Research on ICN Caching and Pricing Strategies under the Package Billing Model

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***Abstract*—Information-Centric Networking (ICN) is a commercially viable network architecture that enables content and location separation through in-network caching, reducing duplicate traffic and improving network resource utilisation. As with other networks, a reasonable pricing mechanism can facilitate the deployment of ICNs by encouraging operators to participate in the deployment of ICNs. A large number of studies on ICN pricing mechanisms have been conducted in which users pay for traffic on a per-unit basis, as opposed to the real-life method of paying for traffic on packages set by operators. In this paper, based on studying the interaction between users and ISPs and CPs and establishing the utility functions of each role, we analyse the caching and pricing strategies of each entity under NASH equilibrium and compare and analyse which charging model is more able to meet the needs of network entities in the ICN environment. It is found that the package billing model is more in line with the needs of operators and users in ICNs, and can achieve the objective of incentivising ICN development. This paper also contributes to the development of the best pricing strategy for ICN networks.**

***Index Terms*—ICN, pricing mechanism, cache, nash equilibrium, package mechanism**

I. Introduction

Traffic in the Internet has grown at an alarming rate in recent years and its usage patterns have changed dramatically, with the vast majority of traffic being related to content requests and services. Information Centre Networks (ICNs) have been proposed as a new network architecture [3], where users simply request and obtain content without caring about the address of the host where the content resides [1], [2]. the main mechanism of ICNs is to allow users to access content cached in the nearest network node through intra-network caching, thus reducing duplicate traffic, improving the utilisation of network resources and enhancing the user experience [3]. ICNs offer significant technical advantages over IP networks in terms of their ability to contain traffic surges. The deployment of emerging network architectures requires not only the technical advantages of new networks, but also reasonable economic interests driven by various participants. A reasonable fee settlement model is conducive to operators' participation in ICN deployment and promotes the development of ICNs.

IP networks operate with different mechanisms than ICNs, and therefore the study of their charging models and pricing mechanisms is not suitable for ICN networks [5]. In the Internet service model, content providers (CPs) provide appropriate content and charge users for subscriptions, whereas in ICNs, due to the existence of in-network caching, ISPs can perform content services on cached content instead of CPs, and this part of traffic does not pass through the CPs. if the charging model of IP networks is followed, CPs cannot perceive that content is being served locally and cannot charge for content services, and there are many studies based on ICN-based pricing mechanisms have been studied [6]–[12], and these studies are all based on the traffic billing model, i.e., the charge is linearly related to the amount of traffic. However, this traffic billing model has been proven to be ineffective by the Internet in recent years, and users do not like this billing model, and the majority of the current Internet charging model is the package model [13]. The current research on ICN pricing mechanism does not involve the package model. This paper focuses on the ICN pricing mechanism under the package billing model, comparing and analysing which of the traffic billing model and the package billing model is more in line with the needs of ICNs.

The structure of this paper is organised as follows: Section 1 introduces the main motivation of this paper; Section 2 presents the research work related to ICN pricing mechanism; Section 3 establishes the cost model of each ICN entity under the package billing model; Section 4 analyses the utility function of the entity; Section 5 conducts numerical simulations and analyses the experimental results; Section 6 concludes the work.

II. Related Work

There have been many studies to improve the revenue of entities in ICNs, focusing on aspects such as caching and price games, cooperation between entities, and still mainly on pricing mechanisms under the traffic model.

Agyapong et al. evaluated the economic incentives received by different types of network participants in ICN networks, demonstrating that ICN entities will not cache content or will not cache optimal amounts of content if there are not sufficient economic incentives [4]. [6] investigates the price game between network entities in an ICN model with a fixed caching policy and demonstrates that caching investments in ICNs are profitable. [7] examines current economic flows in content delivery networks (CDNs) and explores their possible evolution in an ICN interconnection scenario, proposing a pricing model in ICN interconnection; also considers the migration behaviour of users between different access ISPs and demonstrates the economic viability and stability of ICN interconnection. A three-stage Stackelberg game is formulated to analyse the perfect equilibrium of the dynamic game in two different pricing scenarios and to demonstrate the economic feasibility of mobile edge caching [8].

Some ICN-related studies have analysed the differences between ISPs and CPs in ICNs, where the partnership between ISPs and CPs is more diverse than in IP networks, and have investigated the impact of the corresponding pricing mechanisms on the participation level and motivation of each player. [9] analyses the possibility of access ISPs forming alliances with multiple CPs to reduce operational costs, and examines the stability of alliances and the impact of network neutrality on alliances. [10] considers a bilateral market with multiple types of demand, especially latency-sensitive demand, analyses how caching parameters are optimised under Nash equilibrium, and demonstrates that the payment relationship between ISPs and CPs may change in different market environments.

The above studies on ICN pricing mechanisms are mainly based on the traffic billing model, but for users, the value of content is non-linearly related to content size and most users do not prefer to use this type of billing [13]. The package billing model, in which a fixed fee is charged if the traffic usage does not exceed a certain threshold and the portion exceeding the threshold is charged at the unit price of the traffic, is currently the dominant billing model in China [13], and studying the impact of package billing models in the ICN scenario is necessary to investigate the pricing strategies of each ICN entity. Studying the pricing mechanisms under the more popular package models and obtaining trends in the relationship between pricing and role behaviour will facilitate the deployment of ICN scenarios at scale for operators and the active participation of CPs and end users in ICN operations.

III. System Model

A. Basic Framework

In order to better analyse the pricing mechanism of the ICN architecture, an ICN model is created that contains a number of CPs, a transport ISP, an access ISP and a certain number of subscribers. In the ICN architecture, ISPs can cache content and respond directly to requests from users when the local cache hits. Each access ISP has a certain number of subscribers, which varies according to cost and quality of service. When a request arrives at the access ISP, if the cache does not hit, it is forwarded to the transport ISP, which sits between the access ISP and the CP and is responsible for providing the content, both the content pre-cached by the ISP and the content requested by the user.

In this paper, two billing models are proposed under the package billing model: the unlimited model and the fixed package model. In the unlimited mode, the ISP charges the user a flat rate, regardless of traffic usage; in the fixed package mode, a package threshold is set and the portion of traffic usage up to the threshold is charged at a fixed rate, and the portion beyond that is billed at the unit price of the traffic. A traffic billing model where traffic is billed on a per unit basis can be seen as a special case of a fixed package model (with a package threshold of 0).

B. Fee model and User model

To simplify the calculations, only a network model with two access ISPs (A and B), one transmission ISP (C) and one CP (D) is considered, as shown in Fig. 1. The symbols used in this paper are described in Table. I, where $k \in \{A, B\}$,$K \in \{A, B, C\}$ and $M \in \{A, B, C, D\}$.

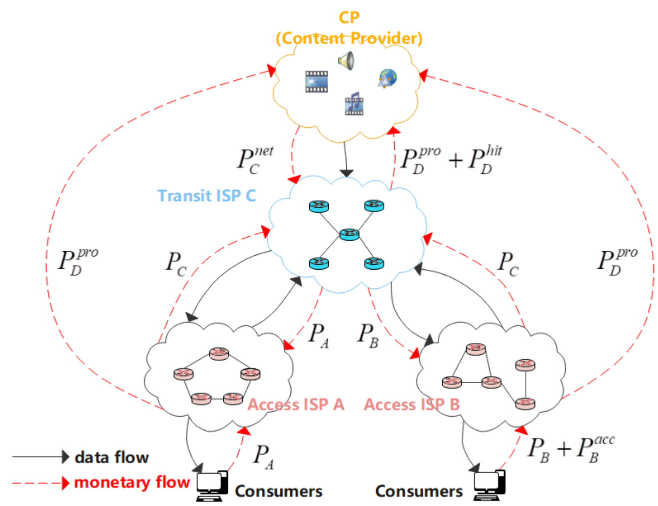

Fig. 1. Data and payment models between entities in ICN

TABLE I
Symbol Description

Symbol	Description
$\alpha_{k,M}$	Cache hit rate of requests from ISP k at entity M
β_k	ISP k's service bandwidth for users
ϵ	The price elasticity constants of ISP
ρ	Ratio of transmission fee to content fee
c_{KM}	ISP K's Policy cost of forwarding the request to entity M to be satisfied
c_{CC}	Cost of ISP C's caching strategy when no content is cached by the access ISP
c_M	Caching cost per unit of content of entity M
p_k	Average content service price of ISP k
t_k	Cost per unit of bandwidth for ISP k
u_k	Actual number of users of ISP k
U	User base of ISP
N	Average content usage by users
N_k	Package Threshold of ISP B
P_k^{acc}	ISP k's network access price
P_D^{pro}	CP's content one-off sale price
P_K	ISP K's total price of service per unit of content of ISP K
P_K^{net}	ISP K's price of service per unit of content
P_M^{hit}	entity M's price of unit content

In the model each entity provides services to other entities and charges a corresponding fee. ISP K provides transmission services or provides content to other entities or users and sets the price [8]: transmission price per unit of content P_K^{net} and price per unit of content P_K^{hit}, so the ISP charges $P_K = P_K^{net} + P_K^{hit}$ for a unit of content service. Assume that $P_K^{net} = \rho P_K^{hit}$, where $\rho > 1$ [11].

ISP A charges subscribers fixed network access price P_A^{acc} based on the unlimited model. ISP B charges a fixed fee P_B^{acc} for the portion of traffic usage below the threshold and a unit content service price P_B for the portion above the threshold. And ISP charges a uniform unit content service price P_K when forwarding requests between ISPs. When ISP C forwards a request to CP, CP receives the corresponding content fee P_D^{hit}. When CP transmits content with the help of ISP C, ISP C receives the transmission fee P_C^{net}. When an ISP caches content, the CP receives a one-off content sale fee P_D^{pro}.

Each ICN entity incurs a corresponding cost when providing the service. ISPs and CPs incur a cost c_M for per unit of content cached in order to provide content. Access ISPs incur a cost t_k for per unit of bandwidth when providing network services to users.

Using the user model in [12], the number of users accessing ISP k depends on two main factors, price and quality of service (QoS), and will be given as a product

$$u_k = \frac{U}{p_k^{\epsilon}} log(1 + \beta_k) \tag{1}$$

where p_k is the average content service fee charged by ISPs to subscribers, and β_k is the network bandwidth used by ISPs to provide service to subscribers and ϵ is the price elasticity constant, assuming that $\epsilon > 1$ [14].Assuming that the average amount of content acquired by users is N, $p_A = \frac{P_A^{acc}}{N}$ and $p_B = \frac{P_B^{acc} + P_B(N - N_B)}{N}$. From (1), it can be seen that the number of subscribers is influenced by the price and QoS provided by the ISP and is independent of other ISPs.

C. Utility Functions

To better analyse the pricing strategies of each ICN entity, the utility functions of ISPs A, B, C and CP are expressed using price, bandwidth service cost, caching cost, content caching ratio and user request hit ratio. Since the amount of content cached is proportional to the cost of caching [15], to facilitate the mathematical calculations, the following assumptions are made for the model: the one-time cost of selling content charged by the CP to the ISP is proportional to the amount of content cached by the ISP and the proportion of content cached by the ISP to all content is the same as the local cache hit ratio of user requests.

Considering ISP A, let

$$\begin{cases} E(A_1) = u_A[P_A^{acc} - t_A\beta_A - N\alpha_{A,A}c_A - N\alpha_{A,out}P_C] \\ E(A_2) = u_B N\alpha_{B,A}(P_A - c_A) \\ E(A_3) = -\alpha_{A,A}P_D^{pro} \end{cases} \tag{2}$$

where $\alpha_{A,out} = 1 - \alpha_{A,A}$ is the probability that the request is not hit. $E(A_1)$ represents the utility that ISP A's subscribers generate for ISP A, including the network access fees charged to subscribers, the bandwidth costs incurred to serve subscribers, the caching costs, and the forwarding costs. $E(A_2)$ represents the utility that ISP A receives when ISP B's request is forwarded to ISP A by ISP C. $E(A_3)$ represents the fees paid to the CP by ISP A for caching the content. Thus the utility function of ISP A is $E(A) = E(A_1) + E(A_2) + E(A_3)$.

Similarly, the utility function for ISP B is

$$\begin{aligned} E(B_1) = u_B[&P_B^{acc} + P_B(N - N_B) - t_B\beta_B - N\alpha_{B,B}c_B \\ &- N\alpha_{B,out}P_C] + u_A N\alpha_{A,B}(P_B - c_B) - \alpha_{B,B}P_D^{pro} \end{aligned} \tag{3}$$

Considering ISP C, let

$$\begin{cases} E(C_1) = (u_A N\alpha_{A,C} + u_B N\alpha_{B,C})(P_C - c_C) \\ E(C_2) = (u_A N\alpha_{A,D} + u_B N\alpha_{B,D})(P_C + P_C^{net} - P_D^{hit}) \\ E(C_3) = u_A N\alpha_{A,B}(P_C - P_B) + u_B N\alpha_{B,A}(P_C - P_A) \\ E(C_4) = -\frac{\alpha_{A,C} + \alpha_{B,C}}{2}P_D^{pro} \end{cases} \tag{4}$$

Where $E(C_1)$ denotes the utility from the request to access the ISP in the ISP C cache hit. $E(C_2)$ denotes the utility from the request being forwarded to the CP via ISP C. $E(C_3)$ denotes the utility from the request from the ISP being forwarded in another ISP cache hit via ISP C. $E(C_4)$ denotes the fee paid to the CP for the ISP C cache content. Thus the utility function for ISP C is $E(C) = E(C_1) + E(C_2) + E(C_3) + E(C_4)$.

Considering CP, let

$$\begin{cases} E(D_1) = (u_A N\alpha_{A,D} + u_B N\alpha_{B,D})(P_D^{hit} - P_C^{net} - c_D) \\ E(D_2) = (\alpha_{A,A} + \alpha_{B,B} + \frac{\alpha_{A,C} + \alpha_{B,C}}{2})P_D^{pro} \end{cases} \tag{5}$$

where $E(D_1)$ denotes the utility gained by the user request hitting at the CP. $E(D_2)$ denotes the one-time sale fee charged by the CP for the content when the ISP caches the content. Thus, the utility function for the CP is $E(D) = E(D_1) + E(D_1)$.

IV. Analysis of the Model

A. Caching Strategy Analysis

The caching strategy of each entity is first analysed. To understand the effect of caching variables on the utility function, i.e. to solve the following system of equations

$$\begin{cases} \frac{\partial E(A)}{\partial \alpha_{A,A}} = 0, \frac{\partial E(B)}{\partial \alpha_{B,B}} = 0, \frac{\partial E(C)}{\partial \alpha_{A,C}} = 0, \frac{\partial E(C)}{\partial \alpha_{A,B}} = 0, \\ \frac{\partial E(C)}{\partial \alpha_{A,D}} = 0, \frac{\partial E(C)}{\partial \alpha_{B,C}} = 0, \frac{\partial E(C)}{\partial \alpha_{B,A}} = 0, \frac{\partial E(C)}{\partial \alpha_{B,D}} = 0 \end{cases} \tag{6}$$

where $\alpha_{k,A} + \alpha_{k,B} + \alpha_{k,C} + \alpha_{k,D} = 1$. Solving for (6) yields the following conclusion.

Conclusion 1: The cache variable $\alpha_{k,M}$ can only take on a value of 0 or a maximum value at the equilibrium point and the ISPs decide caching and forwarding policy based on the principle of least cost.

Proof 1: Take the utility function of ISP A as an example:

$$\frac{\partial E(A)}{\partial \alpha_{A,A}} = u_A N(P_C - c_A) - P_D^{hit} \tag{7}$$

It can be observed that $E(A)$ is a monotonic function of $\alpha_{A,A}$. In order for $E(A)$ to reach its maximum value, $\alpha_{A,A}$ should take either 0 or the maximum value. Let $c_{AA} = \frac{P_D^{pro}}{u_A N} + c_A$. It can be observed that when $P_C \geq c_{AA}$, $\frac{\partial E(A)}{\partial \alpha_{A,A}} \geq 0$, so ISP A will cache as much content as possible, and when $P_C \leq c_{AA}$, no content will be cached. c_{AA} can be seen as the cost of

ISP A's caching policy for a user request per unit of content, and P_C can be seen as the cost of ISP A's forwarding policy. Therefore, when ISP A receives a request, it will choose the policy with the lower cost. The other policy costs are

$$\begin{cases} c_{BB} = \frac{P_D^{pro}}{u_B N} + c_B, c_{CA} = P_A, c_{CB} = P_B, \\ c_{CD} = P_D^{hit} - \frac{\rho}{\rho+1} P_C, c_{AC} = \frac{P_D^{pro}}{u_A N} + c_C, \\ c_{BC} = \frac{P_D^{pro}}{u_B N} + c_C, c_{CC} = \frac{P_D^{pro}}{(u_A+u_B)N} + c_C \end{cases} \quad (8)$$

Based on the cache parameters, the gaming scenarios in ICNs are classified into 9 categories, as shown in Table. II.

TABLE II
CACHE STRATEGY TABLE

Conditions	Cache Parameter
$P_C \geq \max(c_{AA}, c_{BB})$	$\alpha_{A,A} = \alpha_{B,B} = 1$
$c_{AA} \leq P_C \leq c_{BB}, c_{BC} \leq \min(c_{CA}, c_{CD})$	$\alpha_{A,A} = \alpha_{B,C} = 1$
$c_{AA} \leq P_C \leq c_{BB}, c_{CA} \leq \min(c_{BC}, c_{CD})$	$\alpha_{A,A} = \alpha_{B,A} = 1$
$c_{AA} \leq P_C \leq c_{BB}, c_{CD} \leq \min(c_{BC}, c_{CA})$	$\alpha_{A,A} = \alpha_{B,D} = 1$
$c_{BB} \leq P_C \leq c_{AA}, c_{AC} \leq \min(c_{CB}, c_{CD})$	$\alpha_{A,C} = \alpha_{B,B} = 1$
$c_{BB} \leq P_C \leq c_{AA}, c_{CB} \leq \min(c_{AC}, c_{CD})$	$\alpha_{A,B} = \alpha_{B,B} = 1$
$c_{BB} \leq P_C \leq c_{AA}, c_{CD} \leq \min(c_{AC}, c_{CB})$	$\alpha_{A,D} = \alpha_{B,B} = 1$
$P_C \leq \min(c_{AA}, c_{BB}), c_{CC} \leq c_{CD}$	$\alpha_{A,C} = \alpha_{B,C} = 1$
$P_C \leq \min(c_{AA}, c_{BB}), c_{CD} \leq c_{CC}$	$\alpha_{A,D} = \alpha_{B,D} = 1$

B. Analysis of Pricing Strategy

Based on the 9 cache scenarios in Table. II, the pricing strategy for each entity is analysed by solving the following set of equations

$$\begin{cases} \frac{\partial E(A)}{\partial \beta_A} = 0, \frac{\partial E(A)}{\partial P_A} = 0, \frac{\partial E(A)}{\partial P_A^{acc}} = 0, \\ \frac{\partial E(B)}{\partial \beta_B} = 0, \frac{\partial E(B)}{\partial P_B} = 0, \frac{\partial E(B)}{\partial P_B^{acc}} = 0, \\ \frac{\partial E(C)}{\partial P_C} = 0, \frac{\partial E(D)}{\partial P_D^{hit}} = 0, \frac{\partial E(D)}{\partial P_D^{pro}} = 0 \end{cases} \quad (9)$$

Conclusion 2: In the unlimited model and fixed package model, the fee charged by the access ISP to individual users is proportional to the total cost of serving the user, and the value of P_A should be as high as possible.

Proof 2: Taking ISP B as an example, solving for $\frac{\partial E(B)}{\partial P_B^{acc}} = 0$ gives that

$$\begin{aligned} & P_B^{acc*} + P_B(N - N_B{}^*) = \\ & \tfrac{\epsilon}{\epsilon-1}(t_B\beta_B + N\alpha_{B,B}c_B + N\alpha_{B,out}P_C) \end{aligned} \quad (10)$$

In (10), the items in brackets are the bandwidth, the caching cost when the local cache hits, and the forwarding cost when the cache does not hit. The polynomial in brackets is the total cost of ISP A serving a single subscriber. From (10), the total cost charged by ISP B to a subscriber is $\frac{\epsilon}{\epsilon-1}$ multiple of the total cost.

When $P_B^{acc} = P_B^{acc*}$, $\frac{\partial E(B)}{\partial P_B} = u_A N \alpha_{A,B}$. If $\alpha_{A,B} > 0$. To maximise the utility of ISP B, P_B should be as large as possible. However, P_B receives restrictions from P_B^{acc} and other entities pricing strategies. For ISP A in the unlimited model, P_A is only limited by the other entities' pricing strategies.

Conclusion 3: The traffic billing model does not apply to ICNs and users are more likely to benefit from the package billing model while maintaining operator utility.

Proof 3: The traffic billing model can be seen as a special case of the fixed package model where $N_B = 0$ and $P_B^{acc} = 0$. From (10), we obtain the unit content service fee charged by ISP B to the subscriber as

$$P_B{}^* = \frac{u_B\epsilon(t_B\beta_B + N\alpha_{B,B}c_B + N\alpha_{B,out}P_C)}{N((\epsilon-1)n_B - n_A\alpha_{A,B})} \quad (11)$$

From (11), $P_B{}^*$ is affected by u_A, and the larger u_A is, the higher $P_B{}^*$ is. This is because the request forwarding between ISPs makes ISPs gain some non-local users, and the increase in the user number allows ISPs to charge higher prices to users. u_A increases due to lower price or higher QoS of ISP A. However the users of ISP B who do not enjoy these benefits need to pay for it, which is unacceptable to users. From (11), it can be observed that the package model is only related to the cost of service and can shield the influence of other ISPs. Under package model, users only need to pay for the services they enjoyed. Therefore, the package model is more in line with the needs of users.

V. SIMULATION EXPERIMENTS

The ICN model in Fig. 1 is simulated numerically and the model is evaluated. The experiment includes two access ISPs, one transmission ISP and one CP, with the entities adjusting their own pricing strategies to maximise utility between them. Unless otherwise specified, the parameters are set as in Table. III

TABLE III
CACHE STRATEGY TABLE

Parameter	Value	Parameter	Value
$\alpha_{A,A}$	0.5	$\alpha_{A,B}$	0.1
$\alpha_{A,C}$	0.1	$\alpha_{A,D}$	0.3
$\alpha_{B,A}$	0.2	$\alpha_{B,B}$	0.4
$\alpha_{B,C}$	0.2	$\alpha_{B,D}$	0.2
ϵ	2	t_A	1
t_B	1	c_A	0.05
c_B	0.05	c_C	0.05
c_D	0.05	U	1000
N	1000	N_B	500

Fig. 2 illustrates the impact of P_A^{acc} on u_A and $E(A)$. u_A has been scaled up to better show the overall trend. As can be seen from the graph, u_A tends to decrease as P_A^{acc} increases, and the downward trend becomes slower. Analysing $E(A)$: when $P_A^{acc} < P_A^{acc*}$, u_A decreases sharply, the overall utility of the ISP still shows an upward trend. When $P_A^{acc} < P_A^{acc*}$, as u_A continues to decrease, even if fees continue to be added to individual subscribers, it still does not stop the downward trend in overall revenue, but the the downward trend slows down.

Fig. 3 shows the impact of P_A^{acc} on ISP A and ISP C. To better demonstrate the overall trend, the user base of ISP B is set to 3000. It can be observed from Fig. 3 that $E(C)$ tends to decrease as the P_A^{acc} increases, and the downward

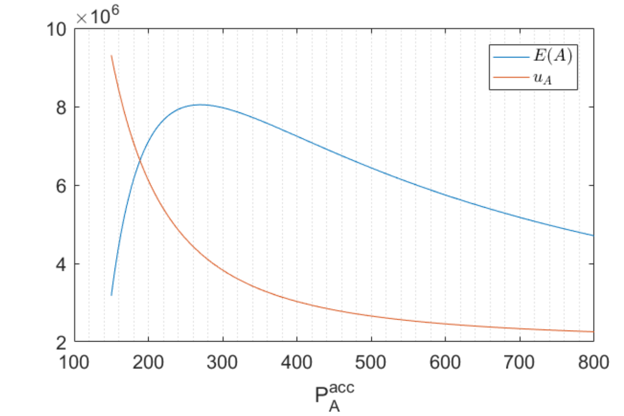

Fig. 2. Impact of ISP A's network service bandwidth on ISP A's optimal price

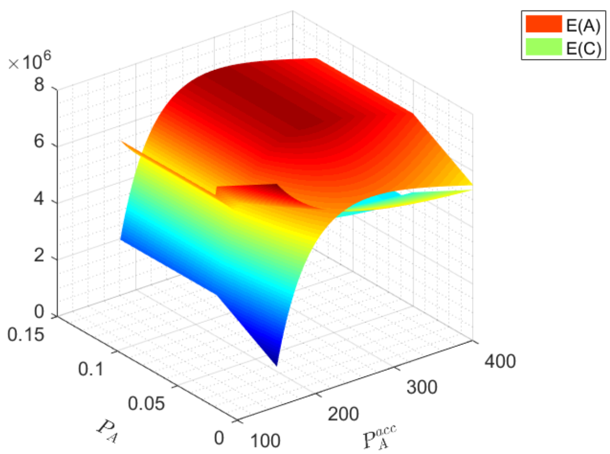

Fig. 3. Impact of ISP A's network access costs and unit content service costs on the utility of ISP A and ISP C

trend is similar to the downward trend in u_A in Fig. 2. This is because the increase in P_A^{acc} leads to a decrease in u_A, which in turn leads to a decrease in the utility that ISP C receives from the subscriber requests from ISP A. As P_A^{acc} increases, $E(A)$ tends to increase and then remain the same, while $E(C)$ decreases and then falls off a cliff. This is due to the fact that when $P_A \leq \min(c_{BC}, c_{CD})$, the increase in P_A^{acc} increases the portion of ISP A's utility that comes from ISP B's requests, and the cost of ISP C's forwarding strategy to ISP A increases. When $P_A \geq \min(c_{BC}, c_{CD})$, it is no longer sensible for ISP C to continue forwarding requests to ISP A and the forwarding policy is changed. As ISP C has limited cache content of its own, it can only forward the request to the CP, at which point $\alpha_{B,A} = 0$ and $\alpha_{B,D} = 0.4$. So for ISP A, a reasonable upper limit should be determined based on ISP C's policy cost.

Fig. 4 shows the impact of P_B and P_B^{acc} on $E(B)$ for the case where $\alpha_{A,B} = 0$, i.e. ISP A's content requests will not be forwarded to ISP B. The cache parameters are set to $\alpha_{A,A} = 0.5$, $\alpha_{A,B} = 0$, $\alpha_{A,C} = 0.3$ and $\alpha_{A,D} = 0.2$. As shown in Fig. 4, $E(B)$ tends to grow first and then decrease as P_B and P_B^{acc} grow, due to the fact that growth in both leads to a decrease in u_B. When P_B and P_B^{acc} are small, u_B is large and an appropriate price increase can overcome the negative effects in terms of u_B, allowing $E(B)$ to increase. When the price is larger, the utility function tends to decrease as u_B has fallen to a sufficiently low number that the effect on overall utility is difficult to mask. Moreover, there are multiple sets of optimal price combinations in Fig. 4, and they are distributed on a straight line. This is due to a linear combination of P_B and P_B^{acc}, i.e. the total service fee charged by the ISP to the user reaches a specific value.

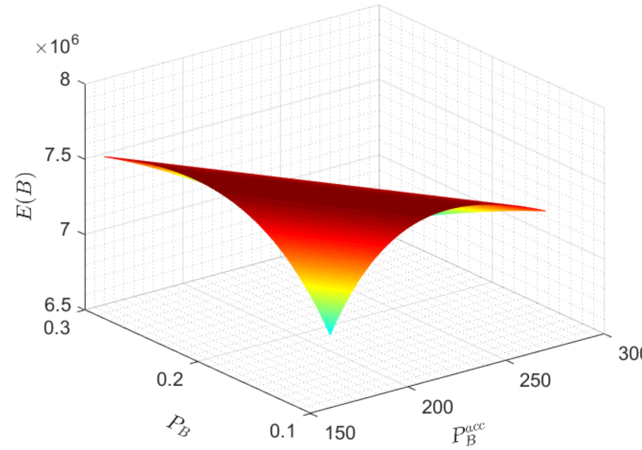

Fig. 4. Impact of ISP A's network access costs and unit content service costs on ISP A's utility when $\alpha_{A,B} = 0$

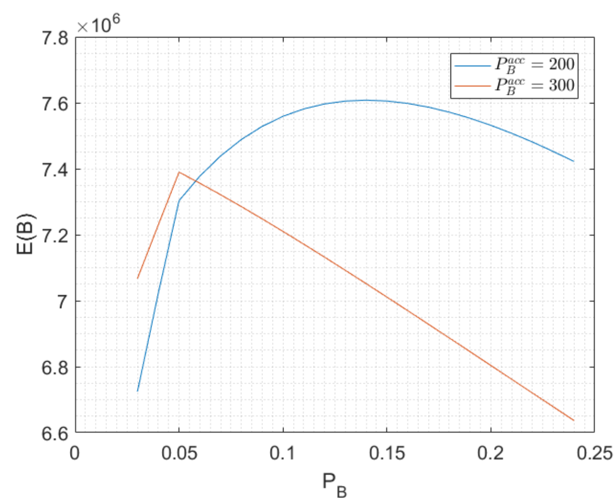

Fig. 5. Impact of ISP B's unit content service costs on ISP B's utility when $\alpha_{A,B} > 0$

Fig. 5 depicts the impact of P_B on $E(B)$ when $\alpha_{A,B} > 0$, with the user base of ISP A set to 3000. From Fig. **??**, it can be seen that $E(B)$ tends to increase first and then decrease.

When $P_B^{acc} = 200$, there is a significant difference in the growth rate on both sides of $P_B = 0.05$. This is due to the fact that when P_B is small, the forwarding cost from ISP C to ISP B is small and ISP B can obtain the utility requested from ISP A. When P_B is larger, ISP C changes its forwarding policy and ISP B can only gain from local users, when the total fee $P_B^{acc} + P_B(N - N_B)$ charged to users is smaller, u_B is larger, and the growth of P_B still enables the overall utility to increase. With $P_B^{acc} = 300$, a larger P_B^{acc} causes u_B to fall rapidly. And by the time ISP C changes its forwarding policy, u_B has fallen low enough to cause a reduction in overall utility. Therefore, access ISPs should take full account of other entities' pricing strategies and changes in subscriber numbers when determining the cost per unit of content service, and make reasonable judgments about the cap.

VI. Conclusions and Perspectives

This paper investigates the cache pricing mechanism in ICNs based on the package billing model, considering both the unlimited and fixed package models, and examining the interaction between various entities such as subscribers, ISPs and CPs. By solving the Nash equilibrium point through a utility function, the optimal caching and pricing strategy for each entity in the package billing model is derived. The analysis reveals that the caching and pricing strategies of ICN entities are influenced by other entities in the network architecture, and also influence the strategies of other entities. At the same time, the package billing model is more in line with the needs of operators and users in ICNs, and is more conducive to the development of ICNs. The paper also investigates the impact of caching parameters, prices and other conditions on the utility function through numerical simulations of the model, and the experimental results demonstrate the rationality and accuracy of the proposed caching and pricing strategy.

In this paper, the time and geographical characteristics of users have not been taken into account, and the analysis of users' demand patterns still needs to be improved.

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References

[1] B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher and B. Ohlman, "A survey of information-centric networking", IEEE Communications Magazine, vol. 50, no. 7, pp. 26-36, July 2012.

[2] G. Xylomenos et al, "A Survey of Information-Centric Networking Research", IEEE Communications Surveys & Tutorials, vol. 16, no. 2, pp. 1024-1049, Second Quarter 2014.

[3] Quan Zheng, Yang Tao, et al, "On the Analysis of Cache Incalidation With LRU Replacement", IEEE Trans. Parallel Distributed Syst, vol. 33, no. 3, pp. 654-666, March 2022.

[4] P. Agyapong, M. Sirbu, "Economic Incentives in Content-Centric Networking: Implications for Protocol Design and Public Policy", Proquest Llc, vol. 50, no. 12, Dec. 2012.

[5] Abylay Satybaldy, Changhee JooHanawal, "The effect of (non-)competing brokers on the quality and price of differentiated internet services", Computer Networks, vol. 160, no. 4, pp. 144-164, Sep. 2019.

[6] T. -M. Pham, "Analysis of ISP caching in information-centric networks", The 2015 IEEE RIVF International Conference on Computing & Communication Technologies - Research, Innovation, and Vision for Future (RIVF), pp. 151-156, 2015.

[7] T. -M. Pham, S. Fdida and P. Antoniadis, "Pricing in Information-Centric Network interconnection", 2013 IFIP Networking Conference, pp. 1-9, 2013.

[8] Changkun Jiang, Lin Gao, Tong Wang, et al, "On Economic Viability of Mobile Edge Caching", 2020 IEEE International Conference on Communications (ICC), pp. 1-6, 2020.

[9] D. Mitra and A. Sridhar, "Consortiums of ISP-Content Providers Formed by Nash Bargaining for Internet Content Delivery", IEEE INFOCOM 2019 - IEEE Conference on Computer Communications, pp. 631-639, 2019.

[10] F. Kocak, G. Kesidis, T. -M. Pham and S. Fdida, "The Effect of Caching on a Model of Content and Access Provider Revenues in Information-centric Networks", 2013 International Conference on Social Computing, pp. 45-50, 2013.

[11] M. Hajimirsadeghi, N. B. Mandayam and A. Reznik, "Joint Caching and Pricing Strategies for Popular Content in Information Centric Networks", IEEE Journal on Selected Areas in Communications, vol. 35, no. 3, pp. 654-667, March 2017.

[12] J. Duan, et al, "A Collaborative Pricing Framework for In-Network Caching in Information- Centric Networking", IEEE Access, vol. 6, pp. 40485-40493, 2018.

[13] Tingxiang Shi, Lu Zhang, et al, "Exploring Operator Billing Models in the 5G Era", Information and Communications Technology and Policy, vol. 47, no. 5, pp. 73-79, May 2021.

[14] R. Edell and P. Varaiya, "Providing Internet access: what we learn from INDEX", IEEE Network, vol. 13, no. 5, pp. 18-25, Sept.-Oct. 1999.

[15] H. Wang, J. Hu, G. Min, W. Miao and N. Georgalas, "Cost-Aware Optimisation of Cache Allocation for Information-Centric Networking", GLOBECOM 2017 - 2017 IEEE Global Communications Conference, pp. 1-6, 2017.