Cache Pricing Mechanism for ICN in the Scenario of Multiple Content Providers

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***Abstract*—Information-Centric Networking (ICN) has the characteristics of in-network caching, which can reduce the transmission of duplicate traffic, reduce the load on the servers and improve the user experience. From a technical point of view, it is a very promising network architecture. A reasonable pricing mechanism can encourage internet service providers, content providers and users to participate in the operation and use of ICN, and convert ICN technical advantages into economic benefits, thereby promote the large-scale deployment of ICN. The current research focuses on ICN pricing to analyze the pricing mechanism on the internet service provider (ISP) side and the corresponding market equilibrium results. But the model of content providers (CPs) is usually relatively simple in this research. The model assumes the existence of one single CP operator, which will be very different from future deployment scenarios. Multiple CPs will introduce competition and stimulate end users to use ICN networks and ISPs to deploy ICN networks. Moreover, the relationship between CPs is not only competitive but also cooperative. This paper focuses on the complex relationship of competition and cooperation among multiple CPs, solves the non-cooperative game model based on game theory, and studies the interaction between cache and pricing strategies of ICN entities. The optimal cache share of ISPs and the optimal pricing of ISPs and CPs are obtained by establishing the optimal utility function of each entity. Finally, numerical analysis is performed to derive the utility function of ICN entities as the critical pricing and caching parameters change, while verifying the consistency with the equilibrium solution.**

***Index Terms*—Information-Centric Networks; Pricing Mechanism; Caching; Game; Nash Equilibrium**

I. Introduction

The ultimate purpose of internet access is to obtain content, therefore the vast majority of internet traffic relates to content access [1]. Due to the exponential growth of internet traffic in recent years, the emerging Information-Centric Networking (ICN) architecture has been proposed [2]. Compared to existing IP networks, ICN can cache content at in-network routing nodes, thereby reducing user access latency and repetitive traffic in the network, which will improve network utilization. Although ICN is technologically advanced, internet service providers are not as enthusiastic about the deployment of this new network, because they are concerned about the return on investment after the deployment of ICN. Therefore, to promote the large-scale deployment of ICN, it is important to study the pricing mechanism, formulate reasonable pricing strategies, and promote the participation of all parties in the deployment, operation and use of ICN [3]–[6].

The current research on ICN pricing mechanisms is mainly on single-CP models [10]–[15], which assume only one CP, and there is almost no research on multi-CP ICN pricing mechanisms. In the future, the complex pattern of cooperation and competition between multiple CPs providing content at the same time will definitely become a major model. Therefore, in ICN networks where multiple CPs provide content services simultaneously, it is important to establish a reasonable pricing model and study the relationship between pricing strategies affecting caching behavior, and user content request behavior, to develop a reasonable pricing strategy and promote the deployment of ICN.

This paper focuses on the pricing mechanism of ICN in a multi-CP scenario and explores the interplay between key factors in pricing strategies and entity behaviors, mainly including: 1) Establish a pricing model for ICN networks with competing multi-CPs. 2) In a multi-CPs scenario, establish utility functions for each entity in the ICN. The optimal solution of the non-cooperative game model is solved by Nash equilibrium. 3) Numerical analysis is used to study the overall trend of each entity's revenue change with the key parameters of pricing, and to study the change of the optimal solution of ISP and CP equilibrium.

II. Related Work

ICN networks work in a very different mode from IP networks due to the key feature of in-network caching, thereby the pricing studies of IP networks are not fully applicable to ICN. The main difference is that in ICN, ISPs need to pay CPs for content, which is the opposite of the economic flow of existing IP pricing mechanisms. Abylay studies the revenue of CPs sponsoring content to users in a multi-ISPs scenario based on the Stackelberg game [8]. The literature [9] analyzes the interaction between price and service quality, and gives results on the behavior of ISPs and CPs and the effect of price competition on their market shares. The literature [10] analyzes the different economic flows of ICN networks and IP networks considering a two-way market with delay-sensitive demand. The literature [11] analyzes the existing value and money

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flow in Content Delivery Network (CDN), designs a future evolution path from CDN to ICN interconnection scenarios, and proposes a simplified pricing scheme. The literature [12] proposes a non-cooperative game model between ISPs and CPs with a different one-way payment from the traditional pricing model. Hajimirsadeghi studies static Nash policies in various typical scenarios and observes that ICN always chooses a 0-1 (all or nothing) caching policy based on the caching cost and price of the transport ICN [13]. Hajimirsadeghi proposes a pricing strategy for content with different popularity [14]. The literature [15] proposes an optimal caching strategy for free cache pricing and gives equilibrium solutions for nine cases.

III. System Model

This section proposes a pricing and caching model for ICN in a multi-CPs scenario, in which there is competition among multiple CPs and cooperation between ISPs and CPs. Similar to existing IP networks, the competitive cooperation pattern under this model will almost certainly be adopted in the actual operation of ICN. The model adopts a non-cooperative game modeling approach. Additionally, actors involved in the game are users, ISPs and CPs. In the model, the interaction between users and each ICN entity (including payment and data flows) is defined, the utility function of each entity is established, and the change in the number of users is described.

A. Basic Framework

The network model is shown in Figure 1, which consists of two access ISPs (A and B), a transit ISP (C), two content providers (CP A and CP B) and users. The access ISPs can connect users to the ICN, and users can switch between access ISPs to access the ICN for the required content based on fee and quality of service. The transit ISP can provide a wide range of content delivery services to the access ISPs, and the CPs access the ICN through the transit ISP, which provides the required content for the user. Figure 1 clearly displays the data and payments between entities.

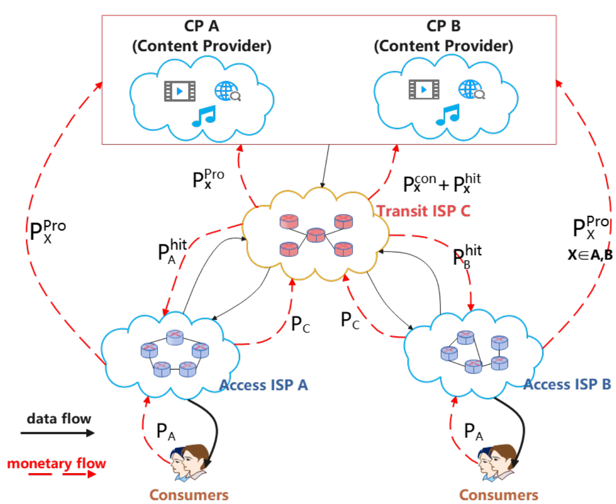

Fig. 1. Simplified Payment Model between Different Entities in ICN

B. Cost Model

In the ICN model, the ISP $K(K = A, B, C)$ gets revenue by providing services to other network entities, the price set by each ISP includes two parts [12]: 1) the transmission price for forwarding content P_K^{net}; 2) the storage price for satisfying users' requests from its cache P_K^{hit}. For example, when a user's requests are satisfied by ISP A, ISP A charges the user a transmission fee of P_A^{net} and a storage fee of P_A^{hit}. Define P_A as ISP A's price to users, so the total fee charged by ISP A is : $P_A = P_A^{net}+P_A^{hit}$. Similarly, the pricing strategies of ISP B and ISP C can be expressed as P_B and P_C. Referring to existing internet storage pricing strategies [14], there is a linear relationship between storage and transmission prices, this assumption can be expressed as: $P_K^{net}=\beta_K P_K^{hit}$, $\beta_K > 1$.

CP's service charge consists of the following three parts: 1) CP's storage price $P_X^{hit}(X = a, b)$ for caching content; 2) When the user's requests are satisfied by the CP, the CP will charge a content fee P_X^{con}; 3) ISPs purchase content from the CP for caching under a reasonable pricing mechanism. Therefore, the CP will charge ISPs a one-time content fee P_X^{pro}. That is, CP's pricing strategy includes P_X^{hit}, P_X^{con} and P_X^{pro} .

In this network, if users request content from access ISP A and ISP B, ISP A and ISP B charge them P_A, P_B, and the transit ISP C charges access ISPs with price P_C. When the user's requests are satisfied by the ISP, the content will be returned directly; otherwise, the user content requests will be eventually forwarded to the CP. The prices of access ISPs affect whether or not a user accesses the network and which access ISP they will choose to access. In order to reflect how the price of an ISP affects users' demand, we assume that the number of users at ISP A and ISP B has a linear relationship with their price. σ_A and σ_B represent the proportion of the actual users accessing ISP A and ISP B to the total users, the expressions are as follows:

$$\begin{cases} \sigma_A = \frac{1}{2} - \rho_A P_A + \rho_B P_B \\ \sigma_B = \frac{1}{2} - \rho_B P_B + \rho_A P_A \end{cases} \tag{1}$$

where ρ_A, ρ_B represent the influence factors of price on the number of users. From Eq.(1), it can be seen that the price of ISP A and ISP B will have a direct impact on the choice of users. For example, when the price of ISP A rises, users will choose to switch from ISP A to ISP B. Accordingly, the number of users in ISP B will increase.

Through analysis, it can be found that when ISPs and CPs adopt strategies to maximize their profits, the strategies of different entities will inevitably conflict. The benefits of each entity will eventually stabilize at the corresponding equilibrium point under the formulated strategies, and different key parameters will have an impact on the equilibrium point. In the following sections, we will use the knowledge of game theory to analyze the impact of caching and pricing strategies on the benefits of various entities. The notation used in this paper is illustrated in Table 1.

TABLE I
SYMBOL DESCRIPTION TABLE

$\alpha_{K,M}$	The portion of the request at ISP K that is fulfilled at M($M = A, B, C, O_a, O_b$)
β_K	Ratio of traffic charge to cache charge
ρ_K	ISP Factor of the price of K on the number of users
σ_K	Number of ISP K users visiting as a percentage of total
c_M	Initial cache cost at M (including ISP and CP)
$D(C)$	Initial number of users
P_K^{net}	ISP Traffic charges per unit of data charged by K
P_K^{hit}	ISP K and the caching fee per unit of data charged by CP
P_X^{con}	Content cost per unit of data charged by CP (X = a,b)
P_X^{pro}	CP's revenue from selling all content at once
P_K	Total cost per unit of data charged to the user by ISP K
E_K	The utility of ISP K or CP k

C. Utility Function

Since ISPs in ICN have in-network storage to cache content, ISPs can earn revenue by providing cached content when user's requests are satisfied and by forwarding user requests for other content. The c_M is defined as the caching cost in ICN. Given parameters such as price, caching cost, and content cache ratio, we can obtain the utility functions of ISP A and ISP B, transit ISP C, and content providers CP A and CP B.

The size of cached content is positively correlated with the caching cost and is related to the request satisfied rate [16]. To describe the relationship between the factors and to describe the overall utilities of each entity, the following assumptions are made: 1) The one-time payment paid by ISPs to the CPs is positively correlated with the amount of cached content; 2) The proportion of ISP's cached content is equal to the proportion of users' requests here. Specifically, the content cache ratio $\alpha_{K,M}$ is used to represent the proportion of requests arriving at $K (K \in A, B)$ that are satisfied in entity $M (M \in A, B, C, O_a, O_b)$ [14].

Access ISP A can purchase content from the CP for caching. Therefore, each part of the utility of ISP A can be modeled as:

$$\begin{cases} E_{A1} = D(C)\left[\sigma_A \alpha_{A,A}(P_A - c_A)\right] \\ E_{A2} = D(C)\left[\sigma_A \alpha_{A,out}(P_A - P_C)\right] \\ E_{A3} = D(C)\left[\sigma_B \alpha_{B,A}(P_A^{hit} - c_A)\right] \\ E_{A4} = \alpha_{A,A} min(P_a^{pro}, P_b^{pro}) \end{cases} \tag{2}$$

The utility function for access ISP A is :

$$E_A = E_{A1} + E_{A2} + E_{A3} - E_{A4} \tag{3}$$

where $\alpha_{A,out} = 1 - \alpha_{A,A}$. E_{A1} in Eq.(3) indicates the part of the users' request of ISP A that is satisfied at ISP A. E_{A2} represents that the users' requests of ISP A are forwarded to other entities. E_{A3} represents the part that access ISP C forwards the request from ISP B to ISP A and the request is satisfied there. E_{A4} is the one-time content fee paid by ISP A to the CP. Since there are multiple CPs in the model, ISP A needs to compare the one-time selling price of two CPs and choose the lower one to buy from. ISP A can control cache share $\alpha_{A,A}$ and content cost P_A to maximize its utility as pricing-related strategies.

Symmetrically, the parts of the utility of access ISP B are described as the following equation:

$$\begin{cases} E_{B1} = D(C)\left[\sigma_B \alpha_{B,B}(P_B - c_B)\right] \\ E_{B2} = D(C)\left[\sigma_B \alpha_{B,out}(P_B - P_C)\right] \\ E_{B3} = D(C)\left[\sigma_A \alpha_{A,B}(P_B^{hit} - c_B)\right] \\ E_{B4} = \alpha_{B,B} min(P_a^{pro}, P_b^{pro}) \end{cases} \tag{4}$$

The utility function for access ISP B is :

$$E_B = E_{B1} + E_{B2} + E_{B3} - E_{B4} \tag{5}$$

The utility function of ISP B and the controllable variables are the same as those of ISP A.

For the transit ISP C, the utility components are as follows:

$$\begin{cases} E_{C1} = D(C)\left[\sigma_A \alpha_{A,C}(P_C - c_C) \right. \\ \quad \left. + \sigma_B \alpha_{B,C}(P_C - c_C)\right] \\ E_{C2} = D(C)\left[\sigma_A \alpha_{A,B}(P_C - P_B^{hit}) \right. \\ \quad \left. + \sigma_B \alpha_{B,A}(P_C - P_A^{hit})\right] \\ E_{C3} = D(C)\left[\sigma_A \alpha_{A,O_a}(P_C - P_a^{hit} - P_a^{con}) \right. \\ \quad \left. + \sigma_B \alpha_{B,O_a}(P_C - P_a^{hit} - P_a^{con})\right] \\ E_{C4} = D(C)\left[\sigma_A \alpha_{A,O_b}(P_C - P_b^{hit} - P_b^{con}) \right. \\ \quad \left. + \sigma_B \alpha_{B,O_b}(P_C - P_b^{hit} - P_b^{con})\right] \\ E_{C5} = \frac{\alpha_{A,C} + \alpha_{B,C}}{2} min(P_a^{pro}, P_b^{pro}) \end{cases} \tag{6}$$

The utility function of the transit ISP C is :

$$E_C = E_{C1} + E_{C2} + E_{C3} + E_{C4} - E_{C5} \tag{7}$$

E_{C1} in Eq. (7) denotes the part of the users' requests of ISP A and ISP B satisfied at ISP C; E_{C2} denotes the fee when the requests of ISP A and ISP B are satisfied at each other through access ISP C; E_{C3} denotes the gain from the requests of ISP A and ISP B transmitted through the ISP C to CP A; similarly, E_{C4} denotes the gain from ISP A's and ISP B's requests transmitted through transit ISP C to CP B; E_{C5} is the one-time content fee paid by ISP C to the CP. The transit ISP C controls the caching and pricing parameters $\alpha_{A,B}$, $\alpha_{A,C}$, α_{A,O_a},α_{A,O_b}, $\alpha_{B,A}$, $\alpha_{B,C}$, α_{B,O_a},α_{B,O_b}, and the transmission fee P_C for providing wide-area services as a pricing-related strategy to maximize its utility.

The utility function of the content provider CP A is as follows:

$$\begin{aligned} E_{O_a} = {} & D(C)[(\sigma_A \alpha_{A,O_a} + \sigma_B \alpha_{B,O_a})(P_a^{hit} + P_a^{con} - c_{O_a})] \\ & + (\alpha_{A,A} + \alpha_{B,B} + \tfrac{\alpha_{A,C} + \alpha_{B,C}}{2}) \tfrac{1 + Sign(P_b^{pro} - P_a^{pro})}{2} P_a^{pro} \end{aligned} \tag{8}$$

The first term in Eq. (8) represents the part of ISP A's and ISP B's requests satisfied at the CP, and the second term is the revenue from selling content to the ISPs. Because of the competition between CP A and CP B, a symbolic function is used to model the one-time sale to ISPs, and when both prices are the same, each CP sells half of the content and receives half of the revenue. Only when the one-time sale price of CP A is lower than that of CP B, CP A will have the revenue from the content purchased by the ISP; otherwise, CP B will get this part of the revenue. The controllable variables associated with the CP A's pricing strategy are: Content caching fees P_a^{hit}, content fees paid by users P_a^{con}, and one-time fees P_a^{pro} for selling content to ISPs.

Similarly, the utility function of content provider CP B is as follows:

$$E_{O_b} = D(C)[(\sigma_A \alpha_{A,O_b} + \sigma_B \alpha_{B,O_b})(P_b^{hit} + P_b^{con} - c_{O_b})] \\ +(\alpha_{A,A} + \alpha_{B,B} + \tfrac{\alpha_{A,C}+\alpha_{B,C}}{2})\tfrac{1+Sign(P_a^{pro}-P_b^{pro})}{2} P_b^{pro} \quad (9)$$

The utility function of CP B and the controllable variables are the same as CP A.

IV. Model Analysis

A. Analyze of Equilibrium

According to the non-cooperative game solution method of Nash equilibrium in game theory, in order to solve the equilibrium point of the game, the utility function of each ICN entity needs to be derived to solve for the maximum value, and the system of equations shown in Eq. (10) needs to be solved. The equilibrium point obtained can be called the Nash equilibrium point. At this equilibrium point, none of the participants can independently change their strategies and increase their own gains only.

$$\begin{cases} \frac{\partial E_A}{\partial P_A} = 0, \frac{\partial E_B}{\partial P_B} = 0, \frac{\partial E_C}{\partial P_C} = 0, \frac{\partial E_{Oa}}{\partial P_a^{hit}} = 0, \\ \frac{\partial E_{Oa}}{\partial P_a^{con}} = 0, \frac{\partial E_{Oa}}{\partial P_a^{pro}} = 0, \frac{\partial E_{Ob}}{\partial P_b^{hit}} = 0, \frac{\partial E_{Ob}}{\partial P_b^{con}} = 0, \\ \frac{\partial E_{Ob}}{\partial P_b^{pro}} = 0, \frac{\partial E_A}{\partial \alpha_{A,A}} = 0, \frac{\partial E_B}{\partial \alpha_{B,B}} = 0, \frac{\partial E_C}{\partial \alpha_{A,C}} = 0, \\ \frac{\partial E_C}{\partial \alpha_{A,B}} = 0, \frac{\partial E_C}{\partial \alpha_{A,O_a}} = 0, \frac{\partial E_C}{\partial \alpha_{A,O_b}} = 0, \frac{\partial E_C}{\partial \alpha_{B,C}} = 0, \\ \frac{\partial E_C}{\partial \alpha_{B,A}} = 0, \frac{\partial E_C}{\partial \alpha_{B,O_a}} = 0, \frac{\partial E_C}{\partial \alpha_{B,O_b}} = 0, \end{cases} \quad (10)$$

Conclusion 1. At the equilibrium point, the cache variable α can only be 0 or 1 [13].

Proof 1: The derivative results of $\alpha_{K,M}$ are all constant in Eq. (10), for example, the derivative process of $\alpha_{A,A}$ is as follows:

$$\frac{\partial E_A}{\partial \alpha_{A,A}} = D(C)\sigma_A[P_C - (c_A + \frac{min(P_a^{pro}, P_b^{pro})}{D(C)\sigma_A})] \quad (11)$$

From Equation (11), it is clear that for ISP A, P_C, P_a^{pro} and P_b^{pro} are not controllable variables, so the derivative result of the variable $\alpha_{A,A}$ is a constant, the maximum and minimum of the function can only be taken at the boundary point of the interval, and $\alpha_{A,A}$ is 0 or 1.

The value of $\alpha_{K,M}$ depends on the derivative result. When the derivative result is larger than 0, the function increases when $\alpha_{K,M}$ increases, and the maximum value of the function is obtained at $\alpha_{K,M}$=1. When the derivative result is less than 0, the value of the function increases with the decrease of $\alpha_{K,M}$, and the maximum value of the function is obtained at $\alpha_{K,M}$=0. The final equilibrium solution is consistent with Conclusion 1.

Conclusion 2. The proportion of content cached by ISPs is affected by the caching cost and the cost of obtaining content from others.

Proof 2: Since ISP B and ISP C are proved in the same way as ISP A, only ISP A is proved to verify conclusion 2. The sum of the last two terms of Eq. (11) represents: the caching fee to be paid by access ISP A for content caching and the fee to be paid to the CP, so it can be noted as the equivalent caching cost c'_A. When $c'_A > P_C$, it indicates that it will cost ISP A less to cache the content locally and ISP A will choose to purchase the content for caching. On the contrary, when $c'_A < P_C$, it means that the cost of caching the content of ISP A is greater than the cost of forwarding the request out, so it prefers to forward the user's request out.

Based on the above conclusions, and after calculation, the game in ICN can be divided into 10 cases in Table 2. Table 2 depicts the ISPs' willingness to cache content under different pricing policies. In general, ISPs choose the one that costs less between caching the requested content and forwarding the request out. From the table, we can analyze that in case 1, the cost of ISP A and ISP B to cache content is less than the cost of forwarding users' requests, so access ISPs choose to cache all content. This situation causes transmission ISP C useless. In cases 2-5, it costs less for ISP A to cache the content and ISP A chooses to cache the content, but the cost of ISP B forwarding the request out is less, so ISP B does not cache the content. Cases 6-9 show the opposite behavior of ISP A and ISP B compared to cases 2-5. Case 10 indicates that the cost of caching the content of ISP A and ISP B is higher than the cost of forwarding the users' requests. Therefore, neither ISP A nor ISP B will cache any content.

V. Simulation Experiments

In this section, we simulate and evaluate our scheme based on the network structure shown in Figure 1. The experiment includes two access ISPs, one transit ISP and two CPs, and considers a repeated game between ICN entities, where each entity competes to maximize its utility. The experiments use Matlab, and the utility trends of ISPs and CPs are obtained by setting different variations of pricing parameters. We use $\alpha_{K,M}$ to denote the proportion of users' requests visiting ISP K that are satisfied at M. According to the literature [11]–[14], when there is no special instruction, the ISP A's caching parameters in the experiment are as follows: $\alpha_{A,A} = 0.5$, $\alpha_{A,B} = \alpha_{A,C} = 0.1$, $\alpha_{A,O_a} = 0.15$, $\alpha_{A,O_b} = 0.15$. Caching parameters of ISP B are set as: $\alpha_{B,A} = 0.2$, $\alpha_{B,B} = 0.4$, $\alpha_{B,C} = 0.2$, $\alpha_{B,O_a} = \alpha_{B,O_b} = 0.1$. For each unit of data, the initial caching cost for each entity is : $c_A = c_B = c_C = c_{Oa} = c_{Ob} = 0.5$. The initial number of users for both ISP A and ISP B is set to 10000.

TABLE II
CACHING STRATEGY TABLE

	Conditions	$\alpha_{A,A}$	$\alpha_{A,B}$	$\alpha_{A,C}$	α_{A,O_a}	α_{A,O_b}	$\alpha_{B,B}$	$\alpha_{B,A}$	$\alpha_{B,C}$	α_{B,O_a}	α_{B,O_b}
	$P_C > c'_A \& P_C > c'_B$										
1	/	1	0	0	0	0	1	0	0	0	0
	$c'_A < P_C < c'_B$										
2	$\frac{\partial E_C}{\partial \alpha_{B,C}} > 0$	1	0	0	0	0	0	0	1	0	0
3	$\frac{\partial E_C}{\partial \alpha_{B,A}} > 0$	1	0	0	0	0	0	1	0	0	0
4	$\frac{\partial E_C}{\partial \alpha_{B,O_a}} > 0$	1	0	0	0	0	0	0	0	1	0
5	$\frac{\partial E_C}{\partial \alpha_{B,O_b}} > 0$	1	0	0	0	0	0	0	0	0	1
	$c'_B < P_C < c'_A$										
6	$\frac{\partial E_C}{\partial \alpha_{A,C}} > 0$	0	0	1	0	0	1	0	0	0	0
7	$\frac{\partial E_C}{\partial \alpha_{A,B}} > 0$	0	1	0	0	0	1	0	0	0	0
8	$\frac{\partial E_C}{\partial \alpha_{A,O_a}} > 0$	0	0	0	1	0	1	0	0	0	0
9	$\frac{\partial E_C}{\partial \alpha_{A,O_b}} > 0$	0	0	0	0	1	1	0	0	0	0
	$P_C < c'_A \& P_C < c'_B$										
10	$\frac{\partial E_C}{\partial \alpha_{A,C}} > 0 \& \frac{\partial E_C}{\partial \alpha_{B,C}} > 0$	0	0	1	0	0	0	0	1	0	0

A. The Effect of ISP A's Price on the Utility of ISP A

Figure 2 shows the effect of ISP A's price on its utility. From the figure, it can be seen that as the price of ISP A increases, its overall revenue tends to increase and then decrease. This trend indicates that there is an optimal charging point for ISP A, i.e., the extreme value point in the figure. When ISP A's price increases until it exceeds this point, ISP A's revenue decreases because a brief price increase will increase ISP A's revenue, but the number of users will decrease when the price is too high.

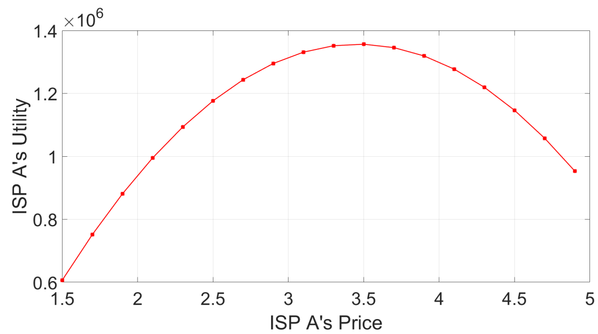

Fig. 2. The Effect of ISP A's Price on ISP A's Utility

B. The Effect of CP A's One-off Selling Price on CP's Utility

Figure 3 shows the effect of the one-time selling price of CP A on the CP's revenue. The experiment sets P_b^{pro} to be a constant value and P_a^{pro} to be an increasing price. From the figure, when $P_a^{pro} < P_b^{pro}$, the revenue of CP B is constant and the revenue of CP A is increasing because the ISP chooses to buy content from CP A, which has a lower price for caching. When $P_a^{pro} = P_b^{pro}$, the revenues of both CPs are the same. When $P_a^{pro} > P_b^{pro}$, the ISP chooses to purchase content from CP B. The revenue of CP A is constant and the same as the initial revenue of CP B. CP B's revenue is fixed because the one-time price is set and does not change with the continuous increase of P_a^{pro}.

Fig. 3. The Effect of one-off Selling Price of CP A on CP's Utility

C. The Effect of ISP A's and ISP C's prices on ISP A's Revenue

Figure 4 shows the effect of access ISP A's and transit ISP C's prices on ISP A's revenue. From the figure, it can be seen that the revenue of ISP A decreases when the price of ISP C gradually increases; when ISP C forwards ISP A's requests for free, the revenue of ISP A is the greatest. And the figure shows that there is an optimal point for ISP A to set its price.When ISP A's price increases until it exceeds this point, ISP A's revenue decreases because a brief price increase will increase ISP A's revenue, but the number of users will decrease when the price is too high.

D. The Effect of ISP A's Price and CP A's one-time Content Fee on the Utility Functions of ISP A and CP A

Figure 5 shows the effect of ISP A's and CP A's one-time content fee on the entity's revenue. When the one-time content fee of CP A increases, the revenue of CP A also increases, but the revenue of ISP A decreases. The experiment sets the one-time selling price of CP B to be a constant value, and when the pricing of CP A is higher than it, the ISP will choose to purchase content from CP B and cache it, i.e., the part of the

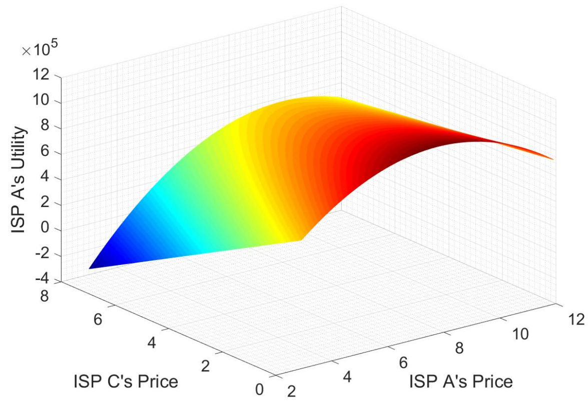

Fig. 4. The Effect of ISP A's and ISP C's Prices on ISP A's Utility

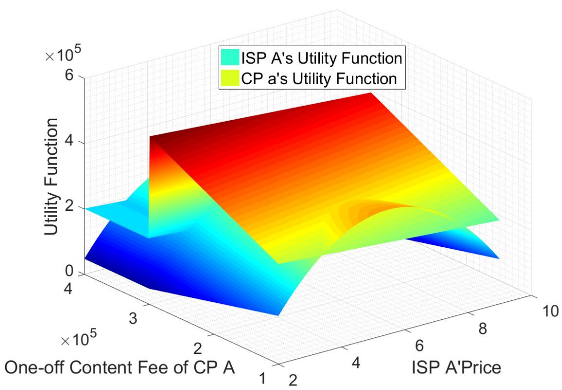

Fig. 5. The Effect of of ISP A's Price and CP A's one-time Content Fee on the Utility Functions of ISP A and CP A

figure where the utility of CP A falls off a cliff. Therefore, when multiple CPs exist, a competitive pattern will be formed among the CPs, so the CPs need to set a reasonable price. If the one-time content fee of CP is too high, ISP A's revenue may turn negative, which will lead ISP A to be reluctant to deploy caching. Therefore, CPs must set an appropriate price for one-off sale of content, which can not only ensure their income but also facilitate ISP to deploy caching service nodes and improve users' access experience.

VI. Conclusion

This paper proposed a cache pricing mechanism for ICN in the scenario of multiple content providers. By establishing the utility function of each entity, we have studied the interaction of key pricing parameters of users, ISPs and CPs on utility and caching access behavior. And the Nash equilibrium was solved by using a non-cooperative game to derive the pricing strategy that can maximize the benefits of each entity. In this case, ISPs are willing to purchase content from CPs for caching. In this paper, numerical analysis was performed using Matlab to evaluate the model. The trend of the variation of each entity's utility can be derived from the variation of different parameters, and the experimental results also verified the accuracy of the proposed model.

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