Relation between Willingness to Pay and Guaranteed Minimum Bandwidth in Multiple-Priority Service

Kyoko YAMORI [1]
1. Global Information and Telecommunication Institute, Waseda University
69 Waseda-cho, Shinjuku-ku, Tokyo, 162-0042 Japan
E-mail: yamo@aoni.waseda.jp

Yoshiaki TANAKA [1,2]
2. Advanced Research Institute for Science and Engineering, Waseda University
17 Kikuicho, Shinjuku-ku, Tokyo, 162-0044 Japan
E-mail: ytanaka@waseda.jp

***Abstract*— In recent years, the necessity of quality guaranteed services is increasing in the Internet. The differentiated services, which have multiple classes using priority control, are being introduced. Various issues need to be addressed when providing differentiated services, such as what sort of quality should be guaranteed, and what kind of pricing should be made for the service. We address this problem by making it easier for test subjects to visualize the quality of service available with a minimum guaranteed bandwidth when evaluating willingness to pay. In this paper, the quantitative relation between the guaranteed minimum bandwidth and the willingness to pay is shown by the subjective experiment of streaming contents and by the questionnaire survey of the waiting time for download.**

I. INTRODUCTION

The Internet has so far only been able to support uniform "best-effort" services, where available bandwidth is sometimes severely limited due to network congestion, but recently there has been a growing need for services with guaranteed quality. In particular, recent research has been focused on differentiated services which use priority control techniques to provide users with a minimum guaranteed bandwidth.

Various issues need to be addressed when providing differentiated services, such as what sort of quality should be guaranteed, and what sort of charge should be made for the service. These issues are being investigated in numerous studies.

For example, some studies have investigated the relationship between guaranteed bandwidth and willingness to pay [1][2]. Reference [1] investigates the degree of satisfaction with a service (an important parameter for representing the willingness to pay for the service), and shows that if the degree of satisfaction is greater than or equal to a certain value then most people would be willing to pay for the service. Reference [2] uses a questionnaire to investigate and clarify the structure of willingness to pay for guaranteed bandwidth. However, since users experience the quality of a network through the applications they are using, it is difficult for them to visualize the quality of service that would be provided by a bandwidth presented numerically on a sheet of paper.

Here, we address this problem by making it easier for test subjects to visualize the quality of service available with a minimum guaranteed bandwidth when evaluating willingness to pay. This is done by showing them how different bandwidths affect the quality of service achievable in the applications used on the network, thereby clarifying the relationship between guaranteed bandwidth and willingness to pay.

II. MULTIPLE-PRIORITY SERVICE

With the arrival of new services such as content delivery, it is becoming increasingly important to provide services with guaranteed quality. Internet businesses such as ISPs are therefore studying services in which priority control is used to provide multiple classes of quality. In this paper, services that provide multiple levels of quality in this way are defined as "differentiated services".

The service model of differentiated services is thought to be as follows.

- Basic services: Services connected to the Internet No guaranteed minimum bandwidth
- Optional services: Services with a guaranteed minimum bandwidth

Basic services have no guaranteed quality because they are connected via the Internet, where bandwidth varies depending on the state of network congestion. Optional services are services for which a minimum bandwidth is guaranteed, thereby ensuring that the bandwidth never falls below a minimum guaranteed bandwidth even when the network is congested.

DiffServ would be an effective scheme for implementing differentiated services [3]. However, it is not easy to evaluate the quality of DiffServ, because it has various factors which degrade the quality. Therefore, in this paper, an ideal scheme is assumed, in which, the minimum bandwidth is guaranteed, there is no call blocking, and there is no packet loss.

0-7803-8601-9/04/$20.00

III. APPLICATIONS AND WILLINGNESS TO PAY

In this study, we determine the relationship between the minimum bandwidth assured by differentiated services and the willingness to pay for these services. The willingness to pay (WTP) is one of the methods of social sciences, and means a price of how much a user (client) is "willing to pay" for a certain service. Since willingness to pay makes it possible to measure the limits of a service's usefulness to users, it can be used as a measure of a service's utility [4],[5].

Previous studies determined the relationship between bandwidth and willingness to pay based on questionnaires in which the guaranteed bandwidth was presented as a numerical figure. However, a problem with these studies is that it is difficult to envisage the sort of quality provided by a bandwidth presented as a numerical figure because the quality of a network is experienced indirectly through applications. So far there have been no studies into how the applications that are used affect the willingness to pay.

The applications that are mainly used on the Internet can be thought of as coming under two categories: applications for downloading data, and applications for the streaming delivery of video data. Download type applications force users to wait until all the data has been received, so the waiting times are affected by the bandwidth. On the other hand, in streaming contents delivery applications the data is played back as it is received, so the video quality is affected by the delivery bandwidth.

In this study, with a focus on the download service and the streaming contents service, we determine the relationship between minimum guaranteed bandwidth and willingness to pay by presenting the test subjects with the application quality corresponding to the guaranteed bandwidth.

IV. DOWNLOAD SERVICE

The waiting time incurred in download type applications becomes longer when the amount of data increases, so we used a questionnaire study in which the waiting times were presented numerically. In this study, taking the downloading of data as an example of the use of differentiated services, we studied the test subjects' willingness to pay for different minimum guaranteed bandwidths based on the corresponding waiting times. An example of the data used to present the waiting times is shown in Table 1.

In this study, we assume that a basic service has a peak bandwidth of 25 Mbps with no bandwidth guarantee. We also assume 5 types of optional services with minimum guaranteed bandwidths of 1 Mbps, 2 Mbps, 5 Mbps, 10 Mbps and 20 Mbps.

TABLE I. DATA EXAMPLES

Reference data quantity	Amount of data
One minute of MP3 music	About 4 MB
10-page Word document	About 300 KB
Floppy disk's data volume	1.44 MB
CD-ROM's data volume	700 MB
DVD-ROM's data volume	4.7 GB

In this questionnaire, we presented the waiting times corresponding to the maximum time that it would be necessary to wait when operating at the minimum guaranteed bandwidth, and the waiting times that could be achieved at communication speeds higher than the minimum guaranteed bandwidth during periods when the network efficiency is low.

The questionnaire respondents were asked to respond freely about their willingness to pay by writing down how much they would pay for the basic service and how much they would pay for the differentiated service options. The respondents answered those prices as a monthly fee.

Since the purpose of the questionnaire was to study the willingness to pay for guaranteed bandwidth, we selected the respondents from people that use the Internet on a daily basis

V. STREAMING SERVICES

Since the quality of streaming video data is difficult to describe with numbers and words. In this paper, we show the relationship between the waiting time and the willingness to pay from a subjective evaluation experiment, while considering a simple contents delivery system involving the streaming video qualities. The subjective evaluation experiment allows assessors to actually experience objects and evaluate them based on their subjectivity. It is difficult to know one's utility (satisfaction) clearly, but not so difficult to know one's utility relative to one's preference. Namely, we quantitatively analyze a factor that influences a user's selection from an experiment [6]-[8].

The subjective evaluation is made under the same conditions and basis as the standardized method in spite of different circumstances. This makes the comparison easy and precise. The organization called the International Telecommunication Union-Radiocommunication Sector (ITU-R), provides the methodology for the quality evaluation of television pictures [6]. Our subjective evaluation experiment was carried out under the methodology. For the subjective quality evaluations we used the double stimulus continuous quality scale (DSCQS) method conforming to ITU-R Rec. BT500-10 [6], in which the quality of the video to be evaluated is measured relative to a reference sample.

Since the service is assumed to have a guaranteed minimum bandwidth in this test, a bandwidth of at least the minimum guaranteed bandwidth is available during periods when the network efficiency is low. Therefore, in these tests the test subjects are presented with the video quality that can be seen when the network efficiency is low and the video quality that can be seen with the minimum guaranteed bandwidth, and are asked to subjectively evaluate the quality of the video data and their willingness to pay for the minimum guaranteed bandwidth.

In this study, we assume that a basic service has a peak bandwidth of 25 Mbps with no bandwidth guarantee. We also assume 5 types of optional services with minimum guaranteed bandwidths of 1 Mbps, 2 Mbps, 5 Mbps, 10 Mbps and 20 Mbps.

The streaming video data used in these tests consisted of 10-second video clips containing three types of movements. These clips were encoded using MPEG-4 encoding with a resolution of 720 × 540 pixels and five different bit rates: 1 Mbps, 2 Mbps, 5 Mbps, 10 Mbps and 20 Mbps. The video content is shown in Table 2.

TABLE II. VIDEO CLIP TYPES

Type of video	Description
News	Upper-body shot of a male newscaster containing very little movement.
Video drama	Several people having a meal together. Some scenes show people sitting at the table eating, others show them moving around.
Sports	Live footage of a soccer match. Includes close-ups of players passing and dribbling the ball.

For the reference sample, we used the video seen during periods when the network efficiency is low, and for the evaluation sample we used a video sample corresponding to the minimum guaranteed bandwidth. The evaluation process is illustrated in Fig. 1.

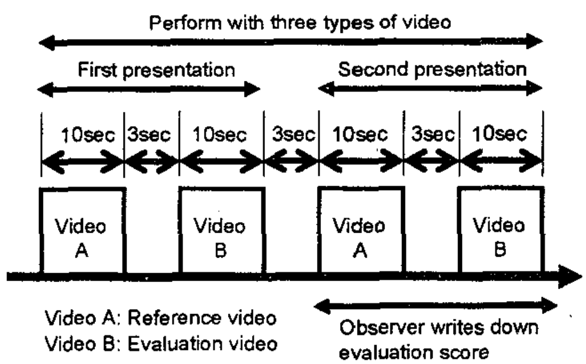

Figure 1. Evaluation flow

In these tests, the observers evaluate the video quality by drawing a horizontal line on a continuous scale annotated on the left with five quality level descriptors (ranging from "Excellent" to "Bad"), and the DSCQS value is taken as the difference in quality between the standard video and the evaluation video. To evaluate the willingness to pay for guaranteed bandwidth, we asked the observers to write down the amount of money they would be willing to pay. This was done for each type of video, and after evaluating all three types the observers wrote down their overall willingness to pay for the minimum guaranteed bandwidth. The tests were arranged so that the observers spent no more than 30 minutes in total evaluating video clips. The viewing conditions are shown in Table 3.

For the observers, we chose people with previous experience of this kind of evaluation test. Also, since we were investigating the willingness to pay for guaranteed bandwidth, we chose observers who use the Internet on a daily basis.

TABLE III. VIEWING CONDITIONS

Monitor	16-inch TFT monitor
Resolution	1280 × 1024 pixels
Color depth	True color 32-bit
Viewing distance	40–60 cm

VI. RESULTS

Table 4 shows the numbers of test subjects used in the questionnaire study and subjective evaluation experiment, together with other details such as their Internet use patterns.

TABLE IV. NUMBER OF TEST SUBJECTS AND ATTRIBUTES

	Questionnaire study 15 test subjects		Subjective evaluation experiment 20 test subjects	
	Ave.	*Std.*	*Ave.*	*Std.*
Line speed	4.05 Mbps	4.19	24.11 Mbps	42.54
Age	24.40 years	2.27	23.24 years	0.994
No. of days Internet use per week	6.75 days	0.54	6.50 days	1.18
No. of hours Internet use per day	6.25 hours	4.44	4.73 hours	2.57

From the results obtained in the questionnaire study and subjective evaluation experiment, we discarded the highest and lowest values and used the remaining results to calculate the MOS (mean opinion score) values. These MOS values were normalized so that the willingness to pay for the basic service corresponded to a value of 1.

Based on these MOS values, we used the least-squares method to estimate respective WTP functions (willingness-to-pay functions). These functions were approximated with linear, logarithmic, power-law and exponential approximation methods. For the resulting four functions, we judged their goodness-of-fit based on their rates of contribution. As the rate of contribution approaches 1, it shows that the regression formula produces a better fit.

First, we investigated download service. When the bandwidths were presented in terms of waiting times, the WTP function estimated by linear approximation had a larger contribution rate than the WTP functions estimated by the other approximation methods. The function estimated by linear approximation is shown in Eq. (1), where ν is the minimum guaranteed bandwidth and U is the willingness to pay.

$$U_d = 0.015\nu + 1.0632 \qquad (1)$$

Next we investigated streaming delivery. When the bandwidths were presented in terms of video quality, the contribution rate of the WTP function estimated by logarithmic approximation was larger than the contribution rates of the other approximation methods. The function estimated by logarithmic approximation is shown in Eq. (2).

$$U_s = 0.0635\ \log(\nu) + 1.0567 \qquad (2)$$

The respective MOS values and WTP functions are shown in Fig.2.

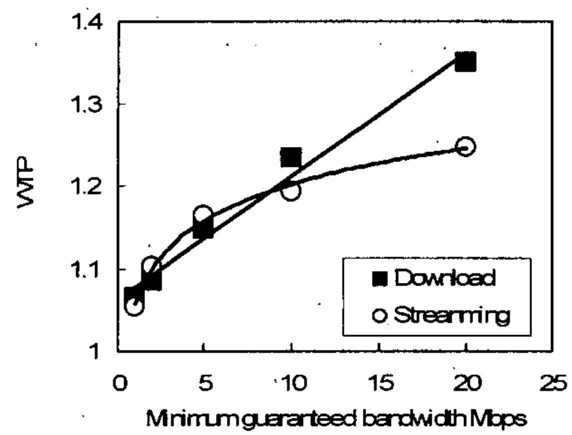

Figure 2. MOS values and WTP functions

VII. Discussion

As Fig. 2 shows, the relationship between minimum guaranteed bandwidth and willingness to pay varies depending on the application in which the bandwidth is presented. This is thought to be because the degree of satisfaction with bandwidth differs according to the application that is used.

In the case of download service, the willingness to pay increases as the minimum guaranteed bandwidth increases, linearly. It is consider that the waiting time is possible to visualize the difference in quality. Therefore the degree of satisfaction increases as the minimum guaranteed bandwidth increases. and it is expected that the willingness to pay will eventually saturate as the minimum guaranteed bandwidth increases to the point where the difference in waiting time becomes imperceptibly small.

In the case of streaming contents delivery service, the willingness to pay increases substantially with increases in the minimum guaranteed bandwidth up to 5 Mbps, but tends to saturate above 5 Mbps. This is thought to be because differences in video quality become harder to perceive at bandwidths of 5 Mbps and above, so the degree of satisfaction does not increase as the minimum guaranteed bandwidth increases.

Fig.3 shows the MOS values of the DSCQS values. The DSCQS values are numerical values expressing the difference in quality between the reference video and the video being evaluated, and values closer to zero indicate that there is less difference in quality. At bandwidths of 5 Mbps and above, the subjective quality (DSCQS value) of the video data as determined by the subjective evaluation experiment also tends to differ less, which agrees with the previous result.

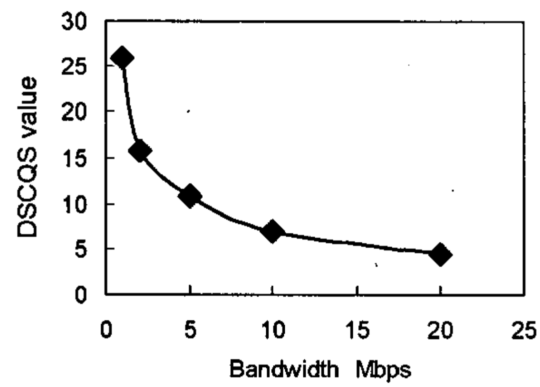

Figure 3. MOS values of the DSCQS values

The result of our experiment clearly shows that the willingness to pay increases as minimum guaranteed bandwidth increases until the quality difference perceived.

VIII. Conclusion

We have conducted a questionnaire study in which the respondents were presented with download waiting times based on differentiated services with different guaranteed minimum bandwidths, and we have performed subjective evaluation experiment in which the test subjects were presented with streaming video data with different levels of quality. We have thereby determined the relationship between minimum guaranteed bandwidth and willingness to pay.

In case of the download service, the willingness to pay increases linearly, because the differences in waiting times are within an imaginable range. In the case of streaming service, the willingness to pay increases until the differences in streaming video quality start to become imperceptible, and tend to saturate. There exists a pattern, in accordance with which the willingness of pay saturates in the event of bandwidth increase beyond the perceptible by humans range.

Further study is needed to obtain a comprehensive understanding of the relationship between minimum guaranteed bandwidth and willingness to pay by presenting waiting times and video quality. It would also be worth investigating how the maximum bandwidth affects the willingness to pay for the minimum guaranteed bandwidth.

REFERENCES

[1] Okamoro,T. and Hayashi,T. :Analysis of service Provider's profit by modeling customer's willingness to pay for IP QoS, Proc. IEEE Globecom 2002, CQRS-04-7, pp.1546-1553, November 2002.

[2] Yamori, K., Tomita, T. and Tanaka, Y. : Relationship between content attribute and waiting time sensitivity in contents delivery, 5th Asia-Pacific Symposium on Information and Telecommunication Technologies (APSITT 2003), Noumea, New Caledonia, pp287-292, November, 2003.

[3] Carlson, M., Weiss, W., Blake, S., Wang, Z., Black, D. and Davies, E.: An architecture for differentiated services, RFC 2475, December, 1998.

[4] Bjornstad, J. and Kahn, J.R.: The contingent valuation of environmental resources, Edward Elgar, 1996.

[5] Yamori, K., Tanaka, Y. and Akimaru, H. :Price optimization of contents delivery systems with priority, IEEE International Conference on Networking (ICN 2001), Colmar, France, Lecture Notes in Computer Science 2093, Springer, pp.65-74, July 2001.

[6] ITU-R: Recommendation 500-11 ; Methodology for the subjective assessment of television pictures, June 2002.

[7] Matsumoto, S., Fukuda, I., Morino, H., Hikichi, K., Sezaki, K. and Yasuda, Y.: The influence of network issues on haptic collaboration in shared virtual environments, Fifth PHANToM Users Group Workshop, Colorado, the U. S., Oct. 2000.

[8] Watson, A. and Sasse, M.: Measuring perceived quality of speech and video in multimedia conferencing applications, ACM Multimedia, pp. 55-60, Bristol, United Kingdom, September 1998.