Analysis of Content Charge by ISPs

Noriaki Kamiyama and Ryoichi Kawahara
NTT Network Technology Laboratories
Tokyo 180-8585, Japan
E-mail: kamiyama.noriaki@lab.ntt.co.jp

***Abstract*—When rich content is delivered, a huge amount of traffic is transmitted over the network. For ISPs, the increase in investment cost required to maintain stable quality is a problem, and ISPs need content providers to cover the investment cost because increase of the user fee may not be accepted by users. However, content providers usually pay an access fee whose increase ratio diminishes as the volume of data transmitted increases, so ISPs cannot obtain enough profit to cover the required investment cost. For this problem, content charge, in which ISPs charge content providers for each content delivery, seems effective. This work models the business relationship between ISPs and content providers, and we investigate the conditions for introducing content charge by ISPs. We also investigate the effects of content charge on the revenue of ISPs by numerically comparing the content charge and the transit charge. We show that major ISPs in Japan can expect to increase their monthly income from about 100,000 USD to about one million USD when the charging ratio of content charge is set to 20%.**

I. Introduction

In video delivery services on networks, users mainly view small-sized content produced by content providers and users. However, as the transmission capacity of access links grows, large-sized rich content, such as TV dramas and movies produced by major content producers, is being widely provided by many content providers. When providing rich content on networks, content providers need to pay a royalty to copyright holders, so they need a business model to earn profit after paying the royalty fee. Although a business model of obtaining profits through advertisements has been widely used, a business model in which content providers obtain a fee directly from users has recently been introduced and is expected to become common in the near future [5][8][19][21].

When rich content is delivered, a huge amount of traffic is transmitted over the network. For example, when delivering content with high definition TV (HDTV) quality and 100 minutes length at about 25 Mbps bitrate [12], the total amount of data transmitted is about 19 Gbytes. ISPs need to construct a network infrastructure that maintains stable service quality, so increase in the investment cost of the network infrastructure is a serious issue for ISPs. ISPs need to cover the investment cost by obtaining fees from users and content providers. However, the access network market is highly competitive, so it is difficult for ISPs to ask users to pay the additional charge for rich content delivery. Moreover, if users pay a fee to content providers for each content delivery, it is difficult to ask users to pay an extra fee to the ISPs in addition to the fee paid to content providers. On the other hand, content providers can obtain large revenue from content delivery services [4], and content providers seem able to afford to return a part of the profit to the ISPs as a reward for the ISP contributions in supporting the business of content providers.

Content providers normally connect their servers to ISPs and become customers of the ISP transit services. Content providers pay ISPs a transit fee, which is usage-based charge based on the 95% value of the transmission bit rate of data in many cases [3][7]. If the transit fee is proportional to the total amount of data transmitted, ISPs can basically obtain enough profit to cover the investment cost of networks. However, in many cases, the increase ratio of the transit fee decreases as the amount of data transmitted increases [3][7], so ISPs cannot obtain enough profit to cover the investment cost, which is rapidly increased by rich content delivery.

How to allocate the network cost among players has been widely discussed as a *network neutrality* problem [4][22]. The discussion on network neutrality can be classified into two categories: (i) who should pay for the investment cost of networks caused by rapid increase of traffic and (ii) how to maintain fairness for all users in using networks [20]. In the USA, the Federal Communications Commission regards the principle of network neutrality as to satisfy user rights to freely access content and receive services. They also judged that regulation of ISPs should be avoided because network neutrality is already satisfied [10]. Moreover, in Europe, the European Commission judged that network neutrality should be considered as a general principle and that regulation of ISPs should also be avoided [9]. In Japan, the government judged that content provider and ISP markets have free competition and that the charging methods between content providers and ISPs should be based on agreements between those players [20].

Therefore, to achieve fair allocation of the network investment cost among players and enable ISPs to cover that cost, content charging in which ISPs obtain a fee from content providers for each content delivery seems effective. By receiving part of the fee that content providers obtain from users, ISPs can cover the investment cost of networks. Recently, many studies have modeled the business relationship among ISPs and content providers and investigated desirable charging methods and ways that ISPs can obtain revenue from content delivery services [15][16][17][18][24]. Although these studies assumed content charging by ISPs to content providers, content

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charging has still not been realized [4], and transit charging is used.

When introducing content charge by ISPs to content providers, it is important to investigate the conditions for achieving it and the effect on ISPs. However, no studies have reported such investigations. In this paper, we model the business relationship between ISPs and content providers, and we investigate the conditions for introducing content charge by ISPs. We also investigate the effects of content charge on the revenue of ISPs by numerically comparing the content charge and the transit charge. In Section II, we briefly summarize the related works. In Section III, we model the relationship between ISPs and content providers and describe the charging methods compared in this paper. Section IV investigates the possibility of content charge and the effects of content charge on ISPs, and Section V shows the numerical results. Finally, we conclude this paper in Section VI.

II. Related Works

There are many works modeling the relationships among ISPs, content providers, and users in content delivery services, and investigating the price at the equilibrium state as a result of autonomous behaviors of these players. For example, P. Hande et al. investigated the price resulting from each player autonomously maximizing its utility function when both ISPs and content providers charge users a fee proportional to the amount of data transmitted [11]. However, accurately defining the utility function is difficult, and it is unrealistic to assume that each player behaves with the target of maximizing the utility function. Moreover, they did not consider content charge as a charging method by ISPs to content providers.

J. Musacchio et al. and Z. Zhang et al. derived the optimum price at which each player (ISP, content provider, and user) maximizes revenue at the equilibrium state [18][24]. They assumed that each player behaves to maximize its profit without using the utility function, so their works are more realistic. Moreover, R. Ma et al. proposed rational methods of allocating profit among players based on their contribution by regarding the transit relationship between one content provider and multiple ISPs as a kind of coalition and by distributing profit among players based on the Shapley value of a coalitional game [15][16][17]. However, the service prices depend on various factors, including the prices of other competitive services and competitive players, so it is difficult to achieve theoretically optimum and rational prices.

J. Musacchio et al. showed the results of a more practical evaluation, i.e., investigating the profit of each player when ISPs arbitrarily set the price for content providers [18]. However, the conditions of introducing content charge are not investigated in [18] or in all the works mentioned above. Moreover, as the charging model of ISPs for content providers, they assumed that the content charge or usage-based charge is simply proportional to the total amount of data transmitted. They did not compare the content charge with the usage-based charge of common use in which the increase ratio of the charge decreases with increase in the amount of data transmitted, and they did not investigate the effects of content charge on the revenue of ISPs.

III. Modeling ISP Content Charge

In this section, we describe the structure model among players and the charging models of ISPs against a content provider. Table I summarizes the semantics of variables.

A. Structure among Players

As the players constructing the content delivery services, we consider content providers, users, and ISPs delivering content from content providers to users. We assume that content providers obtain a fee directly from users, i.e., a paid delivery service, and we do not consider the business model based on advertisements. When there are multiple content providers, users can choose their provider, and a competitive environment among the providers is created. However, we assume a single content provider in this work, and we focus on autonomous players of N ISPs and a single content provider as shown in Figure 1. The content provider can freely connect its delivery server and make a transit agreement with any ISP, and we define $\mathcal{C}$ and $\overline{\mathcal{C}}$ respectively as the set of ISPs making a transit agreement with the content provider and the set of remaining ISPs. We assume that each ISP-i accommodates u_i users, and u_i is fixed independently of $\mathcal{C}$ and the charging model of each ISP for the content provider.

There are mainly two types of agreements, i.e., transit and peering agreements, when ISPs connect with other ISPs. Transit agreement is mainly used between a regional ISP and a transit ISP, and the regional ISP pays the transit fee to the transit ISP based on the amount of generated traffic. In peering agreement, on the other hand, no transit fee is paid between connected ISPs. We assume that each ISP connects with other ISPs by transit or peering agreements and that connectivity among all N ISPs is satisfied, i.e., no ISPs are isolated[1]. Therefore, by making a transit agreement with at least one ISP, the content provider can deliver content to all users accommodated by all N ISPs. However, if the video server is not connected to any ISP, the content provider cannot provide services, so we assume that the content provider makes a transit agreement with at least one ISP. Although traffic on network of an ISP will increase when making a transit agreement with the content provider, we assume that the cost for an ISP to make a transit agreement is negligible. In this assumption, ISPs always have motivation to make a transit agreement with the content provider. On the other hand, we assume that the content provider makes a transit agreement with an ISP only when the income of the content provider will increase by this transit agreement.

[1]In this paper, we do not consider the topology of ISP connectivity.

There are two common content provider charging models for users: a flat-based charge in which users can view content any number of times by paying a fixed amount each month, and a usage-based charge in which users pay a fee for each view of a content [13]. In this work, we assume a usage-based charge in which the content provider receives from users a fixed amount of fee P for each content delivery, independently of the content title. It is anticipated that the service quality, i.e., throughput and stability, at content delivery differs between the users of ISPs that have a transit agreement with the content provider and the users of ISPs that do not have a transit agreement with the content provider. User satisfaction with content delivery services depends on the service quality, so d_i, the average number of requests generated from each user accommodated by ISP-i within one month, depends on the service quality.

d_i depends on various factors, including the link capacities or link load in each network, the connectivity among ISPs, and the capacities and loads of transit or peering links between ISPs. However, to investigate the general trend, we ignore the structure of connectivity among ISPs and simply assume that d_i depends on only whether or not ISP-i has a transit agreement with the content provider, and we simply set $d_i = d$ in ISPs of $i \in \mathcal{C}$ and $d_i = \gamma d$ in ISPs of $i \in \overline{\mathcal{C}}$, where γ is a parameter taking a real number in the range of $0 < \gamma < 1$. By evaluating the performance with various γ, we can investigate the influence of γ on the ISP revenue.

For users of ISP-i, $i \in \overline{\mathcal{C}}$, content is delivered from the content provider through one or more other ISPs. We simply assume that the traffic created by content delivery to users of ISP-i, $i \in \overline{\mathcal{C}}$, is equally generated in the networks of each ISP-i of $i \in \mathcal{C}$. In other words, the traffic of z_i content deliveries on average for one month is transferred on the transit link between the content provider and ISP-i of $i \in \mathcal{C}$, where $z_i = d \cdot u_i + \gamma d \sum_{j \in \overline{\mathcal{C}}} u_j / x$, and x is the number of ISPs that have a transit agreement with the content provider, i.e., $x = \mid \mathcal{C} \mid$.

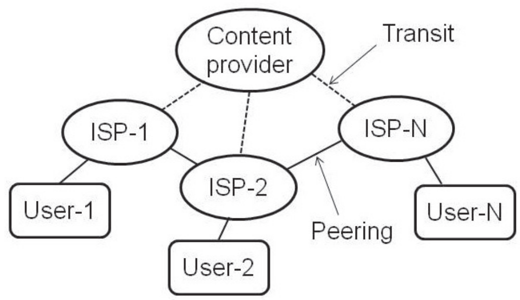


Fig. 1. Model of relationship among players.

B. Charging Model of ISPs for Content Provider

We compare three ISP charging models (CMs) for the content provider: (1) transit charge, (2) content charge, and (3) combination of transit and content charges. In this section, we formalize the fee obtained by each ISP from the content provider per month in each charging model.

TABLE I. SUMMARY OF VARIABLES.

Variable	Semantics
N	number of ISPs
u_i	number of users accommodated by ISP-i
U	total number of users accommodated by all N ISPs
$\mathcal{C}$	set of ISPs with transit contract to content provider
$\overline{\mathcal{C}}$	set of ISPs without transit contract to content provider
x	number of ISPs with transit contract to content provider
P	fee charged by content provider to user for each content delivery
d	average number of requests generated from each user of ISP-i of $i \in \mathcal{C}$ within one month
γd	average number of requests generated from each user of ISP-i of $i \in \overline{\mathcal{C}}$ within one month ($0 < \gamma < 1$)
θ_i	virtual user count of ISP-i
c_i	transit fee obtained by ISP-i of $\mathcal{C}$ from content provider
$\alpha_{i,j}$	charging parameter of ISP-i using CM-j ($j = 2, 3$)
$G_{i,j}$	monthly income of ISP-i using CM-j
R	monthly revenue of content provider
$R_{i,j}$	increase of monthly revenue of content provider obtained by making transit contract with ISP-i using CM-j
$\hat{\gamma}$	upper limit of γ satisfying condition that transit contract between content provider and ISP-i using CM1 is formalized
$\hat{u}$	lower limit of u_i satisfying condition that transit contract between content provider and ISP-i using CM3 is formalized
$\hat{\alpha}_{i,j}$	upper limit of $\alpha_{i,j}$ satisfying condition that transit contract between content provider and ISP-i using CM-j is formalized ($j = 2, 3$)
$\hat{G}_{i,j}$	achievable upper limit of $G_{i,j}$
$\Delta G_{i,j}$	increase of monthly income of ISP-i obtained by using CM-j compared with using CM1
$\Delta \hat{G}_{i,j}$	achievable upper limit of $\Delta G_{i,j}$

1) CM1 (Transit Charge): This is the charging model most commonly used by ISPs for content providers: ISPs charge the content provider based on the amount of data transmitted per second on the transit link. According to an analysis of transit charges of ISPs in 20 areas of the USA in 2004, the transit fee in one month, c, is proportional to the amount of data transmitted per second, V, powered by 0.75, and c can be approximated as $c = 100V^{0.75}$ [3]. For example, $c = 560$ USD when $V = 10$ Mbps, and $c = 100,000$ USD when $V = 10$ Gbps.

Many ISPs use the 95th percentile of the data transmission rate within every 5 minutes as V, and we assume that the 95th percentile of the data transmission rate is three times the average data transmission rate [7]. Because content is delivered through other ISPs for users accommodated by ISPs of $\overline{\mathcal{C}}$, transit traffic occurs on the networks of the traversed ISPs. Therefore, a part of the traffic delivering content to users of ISPs of $\overline{\mathcal{C}}$ is transferred on the networks of ISP-i of $i \in \mathcal{C}$, in addition to the traffic delivering content to users of ISP-i. The ratio of transit traffic created in each ISP-i of $i \in \mathcal{C}$ depends on the connectivity structure and transit relationship among the ISPs. However, we simply assume that transit traffic is equally generated on ISPs of $\mathcal{C}$, and $1/x$ of traffic created by delivering content to users of ISPs of $\overline{\mathcal{C}}$ is generated on the transit link between the content provider and each ISP-i of $i \in \mathcal{C}$.

Assuming that the average content size is $L = 300$ Mbytes [23], and the number of days in one month is 30, we have V_i, the value of V applied to the content provider by ISP-i of $i \in \mathcal{C}$:

$$V_i = \frac{3dL}{30 \times 24 \times 3600}\Big(u_i + \frac{\gamma}{x}\sum_{j \in \overline{\mathcal{C}}} u_j\Big) = \frac{d}{360}\theta_i, \quad (1)$$

where we define the virtual user count of ISP-i, θ_i, as

$$\theta_i = u_i + \frac{\gamma}{x}\sum_{j \in \overline{\mathcal{C}}} u_j. \quad (2)$$

The virtual user count of ISP-i is the effective number of users of ISP-i from the viewpoint of the amount of data transmitted on the transit link between ISP-i and the content provider. Moreover, defining κ as $\kappa = 100 \times 360^{-0.75}$, we have c_i, the transit fee obtained by ISP-i of $i \in \mathcal{C}$ from the content provider:

$$c_i = \kappa d^{0.75} \theta_i^{0.75}. \quad (3)$$

$G_{i,1}$, the monthly income of ISP-i using CM1 from the content provider, is $G_{i,1} = c_i$. To preserve the network neutrality, we assume that each ISP-i charges the content provider based on only the traffic transferred on the transit link between the content provider and ISP-i [18]. In other words, we assume that the content provider does not pay a transit fee to ISPs that are two or more hops from the content provider, even when content is delivered to users from the content provider through two or more ISPs.

2) CM2 (Content Charge): ISP-i of $i \in \mathcal{C}$ obtains a fixed ratio $\alpha_{i,2}$ of P, the fee a user pays for each content delivery to the content provider, for each content delivery transferred on the transit link between the content provider and ISP-i. $\alpha_{i,2}$ is a parameter taking a real number in the range of $0 < \alpha_{i,2} < 1$, and it is determined through negotiation between the content provider and ISP-i. Even for content deliveries to users of ISPs of $\overline{\mathcal{C}}$, we assume that the content provider pays a fee of $\alpha_{i,2}P$ to ISP-i when the delivery flows take the transit link between the content provider and ISP-i.

$G_{i,2}$, the monthly income of ISP-i using CM2 from the content provider, is given by

$$G_{i,2} = \alpha_{i,2} P d \theta_i. \quad (4)$$

As in CM1, the content provider does not pay a fee to ISP-i for traffic traversing ISP-i without taking the transit link between the content provider and ISP-i, to preserve the network neutrality.

3) CM3 (Combination of Transit and Content Charges): ISPs can also introduce a content charge while continuing the transit charge for content providers. For the content charge, we also assume that ISPs obtain a fixed ratio $\alpha_{i,3}$ of P from the content provider for each content delivery. $G_{i,3}$, the monthly income of ISP-i using CM3 from the content provider, is

$$G_{i,3} = \alpha_{i,3} P d \theta_i + c_i. \quad (5)$$

From Eqs. (4) and (5), we find that ISPs can obtain the same income when using CM2 as that when using CM3 by setting $\alpha_{i,2} = \alpha_{i,3} + \kappa/P/(d\theta_i)^{0.25}$.

IV. Analyzing ISP Content Charge

A. Strategies of Players

There are various cost components for the content provider, such as facility and operating costs of video servers, in addition to the fee paid to the ISPs. In this work, however, we consider only the fee paid to ISPs due to the transit agreement as the cost for the content provider. Let $\mathcal{I}_1$, $\mathcal{I}_2$, and $\mathcal{I}_3$ denote the set of ISPs using CM1, CM2, and CM3, respectively, as the charging model for the content provider. Under the assumption that the content provider makes the transit agreement with one or more ISPs, i.e., $\mathcal{C} \neq \phi$, the monthly revenue of the content provider, R, is derived as

$$\begin{aligned} R &= \sum_{i \in \mathcal{C} \bigcap \mathcal{I}_1} \Big\{Pdu_i - G_{i,1}\Big\} + \sum_{i \in \mathcal{C} \bigcap \mathcal{I}_2} \Big\{Pdu_i - G_{i,2}\Big\} \\ &\quad + \sum_{i \in \mathcal{C} \bigcap \mathcal{I}_3} \Big\{Pdu_i - G_{i,3}\Big\} + \sum_{i \in \overline{\mathcal{C}}} \gamma P d u_i \\ &= \sum_{i \in \mathcal{C} \bigcap \mathcal{I}_1} R_{i,1} + \sum_{i \in \mathcal{C} \bigcap \mathcal{I}_2} R_{i,2} \\ &\quad + \sum_{i \in \mathcal{C} \bigcap \mathcal{I}_3} R_{i,3} + \gamma P d U, \end{aligned} \quad (6)$$

where U is the total number of users accommodated by all N ISPs, i.e., $U \equiv \sum_{i=1}^{N} u_i$, and $R_{i,j}$ is the increase of monthly revenue of the content provider obtained by making a transit agreement with ISP-i using the charging model j. Without the transit agreement with ISP-i, the content provider can expect the income of $\gamma P d u_i$ from u_i users of ISP-i, so $R_{i,j}$ is derived as

$$R_{i,1} = Pd(1-\gamma)u_i - c_i, \quad (7)$$

$$R_{i,2} = Pd(1-\gamma-\alpha_{i,2})u_i - \alpha_{i,2} P d \frac{\gamma}{x} \sum_{j \in \overline{\mathcal{C}}} u_j, \quad (8)$$

$$R_{i,3} = Pd(1-\gamma-\alpha_{i,3})u_i - \alpha_{i,3} P d \frac{\gamma}{x} \sum_{j \in \overline{\mathcal{C}}} u_j - c_i. \quad (9)$$

From Eq. (6), we find that R is the linear combination of the increase parts, $R_{i,j}$, obtained by making the transit agreement with each ISP-i, and the fixed part, $\gamma P d U$, determined independently of the transit strategies of the content provider with ISPs. Moreover, from Eqs. (7)–(9), we find that

$R_{i,j}$ is independent of the strategies of other ISPs in selecting charging models and depends on only u_i, $\mathcal{C}$, and α_i[2]. Only when $R_{i,j} > 0$, the content provider can increase the monthly revenue by making the transit agreement with ISP-i with CM-j, and the content provide has an incentive to make the transit agreement with ISP-i. Therefore, the content provider judges whether or not to make the transit agreement with each ISP-i based only on the value of $R_{i,j}$.

Thus, each ISP can autonomously select the charging model for the content provider from the three models described in Section III-B independently of the strategies of other ISPs. Moreover, when using the content charge, i.e., CM2 or CM3, each ISP can autonomously set the charging parameter α_i with the constraint that $R_{i,j} > 0$ is satisfied. As α_i increases, the income of ISP-i increases, whereas the revenue of the content provider decreases. Therefore, regarding the decision of α_i, the interests of the content provider are completely opposed to those of each ISP, and α_i is determined through negotiation between them. When considering other costs, i.e., the facility and operation costs of video servers in R, these costs are also independent of the strategies of other ISPs, so we have the same observation. Moreover, we can also discuss the following by including the cost terms into $R_{i,j}$.

In this work, we assume that all ISPs can obtain a transit agreement with the content provider, at least when using the ordinary charging model, i.e., CM1. When $R_{i,1} > 0$, the revenue of content provider R increases through the making of a transit agreement with ISP-i using CM1, so the transit agreement with ISP-i is advantageous to the content provider. Therefore, the condition that the transit agreement between the content provider and ISP-i using CM1 is formalized as

$$Pdu_i > Pd\gamma + \frac{\kappa d^{0.75}}{u_i}\Big(u_i + \frac{\gamma}{x}\sum_{j\in\overline{\mathcal{C}}} u_j\Big)^{0.75}. \qquad (10)$$

The right-hand side monotonously increases as γ grows, so $\hat{\gamma}$, the upper limit of γ satisfying this condition, exists. $\hat{\gamma}$ is minimized when x takes the minimum value, i.e., $x = 1$, and decreases with u_i, so $\hat{\gamma}$ is given by

$$Pd^{0.25}u_{min} = Pd^{0.25}u_{min}\hat{\gamma} + \kappa(u_{min} + \hat{\gamma}U)^{0.75}, \qquad (11)$$

where u_{min} is the minimum u_i among N ISPs. By numerically solving Eq. (11), we can obtain $\hat{\gamma}$. Hereafter, we assume that γ satisfies $0 < \gamma < \hat{\gamma}$.

B. Realization Conditions and Effects of Content Charge

We investigate the conditions for ISPs to introduce content charge and the effects of content charge on the income of ISPs.

[2]We describe $\alpha_{i,2}$ and $\alpha_{i,3}$ as α_i when showing both in a single symbol. We use the same description for other parameters.

1) Case of CM2: The content provider makes the transit agreement with ISP-i using CM2 when $R_{i,2} > 0$ is satisfied, so $\hat{\alpha}_{i,2}$, the upper limit of $\alpha_{i,2}$ to achieve the transit agreement for ISP-i, is given by

$$\hat{\alpha}_{i,2} = \frac{(1-\gamma)u_i}{\theta_i}. \qquad (12)$$

The achievable upper limit of $G_{i,2}$, $\hat{G}_{i,2}$, is obtained by substituting $\alpha_{i,2} = \hat{\alpha}_{i,2}$ in Eq. (4):

$$\hat{G}_{i,2} = P(1-\gamma)du_i. \qquad (13)$$

$\hat{G}_{i,2}$ corresponds to the increase in monthly revenue for the content provider obtained by making the transit agreement with ISP-i, and it agrees with the amount of contribution by ISP-i to the content provider, i.e., improvement of throughput for users of ISP-i. This contribution is independent of x, the number of ISPs that have a transit agreement with the content provider, and the number of users of other ISPs. From Eq. (4), we find that $G_{i,2}$ decreases with increase of x for a certain value of $\alpha_{i,2}$, whereas we also find from Eq. (12) that the upper limit of $\alpha_{i,2}$ increases with x. As a result, $\hat{G}_{i,2}$ is independent of x.

We define $\Delta G_{i,2}$ as the increase in the monthly income of ISP-i obtained by using CM2 compared with that when using CM1, and we have $\Delta G_{i,2} = \alpha_{i,2}Pd\theta_i - c_i$ from Eqs. (3) and (4). By substituting $\alpha_{i,2} = \hat{\alpha}_{i,2}$ in these equations, we obtain $\Delta\hat{G}_{i,2}$, the achievable upper limit of $\Delta G_{i,2}$:

$$\begin{aligned}\Delta\hat{G}_{i,2} &= P(1-\gamma)du_i - c_i,\\ &= P(1-\gamma)du_i - \kappa(du_i)^{0.75}.\end{aligned} \qquad (14)$$

$\Delta\hat{G}_{i,2}$ increases with u_i. Therefore, the effect of using CM2 is higher for larger-scale ISPs.

As mentioned in Section IV-A, when the number of requests generated by each user of ISP-i depends on only the transit agreement between ISP-i and the content provider, whether the content provider makes the transit agreement with ISP-i using CM2 or not depends on only $\alpha_{i,2}$, the charging parameter set by ISP-i. When all N ISPs use CM2 and set $\alpha_{i,2} < \hat{\alpha}_{i,2}$, making a transit agreement with all N ISPs is advantageous for the content provider, so $x = N$ is achieved. Here, we have $\theta_i = u_i$, so the upper limit of $\alpha_{i,2}$ becomes $\hat{\alpha}_{i,2} = 1-\gamma$. Because γ is less than unity, $\hat{\alpha}_{i,2} > 0$ is always satisfied, so each ISP-i can always use CM2 independently of u_i. When $x = N$, the monthly income of ISP-i, $G_{i,2}$, is given by

$$G_{i,2} = \alpha_{i,2}Pdu_i, \qquad (15)$$

so $G_{i,2}$ is proportional to u_i. Moreover, $\hat{G}_{i,2}$ and $\Delta\hat{G}_{i,2}$ are also given by Eqs. (13) and (14).

2) Case of CM3: The content provider makes the transit agreement with ISP-i only when $R_{i,3} > 0$ is satisfied, so $\hat{\alpha}_{i,3}$, the upper limit of $\alpha_{i,3}$, is obtained by

$$\begin{aligned}\hat{\alpha}_{i,3} &= \frac{(1-\gamma)u_i}{\theta_i} - \frac{\kappa}{P(d\theta_i)^{0.25}} \\ &= \hat{\alpha}_{i,2} - \frac{\kappa}{P(du_i)^{0.25}}. \end{aligned} \quad (16)$$

Because the transit charge is used together with a content charge in CM3, $\hat{\alpha}_{i,3}$ decreases compared with $\hat{\alpha}_{i,2}$. By substituting $\alpha_{i,3} = \hat{\alpha}_{i,3}$ in Eq. (5), the achievable upper limit of $G_{i,3}$, $\hat{G}_{i,3}$, is derived as

$$\hat{G}_{i,3} = P(1-\gamma)du_i. \quad (17)$$

From Eq. (13), we find that $\hat{G}_{i,3}$ agrees with $\hat{G}_{i,2}$, and the achievable maximum income of the ISP when using a content charge is independent of whether or not the ISP uses the transit charge together with the content charge. This is because the capital that the content provider can pay to ISP-i is the amount of contribution by ISP-i to the content provider, i.e., $P(1-\gamma)du_i$, and the upper limit of G_i is bounded by this capital.

Moreover, the effect of using CM3 compared with that of using CM1 is $\Delta G_{i,3} = \alpha_{i,3}Pd\theta_i$, and the upper limit of $\Delta G_{i,3}$ is given by

$$\Delta\hat{G}_{i,3} = P(1-\gamma)du_i - c_i, \quad (18)$$

so we find that both $\Delta G_{i,3}$ and $\Delta\hat{G}_{i,3}$ agree with those when using CM2, and the effect of using CM3 is higher for larger-scale ISPs as well.

When $x = N$ is achieved, the upper limit of $\alpha_{i,3}$ is obtained by

$$\hat{\alpha}_{i,3} = 1 - \gamma - \frac{\kappa}{P(du_i)^{0.25}}. \quad (19)$$

In ISPs with larger u_i, the contribution to the content provider is larger, so $\hat{\alpha}_{i,3}$ is also larger. ISP-i can use CM3 only when $\hat{\alpha}_{i,3} > 0$ is satisfied, so the condition to use CM3 is

$$u_i > \frac{\kappa^4}{P^4 d(1-\gamma)^4} \equiv \hat{u}. \quad (20)$$

Therefore, there is a lower limit for u_i, $\hat{u}$, in CM3, unlike in the case of CM2. When $x = N$, the monthly income of ISP-i is

$$G_{i,3} = \alpha_{i,3}Pdu_i + \kappa(du_i)^{0.75}. \quad (21)$$

$\hat{G}_{i,3}$ and $\Delta\hat{G}_{i,3}$ are also given by Eqs. (17) and (18).

Table II summarizes the equations of main variables derived in Section III and IV.

V. Numerical Evaluation

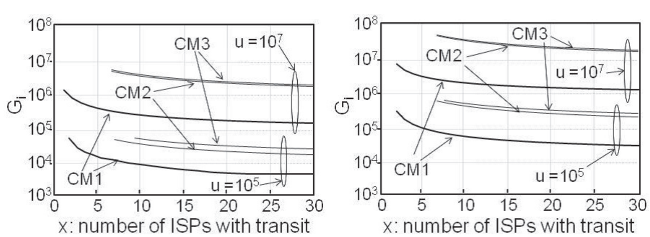
We set the fee the content provider obtains from users for each content delivery as $P = 1$ USD based on the actual VoD service operated by NTT [13]. When using a plan in which users can view content any number of times by a fixed fee in HikariTV, the average number of views by each user within one month is 10 [2]. We can regard this number as the average upper limit of the view count within one month determined by various restrictions, such as the amount of free time. In usage-based charge, the number of views should decrease from 10, so we set d, the average number of views per month by each user of the ISPs with transit agreements with the content provider, as $d = 1$ or 10.

TABLE II. Summary of equations of main variables.

Variable	Equations
θ_i	$u_i + \frac{\gamma}{x}\sum_{j\in\overline{\mathcal{C}}} u_j$
$\hat{u}$	$\frac{\kappa^4}{P^4 d(1-\gamma)^4}$
$\hat{\alpha}_{i,2}$	$\frac{(1-\gamma)u_i}{\theta_i}$
$\hat{\alpha}_{i,3}$	$\hat{\alpha}_{i,2} - \frac{\kappa}{P(du_i)^{0.25}}$
$G_{i,1}$ $(= c_i)$	$\kappa d^{0.75}\theta_i^{0.75}$
$G_{i,2}$	$\alpha_{i,2}Pd\theta_i$
$G_{i,3}$	$\alpha_{i,3}Pd\theta_i + c_i$
$\hat{G}_{i,2}$, $\hat{G}_{i,3}$	$P(1-\gamma)du_i$
$\Delta\hat{G}_{i,2}$, $\Delta\hat{G}_{i,3}$	$P(1-\gamma)du_i - c_i$

First, we evaluate the case that a part of homogenous ISPs with the identical u_i have a transit agreement with the content provider and investigate the influence of x, the number of ISPs that have a transit agreement with the content provider, on the income of ISPs. We set $\gamma = 0.45$.

For $N = 30$, and $u = 10^5$ or $u = 10^7$, Figure 2 plots G_i, the monthly income of each ISP, obtained from Eqs. (4) and (5) against x when setting $\alpha_{i,2}$ and $\alpha_{i,3}$ to 0.2. We show the results in the range of x in which $\hat{\alpha}_{i,2} \geq 0.2$ and $\hat{\alpha}_{i,3} \geq 0.2$ are satisfied. As x increases, the monthly income of each ISP-i of $i \in \mathcal{C}$ obtained by delivering content to users of ISPs of $\overline{\mathcal{C}}$ decreases. Therefore, as x increases, G_i rapidly decreases in the small-x region and gradually decreases in the large-x region. Even when setting $\alpha = 0.2$, the monthly income of an ISP with content charge, i.e., $G_{i,2}$ and $G_{i,3}$, is about 5 times and 10 times larger than that of an ISP without content charge, i.e., $G_{i,1}$, when $u = 10^5$ and $u = 10^7$, respectively. When setting $\alpha_{i,3}$ to the same value with $\alpha_{i,2}$, $G_{i,3}$ is larger than $G_{i,2}$ because of the transit income. However, the difference between $G_{i,2}$ and $G_{i,3}$ is small.



(a) N = 30, d = 1 (b) N = 30, d = 10

Fig. 2. G_i, the monthly income of each ISP, against x when setting $\alpha_{i,2}$ and $\alpha_{i,3}$ to 0.2. The monthly income of an ISP with content charge is about 5 times and 10 times larger than that of an ISP without content charge, when $u = 10^5$ and $u = 10^7$, respectively.

Next, we investigate the case when all the N heterogeneous ISPs have the transit agreement with the content provider, i.e., $x = N$. We set the number of ISPs N to 5 and set u_i to the values shown in Table III, assuming the five ISPs with the largest numbers of users in April 2006 in Japan [6]. The number of users accommodated by these five ISPs was 53.4% of the total number of users in Japan. The allowable upper limit of γ achieving CM1 obtained from Eq. (11) is 0.829 when $d = 1$ and 0.899 when $d = 10$. $\hat{u}$, the lower limit of u_i required to use CM3 at $\gamma = \hat{\gamma}$ is $\hat{u} = 2,523$ ($\hat{u} = 2,031$) when $d = 1$ ($d = 10$). Therefore, we confirm that ISPs of a similar scale to major ISPs in Japan can use CM3.

Figure 3 shows $\hat{\alpha}_{i,2} = 1-\gamma$, the upper limit of the content charge parameter when using CM2, in the range of $\gamma < \hat{\gamma}$. We also plot $\hat{\alpha}_{i,3}$ derived from Eq. (19) for each of the five ISPs. Although compared with $\hat{\alpha}_{i,2}$, $\hat{\alpha}_{i,3}$ is decreased due to the terms related to the transit income, which depends on d and u_i, the decrease ratio is small compared with the value of γ, and $\hat{\alpha}_{i,3}$ is close to $\hat{\alpha}_{i,2}$. Therefore, even when CM3 is used, the difference of $\hat{\alpha}_{i,3}$ among ISPs and the influence of d on $\hat{\alpha}_{i,3}$ is small.

Figure 4 plots $G_{i,2}$ and $G_{i,3}$, the monthly income in CM2 or CM3 obtained from Eqs. (15) and (21), for ISP-1 and ISP-5 when α_i varies in the range of $\alpha_i < \hat{\alpha}_i$. We set γ to 0.45, i.e., about half of the upper limit 0.899, when $d = 10$. We also plotted $G_{i,1}$, the monthly income of ISP-i when using CM1, for comparison. Although $G_{i,1}$ is independent of α_i, $G_{i,2}$ is proportional to $\alpha_{i,2}$. Therefore, compared with when CM1 is used, the income of each ISP in CM2 increases in the large-$\alpha_{i,2}$ region, whereas it decreases in the small-$\alpha_{i,2}$ region. When using CM3, ISPs can obtain the income of a transit charge in addition to that of a content charge, so $G_{i,3}$ approaches $G_{i,1}$ in the small-$\alpha_{i,3}$ region, and the income of ISPs always increases.

The income of ISPs obtained from a content charge is proportional to d and u_i, whereas that obtained from a transit charge is proportional to d powered by 0.75 and u_i powered by 0.75. Therefore, with the increase of d and u_i, $\Delta G_{i,2}$ and $\Delta G_{i,3}$, the increase in the monthly income of ISP-i when using CM2 or CM3 compared with that when using CM1, increase.

In CM2 and CM3, the monthly income of each ISP, G_i, depends on the charging parameter α_i. Each ISP needs to set charging parameter α_i in the range of $0 < \alpha_i < \hat{\alpha}_i$ through negotiation with the content provider. If the content provider sells content to users of App Store, for example, the content provider pays 30% of the sales to Apple [1]. In App Store, Apple constructs the content delivery platform by using unique terminals, so the market power of Apple is strong. The data transmission service provided by ISPs is more of a commodity service, so the commission ratio paid by content providers is expected to fall below 30%. For example, when $\alpha_i = 0.2$ is set and $d = 1$ is assumed, $\Delta G_{1,2} = 1.35 \times 10^6$ and $\Delta G_{1,3} = 1.52 \times 10^6$ for ISP-1 with the largest user count, and $\Delta G_{5,2} = 3.82 \times 10^5$ and $\Delta G_{5,3} = 4.52 \times 10^5$ for ISP-5 with the smallest user count. Therefore, by introducing a content charge, major ISPs in Japan can expect to increase their monthly income from about 100,000 USD to about 1 million USD.

Figure 5 plots $\Delta \hat{G}_i$, the maximum increase in the monthly income of ISP-i expected when content charge is used, obtained from Eqs. (14) and (18), against γ for each of the five ISPs in the range of $\gamma < \hat{\gamma}$. When the content provider makes transit agreements with all the ISPs, the monthly income of each ISP when using CM1 is independent of γ. On the other hand, $\hat{G}_i$, the maximum monthly income of ISP-i when using content charge, decreases as γ increases and rapidly decreases as γ approaches the upper limit $\hat{\gamma}$, as found in Eqs. (13) and (17). Therefore, $\Delta \hat{G}_i$ becomes a concave function of γ and decreases with increase of γ. Moreover, $\Delta \hat{G}_i$ increases as d or u_i increases.

TABLE III. u_i, NUMBER OF USERS ACCOMMODATED IN EACH ISP-i.

i	u_i
1	7,622,711
2	6,583,633
3	4,344,520
4	2,762,724
5	2,262,270

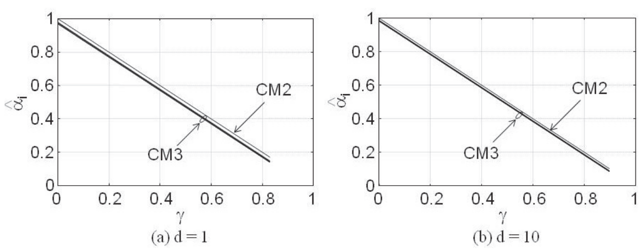


Fig. 3. Upper limit of charging parameter α_i. Even when CM3 is used, difference of $\hat{\alpha}_{i,3}$ among ISPs and influence of d on $\hat{\alpha}_{i,3}$ is small.

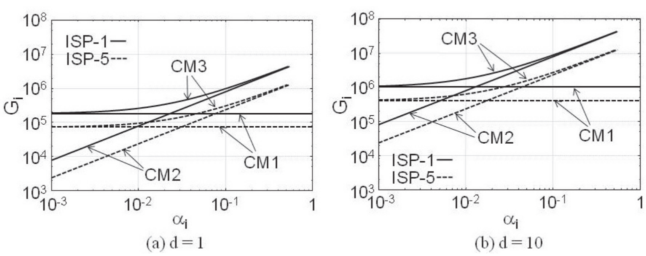


Fig. 4. Monthly income of each ISP against charging parameter α_i. With increase of d and u_i, increase in monthly income of ISP-i when using CM2 or CM3 compared with that when using CM1 increases.

VI. Conclusion

In this paper, we focused on content charge as a way for ISPs to cover network investment costs, which are rapidly increasing with the growth of traffic delivering rich content. We investigated the conditions for realization and the effects of content charge. When the request count of each user is determined only by the existence of a transit agreement

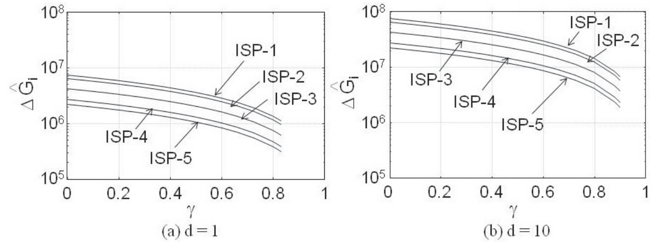


Fig. 5. Maximum increase in monthly income of each ISP expected when using content charge. $\Delta\hat{G}_i$ becomes concave function of γ.

between the content provider and the accommodating ISP, we obtained the following results.

1) The contribution of ISP-i to the content provider through the transit agreement is the revenue increase for the content provider. This increase is obtained by increasing the view count of users of ISP-i through the improvement of the service quality of content delivery. The contribution of ISP-i to the content provider is determined by only the user count u_i, independent of the strategies of other ISPs and the content provider. The monthly income of ISP-i when using content charge is bounded by the amount of contribution, so the charging ratio α_i that ISP-i can set has an upper limit. Moreover, when ISPs use a transit charge together with a content charge, the user count has a lower limit. Although the revenue of the content provider decreases when ISPs introduce content charge, making a transit agreement is still advantageous for the content provider as long as ISPs satisfy these constraints, so ISPs can introduce content charge as the charging method for the content provider.
2) As x, the number of ISPs with transit contract to content provider, increases, the monthly income of each ISP-i of $i \in \mathcal{C}$ obtained by delivering content to users of ISPs of $\overline{\mathcal{C}}$ decreases. Therefore, as x increases, G_i, the monthly income of ISP-i, rapidly decreases in the small-x region and gradually decreases in the large-x region. Even when setting $\alpha = 0.2$, the monthly income of an ISP with content charge, i.e., $G_{i,2}$ and $G_{i,3}$, is about 5 times and 10 times larger than that of an ISP without content charge, i.e., $G_{i,1}$, when $u = 10^5$ and $u = 10^7$, respectively.
3) When all the five major ISPs in Japan have transit agreement with the content provider, when the number of views of each user accommodated by an ISP that has a transit agreement with the content provider is about two times that of each user accommodated by an ISP without such an agreement, and when the charging ratio is set to 20%, these five ISPs can expect to increase their monthly income from about 100,000 USD to about one million USD.

As future work, we leave the issue of how to estimate parameter γ in the actual networks. Based on the actual AS level topology consisting multiple ISPs, we will evaluate γ by investigating how the transit agreement between each ISP and the content provider affects the service quality of content delivery. Moreover, we will investigate content charge when the frequency of user requests also depends on the strategies of other ISPs. We will also investigate other models of structure among players, e.g., the case when ISPs can select content providers from multiple candidates, and the case when CDN providers exist between content providers and ISPs. Although we assumed a single-layer structure of ISPs in this paper, we will also investigate the case when ISPs form multiple layers considering the current trend of the structure of ISP connectivity [14] in future.

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