards [12]-[13], [18]-[26]. To estimate consumer preferences among various broadband access services and bundled additional services, we used five attributes, namely, monthly cost, access technology, data transfer speed, quality stability, and additional services since they were found to be important criteria in a previous study of consumer preferences for broadband Internet services in Korea [12]. Table 1 describes the corresponding attribute levels.

Using an orthogonal design,[3] we obtained 25 conjoint cards, which we divided into five sets with five cards each. In the course of the survey, respondents were asked to rank the sets of conjoint cards according to their preference from 1 to 5 for each set.[4] An example of conjoint card used in our survey

3) For orthogonal design to reduce the number of conjoint cards to a reasonable level, we used SPSS 10.0.

4) We used rank data rather than choice data because it can provide more information regarding consumer preferences for attributes from each respondent at the same cost as choice data [26].

Table 2. Summary of sample characteristics.

Individual characteristics (Sample size =500)	Details
Gender distribution	Male: 54.6% Female: 45.4%
Age distribution	Average: 28.2 Standard deviation: 9.28
Monthly household income distribution (1,000 won)	Average: 3,030 Standard deviation: 1,422
Regional distribution	Rural area: 16.4% Mid-size city: 46.4% Metropolis: 37.2%
Subscription to broadband access distribution	With subscription: 98 % Without subscription: 2 %
Amount of time using Internet service per day (hour) distribution	Average: 2.27 Standard deviation: 1.31

can be seen in the appendix.

The survey was administered to 500 residents of the metropolitan area of Seoul (186 respondents); a mid-size city, Daejeon (232 respondents); and the rural area of Gyeonggi-do (82 respondents), Korea, in January 2005. All of them had been contacted by telephone in advance and participated in the survey after agreement. Stratification by residential region, age, income, and gender, was used to draw the sample. Responses were obtained face-to-face by well-trained interviewers. In addition to the conjoint survey, demographic data such as age, gender, monthly income, subscription to broadband access service, and average amount of time each respondent spent using Internet services per day, were obtained. All respondents were knowledgeable about the Internet and were between 15 and 60 years old. Some basic information regarding survey respondents is shown in Table 2.

As shown in Table 2, most respondents (98%) now subscribe to broadband access services. Since the research aim of this study is to examine the competitiveness of BPLC in sufficiently mature broadband access service markets, even though the ratio of subscription of sample is more than that of the general population (approximately 70% [29]), this feature of our sample is suitable for accomplishing our objective. Other demographics, such as the ratio between male and female respondents, and average monthly income are close to those of the population of Korea, which suggests the sample is sufficiently representative.[5)]

5) Ratio of male to population (between 15 to 64 years old, 2005) in Korea is 0.505 (50.5%) and average monthly household income in Korea (the third quarter, 2007) is 3,280 (1,000 won) [31].

2. Model Specifications

We use the rank-ordered logit model for the purpose of estimation. Assuming that individual n faces a choice among J alternatives, we can represent an individual's random utility as consisting of a deterministic part and a random part as

$$U_{nj} = V_{nj} + \varepsilon_{nj} = V(x_{nj}, S_n) + \varepsilon_{nj} = (\beta + \alpha S_n)' x_{nj} + \varepsilon_{nj}, \quad (1)$$

where x_{nj} is the vector of attributes associated with alternative j individual n faces; β is a parameter vector representing mean consumer preferences for each attribute level; S_n is the vector of individual characteristics; α is a parameter vector representing observed heterogeneity in consumer preferences, which are specified to interact with attributes of alternative; ε_{nj} is a random disturbance, which is assumed to follow an independent and identical type I extreme value distribution. In the rank-ordered logit model, individual n's probability of ranking responses in a choice set to be $(ranking = r_1, r_2, r_3, \cdots, r_J)$ has the following simple closed form:

$$\Pr_n(ranking = r_1, r_2, r_3, \cdots, r_J) = \frac{e^{V_{nr_1}}}{\sum_{j=r_1,\cdots,r_J} e^{V_{nj}}} \cdots \frac{e^{V_{nr_{J-1}}}}{\sum_{j=r_{J-1},r_J} e^{V_{nj}}}. \quad (2)$$

With the choice probability being defined for each individual n, the likelihood can be obtained, and we estimate the parameters β and α using the maximum likelihood estimation method [23], [26], [30].

III. Estimation Results and Main Findings

To estimate the coefficients of the dummies for access technologies and additional services, *satellite* and *no additional service* were chosen as references. Therefore, the estimated coefficients for those attribute levels represent the consumer preferences relative to the references. Since each of the 500 respondents faced five choice sets, a total of 2,500 observations were used in estimation.[6)] Additionally, we estimated two model specifications, model 1 and model 2, to examine both the mean and heterogeneous preferences. Model 1 is specified with only mean preferences ($\alpha = 0$), and model 2 is specified with additional interaction terms between individual characteristics and attributes ($\alpha \neq 0$).[7)] Table 3 shows the estimation results of the two model specifications. Finally, we obtained the marginal willingness to pay (MWTP) for each

6) Estimation was conducted using NLOGIT 3.0.

7) Individual characteristics such as age, gender, monthly income, and average amount of time each respondent spend using Internet service per day, are checked to determine whether they have significant interactive effects on preferences.

Table 3. Estimation results of coefficients.

Attribute level	Model 1		Model 2	
	Coeff.	S.E.	Coeff.	S.E.
Monthly cost	–0.2006*	0.0074	-0.0791*	0.0175
XSDL	0.0803*	0.0382	0.1755*	0.0519
CABLE	–0.1440*	0.0372	-0.1450*	0.0373
BPLC	0.1317*	0.0385	0.1309*	0.0386
WLAN	0.1491*	0.0384	0.1475*	0.0384
AMR	0.4272*	0.0325	0.4921*	0.0468
VoIP	0.2630*	0.0385	0.3551*	0.0556
TV service	0.6420*	0.0388	0.7604*	0.0564
Quality stability	–0.1542*	0.0082	-0.1544*	0.0082
Data transfer speed (Mbps)	0.0437*	0.0010	0.0385*	0.0015
Male×Monthly cost			0.0416*	0.0138
Male×XDSL			-0.1730*	0.0651
Male×AMR			-0.1122**	0.0616
Male×VOIP			-0.1683*	0.0744
Male×TV service			-0.2124*	0.0752
Male×Data transfer speed			0.0099*	0.0020
Age×Monthly cost			-0.0042*	0.0004
Time_Internet ×Monthly cost			-0.0125*	0.0027

*: Significant at the 1% level, **: Significant at the 10% level.

attribute level using the negative ratio of the estimated coefficient relative to the estimated coefficient of monthly cost.[8)] Table 4 shows MWTP values for the two model specifications. As seen in Table 3, all of the coefficients are highly significant. Also, coefficients of monthly cost, quality stability, data transfer speed, and additional service have the correct signs, as expected.

The main findings and related discussion regarding BPLC's competitiveness are presented as follows. First, we discuss the implications regarding mean preferences from Model 1.

The estimated coefficients for the access technologies show that consumers generally favor WLAN the most and cable the least. They prefer BPLC to xDSL or cable, technologies that in many countries, including Korea, occupy most of the market. Since the coefficients of the access technology dummies capture all intrinsic access-technology-specific effects on choice that are distinct from the effects of attributes considered in the model [32], this may indicate the effects of omitted variables that are related to the specific access technologies. For example, we can infer that common characteristics of WLAN and BPLC that are not included in the other attributes and are unique to the two services relative to the others make them more preferable. As a result, by comparing the estimation and WTP results for WLAN and BPLC with those for the other access technologies, it can be expected that additional benefits such as those mentioned in section I (namely, fewer restrictions on location of connection devices and ease of connection of extra terminals) are valued by consumers. Therefore, it can be inferred that such beneficial features of BPLC may help it to be competitive. However, because we have compared only the coefficients of the access technology dummy variables, which reflect consumer preferences for omitted technology-specific characteristics only, the results do not reflect overall competitiveness. Therefore, a complete comparison among access technologies that takes into account other important attributes is necessary. Data transfer speed and quality stability are precisely the attributes that we would expect to have a noticeable effect on the overall competitiveness of BPLC. The absolute magnitude of the WTP for BPLC technology is 6,562 won, which can offset only one level of degradation of quality or a 3 Mbps decrease in data transfer speed. In fact, at the current level of technology, BPLC is inferior to xDSL in terms of data transfer speed by more than 3 Mbps, and in terms of quality stability by more than one level. Therefore, although BPLC brings with it new benefits that can boost its competitiveness to some degree, if it does not reach a sufficient level of data transfer speed and quality stability, it may not become competitive.

Next, it is revealed that consumers prefer bundling of additional services in this order: television service, AMR, and voice over Internet protocol (VoIP). Although TV service is the most preferred add-in, bundling it with BPLC may not work because TV service requires a wide range of bandwidth and causes heavy traffic over the network, which results in degraded quality or a decrease in the data transfer speed of BPLC. Since xDSL or cable can easily be bundled with TV service in the form of Internet protocol TV (IPTV) or cable TV, BPLC's inability to be bundled with TV service will play a significant negative role in competitiveness. Meanwhile, being the easiest to harmonize with BPLC, real-time AMR may compensate for the inferiority of BPLC in terms of bundle offerings. Since VoIP can be provided easily by any of the access technologies, and it does not show a large estimated coefficient, it will not have much effect on the competitiveness of BPLC.

Finally, we will discuss the implications regarding observed heterogeneity in consumer preferences from Model 2.

First, among the considered individual characteristics, monthly income does not show any significant interaction with

8) For model 1, MWTP is determined as a constant, while for model 2, MWTP is determined as a function of individual characteristics.

Table 4. Marginal willingness to pay for attributes.

	MWTP[a)]	
Attributes	Model 1[b)]	Model 2
XSDL	4,000 [3.85]	$\frac{0.1755-0.1730\times Male}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
CABLE	−7,178 [-6.92]	$\frac{-0.1450}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
BPLC	6,562 [6.32]	$\frac{0.1309}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
WLAN	7,429 [7.16]	$\frac{0.1475}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
AMR	21,294 [20.51]	$\frac{0.4921-0.1122\times Male}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
VoIP	13,111 [12.63]	$\frac{0.3551-0.1683\times Male}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
TV service	31,996 [30.82]	$\frac{0.7604-0.2124\times Male}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
Quality stability	−7,688 [−7.41]	$\frac{-0.1544}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$
Data transfer speed	2,179 [2.10]	$\frac{0.0385+0.0099\times Male}{0.0791-0.0416\times Male+0.0042\times Age+0.0125\times Time}$

a) MWTP for a certain attribute level can be obtained as $-\left(\frac{\beta_k+\alpha_k{}'S_n}{\beta_{price}+\alpha_{price}{}'S_n}\right)$.

b) in won [US$]

attributes. In contrast, gender difference shows many significant interaction effects. Relative to female consumers, male consumers are less sensitive to monthly cost, show less preferences for xDSL and all additional services, and value increase of data transfer speed more. Older consumers and consumers who use Internet service heavily during one day are more likely to be sensitive to the monthly cost. Because of the existence of some significant interaction terms in Model 2, MWTP is determined as a function of individual characteristics as shown in Table 4. More detailed information on MWTP can help service providers and regulators set proper price ranges for broadband access services.

IV. Demand Prediction Simulation

To predict the consumer demand for BPLC in the future and to discern under what conditions of BPLC can be competitive, we simulated the market using the estimation results reported in section III. This section describes and reports the results of that simulation.

The choice probability of access technology j with attribute level x_{jt} at time t can be defined as in [30] as

$$\Pr_t^j=\frac{\exp(V_{jt})}{\sum_i \exp(V_{it})}=\frac{\exp(\beta' x_{jt})}{\sum_i \exp(\beta' x_{it})}. \quad (3)$$

Using (3) and following the common tradition in specifying the demand evolution over time in Markov switching models [33]-[37], and by assuming that it consists of the number of remaining subscribers among those of access technology j at t-1 and newly obtained subscribers of access technology j coming from other broadband services, we define the number of subscribers of access technology j at time t as

$$d_t^j=(1-a_t^j)\times d_{t-1}^j+\sum_{i\neq j}\left(a_t^i\times d_{t-1}^i\times \Pr_t^{j(-i)}\right) \quad (4)$$

where i (or j) is xDSL, cable, WLAN, satellite, or BPLC, and d_t^j and d_{t-1}^j are the cumulative numbers of subscribers to access technology j at time period t and t–1 respectively. Here, a_t^j is the average ratio of subscribers who change or switch from j type of broadband service to another access technology at time period t. Therefore, multiplication of $(1-a_t^j)$ and d_{t-1}^j in (4) produces the cumulative number of remaining subscribers of access technology j at t-1. We define $\Pr_t^{j(-i)}$, which means access technology j's choice probability given that access technology i is excluded from the choice set when calculating service j's choice probability, based on the hypothetical features of the access technology j at time t, according to the various scenarios considered. Therefore, $\sum_{i\neq j}\left(a_t^i\times d_{t-1}^i\times \Pr_t^{j(-i)}\right)$ determines the number of newly obtained subscribers of access technology j at time t coming from the other broadband services.

Finally, the cumulative number of subscribers of BPLC at time t is specified as

$$d_t^{BPLC}=(1-a_t^{BPLC})\times d_{t-1}^{BPLC}+\sum_i\left(a_t^i\times d_{t-1}^i\times \Pr_t^{BPLC(-i)}\right), \quad (5)$$

where i is xDSL, cable, WLAN, or satellite.

Because there is no exact information on how many subscribers switch to the other broadband services, we assume two different specifications for a_t^j. We first assume the same constant average ratios for all services in that $a_t^j=a$. For this restricted specification, we assume switching rates a_t= 1% and 2%.[9)] On the other hand, the assumption that the switching rate is constant over alternative services may be somewhat

9) In the survey, we asked the respondents whether they switched their broadband service providers within the past year. Actually, 1.8% (9 respondents) reported switching. However, since switching among service providers may be different from switching among access technologies, we do not have complete information regarding switching among access technologies. These are the reasons we assumed the chosen switching rates.

Table 5. Attribute levels of broadband services other than BPLC used in the simulation analysis.

Access technology	Monthly cost	AMR	VoIP	TV	Quality degrades	Data transfer speed
1. xDSL	50,500	No	No	No	1	17.4
2. xDSL	41,000	No	No	No	2	15.4
3. xDSL	31,500	No	No	No	2	7.6
4. xDSL	31,500	No	No	No	3	3.3
5. Cable	37,500	No	No	Yes	3	6.4
6. Cable	31,600	No	No	Yes	3	4.8
7. xDSL	36,100	No	No	No	1	32.8
8. WLAN	54,000	No	No	No	1	3.8
9. Satellite	33,000	No	No	No	0	3.5
10. BPLC	*	Yes	No	No	*	*

* These values are manipulated based on possible future technological changes in BPLC.

unrealistic. To impose a more plausible assumption on the model without a sufficient level of real data regarding switching rates, in the second specification for a_t^j, we allow it to vary with market share[10)] as follows:

$$a_t^j = \frac{1}{k} \times \exp(-MS_t^j) \tag{6}$$

(j=xDSL, cable, WLAN, satellite, BPLC),

where MS_t^j is the market share of j access technology at time t. Note that the switching rate of each access technology varies over time and across access technologies because it is function of MS_t^j, which also varies with access technologies and time. However, because of lack of real data to determine parameter k, we have to assume certain values for it. We use two values for k, 50 and 100.[11)]

Finally, we designed various hypothetical scenarios for the attribute levels of BPLC: monthly cost from 20,000 won to 35,000 won, data transfer speed from 1 Mbps to 20 Mbps, and quality stability degrades from 1 to 5. These were manipulated reflecting future technological changes in BPLC and the switching from one broadband service to another under each scenario, ranging from the most optimistic case to the most pessimistic or conservative one. In all scenarios, we assumed that BPLC is bundled with AMR, which is the most probable and conformable case for BPLC. Next, we set the attribute levels of the broadband services other than BPLC as in Table 5 in accordance with information on the current technological

10) According to [38], there is a clear pattern of increasing switching rates as market share decreases.

11) We chose these two values for references because with k =50, $0\% < a_t^j \le 2\%$, and with k=100, $0\% < a_t^j \le 1\%$, which might be close to the reality.

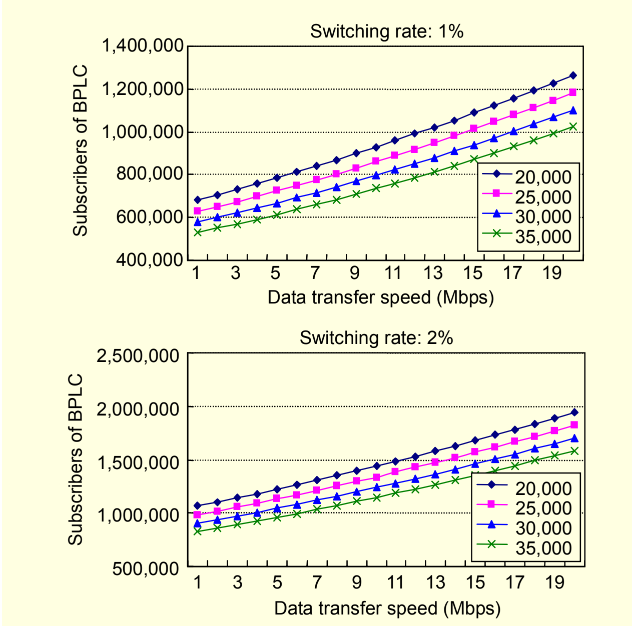

Fig. 1. Demand predictions for BPLC with quality degradation fixed at 5 and varying monthly degradation.

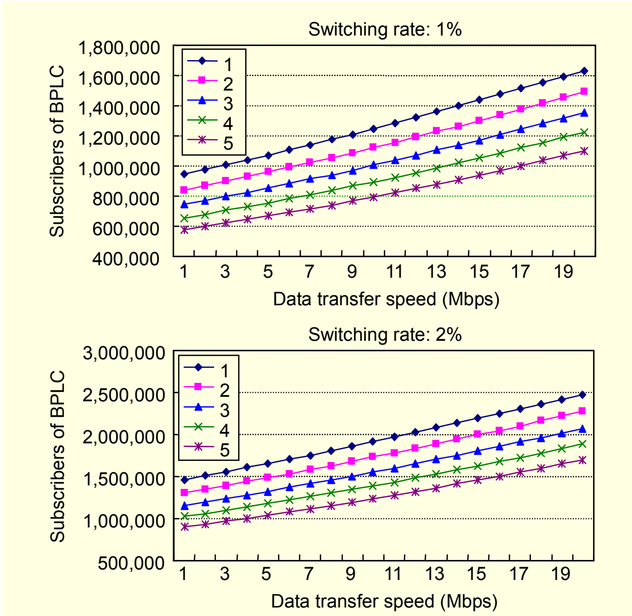

Fig. 2. Demand predictions for BPLC with monthly cost fixed at 30,000 won and varying quality degradation.

status of each service.[12)] Meanwhile, in conducting the dynamic market simulation in practice, we assumed that the broadband Internet market is almost saturated, as it is in Korea in order to see the competitiveness of BPLC in mature markets

12) Information on the current technological status of each service was gathered from the websites or brochures of service providers, such as Korea Telecom (KT) and Hanaro Telecom in Korea and from some professional websites, such as www.benchbee.co.kr, which provide services such as measuring the real data transfer speed and quality degradation.

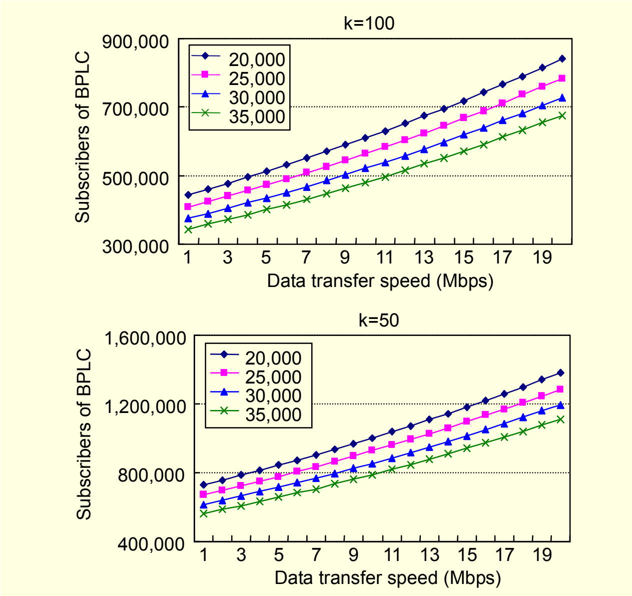

Fig. 3. Demand predictions for BPLC with quality degradation fixed at 5 and varying monthly cost when switching rate varies over time and across access technologies.

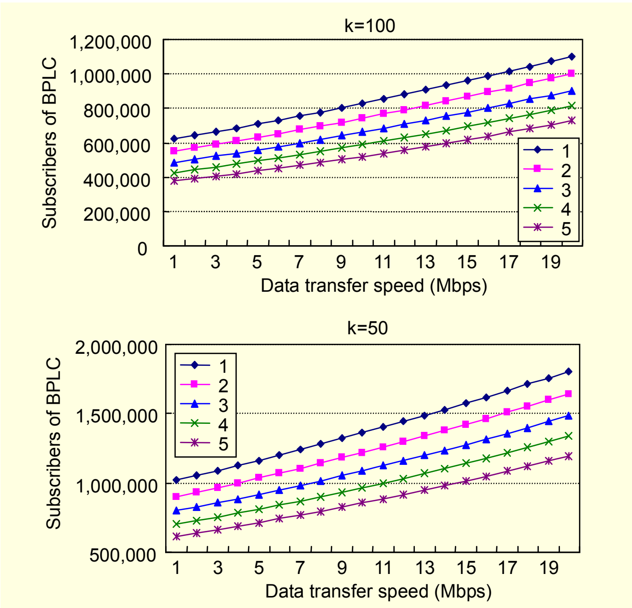

Fig. 4. Demand predictions for BPLC with monthly cost fixed at 30,000 won and varying quality degradation when switching rate varies over time and across access technologies.

more clearly.[13)]

Under constant a_t^j specification, the BPLC demand forecasts for the cumulative number of subscribers when four years have passed after its introduction to the market, under various scenarios, are summarized in Figs. 1 and 2.

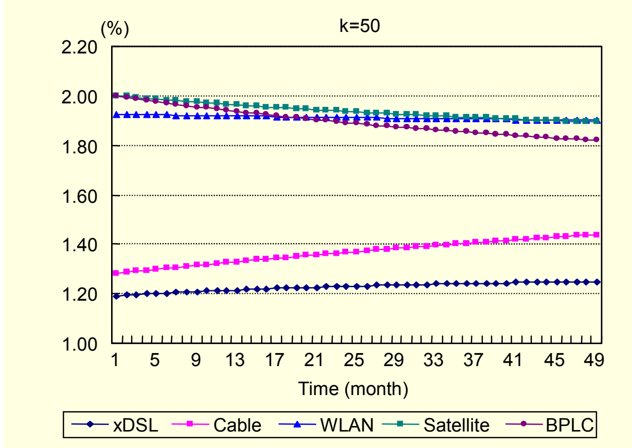

Fig. 5. Time-varying pattern of a_t^j with k=50.

The BPLC demand forecasts for four years after its introduction to the market, under the time-alternative-varying a_t^j specification, are summarized in Figs. 3 and 4.

Also, time-alternative-varying patterns of a_t^j s over time are shown in Fig. 5. As time goes on, the market share of BPLC increases while its switching rate decreases.

Note that the predicted cumulative number of subscribers of BPLC with varying switching rate is smaller than that of the constant switching rate case. This is because of the high market share of existing technologies, such as xDSL and cable, and their resultant low switching rates (see Fig. 5). The number of newly obtained subscribers of BPLC coming from existing broadband services is smaller than in the constant switching rate case.

To sum up, in all simulation results, BPLC is expected to occupy a rather small portion of the broadband market in Korea, and its future demand is expected to vary from 530,000 to 2,500,000 subscribers under the constant switching rate case and from 350,000 to 1,800,000 under the varying switching rate case. At best, the market share of BPLC would not exceed 20% of the total market.

Additionally, we found that the degree of broadband service subscribers' switching affects the future demand for BPLC more critically than the attribute levels of BPLC do. All other things being equal, as switching from one broadband service to another is activated, the demand for BPLC increases by more than one and a half times. Changes in the other attribute levels cannot achieve this increase. This applies to both the constant and time-varying switching cases.

However, when the market reaches the point of saturation, as the broadband access service market in Korea has, the cost of switching may become a more serious hurdle preventing consumers changing their access technology. If BPLC is to

13) We assume that there are no new subscribers of any broadband Internet services at time t coming from a non-user group, and the total number of subscribers ($N_t = \sum_j d_t^j$) who use any broadband Internet services at time t is set to be 12,674,711 over time according to the total number of subscribers who use a broadband Internet service reported in December, 2005 [29].

attract customers from existing access services, it may need to promote competition by preventing consumers experiencing switching as inconvenient, even though that would not guarantee a dominant market share.

V. Concluding Remarks

This study has analyzed the factors which affect the competitiveness of broadband over power line communication and predicts future demand for BPLC based on quantitative information about consumer preferences.

The main findings with regard to consumer preferences and competition are the following. First, with respect to the technology itself, BPLC is preferred to xDSL and cable, which means that consumers value the beneficial features BPLC offers, such as more freedom regarding location when connecting devices and ease of connection of extra terminals. Second, although those beneficial features may help BPLC to be competitive, if BPLC cannot offer consumers a sufficient level of data transfer speed and quality stability, the technology may not be competitive enough and may be limited to a small niche market. Additionally, the inability to be bundled effectively with a TV service because of the previously mentioned disadvantages can seriously hurt BPLC's competitiveness, although bundling BPLC with AMR, which harmonizes well with BPLC, can compensate for that loss of competitiveness to some degree. Given the current technological status of BPLC, the technology does not appear to be competitive enough compared with existing technologies, at least from the consumer side.

Our market simulation reveals the following results. Although future demand for BPLC in Korea may vary from 350,000 to 2,500,000 subscribers according to the various scenarios, BPLC can be expected to occupy only a small portion of the future market in Korea and in other countries where the market is mostly saturated. Moreover, the degree to which consumers switch among broadband access services could play a more important role in promoting demand for BPLC than the technological features.

The main results of our study support the prediction of the rather limited competitiveness of BPLC obtained by the supply-side cost simulation analysis of [8], rather than the optimistic views given in [2], especially with regard to the mature broadband service market.[14)]

However, since we have not analyzed less mature markets, especially markets in developing countries where broadband access service has not sufficiently penetrated; the result of our study is somewhat limited in generalizing the competitiveness of BPLC for all cases.[15)] Therefore, future studies about the competitiveness of BPLC should concentrate on analyzing markets with less maturity, and the availability of other broadband access services should be considered. We hope the findings presented here can aid those involved in the BPLC industry as they formulate research and development or business strategies and that our study can inform the decision making of those involved in the development of policies and regulations.

Appendix. Example of Conjoint Cards Used in the Survey

Access tech.	xDSL	Satellite	Cable	PLC	WLAN
Additional service	None	AMR	TV	AMR	AMR
Quality degrade	0 times/ hour	4 times/ hour	2 times/ hour	0 times/ hour	0 times/ hour
Data transfer speed	5 Mbps	30 Mbps	5 Mbps	30 Mbps	15 Mbps
Monthly cost	40,000 won	40,000 won	20,000 won	20,000 won	20,000 won
Rank	( )	( )	( )	( )	( )

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14) Indeed, if we look into the current situation related to BPLC, despite a lot of technological improvements and efforts, including establishment of testing towns for BPLC having been conducted after our survey [39], BPLC has not been commercialized and introduced to the market in Korea yet. To make matters worse, new broadband access technologies like fiber-to-the-home (FTTH) with superiority in data transfer speed and quality stability, which was not dealt with in our survey, are now being introduced and are beginning to obtain a significant market share [40]. To be competitive in mature markets for broadband access service, BPLC still needs further improvement.

15) Actually, in rural areas in China or Spain where population densities are very low and other access technologies like xDSL or cable are not established because of the low potential to generate sufficient profit, BPLC is being provided and operated successfully [41].

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