An Efficient Pricing Mechanism for Mobile Video Streaming in Cloud Computing

Mr. Binayak Parashar, Mr. S. Suresh

PG Scholar (M.E., CSE), Ph.D. (Ph.d), Associate Professor Adhiyamaan College of Engineering, Department of Computer Science, India
binayakparashar89@gmail.com

Abstract

Among the most popular consumer devices, the mobile phones are the one whose usage has increased in a rapid manner and along with the development of 3G networks and smart phones, enabled users to use them in an efficient manner and also to watch video programs by subscribing data plans from service providers. Due to ubiquitous access of mobile phones and its features, data-plan subscribers can redistribute the video content to non-subscribers and has become a great difficulty for the mobile service provider to trace the given user’s high mobility. Hence, the service provider has to provide a reasonable price for the data plan in order to prevent such unauthorized redistribution of the video content. In this paper, it is tried to analyze the optimal price setting for the service provider by understanding the equilibrium condition between the subscribers and the secondary buyers, and also to model the behavior between the subscribers and the secondary buyers as a noncooperative game with the concept of Game Theory and to find the optimal price and quantity for both group of users. Such an analysis can help the service provider preserve his/her profit under the threat of the redistribution networks and can improve the quality of service for end users.

Keywords: Game theory, mobile video streaming, pricing.

Introduction

Multimedia processing technologies has increased its popularity in ways that video content is delivered to and consumed by end users. Also, the increased usage and popularity of wireless networks and mobile devices is drawing a lot of interest and attention on ubiquitous access of multimedia content. Network service providers and researchers are focusing on developing efficient solutions to ubiquitous access of multimedia data, particularly videos, from everywhere using mobile devices (laptops, personal digital assistants, or smart phones that can access 3G networks). The users of mobile phone can watch or subscribe the video programs on their devices by using the data plans from the network service providers. In this paper, scalable video coding techniques are being implemented in order to accommodate heterogeneous network conditions and devices. In the research community, video applications have drawn a lot of attentions in the field of quality measure and error control. It also concentrates on the user interactions in electronic commerce which comprises of the secure transactions and cooperative caching. Along with this, it is required to understand the concept of how end users are consuming video in day to day lives. With such a high popularity and the convenient phone-to-phone communication technologies, it is very possible for data-plan subscribers to redistribute the video content without authorization. For example, there are some of the users who do not subscribe to the data plan and henceforth wish to watch television programs and also news programs. Hence, these users have incentives to buy the desired video content from neighboring data subscribers if the cost is lower than the subscription fee charged by the service provider. In comparison to the generic data, multimedia data can be easily retrieved and modified, which carries out the process of video redistribution. Due to the high-mobility, time-sensitivity, and small-transmission-range characteristics of mobile devices, each redistribution action only exists for a short period of time and is very difficult to track. However, the price of the content must be high as because of lesser number of subscribers and secondary buyers. In such a condition the primary subscriber who is paying more amount for the data plan must be avail his/her win-win situation. Hence, setting the content price higher does not necessarily reduce the number of subscriptions, and it is not trivial to find the optimal price that maximizes the service provider’s utility. The service provider, the data-plan subscribers (primary), and the secondary buyers who are interested in the video data interact with each other and influence each other’s decisions and performance. So, a strategic decision making must be carried out for overcoming this situation. And as such the Game theory is being
implemented for analyzing the strategic interactions among rational decision makers. Recently, the game theory has drawn great attention in multimedia signal processing [13], [14]. We first model the user dynamics in the redistribution network as a multiplayer noncooperative game and obtain the equilibrium price from which all users have no incentives to deviate. Hence, such an equilibrium price will serve as the upper bound for the price set by the network service provider to prevent copyright infringement. We add the service provider as a player to the game to analyze the optimal pricing for the service provider in the video streaming marketing network. Since the mobile users can change their decisions on subscribing or resubscribing, the content owner is interested in the number of subscribers that is stable over the time. Therefore, a robust equilibrium solution is desired for the service provider. Hence, we formulate the video streaming marketing phenomenon as an evolutionary game and derive the evolutionarily stable strategy (ESS) [15] for the mobile users, which is the desired stable equilibrium for the service provider.

Model Description

1. Game theory
2. Subscriber Module
3. Secondary Buyers
4. Admin module

Game theory is the formal study of conflict and cooperation. Game theoretic concepts apply whenever the actions of several agents are interdependent. These agents may be individuals, groups, firms, or any combination of these. The concepts of game theory provide a language to formulate structure, analyze, and understand strategic scenarios.

In the subscriber module, subscriber chooses video and downloads the video from service providers. Subscribers pay the amount to service provider. Service provider provides that video key to subscriber. So subscribers watch the video using video key. Also subscriber, redistribute the video to another user such as using blue tooth or Wi-Fi technologies.

In the secondary buyer module, the secondary buyers easily getting the video from subscriber using Wi-Fi or blue tooth technologies. Secondary buyers don’t pay the amount to service provider. And same time secondary buyers don’t have a video key.

In the Admin module, admin upload the video to database. Also view the subscriber details and user details. Admin find the redistribute details. Also who send the video and receive the video.

System Model

In this section, we will introduce the channel, transmission, and video rate distortion models for the transmission of video streams over wireless networks. The system model is shown in FIG 1. There are $N_s$ subscribers in the network, who are trying to sell the video content to $N_b$ secondary buyers. Here, we assume that the content is redistributed through direct links between the subscribers and the secondary buyers, i.e., these mobile users form an ad hoc network. Given the current technology, such direct link can be Bluetooth or Wi-Fi. At the beginning, each subscriber sends his/her own price per unit transmission power, as well as the probing signal to secondary buyers. Since the price information contains only a few bits, we assume that it can be immediately and perfectly received. The probing signal enables secondary buyers to estimate the maximal achievable transmission rate. A secondary buyer has to decide how much power he/she wants to buy from each subscriber. Since scalable video coding [5] is widely used in mobile video streaming, Any higher layer mechanisms for such wireless ad hoc networks such as bootstrapping algorithms [16] can be applied to the redistribution network and will not change the analysis in the following sections.

We assume that there is a channel dedicated for transmissions among users and this channel is a slow-fading channel with channel gain and the variance of the additive white Gaussian noise at the receiver’s side. Assume that the jth secondary buyer purchases a part of the video stream from subscriber $S_i$ with transmission power $P_i^{(j)}$. We assume that there is a channel dedicated for transmissions among users [17], [18] and this channel is a slow-fading channel with channel gain $H_{ij}$; the distance between them is $d_{ij}$, and the variance of the additive white Gaussian noise at the receiver’s side is $\sigma^2$. Let $N$ be the set of subscribers from whom the secondary buyers purchase the video. Assume that the total bandwidth available for the video redistribution network is $W$, which will be evenly allocated to all $N$ subscribers from whom secondary buyers purchase the video stream. The signal-to-noise ratio (SNR) and the maximal achievable bit rate of the video stream between $S_i$ and $B_j$ are

$$\text{SNR}_{ij} = \frac{P_i^{(j)} |H_{ij}|^2}{\sigma^2}$$

$$R_j = W \frac{W}{N+1} \log_2(1 + \frac{\text{SNR}_{ij} \gamma}{\gamma})$$

where $\gamma$ is the capacity gap [19].
Without loss of generality, in this paper, we use the two-parameter rate-distortion model [21], which is widely employed in a medium-to-high bit rate situation, and the analysis for other models is similar. The two-parameter rate-distortion model is given as follows:

\[
\text{Distortion} = \alpha e^{-\beta R} \quad \text{(2)}
\]

Where \( \alpha \) and \( \beta \) are two positive parameters determined by the characteristics of the video content and \( R \) is the rate of the video. Note that a secondary buyer is able to purchase the video from different subscribers in two different ways. The total bandwidth for the redistribution network is \( W \), which is equally shared among the subscribers who are going to transmit.

The total bandwidth for the redistribution network is \( W \), which is equally shared among the subscribers who are going to transmit. Hence, when the number of subscribers from whom the secondary user purchases, i.e., \( N \), increases, the bandwidth for transmitting each layer is smaller. Given the bit rate in (1), the mean square error (MSE) of the video stream reconstructed by the secondary buyer \( B_j \) is:

\[
\text{MSE}_j = \alpha \exp(-\beta \sum R_{ij}) \\
= \alpha \exp(-\beta \frac{W}{N+1} \sum \log_2(1 + \frac{\text{SNR}_{ij}}{\gamma})) \quad \text{(3)}
\]

### A. Video-Stream Redistribution Game Formulation

Since the video-stream redistribution network is a dynamic system in which all users have high mobility that can join and leave anytime, it is very difficult to have a central authority to control the user’s behaviour. Given the fact that there is only one secondary buyer, we propose a Stackelburg game model to analyze how the secondary buyer provide incentives for subscribers to redistribute the video stream and find the optimal price and quantity that the secondary buyer should offer. The ultimate goal of this analysis is to help the content owner to set an appropriate subscription fee such that the equilibrium of the game between the subscribers and the secondary buyers leads to negative payoffs. Thus, subscribers will have no incentive to redistribute the video. Before the game starts, each user, either a subscriber or the secondary buyer, will declare his/her presence to all other users within his/her transmission range.

1). **Game Stages**: The first stage of the game is the subscribers’ (leaders’) move. For each subscriber \( i \), he/she will set his/her unit price \( p_i \) per unit transmission power, as well as his/her maximal transmission power \( p_i^{(\text{max})} \). Then, in the second stage of the game, the secondary buyer (follower) will decide from whom to buy the video and how much power he/she wants the subscriber to transmit. The secondary buyer then pays each subscriber accordingly at the price that the subscriber sets in stage 1.

2). **Utility function of the secondary buyer/follower**: We first define the secondary buyer’s utility function and study his/her optimal action. The secondary buyer \( B \) gains rewards by successfully receiving the video with a certain quality. On the other hand, \( B \) has to pay for the power that the subscribers use for transmission. Let \( P_i \) be the power that the secondary buyer \( B \) decides to purchase from the \( i \)th subscriber \( S_i \), the channel gain between \( S_i \) and \( B \) is \( H_i \), and the distance between them is \( d_i \). Therefore, given the video rate-distortion model, the
utility function of the secondary buyer $B_i$ can be defined as

$$\pi_i = g_0(\text{PSNR}_i-\text{PSNR}_{\text{max}})-g_0(D_B-Dq_i)+g_0((K+1)^i_1)\sum pi Pi - po) \tag{5}$$

where $D_B$ is formulated, $g_0$ is a user-defined constant measuring the received reward if the PSNR of the reconstructed video is improved by 1 dB, and $g_0$ is a constant measuring the user’s loss if the video stream is further delayed by 1 s. $\text{PSNR}_{\text{max}}$ is the maximal PSNR of the video that can be obtained by subscribing to the service, and is the price set by the content owner. If the secondary buyer has subscribed to the data plan, then he/she will receive the video with the maximal PSNR, the delay of the video stream will only be the network delay, and the number of network users who are using the data service will be $K+1$ in this case. The first term reflects the visual quality difference between the subscriber’s video stream and the service provider’s video stream. The second term considers the delay difference between the subscriber’s video stream and the service provider’s video stream. $D_B$ was defined, and $Dq_i$ is the delay profile if the secondary buyer subscribes to the data plan and becomes an extra subscriber in the network. The third term indicates the price difference. The two constants $g_0$ and $g_0$ control the balance between the gain and the loss of the secondary buyer. Since the service provider can always offer better video quality, i.e., all three terms are not positive. If the secondary buyer is very concerned about the video quality, i.e., are high, then may be negative, and the secondary buyer will subscribe to the data plan himself/herself. For other digital contents, the reward terms will change according to the types of the content, but the payment term will remain the same.

3. Utility functions of the subscribers: Each subscriber $S_i$ can be viewed as a seller, who aims to earn the payment that covers his/her transmission cost and also to gain as much extra reward as possible. We introduce parameter $c_i$, i.e., the cost of power for relaying data, which is determined by the characteristics of the device that subscriber $S_i$ uses. Hence, the utility of $S_i$ can be defined as

$$\pi_{S_i} = (P_i-c_i)P_i \tag{6}$$

where is the power that subscriber uses to transmit to the secondary buyer. Thus, subscriber will choose price that maximizes his/her utility $\pi_{S_i}$. The choice of the optimal price is affected by not only the subscriber’s own channel condition but also other subscribers’ prices, since different subscribers noncooperatively play and they compete to be selected by the secondary buyer. Thus, a higher price may not help a subscriber improve his/her payoff.

### Multiple Secondary Buyer Case

In this section, we will extend the optimal strategy for the single-secondary-buyer case to the scenario with multiple secondary buyers.

A. Game Model: Assume that there are $N_s$ subscribers and $N_s > 1$ secondary buyers. The first two stages of the game are the same as the single-secondary-buyer scenario, i.e., each subscriber declares the price per unit energy $p_i$, and then, each secondary buyer $B_j$ chooses the transmission power vector $P^{j}$={$P^{j}_1, P^{j}_2, ..., P^{j}_{N_s}$}, where $P^{j}_i$ is the power that the secondary buyer $B_j$ plans to purchase from subscriber $i$. With multiple secondary buyers, each subscriber $i$ may receive several power purchase orders from different secondary buyers. In our paper, we let one subscriber transmit to one secondary buyer only. Thus, in the multiple secondary-buyer scenarios, the game model has an additional stage in which each subscriber $i$ chooses the secondary buyer $B_j$ who purchases the largest $P^{j}_i$ among all the $N_s$ secondary buyers.

B. Mixed-Strategy Equilibrium: Given the aforementioned definition of the utility functions, our next step is to find the subscribers and the second buyer’s optimal decisions (($P_1^{j}, P_2^{j}, ..., P_{N_s}^{j}$)) from which no one in the system has the incentive to deviate. For the subscribers’ price list $\{p_i\}$, for a secondary buyer $B_j$, the choice of the optimal power quantity $P^{j}$ is not only influenced by the channel conditions and the distances between subscribers and the secondary buyer $B_j$ but also depends on the number of subscribers from whom $B_j$ can purchase the video stream. For instance, if $B_j$ is the only secondary buyer within the transmission range of $S_i$, $B_j$ would always tend to use the optimal power in. If $B_j$ has to compete with other secondary buyers, $he/she$ might need to increase offer $P^{j}_i$ or switch to other subscribers.

### Optimal Pricing for the Content Owner

In the previous sections, we have discussed the equilibria and the optimal pricing strategy in the video redistribution network. Our assumption there is that the content owner would like to set price smaller than the equilibrium price in the redistribution network. Hence the pricing game model and also the evolution dynamics must be carried out in an efficient way that includes the game stages and also the utility function of the service provider. By doing so, the secondary buyers would have no incentives to purchase the video content from the subscribers and will always subscribe to the data plan from the service provider. However, such a strategy may
not always maximize his/her total income, i.e., the price times the number of subscribers. In this section, we consider the scenario where the service provider’s goal is not the prevention of video redistribution but rather the maximization of his/her own income. We include the service provider as a player in the game and find his/her optimal strategies.

A. Pricing Game Model and Evolution Dynamics

Here, we model the video pricing problem for the content owner as a noncooperative game, which can be played several times. For example, in practical scenarios, the service provider can always change the price if the total income is below the expectation. Also, even when the price is fixed, mobile users can change their mind on whether to subscribe to the data plan or to purchase from other subscribers. Such natural repetitions help the players find the equilibrium. The basic elements of the game are listed below:

1). Game Stages: In the video pricing game, the first mover is the service provider, who first sets the price of the video content \( p_o \). Then, \( N_s \) mobile users who are interested in the video content decide whether to subscribe to the video streaming service. Since, based on the analysis in the redistribution of the video content are possible, mobile users also taking into consideration the possible payoffs that they can get in the redistribution network when making the decision.

2). Utility Function Of The Service Provider: Obviously, the content owner’s utility is the price times the number of subscribers, i.e.,

\[
\pi_c = p_o \times N_s
\]

where \( N_s \) is the number of subscribers. With a higher price, there will be fewer subscribers and a smaller \( N_s \) value, particularly when it is possible for mobile users to receive the video content from the redistribution network. Therefore, the service provider cannot arbitrarily increase the data service price \( p_o \) and has to consider mobile users’ utilities. For this the utility function must be included to find for the mobile users and can be done with the equilibrium strategy of mobile users with the help of the data service price.

Conclusion

From the detailed study of the paper, the proposed model has tried to describe the optimal pricing for mobile video data by analyzing the video redistribution network between the data plan subscribers and non-subscribers. From the paper, the proposed model provides a vast elaboration about the analysis of the equilibrium price of the video stream redistributed by the subscribers and secondary buyers. In the entire process, it helped to understand the phenomena of strategic decision making by the utilization of evolutionary Game Theory and from which the strategy known as Stackelburg Strategy can be used for providing the efficient pricing mechanism for the redistribution of the video content. Nevertheless, the service provider should always offer high-quality video stream to prevent the illegal redistribution of video.

Next, we have extended the model by including the content owner in the game and letting the mobile phone users decide whether to subscribe to the data plan. In the extended model, we model the dynamics between the content owner and the users who are interested in the video content, and study how the content owner (the service provider) sets the price for the data plan to maximize his/her overall income. We have used the evolutionary game theory to analyze the evolution of the mobile user’s behavior and have derived the evolutionarily stable equilibrium, which leads to the optimal price for the content owner to maximize his/her total income.

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