Money Adjustment Among ISPs Based on Cooperative Games for ICN Promotion

Masaki Ito
Graduate School of Information Science and Engineering
Ritsumeikan University
Osaka, Japan
Email: is0494vk@ed.ritsumei.ac.jp

Noriaki Kamiyama
College of Information Science and Engineering
Ritsumeikan University
Osaka, Japan
Email: kamiaki@fc.ritsumei.ac.jp

***Abstract*—The introduction of information-centric networking (ICN), which is a content name-based communication, is widely considered as an efficient content delivery method due to the expected rapid growth of traffic volume on the Internet today. The introduction of ICN affects the revenue of each Internet Service Provider (ISP) because ISPs exchange transit fees based on the amount of traffic. Since ICN deployment is based on the decision of each ISP, it is necessary to analyze the impact of ICN deployment on revenue of each ISP to clarify the potential for ICN deployment. We have analyzed the impact of the gradual introduction of ICN on the revenue of each ISP in a hierarchical topology structure among ISPs and found that incentives for Tier 1 ISPs are necessary to promote the introduction of ICN. As a system to provide incentives for ICN deployment, it would be effective to create a fund by collecting a portion of revenues from ISPs whose revenues are increasing, and to subsidize ISPs whose revenues are decreasing. It is also necessary to consider the effect of increased revenue from users due to the effect of reduced latency obtained by efficient delivery through the introduction of ICN. Therefore, in this paper, we analytically derive the impact of ICN deployment on the revenue of each ISP in terms of transit cost and revenue from users, assuming a hierarchical AS topology. Then, we use the Nash bargaining solution to find the adjustment fee among ASes given the ICN penetration rate, and derive the change in revenue due to ICN introduction and adjustment fee, and clarify the diffusion potential of ICN.**

***Keywords*-ICN; ISP; Nash bargaining solution;**

I. Introduction

In addition to the exchange of text and images, large-volume rich content such as video and audio has become mainstream on the Internet in recent years, and the demand for large-volume, low-latency content distribution, such as distribution from video providers represented by YouTube and Netflix, has increased significantly. The above factors are expected to cause a rapid increase in traffic, so information-centric networking (ICN) is being considered as an efficient content delivery method. ICN is a communication system in which content is cached at each router and the communication is mainly based on the name of the content.

In ICN, when a content requester sends a request packet which is called *interest*, each router forwards the interest packet by content name. If the requested content is cached in a router, the content is delivered directly from the router without forwarding the interest. This mechanism avoids the overhead of name resolution and enables efficient content delivery from a location closer to the user, thereby reducing latency and network load. Internet Service Provider (ISP) is connected to transit ISPs to ensure connectivity to the entire Internet, and transit fees are exchanged according to the amount of traffic with neighboring ISPs [13]. The introduction of ICN affects the profit of each ISP because the amount of traffic exchanged between ISPs changes with the introduction of ICN. Since the deployment of ICN is based on the business decision of each ISP, an ISP will not deploy ICN if it does not expect to make a profit. Therefore, it is necessary to analyze the impact of ICN deployment on profit of each ISP to clarify the possibility of ICN deployment.

The deployment of ICN is determined independently by each ISP, and an ISP will not deploy ICN if it does not expect to make a profit. In the previous studies, we have analyzed the topology structure among hierarchical autonomous system (AS) and analyzed the revenue of each layer of AS when ICN was deployed [8]. We found that incentives are necessary to encourage ISPs at layer 1, where the impact of ICN deployment is large, to deploy ICN. However, how to provide incentives to layer 1 ISPs is still unresolved. To provide incentives to layer 1 ISPs, it is effective to create a fund by collecting a portion of revenues from ISPs whose revenues are increasing, and to subsidize ISPs whose revenues are decreasing. Therefore, in this paper, assuming a hierarchical AS topology, we analytically derive the change in revenue when a certain percentage of new ASes introduce ICN and investigate an appropriate adjustment fee system.

II. Related Woeks

Studies that have modeled the relationship between ASes and analyzed the behavior of each ISP when making connection agreements with other ISPs include the following. Lodhi et al. consider the peering strategy of transit providers and derive a viable Nash equilibrium strategy [11]. Dhamdhere et al. analyze the necessary conditions for a peering agreement

979-8-3315-3209-3/24/$31.00 ©2024 IEEE
DOI 10.1109/CyberSciTech64112.2024.00043

between two ISPs from the perspective of each ISP's profit [4]. In addition, Valancius et al. model the traffic demand generated by users and the cost of ISPs to carry traffic. They analyze the effect of ISPs differentiating transit costs [14].

Research on ICN has been active, there has been much discussion about its effectiveness and challenges [7]. Rajahalme et al. show that in CCNs, each AS may not be motivated to cache content in its own NW, and suggest the need to provide incentives [12]. Kamiyama et al. evaluated the revenue impact of ICN deployment based on a tiered AS topology [8]. They showed that incentives are needed, especially for ISPs in the upper layers. We extend the model of Kamiyama et al. and propose a set of adjustment costs among ISPs. Therefore we aim to contribute to the possibility of ICN deployment and the design of an incentive structure for each ISP to cooperate.

III. Assumptions

This section describes the hierarchical topology structure among ISPs, the various conditions, and the modeling of the design among the ASes assumed in this paper in order to analyze the impact of each ISP on the profits of each ISP.

A. Content

Assume that M content is provided on all ASs, that the size of each content is uniform in L (Mbytes), and that each content m is selected in each delivery request with a certain probability q_m. Assume that q_m follows the Zipf distribution of parameter 1.0, and that each content is assigned in descending order of q_m, with q_1 being the most popular content and q_M being the least popular content. Also, let $Q(m)$ be the cumulative distribution of q_m, i.e., $Q(m) = \sum_{i=1}^{m} q_i$. Let U_1 be the total number of users and U_2 be the total number of contents providers (CPs).

B. Cost

An ISP charges a customer ISP who has signed a transit contract a fee based on the data transfer rate over the transit link during a month. The monthly transit cost T is proportional to the 0.75 power of the data transfer rate V (Mbps) and can be approximated by $T = 100V^{0.75}$ [2]. Assuming that V is three times the average transfer rate [3], and the number of content views per month is D, we have $V = 1.08 * 10^{-5}LD$ [8]. The monthly transit cost T is assumed to be a sum model calculated based on the sum of data transfer rates in both directions over the transit link [13], and T is obtained by the following equation,

$$T = 100(\kappa LD)^{0.75}, \tag{1}$$

where $\kappa = 1.08 * 10^{-5}$. It is also assumed that each AS collects a fixed fee of C from each of its own users, and that it can receive A, which is C multiplied by the number of users, as a monthly access fee.

C. Inter-AS topology

When two ASes connect, they can be classified into two types of connections: transit connections that charge a transit fee based on the amount of data transferred, and peering connections in which neither party pays a fee. The upper-layer AS mainly provides transit services as a provider, while the lower-layer AS pays a fee as a customer and enjoys transit services. The link connecting the two ASes, as seen from the upper AS, is called a provider-to-customer (p2c) link, while the link seen from the lower AS is called a customer-to-provider (c2p) link. In other words, the same transit connection link is p2c link for one and c2p link for the other. The direction of the p2c link is downhill, and the direction of the c2p link is uphill. The set of all ASes that can be reached from itself via p2c links only is called its *customer cone* (CC) [5].

Define the number of AS of each layer k denotes as L_kAS as N_k, and define the average number of p2c links to L_{k+1}AS, the average number of c2p links to L_{k-1}AS, and the average number of p2p links to L_kAS are defined as g_k^{pc}, g_k^{cp}, and g_k^{pp}, respectively. Figure1 shows the inter-AS topology model assumed in this paper.

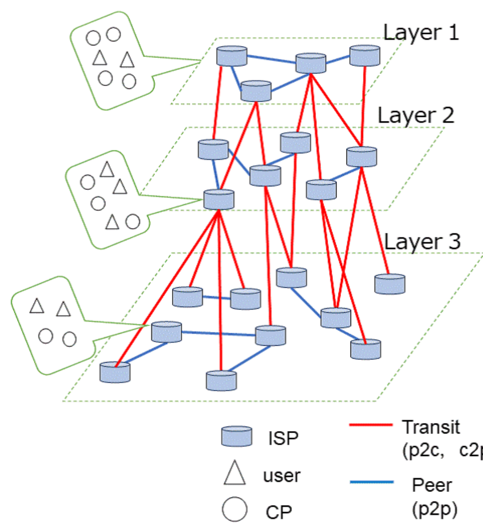

Figure 1. AS topology model

We model the AS topology as a hierarchical tree topology using the following two data on topologies between ASes published on the CAIDA website [1][8].

as_rel file Using the inter-AS topology data estimated in 2005 from BGP table information (RouteView) and the inter-AS routing policy information (IRR: Internet Routing Registries) between ASes, we used the method described in [5], to classify the 85,136 links existing between 18,967 ASes into three categories, p2p, p2c and c2p.

as2attr. file Using the above inter-AS topology data, we classify the 19,537 Asesinto large ISPs, small ISPs, universities, IXPs, NICs, and customers using the method in [6].

As a result of the modeling, the number of layers is $K = 3$, the number of AS for each layer is $N_1 = 49$, $N_2 = 2,123$, and $N_3 = 2,565$, and g_k^{pc}, g_k^{cp}, g_k^{pp} are summarized in tableI. Assume that each L_kAS has a link to each L_{k+1}AS with uniform probability g_k^{pc}/N_{k+1}. Similarly, assume that p2p link exists between each L_kAS with probability $g_k^{pp}/(N_k - 1)$.

Table I
AVERAGE NUMBER OF LINKS OF EACH TYPE FROM EACH AS

Layer	g_k^{pc}	g_k^{cp}	g_k^{pp}
1	440.41	0.00	3.27
2	10.14	10.16	5.72
3	0.00	8.40	0.46

We assume that the ratio of CPs and users accommodated in each L_k AS is W_k. At each layer k, each N_k AS is assumed to accommodate CPs and users uniformly, and the content originals are uniformly distributed among all CPs. Moreover, the delivery request is uniformly generated from users, and each request randomly selects content according to the Zipf distribution.

D. Cache Design

The provider AS advertises all routes it receives because it is obligated to provide transit to the entire Internet for the customer ASes [12]. Since two peering connected ASes can usually send and receive traffic for free, each AS also advertises all routes it receives to the AS to which it has the p2p connection. On the other hand, the customer AS does not advertise routes to the provider AS because it increases the amount of traffic in the downhill direction on the c2p link. However, it is obligated to guarantee the reachability of users to the CC and CPs to the Internet, so it advertises routes to these addresses to the provider AS.

An AS with ICN can freely decide whether or not to cache content, and by caching content that has passed through the c2p link from a provider AS, it can deliver content from its own cache without having to forward interest to the provider AS in the next session, thereby reducing the amount of traffic, or in other words, transit costs. Therefore, content received from the provider AS is cached. On the other hand, they do not cache content received from the customer AS via the p2c link or from the p2p link because there is no advantage in terms of transit costs or cache resources [12][9]. Similarly, from the perspective of transit costs, each AS forwards interest in the routing in the order of priority: p2c, which receives transit costs, p2p, which does not exchange transit costs, and c2p, which pays transit costs. In other words, from the CP to the highest layer via, only c2p links are used to deliver contents to the user, and then only p2c links are used to deliver contents to the user after the appropriate p2p links are used [10].

We do not consider the cache capacity of each router or the topology within an AS, but only the total cache capacity B_k of all the routers in the AS at each layer k in terms of the number of contents. All ASes in the same layer are assumed to have the same B_k, and the cache capacity of each L_k AS is set so that $B_k < B_{k+1}$, since the size of ASes in higher layers is expected to be larger. All other policies such as costs, inter-AS topology, and route advertisements are assumed to be the same as those defined in [8].

IV. DERIVATION OF INTER-AS ADJUSTMENTS OF MONEY

When an AS deploys a new ICN, some content will be delivered directly from the ICN-enabled AS, which is expected to reduce the amount of traffic on p2c and c2p links in some ASes. In addition, by delivering content closer to the user, ICN is expected to reduce the delivery delay time. The decrease in latency is expected to increase user satisfaction and increase the amount of money users are willing to pay. Therefore, among the revenue R_k earned by L_k AS, transit and access fees change before and after the introduction of ICN, and the necessary adjustment is derived by quantifying these changes.

A. transit fee

Based on the assumptions described in Section III, we derive the amount of traffic generated on the links between ASes when partial ICN is introduced. In the status that the ratio of P_k L_k AS has introduced ICN, the probability that a delivery flow passes in the uphill direction $F_{u,k}$ and in the downhill direction $F_{d,k}$ are obtained as follows [8].

$$\begin{aligned} F_{u,k} &= \sum_{r=1}^{K}\sum_{s=k}^{K}\sum_{t=1}^{k-1} G_{r,s,t}\frac{W_r W_s}{N_k g_k^{cp}}[\prod_{n=t}^{r}(1-P_n) \\ &\quad + \sum_{m=t}^{r}\prod_{n=t}^{m-1}(1-P_n)P_m\{1-Q(\sigma_m)\}], \qquad (2) \end{aligned}$$

$$\begin{aligned} F_{d,k} &= \sum_{r=1}^{K}\sum_{s=1}^{K}\phi_{r,s,k}W_r W_s[\prod_{n=k}^{r}(1-P_n) \\ &+ \sum_{m=k}^{r}\prod_{n=k}^{m-1}(1-P_n)P_m\{1-Q(\sigma_m)\}]. \qquad (3) \end{aligned}$$

We note that $G_{r,s,t}$ is the probability that the highest layer through which the delivery flow passes is t when the user is at layer r and the CP is at layer s, and $\phi_{r,s,k}$ is the probability that the delivery flow passes the c2p link at each L_k AS when the user is at layer r and the CP is at layer s. Moreover, σ_k is the upper bound of the cache of L_kAS. As described in

Section III-D, for routing information exchange to provide reachability, an ICN-introducing AS avoids duplication of content. Since the probability that an L_k AS has introduced ICN is P_k, it can avoid caching duplicates with $g_k^{pp}P_k$+1 neighboring ASes including itself, so the probability that each content of an L_k AS introducing ICN is subject to caching is 1-W_k/N_k($g_k^{pp}P_k$+1)/($g_k^{pp}P_k$+1)=1/($g_k^{pp}P_k$+1)-W_k/N_k. The cache upper bound σ_k can be expressed by

$$\sigma_k = \frac{B_k}{\frac{1}{g_k^{pp}P_k+1} - \frac{W_k}{N_k}}. \quad (4)$$

From (1)-(4), the transit cost T_k^{pc} that each L_kAS receives from layer $k+1$ and the transit cost T_k^{cp} that it pays to layer $k-1$ are respectively as follows

$$T_k^{pc} = 100\{\kappa L d U_1 (F_{u,k+1} + F_{d,k+1})\}^{0.75} g_k^{pc}, \quad (5)$$

$$T_k^{cp} = 100\{\kappa L d U_1 (F_{u,k} + F_{d,k})\}^{0.75} g_k^{cp}. \quad (6)$$

By comparing the values before and after changing P_k, we derive the amount of each change. Note that D is the average number of times each user views the content per month.

B. Access Fee

We derive the number of hops of delivery flows as the metrics of user-perceived delay quality. We define $H_{r,n}$ as the probability that the number of hops from a user in L_r AS to any content original is n. For simplicity, we do not consider the topology within an AS or each router and assume that the hop length between adjacent ASes is one.

1) Number of Hops: Because of the obligation to ensure reachability of the Internet to its own CC, routing information is completely exchanged among all L_1 ASes at the top layer. Therefore, at layer 1, a single AS[1] or multiple ASes are traversed using p2p links. On the other hand, the non-highest layer is considered to go through an AS only once, using a single AS or a p2p link, since there is no advantage in terms of revenue. Let $h_{t,n}^{pp}$ denote the probability of going through an AS n times using p2p links at the top-most via layer t, the probability of selecting a single AS, $h_{t,0}^{pp}$, is $1/N_t$. When $t = 2, 3$, we have $h_{t,1}^{pp} = 1 - 1/N_t$. On the other hand, when $t = 1$, it is necessary to consider going through the AS several times. The AS is routed through using a p2p link only once if the target AS has a p2p link to its own AS, and the AS is routed through using a p2p link twice if it has a p2p link to one or more of the ASes that can be routed through the first time. To determine whether we have a p2p link with the desired AS, we consider a general lottery problem. It corresponds to the probability that among a lots, there are b wins, and that we can draw that lot c times and win any one of them. Considering the complementary event of the probability of not winning, we have the following equation,

$$1 - \frac{\prod_{i=0}^{b-1}(a-c-i)}{\prod_{i=0}^{b-1}(a-i)}. \quad (7)$$

In the case of h_n^{pp} with n>0, a is the number of ASes remaining, $a = N_1$-h_{n-1}^{pp}*N_1, b is the number of candidate ASes to go through for $n-1$ times, $b = h_{n-1}^{pp} * N_1$, and c is the number of c2p links, $c = g_1^{pp}$. Therefore, we obtain the following equation,

$$h_{1,n}^{pp} = 1 - \frac{\prod_{i=0}^{h_{1,n-1}^{pp}N_1-1}(N_1 - h_{1,n-1}^{pp}N_1 - g_1^{pp} - i)}{\prod_{i=0}^{h_{1,n-1}^{pp}N_1-1}(N_1 - h_{1,n-1}^{pp}N_1 - i)} \quad (8)$$

The number of hops using p2c and c2p links is

$$r + s - (2t-1) \quad (9)$$

with layer r of user, layer s of CP, and top-most via layer t. Also, if content is cached by an ICN-deployed AS, some contents will be delivered directly from that AS, and the number of hops of delivery flows changes. However, when content that is already cached by a lower-layer AS on the route is requested, the upper layers are not affected. Thus, p_k, the probability of being cached in L_kAS, when $k < K$, is

$$p_k = P_k Q(\sigma_k) \prod_{n=k}^{K} (1 - P_{n+1} Q(\sigma_{n+1})). \quad (10)$$

When $k = K$, we have

$$p_k = P_k Q(\sigma_k). \quad (11)$$

From these equations, the probability distribution of $H_{k,n}$ is obtained as follows,

$$H_{r,n+r+s-(2t-1)} = h_{r,n}^{pp} G_{r,s,t} W_s \prod_{k=1}^{\max(r,s)} (1 - p_k), \quad (12)$$

$$H_{r,r-k} = p_k \frac{1}{g_k^{pp}+1}, \quad (13)$$

$$H_{r,r-k+1} = p_k \frac{g_k^{pp}}{g_k^{pp}+1}. \quad (14)$$

2) Expected Increase of Revenue from Users: We define S as the sensitivity of a user to delivery delays and assume that the revenue from users increases by S% for every 1-hop decrease in the delivery path. From the probability distribution by $H_{k,n}$, we can obtain $h(k)$ and $h'(k)$, the expected number of hops before and after the introduction of ICN, respectively. The expected rate of increase in L_kAS revenue from users, E_k, is obtained by

$$E_k = 1 + S\{h(k) - h'(k)\} \quad (15)$$

Moreover, the monthly access fee A_k from each new L_kAS user after the introduction of ICN is given by

$$A_k = E_k C U_1 W_k. \quad (16)$$

[1]In this case, it will turn around to the CC without using a p2p link.

C. Nash Bargaining Solution

While the monthly transit cost T is a zero-sum game where one side gains and the other loses, the monthly access fee A is the inflow of new money into the market. Therefore, each ISP acts in its own interest, but cooperation between ASes, i.e., the introduction of ICN, can yield greater returns. The Nash bargaining solution, an agreement that maximizes the utility of both parties, is known as a rational distribution method for the results obtained through cooperation. Therefore, in this paper, we propose to set the adjustment fee between ASes by the Nash bargaining solution. The point that maximizes the product of the increase in revenue due to the introduction of ICN from the baseline revenue before the introduction of ICN is obtained, and the adjustment amount between the ASes is derived. From sections IV-A and IV-B2, the revenue R_k (USD) of L_kAS is

$$R_k = T + A = T_k^{pc} - T_k^{cp} + A_k. \quad (17)$$

We set ΔR_k to be the change in revenue of L_kAS before and after the introduction of ICN. Also, we set the total amount of money passed from all L_jAS to all L_kAS to be the adjustment $x_{k,j}$ ($k < j$). Then, we find $x_{k,j}$ that maximizes the product of utility $\Delta R_k + x_{k,,j}$ and $\Delta R_j - x_{k,j}$ by Nash bargaining solution. Since the product is maximized when $\Delta R_k + x_{k,,j} = \Delta R_j - x_{k,j}$, we obtain $x_{k,j}$ by

$$x_{k,j} = \frac{\Delta R_j - \Delta R_k}{2}. \quad (18)$$

V. Numerical Evaluation

A. Evaluation Condition

We set W_k, the ratio of CPs and users accommodated in each L_kAS to $W_1 = 0.460$, $W_2 = 0.426$, and $W_3 = 0.114$ [8]. We also set the original access fee collected by the ISP from each user as $A_k = 50$ USD, the total number of users as $U_1 = 10^9$, the total number of CPs as $U_2 = 10^4$, and the average monthly number of content views by each user as $d = 10$. The total number of contents is $M = 10^6$, and the request ratio of each content is the Zipf distribution of parameter 1.

B. Impact of User Sensitivity on AS Revenue Changes

We derive change in transit cost ΔT_k, change in access fee ΔA_k, and change in revenue ΔR_k of all ASes in each layer when all L_1 ASes introduced ICN from the state where ICNs are not introduced in all L_1 ASes. In other words, only P_1, the ICN penetration ratio of L_1 ASes is changed from 0 to 1, and the ICN penetration ratio of L_2 and L_3 ASes are fixed to zero. Figure 2 plots (a) ΔT_k and (b) ΔA_k against S, the user sensitivity against delay. ΔT_k was constant independently of S. The amount of traffic flowing between links decreased as more L_1AS introduced ICN. As a result, the transit cost T_1 of L_1AS decreased while T_2 and T_3 increased. On the other hand, ΔA_k was positive at all layers, and each A_k increased

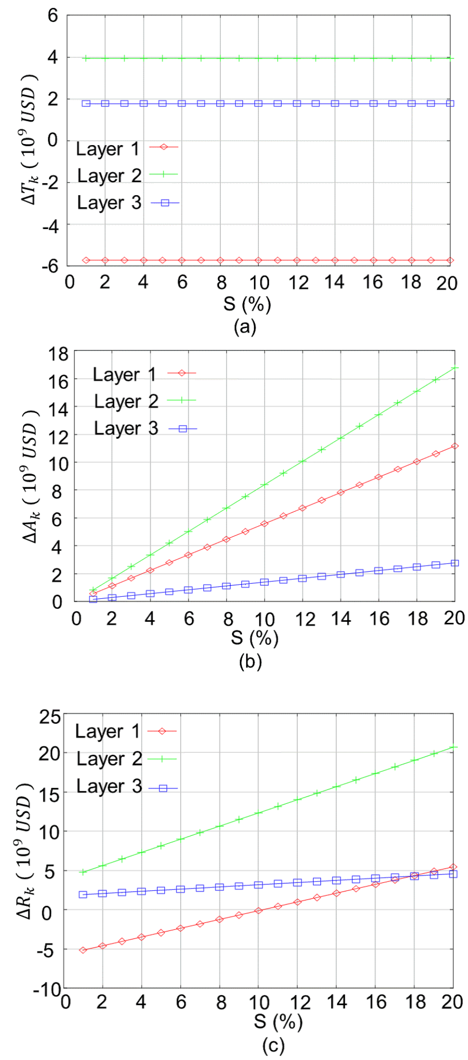

Figure 2. Change of (a) transit fee and (b) access fee and (c) revenue of each AS in each layer against S, sensitivity of users for delay, when only L_1 ASes introduce ICN

monotonically with increasing S. Next, we plot ΔR_k against S in Figure 2(c). According to the sign of ΔR_k, when S was sufficiently small, L_1AS revenue decreased. On the other hand, L_2 and L_3AS revenues increased. When S was large, the effect of the decrease in the number of hops on A was large at all layers, and the introduction of ICN also increased L_1AS revenue. For values of S where $\Delta R_1 < 0$, incentive against L_1AS is necessary for ICN deployment. On the other hand, when the revenue of L_1AS is positive, layer 1 ISPs naturally adopt ICNs without incentives.

C. Adjustment Payment

Next, we investigate the impact of the ICN penetration rate of ASes in each layer on the total adjustment $x_{j,k}$ paid by all L_kAS to all L_jAS. We set $S = 9$ so that $\Delta R_1 < 0$

and the change in revenue from users was large. In Figures 3(a)(b), we plot $x_{1,2}$(paid by all L_2AS to all L_1AS) and $x_{1,3}$(paid by all L_3AS to all L_1AS). against P_1 when setting P_2 and P_3 to 0, 0.5, and 1.0, respectively, and varying only P_1 from 0 to 1. As P_1 increased, $x_{1,2}$ increased. As the ICN penetration rate of L_1AS increased, the transit cost paid by L_2AS to L_1AS decreased, and the access fee increased. Therefore, as P_1 increased, the effect of introducing ICN by L_1AS on the increase of revenue of L_2AS increased, so the adjustment paid by L_2AS to L_1AS also increased. As the ICN penetration ratio of L_2AS and L_3AS, P_2 and P_3, increased, $x_{1,2}$ decreased because the introduction of ICN by L_1AS had a small benefit to other layer ASes, as more contents had been already cached by L_2AS and L_3AS. Moreover, $x_{1,3}$ was negative when P_2 and P_3 were 1.0, which means that an adjustment was paid from L_1AS to L_3AS. For the same reason, the benefit to L_3AS from the introduction of ICN by L_1AS was smaller, and ΔR_1 exceeded ΔR_3.

In Figures 3(c)(d), $x_{1,2}$ and $x_{2,3}$ were plotted against P_2 when only P_2 was changed from 0 to 1. The same trend as in Figure 3(a) was confirmed, with $x_{1,2}$ increasing as P_2 increased. The higher ICN penetration of L_2AS decreased the revenue due to the decrease in transit costs received by L_1AS. Furthermore, the decrease in transit costs paid by L_2AS and the increase in access fees received by L_2AS will increase its revenue. The adjustment that L_2AS received from L_3AS was negative because ΔR_2 exceeded ΔR_3 due to the difference in the number of users accommodated by the layer 2 and layer 3 ASes, as confirmed by Figure 2(c).

Next, $x_{k,j}$ is shown in Figure 4 when $S = 9$ with changing P_1, P_2, and P_3 simultaneously, $P_1 = P_2 = P_3 = P_{all}$. The trends of $x_{1,2}$, $x_{1,3}$, and $x_{2,3}$ were similar to those observed when only P_1 and P_2 were changed, respectively. $x_{1,2}$ and $x_{1,3}$ were positive and monotonically increasing, while $x_{2,3}$ was negative and monotonically decreasing. On the other hand, when only P_1 and P_2 were changed, the amount of increase in the adjustment money increased, and when P_{all} was changed, the amount of increase in the adjustment money decreased. In the former case, this was because it avoided duplicate caches with $g_k^{pp} P_k + 1$ ASes including itself, and it can easily benefit from a hypothetically larger cache capacity when the same layer introduced more ICNs. In the latter case, the introduction of a new ICN had no effect when content already cached by an AS on the route was requested.

Finally, we compare the results between before and after introducing ICN by ASes with proposed adjustment money. The change in revenue $\Delta R'_k$ for each L_kAS with the receipt of adjustment payments after the introduction of ICN is shown in Figure 5. We still varied the ICN penetration ratio of all layers of ASes by the same value. $\Delta R'_k > 0$ for all L_kAS indicates that ICN will become more widespread at all layers. On the other hand, $\Delta R'_2$ was extremely small

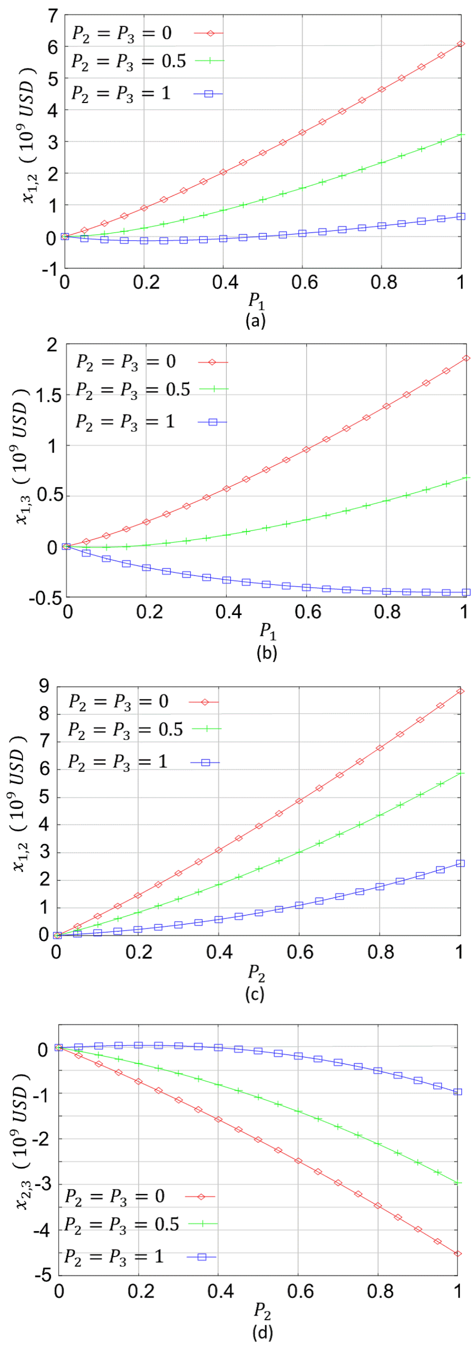

Figure 3. Amount of adjusting money between ASes of different layers against ICN penetration ratio of layer 1 or layer 2 ASes

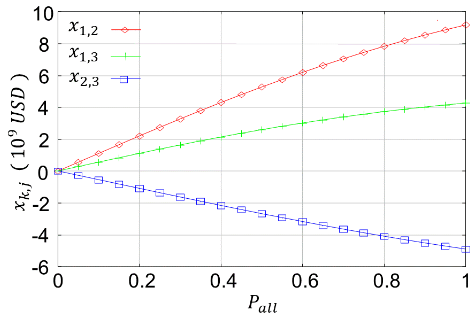

Figure 4. Amount of adjusting money with identical ICN penetration ratio of ASes of all layers

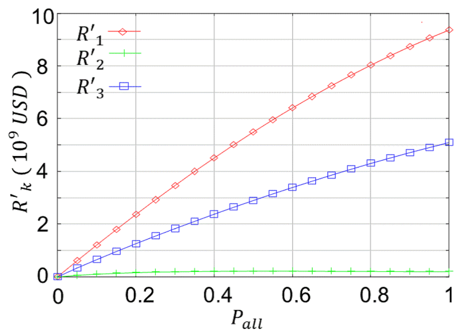

Figure 5. Change of revenue obtained by introducing ICN with adjusting money against identical ICN penetration ratio at all layers

because L_2AS paid the adjustment money to both L_1AS and L_3AS, as can be seen in Figure 4.

Therefore, $x_{2,3}$ was obtained based on after receiving $x_{1,2}$ and $x_{1,3}$, and deriving $\Delta R'_k$. The basis for the negotiations in Figure 5 is the amount of revenue change before and after the introduction of ICN. On the other hand, Figure 6 $x_{2,3}$ is based on the amount of revenue change after exchanging $x_{1,2}$ and $x_{1,3}$. The results are shown in Figure 6. The change in the criteria, i.e., negotiation order, decreased the adjustment $x_{2,3}$ passed from L_2AS to L_3AS, increased $\Delta R'_2$ and decreased $\Delta R'_3$ compared to the previous case. It can be said that fairness had improved in that the side paying the adjustment fee was at a disadvantage. On the other hand, it can be said that advantage and disadvantage also appear in the order of negotiation, and it is necessary to quantify the bargaining power in some way and take it into account.

VI. Conclusion

ICN, which is a communication mainly based on content names, is being considered for efficient content distribution. In this paper, we modeled the topology between ASes in three layers, and derived the impact of ICN on the revenue of each ISP when ICN was deployed, in terms of transit cost and user access fee. The user access fee was assumed to increase with the reduction of delivery delay, and the revenue

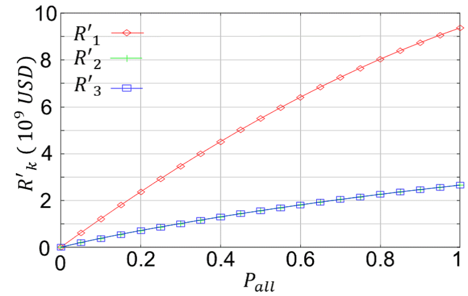

Figure 6. Change of revenue obtained by introducing ICN with adjusting money with identical ICN penetration ratio at all layers when changing negotiation order

of each layer AS changed depending on the sensitivity of the user access fee. In the present model, the ratio of users accommodated by layers 1 and 2 was large, so the revenues of layers 1 and 2 ASes were likely to increase. We also derived the adjustment money among ISPs when the Nash bargaining solution was used. The structure of the adjustment payment was approximately a 50-50 split of the revenue portion that changed due to the introduction of ICN, and the layer 2 ASes paid the ASes in other layers because the revenue of layer 2 ASes tended to increase. Finally, we derived the change in revenues due to the receipt of the derived adjustment money. Although the results differed depending on the order of negotiation, we confirmed that the revenue was positive for ASes of all layers, which was a clue to the spread of ICN.

In the future, we will change the ICN diffusion method for each layer and conduct a numerical evaluation in the same way to better reflect the realistic situation. In addition, since advantages and disadvantages also appear in the order of negotiation, we will quantify and take into account the bargaining power in some form. In the uniform hierarchical network model of this paper may not be a perfect imitation of the current network model. Therefore, we would like to evaluate the feasibility of a similar incentive mechanism for actual topologies.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 23K21664 and 23K21665.

References

[1] The CAIDA Autonomous System Taxonomy Repository, http://www.caida.org/data/as-taxonomy/

[2] H. Chang, S. Jamin, and W. Willinger, "To Peer or not to Peer: Modeling the Evolution of the Internet' s AS-level Topology," IEEE INFOCOM 2006.

[3] A. Dhamdhere and C. Dovrolis, "Can ISPs be profitable Without Violating "Network Neutrality" ?," ACM NetEcon 2008.

[4] A. Dhamdhere, C. Dovrolis and P. Francois, ”A value-based framework for internet peering agreements”, Proc. 22nd ITC, pp. 1-8, 2010.

[5] X. Dimitropoulos, et al, “AS Relationships: Inference and Validation,” ACM CCR, Vol.37, no.1, pp.29-40, 2007.

[6] X. Dimitropoulos, D. Krioukov, G. Riley, and K. Claffy, “Revealing the Autonomous System Taxonomy: The Machine Learning Approach,” PAM 2006.

[7] G. Xylomenos, C. N. Ververidis, V. A. Siris, N. Fotiou, C. Tsilopoulos, X. Vasilakos, et al., ”A survey of information-centric networking research”, Communications Surveys and Tutorials, vol. 16, no. 2, pp. 1024-1049, July 2013.

[8] N. Kamiyama, Analyzing impact of introducing CCN on profit of ISPs, IEEE Trans. Netw. Service Manag., vol. 12, no. 2, pp. 176-187, Jun. 2015.

[9] S. DiBenedetto, C. Papadopoulos, and D. Massey, “Routing Policies in Named Data Networking,” ACM ICN 2011

[10] L. Gao, “On Inferring Autonomous System Relationships in the Internet,” IEEE/ACM ToN, vol.9, no.6, pp.733-745, Dec. 2001.

[11] A. Lodhi, A. Dhamdhere and C. Dovrolis, ”Peering strategy adoption by transit providers in the internet: A game theoretic approach”, ACM SIGMETRICS Perform. Eval. Rev., vol. 40, no. 2, pp. 38-41, Sep. 2012.

[12] J. Rajahalme, et al., “Incentive-Compatible Caching and Peering in Data-Oriented Networks,” ACM ReArch 2008.

[13] R. Stanojevic, I. Castro, and S. Gorinsky, “CIPT: Using Tuangou to Reduce IP Transit Costs,” ACM CoNEXT 2011.

[14] V.Valancius, et al., “How Many Tiers? Pricing in the Internet Transit Market,” ACM SIGCOMM 2011.