An ICN Cache Pricing Mechanism Based on Non-cooperative Game Model of Users and Advertisers

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***Abstract*—To address the problems in end-to-end networks, researchers have proposed an information-centric network(ICN). In-network caching is one of the important features of ICN, which can greatly improve the efficiency of content distribution. However, the Internet Service Providers(ISP) only deploy In-network caching if there is some financial incentives. The existing ICN pricing mechanisms only study paid content but ignore free content in the network. In addition, the existing ICN economic models do not take into account ISP cooperating with Content Provider(CP) to deploy in-network caches. Therefore, the pricing mechanisms already in place cannot be applied in practice. In this paper, different from the existing models which based on the paid content, a new ICN pricing model with free content based on non-cooperative game theory was proposed for the first time and advertisers were effectively added to the ICN pricing model. After analyzing the behavioral relationships between entities within the network, the authors establish the utility function for each entity. The authors analyze the impact of caching and pricing on the revenues of all entities and solve the equilibrium point to develop win-win pricing strategies. Considering the case where paid content coexists with free content in real networks, the authors proposes a more realistic and integrated model. In this paper, many experimental analyses have been conducted in addition to the theoretical analysis, and the experimental results show that the new model is closer to reality than the existing models and can provide better theoretical guidance for network pricing.**

***Index Terms*—Information-centric networks, Game, Pricing mechanism, Caching, Economic incentives**

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I. INTRODUCTION

A. Traditional IP Network to ICN

The contemporary Internet began in the early 1960s, and its predecessors were ARPANET(Advanced Research Projects Agency Network) [1]. In 1983, the ARPANET split into the MILNET network which is used only by the military, and a packet-switched network using the TCP/IP (Transmission Control Protocol/Internet Protocol) protocol, which is now known as the Internet.

Cisco's "Annual White Paper on the Internet (2018-2023)" [2] released on March 9, 2020 stated that, by 2023, more than sixty percent of the world's population will be connected to the Internet. The total number of devices connected to an IP network will more than triple the population, with 29.3 billion network devices connected to the network and the mobile subscribers will grow from 5.1 billion in 2018 up to 5.7 billion. The scale of the network's development and user needs for the network have shifted dramatically compared to the original design of the network. With content distribution becoming a major traffic in the Internet, the style of content distribution services has changed. CDN(Content Delivery Network) [3] is a way to improve the user perceived performance of content distribution. In CDN, content requests sent by users are redirected to a sufficient selection of replica servers via DNS name analysis. CDNs provide an implicit content oriented service to the end user because the user has the impression that their content requests are being sent to the original server. In this sense, the end users do not care where the content is obtained from. In-network caching is a key feature of CDNs. Cache deployment strategies and replacement strategies in CCN/NDN have been well studied, but many deployment plans for CCN/NDN are still being implemented with CCN/NDN development. Researchers have found that how to motivate operators to deploy caching to make CCN/NDN network research more relevant to real-world scenarios is one of the key issues which can not be ignored during the development of CCN/NDN networks.

B. Research on Pricing Mechanisms

With the rapid development of Internet applications, the increasing number of users and the variety of content, the optimal pricing strategy to balance the interests of all aspects are all vital in Internet research [4]–[6]. The study of price pf the internet focus on how to establish a suitable pricing model and find a reasonable set of pricing strategies , which can allocate network resources rationally in order to resolve the contradictory relationship between maximizing profits of internet operators, content operators and user demand for internet services. In various aspects of the profit relationship, users and network service providers (ISP, Internet Service Provider), ISPs and ISPs, ISPs and content providers (CP, Content Provider) have always been the key issue in the study of Internet network pricing strategy.

As shown in Figure 1, on the one hand, when ISPs in the Internet transmitting rich content, network traffic will grow rapidly. To cope with this change, Internet Service Providers (ISPs) need to build a network infrastructure that can maintain consistent quality of service. Therefore increasing the cost of investment in network infrastructure is an important issue for them. ISPs provide transport services to users and content providers (CPs) and need to cover the investment costs by charging users and CPs. However, the market of access to network market is highly competitive. To gain core competitiveness among multiple ISPs and earn more profits, ISPs need to adopt the right operating methods, find their own pricing strategies, and improve their service quality. On the other hand, because the Internet is a collection of multiple ISPs interconnected, ISPs derive benefits by providing services to their users and users can communicate with other users through their ISPs. Therefore, the solution of pricing between ISPs must be resolved to maximize the benefits of different interconnecting ISPs.

The current pricing model in the Internet from the user's perspective involves two types of customer-provider relationships: 1.Access fees, paid by users to ISPs for access services. 2.Content fees, paid by users to CPs directly or indirectly (e.g., through advertising).

C. Content and Structure of this Paper

To solve the problems in the current research on cache pricing mechanisms in information center networks, this paper focuses on developing a pricing model for the case where free and paid content co-exist. The existence of balance was proved under the model of non-cooperative game and the validity of the model was demonstrated through comparative experiments. The details of the study are as follows:

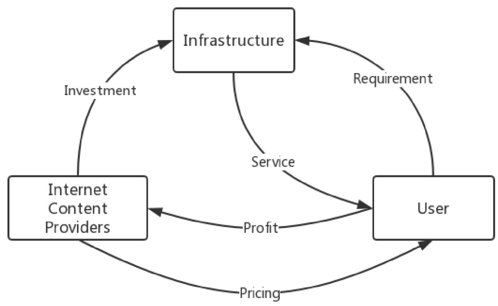

Fig. 1. Relationships between users and operators

(1) For the first time, we study pricing mechanism with the coexistence of free and paid content in the ICN when advertisers' willingness to invest follows a normal distribution. In the case of a non-cooperative game, the utility function of the ISP and the CP entity are given, and the equilibrium point is solved to obtain the a win-win pricing strategy.

(2) In order to evaluate the proposed scenario and to compare it with existing ICN pricing models, we use MATLAB to conduct a numerical analysis. After making comprehensive analysis of the impact of changes in various pricing parameters on the entity's returns, we finally conclude that the integrated model is more practical.

This paper is divided into five chapters:

Chapter one is the introduction, which introduces the background and research content of this paper. The background of the study focuses on the evolution from traditional networks to information-centric networks and the research of pricing mechanism in interconnected networks. The research content section presents the main model and work of this paper.

Chapter two describes the classical pricing mechanism of the traditional Internet in ICN, status of research on cache pricing in CDN and ICN caching, and then identifies the current problems in ICN pricing mechanisms.

Chapter three presents the model of pricing mechanism in the case of co-existence of free and paid content, and discusses the willingness of advertisers to invest. Utility functions for each entity are given in the case of non-cooperative games.

In Chapter four, modeling is applied by MATLAB, numerical analysis is performed, and the derived results are verified. It is concluded that ISP and CP can maintain a stable cooperation situation. A comparison with existing ICN pricing models proves the model to be more practical.

Chapter five summarizes the full work of the paper and draw the conclusion.

II. RELATED RESEARCH

A. Classical Internet pricing mechanisms

We divide papers on pricing strategies for current Internet into two categories. One based on regulation within the market itself and the other using game theoretic approaches. Fixed-rate pricing model [7] is that the operator charges the subscriber a fixed monthly fee for the service. The price remains the same no matter how many network resources the user uses. Improved Paris Metro pricing model [8], [9] dividing Internet resources into subsections and give them different prices for users to choose. Thus higher priced subnets are better served due to the smaller number of subscribers. The capacity-based pricing model [10], [11] is a pricing method for allocating resources based on expected usage, which is easy to manage. Pricing strategies which use game-theoretic instruments are as follows. In paper [4], the authors model the non-cooperative game between ISPs and CPs to describe the behavior of ISPs and CPs to obtain an equilibrium of interests, thus formulate an appropriate pricing strategy. Paper [12] studies a simple two-sided market model for ISPs and CPs based on user demand, considers the game between content providers, and finds the Nash equilibrium. Paper [13] discusses the cooperative and non-cooperative models between multiple ISPs and CPs and derives balance for both models. In paper [14], the authors develop a hierarchical game model, taking into account both the demand and price of content providers and analyze the impact of non-neutral pricing on users and content providers.

B. Status of Research on Cache Pricing in CDN

A large portion of Internet traffic is now accounted for by delivery services, including web content, user-generated content(e.g., YouTube), and rich content (e.g., movies and TV shows) provided by CPs. Content Delivery Network (CDN) [3] is widely used for content delivery services. It makes a significant contribution to improving the quality of service for delivering content to users by deploying caching in the network to improve the response time for delivering content. The dramatic increase in CDN traffic has affected the traffic and economic relationships between network providers [15]. As a result, the pricing mechanism in CDN has received a lot of attention. The study is divided into the following two main areas, some papers [16], [17] focuse on the way to enhance the maximization of individual CDN revenues, and others [18]–[20] focuses on the interactive behavior of multiple CDNs and the interaction of CDNs with other entities in the network.

C. Research on ICN Caching pricing mechanisms

Information-centric networks (ICNs) are gaining a lot of attention due to the drawbacks of the end-to-end nature of IP networks. ICN is an efficient network for transferring information, where content is delivered in the router's cache using an information name rather than a host IP address, and users do not care which router is sending that content. Although pricing for CDN has been well researched, the pricing mechanisms can not be applied to ICN directly because their network architectures are fundamentally different. The earliest study of economic incentives for ICN was conducted in paper [21]. Pricing strategies in ICNs were first proposed by Kocak in paper [6], and Mohammad followed up the work with a collaborative caching pricing strategy which focuses more on popular content [22]. Paper [23] proposes an ICN collaborative pricing strategy which considers two charging approaches: retail sale and one-time sale.

All of the above studies focused only on paid content within the ICN (i.e. content itself and users need to subscribe the fee to the CP). However, there is a lot of contents provided by CPs on the network which is free for users (hereinafter collectively referred to as free contents), and current research on ICN pricing has neglected to consider the mechanism for pricing free content in ICN networks. Inspired by the development of traditional online pricing mechanisms, in practice the vast majority of content on the web is free [4], [13]. So research on pricing mechanisms cannot ignore free content and we need to refine the pricing mechanisms to make them more relevant to reality in order to motivate operators to deploy ICN in-network caching.

III. MODEL BUILDING

Pricing mechanisms based on IP networks can not match well with content-centric network. To encourage operators to deploy ICN networks, appropriate pricing mechanisms need to be developed. In real networks, free content and paid content co-exist. Based on this fact, in this section, we present a comprehensive ICN network pricing model which takes both network of free and paid content into account. The model formulates the funding behavior of new advertisers, the interactive behavior of ISPs and CPs, and the utility functions of the entities. Finally, knowledge of non-cooperative gaming is used to guide ICN entities in developing a pricing mechanism for each ICN to maximize the effectiveness of the entity.

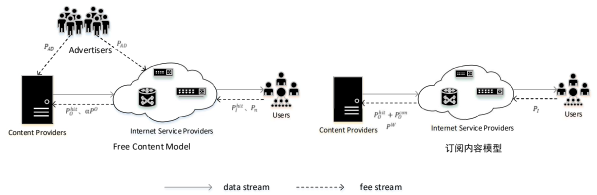

Fig. 2. The payment relationship between the two models

In this paper, we consider a model for a single ISP and CP interaction as shown in Figure 2. The network model is divided into two components, a subscription content model and a free content model. In the subscription content model, three entities are included: an Internet Service Provider (ISP), a Content Provider (CP) and several subscribers. In the free content model, four entities are included: an Internet service provider (ISP), a content provider (CP), several subscribers and a certain number of advertisers. The role of the ISP is to connect subscribers to the network, and the CP provides

TABLE I
INTEGRATED MODEL SYMBOLS DESCRIPTION

	Universal Symbol
α	Portion of request fulfilled at ISP
ρ	Influence of price on the number of users
c_k	Caching costs at K (including ISP, CP)
P_I	Total fee of data charged by the ISP
P_I^{hit}	Caching fee for unit data charged by the ISP
P_K^n	The traffic charge per data charged by the ISP
P_C	Fee for unit data charged by CP
P_C^{hit}	Caching fee for unit data charged by CP
$P^{(c)}$	Content fees charged by ISPs and CPs
P^O	Expected proceeds from CP's one-time sale of all content
p_{ad}	Fees charged by ISPs and CPs to advertisers for unit data
	Subscription Model Section
d_{s0}	Number of initial subscribers under subscription model
d_s	Number of subscribers under subscription model
P_s^W	One-time payments from ISPs to CPs under subscription model
	Free Model Section
d_{f0}	Number of initial subscribers under free model
d_f	Number of subscribers under free model
P_f^W	One-time payments from ISPs to CPs under free model
	Integrated Model Component
γ	Ratio of free content to paid content in the network
P^W	One-time payments from ISPs to CPs under integrated model

content services to subscribers. When a subscriber requests content, if there is content in the ISP that satisfies the user's request, the content is returned directly to the subscribe.If not,then the content is requested from the CP and returned to the user. Figure 2 also depicts the payment relationship between the participants in the model.

A. Subscription Content Model

In the subscription content model, for an ISP, the fee charged by the ISP for providing a service to a subscriber when the subscriber requests content from the ISP is denoted by the symbol P_I. P_I is composed of three parts: 1. Cost of traffic on delivery of content P_I^n; 2. Content storage fees earned when content requests are fulfilled locally at the ISP P_I^{hit} ; 3. Content fees paid by users for access to content $P^{(c)}$; which is $P_I = P_I^{hit} + P_I^n + P^{(c)}$. In addition, when ISPs wholesale (one-time purchase) some content from CP, they also pay a fee to CP, which is denoted by the symbol P_s^W. For CP, two parts contribute to the revenue, one is the fee charged when the content is wholesaled to the ISP for caching. The other part is the fee that the CP will charge when the user's needs are not met at the local cache of ISP but at the CP. We can describe the fee as P_C , in which $P_C = P_C^{hit} + P^{(c)}$. Symbols in this section can be refered in table 1.

The number of subscribers is affected by the fee P_I charged by the ISP and the fee P_C charged by the CP.The initial number of users is d_{s0}, d_s represents the number of people requesting content from the ISP and the expression can be written as:

$$d_s = d_{s0} - \rho_1 P_I - \rho_2 P_C \tag{1}$$

in (1), $P_I = P_I^{hit} + P_I^n + P^{(c)}$. Using α to show the percentage of the ISP cached content to the total content of the CP, then the request hit rate for users at the ISP is α . CP contents are sold in two ways: 1. Retail method, the content of the The retail price is $P^{(c)}$; 2. An one-time sale to the ISP, P_s^O is the revenue that CP expects to receive when it sells all the content at once. The cost to the ISP for a one-time purchase of content is P_s^W. Using c_i to denote the cost of caching each content at the ISP, the ISP utility function can be written as

$$U_I = d_S \left[\alpha \left(P_I - c_i\right) + (1-\alpha)\left(P_I - P_C\right)\right] - P_s^W \tag{2}$$

in (2), $P_s^W = \alpha P_s^O$and after collation

$$U_I = d_S \left[\alpha \left(P_C - c_i\right) + \left(P_I - P_C\right)\right] - \alpha P_s^O \tag{3}$$

The utility function of CP is.

$$U_O = (1-\alpha)\, d_S \left(P_C - c_o\right) + \alpha P_s^O \tag{4}$$

B. Free Content Model

In free content model, when a subscriber requests content from an ISP, the fee charged by the ISP for providing the service to the subscriber can be represented by the notation P_I'. P_I' consists of two components: 1. traffic charges on delivery of content P_I^n; 2. the content storage fee P_I^{hit} obtained when content requests are fulfilled locally at the ISP. So $P_I' = P_I^{hit} + P_I^n$. Just the same as the subscription content model, when an ISP purchases part of its content wholesale (one-time purchase) from CP, the fee to be paid to CP is P_f^W. Supposing CP expects to earn P_f^O by selling all of its free content at once, there are still two components to the revenue of CPs. One is the fee charged when wholesale content is cached to the ISP. The other one is that when users needs cannot be met at the ISP's local cache but met at the CP, the CP will charge the fee of P_O^{hit} .

In this model, because of the join of advertisers, subscribers do not have to pay content fees to ISPs and CPs when they get content from them. When the subscriber requests the content, the advertiser is required to pay an advertising fee to the content cacher. Therefore, the subscriber demand at the ISP is no longer affected by the content fee, and the expression for the subscriber demand in this model can be written as

$$d_f = d_{f0} - \rho_3 P_I' \tag{5}$$

Based on the above analysis, the ISP utility function can be expressed as

$$U_I' = d_f \left[\alpha \left(P_I' + p_{ad} - c_i\right) + (1-\alpha)\left(P_I' - P_C^{hit}\right)\right] - P_f^W \tag{6}$$

in (6), $P_f^W = \alpha P_f^O$ and after collation

$$U_I' = d_f \left[\alpha \left(P_I' + p_{ad} - c_i\right) + (1-\alpha)\left(P_I' - P_C^{hit}\right)\right] - \alpha P_f^O \tag{7}$$

In the advertising model, the requirements of subscribes translate into attention to the content (e.g., clicks). With N advertisers, each advertiser has a fixed budget of E, and the advertiser's willingness to invest is$v, v \in [0, \bar{v}]$. The advertising revenue received by the entire network was $N \cdot E \cdot Prob\left(v \geq p_{ad}\right) = N \cdot E \cdot \left[1 - X\left(p_{ad}\right)\right]$. Then the user requirements in this model can be written as

$$d_{ad} = \frac{NE[1 - X(p_{ad})]}{p_{ad}} \tag{8}$$

The user requirements at the CP are accessed by the ISP and therefore will be limited by the actual number of accesses at the ISP. Taking the actual number of accesses and the advertiser's investment into account, the received user requirements under this model can be represented as

$$d_f = min\left\{d_f, d_{ad}\right\} \tag{9}$$

Then the utility function of CP can be expressed as

$$U_O' = (1-\alpha)\, d_f \left(P_C^{hit} + p_{ad} - c_o\right) + P_f^W \tag{10}$$

C. Integrated Model

In practice, there is both free content and paid content on the web. We consider it from the user's point of view, some users choose to request paid content and some choose to get free content by watching advertisements. We assume that the total user demand for the entire network is d, where $d = d_s + d_f$. We express the proportional relationship between the two demands by γ , and then $d_s = \gamma d, d_f = (1-\gamma)d$. Based on the analysis in the previous two subsections, we can obtain the utility functions for ISPs and CPs.

The utility function of the ISP is

$$\begin{array}{l} U_{isp} = \gamma d\left[\alpha\left(P_I - c_i\right) + (1-\alpha)\left(P_I - P_C\right)\right] \\ +(1-\gamma)d\left[\alpha\left(P_I' + p_{ad} - c_i\right) + (1-\alpha)\left(P_I' - P_C^{hit}\right)\right] - P^W \end{array} \tag{11}$$

The utility function of CP is

$$\begin{array}{r} U_{cp} = \gamma d\,(1-\alpha)\left(P_C - c_o\right) + (1-\gamma)d\,(1-\alpha) \\ *\left(P_C^{hit} + p_{ad} - c_o\right) + P^W \end{array} \tag{12}$$

IV. MODEL ANALYSIS AND SOLUTION

A. Optimal Price of Advertise

In this chapter we study the case where willingness of advertisers to invest obeys a normal distribution. When an advertiser's expectation of willingness to invest is $\mu\,(\mu > 0)$ and the variance of the willingness to invest is σ^2, the willingness of advertisers to invest follows a normal distribution that can be described as$\nu \sim E\left(\mu, \sigma^2\right)$. The probability density function of willingness to invest can be expressed as

$$x\left(v\right) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\nu-\mu)^2}{2\sigma^2}} \tag{13}$$

Then when CP sets an advertising rate of p_{ad}, the advertiser's probability of investment is

$$X\left(p_{ad}\right) = \textstyle\int_{-\infty}^{p_{ad}} x\left(\nu\right) d\nu \tag{14}$$

Thus the advertising revenue across the network can be expressed as

$$\begin{array}{l} N\cdot E\cdot Prob\left(v \geq p_{ad}\right) = N\cdot E\cdot\left[1 - X\left(p_{ad}\right)\right] \\ = N\cdot E\cdot\left[1 - \int_{-\infty}^{p_{ad}} x\left(\nu\right) d\nu\right] \end{array} \tag{15}$$

From the above, it can be seen that the advertising revenue of the whole network is influenced by the combination of the advertiser investment and the actual access users at the ISP. When CPs set the optimal of the advertising charge, the attention of the subscriber in the advertising model is equal to the demand of the subscriber actually accessing the ISP, which can be written as $d_f = d_{ad}$. Thus

$$d_f = \frac{NE[1 - X({p^*}_{ad})]}{{p^*}_{ad}} \tag{16}$$

Therefore, advertising fees can be expressed as follow

$${p^*}_{ad} = \frac{N\cdot E\cdot\left[1 - \int_{-\infty}^{{p^*}_{ad}} x(\nu) d\nu\right]}{d_f} \tag{17}$$

Since willingness of advertisers to invest obeys a normal distribution, in order to solve the optimal value of the advertising charge, we use Matlab and the algorithm 1. The algorithm is used to find the best value for the advertising cost. The algorithm enters N for the number of advertisers, E for the fixed budget of each advertiser, mju for the advertiser's willingness to invest, $sig2$ for the variance of willingness to invest, d_f for subscriber requirements, $UpLimit$ for the advertising cost of the upper limit value, $Step$ for the step size. Step 2 is to solve the probability distribution of the advertiser investment.

Algorithm 1 Solve for the best advertising rates

```
Data: N, E, mju, sig2, d_f, UpLimit, Step
Result: p_ad
for p_ad = 0 : Step : UpLimit do
    prob = normcdf(p_ad, mju, sig2);
    d_ad = (N*E*(1-prob)) / p_ad;
    if d_ad <= d_f then
        break;
    end
end
```

B. Nash Equilibrium Solution

To obtain the equilibrium point for each entity, given the maximum response function of the utility function of each entity, the maximum response function of the ISP is

$$\begin{array}{l} \max\limits_{P_I, P', \alpha} U_{isp} = \gamma d\left[\alpha\left(P_I - c_i\right) + (1-\alpha)\left(P_I - P_C\right)\right] \\ +\,(1-\gamma)\,d\left[\alpha\left(P_I' + p_{ad} - c_i\right) + (1-\alpha)\left(P_I' - P_C^{hit}\right)\right] - P^W \\ s.t. P_I > 0, P_I' > 0, 0 \leq \alpha \leq 1 \end{array} \tag{18}$$

The maximum response function of CP is

$$\begin{array}{l} \max\limits_{P^{(c)}, P^O, p_{ad}} U_{cp} = \gamma d\,(1-\alpha)\left(P_C - c_o\right) \\ +(1-\gamma)d\,(1-\alpha)\left(P_C^{hit} + p_{ad} - c_o\right) + P^W \\ s.t. P^{(c)} > 0, P^O > 0, p_{ad} > 0 \end{array} \tag{19}$$

We consider that there is a linear relationship between the traffic fee P_I^n that an ISP charges for providing content and the fee for storing a unit of content P_I^{hit}, so $P_I^n = \beta P_I^{hit}$ and $P_I^{hit} = \left(\frac{1}{1+\beta}\right) P_I'$. In order to solve the Nash equilibrium point, we need to derive the utility functions for ISP and CP and solve the following set of equations

$$rrrr\ \begin{array}{l} \frac{\partial U_{isp}}{\partial P_I} = 0, \frac{\partial U_{isp}}{\partial \alpha} = 0 \\ \frac{\partial U_{cp}}{\partial P_C} = 0, \frac{\partial U_{cp}}{\partial P^o} = 0 \end{array} \tag{20}$$

We give the value of ISP charge P_I and CP charge P_C when equilibrium is reached as follow

$$P_I = \frac{-\rho_2 P_C + \rho_3 P^{(c)} + d_{s0} + d_{f0}}{2(\rho_1+\rho_3)} + \frac{P^{(c)} + \alpha(c_i - p_{ad}) + (1-\alpha)P_C^{hit} + \gamma\alpha\big(p_{ad} - P^{(c)}\big)}{2} \tag{21}$$

$$P_C = \frac{\gamma\big[(\rho_1+\rho_3)P_I + \rho_3 P_C^{hit} - d_{s0} - d_{f0}\big]}{2\gamma(\rho_3-\rho_2)} - \frac{\big[\big(P_C^{hit}+p_{ad}-c_o\big) - \gamma\big(P_C^{hit}+p_{ad}\big)\big]}{2\gamma} \tag{22}$$

Equation (21) shows the pricing of ISP at the equilibrium point and Equation (22) shows the pricing of CP at the equilibrium point. Both pricing taken at the equilibrium point corresponds to the respective optimal pricing, and any deviation of either party's pricing from the optimal pricing will result in a loss of its own earnings. So the parties will continue to adopt the best pricing to bring the gaming situation to equilibrium without change.

V. NUMERICAL ANALYSIS

In this section, we will use MATLAB to simulate the process of the above analysis and present more experimental results. If not otherwise specified, the experimental parameters are set as follows: the initial user requirements are $d = 1000$, the number of advertisers and budget are $N = 100$ and $E = 50$, the proportion of request which is satisfied at the ISP is $\alpha = 0.5$, the caching costs for the ISP and CP are $c_i = 2$ and $c_o = 1$.

A. Impact of ISP pricing on utility function

In Figure 3 and Figure 4, we analyze the affect of ISP pricing on the utility function of CP and ISP. As can be seen in Figure 3, when other costs in the network keep constant, as the pricing range shown in the figure, the ISP utility increases with the increase of their fees. We also simulated two cases in which the ratio of initial users in the network requesting subscription content to initial users requesting free content are $\gamma = 0.2$ and $\gamma = 0.5$. When $\gamma = 0.2$, utility under the free content model is greater than under the subscription content model. This is because the user demand for the free content model is much higher than that of the subscription content model. When $\gamma = 0.5$ and the initial user requirements are the same for both models, ISP utility is higher in the free content model than in the subscription content model. We can also see that the utility of the corresponding integrated model is higher than both the subscription content model and the free content model.This shows that a well-developed pricing model is more realistic and can also lead to higher revenues for ISPs. Figure 4 shows the impact of ISP pricing increases on CP utility. An increase in ISP pricing will lead to a decrease in CP utility. This is because an increase in ISP pricing leads to a decrease in the number of users accessing the network, and thus lead a decrease in the utility of CP.

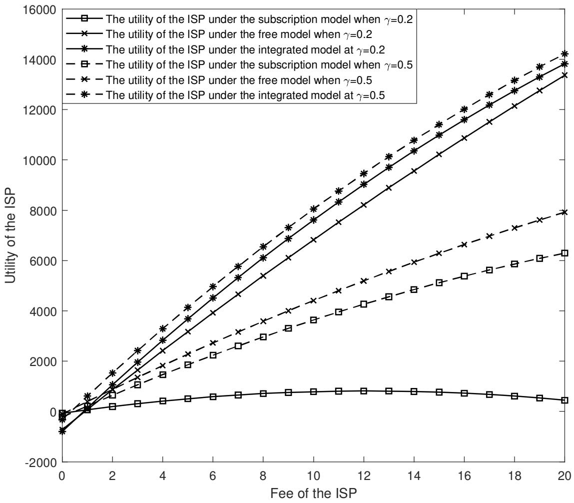

Fig. 3. Impact of ISP pricing on ISP utility

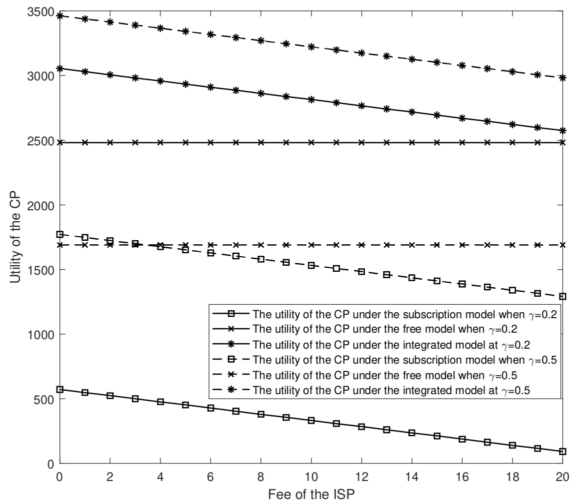

Fig. 4. Impact of ISP pricing on CP utility

B. Impact of CP pricing on utility function

In Figure 5 and Figure 6, we simulate the effect of content fees set by CP on ISP and CP utility under each of the three models. We can see that, because users don't have to pay for content under the free content model, content costs have no impact on the utility of either part. Comparing the experimental results of Figure 5 with Figure 6, we can see that the utility of ISPs and CPs follow similar trends with content fees change. This is because under the subscription content model and the integrated model, content fees are included in the utility of both CP and ISP. ISP charges subscribers for content when it's at the ISP and when the content is at the CP, the CP charges the user for the content, and the effect of the fee acts on both the ISP and the CP. Therefore, the utility of the two varies are same with the change way of content fees. It can also be seen in Figure 5 and Figure 6 that the integrated model generates more benefits for ISPs and CPs than the free content model and subscription content model, which again suggests that a well-developed integrated pricing model is more realistic and leads to higher revenues for ISPs and CPs.

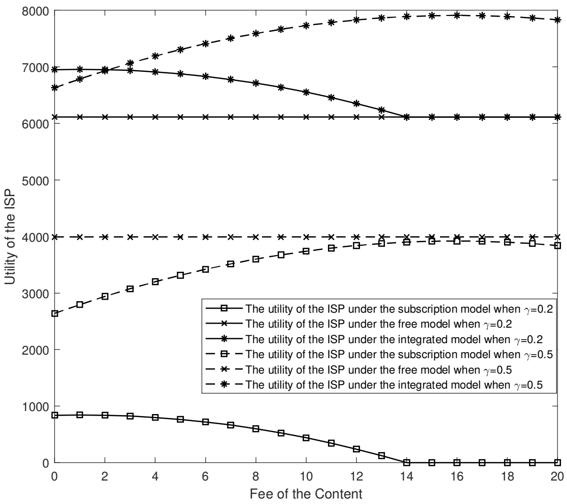

Fig. 5. Impact of content pricing on ISP utility

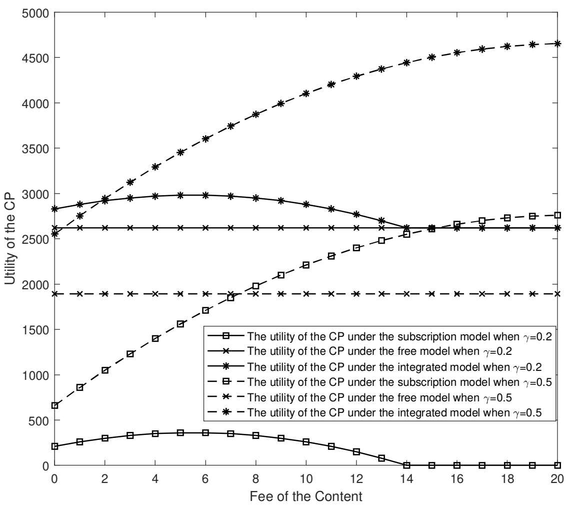

Fig. 6. Impact of content pricing on CP utility

VI. CONCLUSION

In this paper, the pricing mechanism when free and paid content co-exist is first examined and invest willingness of advertisers is then discussed. In the non-cooperative game scenario, the utility function of each entity is given to solve the equilibrium point to arrive at a win-win pricing strategy. In order to evaluate the proposed scenario and compare it with existing ICN pricing models, we use Matlab to perform a numerical analysis to illustrate the impact of the variation of each pricing parameter on the entity's profitability. It is obvious that our model is more practical and profitable.

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