www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 2 Issue 4 April, 2013 Page No. 967 -971

Subscriber Theoretic Pricing for Video Streaming In Mobile Networks

P. Supraja[1], Sd. Afzal Ahmed[2], P. Babu[3], P.Radhika[4]

1, M.Tech (CSE), QCET, Nellore
2,3,4, Associate Professor, CSE, QCET, Nellore

Abstract:

Mobile video surveillance represents a new pattern that encompasses, on the one side, ubiquitous video acquisition and, on the other side, ubiquitous video processing and viewing, addressing both computer-based and human-based surveillance. Mobile phones are among the most popular consumer devices, and the recent developments of 3G networks and smart phones enable users to watch video programs by subscribing data plans from service providers. Due to the ubiquity of mobile phones and phone-to-phone communication technologies, data-plan subscribers can redistribute the video content to nonsubscribers. Such a redistribution mechanism is a potential competitor for the mobile service provider and is very difficult to trace given users'high mobility. We analyze the optimal price setting for the service provider by investigating the equilibrium between the subscribers and the secondary buyers in the content-redistribution network.We model the behavior between the subscribers and the secondary buyers as a noncooperative game and find the optimal price and quantity for both groups of users. Based on the behavior of users in the redistribution network, we investigate the evolutionarily stable ratio of mobile users who decide to subscribe to the data plan. 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.

***Index Terms*—Game theory, Mobile video streaming, Pricing, Network Selection**

1. INTRODUCTION

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). Mobile-phone users can watch video programs on their devices by subscribing to the data plans from network service providers and they can easily use their programmable hand devices to retrieve and reproduce the video content. To accommodate heterogeneous network conditions and devices, scalable video coding is also widely used in mobile video streaming. Video applications over mobile devices have drawn lots of attentions in the research community, such as quality measure, and error control. There is also a rich body of literature onuser interactions in electronic commerce in wireless networks such as cooperative content caching in wireless ad hoc network and secure transactions. the mobile network service provider might be more interested in setting the content price to maximize his/her own profit than protecting copyrights. The service provider's profit can be represented as the total number of subscriptions times the content price. If the content price is high, mobile users have less incentive to subscribe to the data plan, which might result in less subscription. However, on the other hand, the content price in the redistribution network may get higher due to less subscribers and more secondary buyers. In such a case, although a subscriber pays more for the video stream, he/she also gets more compensation by redistributing the data. 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, and the secondary buyers who are interested in the video data interact with each other and influence each other's decisions and performance. In such a scenario, the game theory is a mathematical tool to model and analyzes the strategic interactions amongrational decision makers. 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. Due to the small coverage area and the limited power of each mobile device, a subscriber can only sell the content to secondary buyers within his/her transmission range, and the distance between users and the channel conditions dominate users' decisions. Then, 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) for the mobile users, which is the desired stable equilibrium for the service provider.

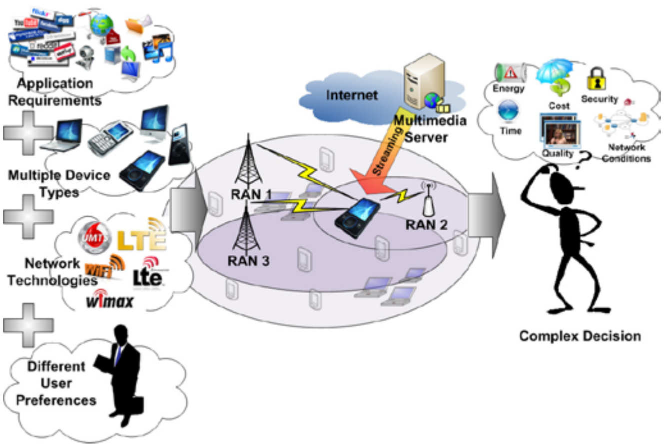

Fig.1: Heterogeneous Wireless Networks Environment - Example Scenario

II. SYSTEM MODEL

The system diagram containes subscribers in the network, who are trying to sell the video content to 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.

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 is widely used in mobile video streaming , secondary buyers can purchase different coding layers of the video from different subscribers and combine these streams during the decoding process.

Fig.2: Example of a mobile video - stream redistribution network

III. OPTIMAL STRATEGIES FOR THE SINGLE-SECONDARY-BUYER CASE

A. Video-Stream Redistribution Game Formulation

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 users' behavior. In addition, since this redistribution is unauthorized and illegal, to minimize their risk of being detected by the

service provider, the participating users (subscribers and secondary buyers) have no incentives to trust one
extra person and the central authority, and a distributed strategy is preferred. 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 willhave 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.

• *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 $P_i^{(max)}$. 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.

• *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 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 .

• *Utility functions of the subscribers*:

Each subscriber 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 , i.e., the cost of power for relaying data, which is determined by the characteristics of the device that subscriber uses.

IV. MULTIPLE SECONDARY BUYER CASE

A. Game Model

Assume that there are N_s subscribers and N_b >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

$$\mathbf{P}^{(j)} = [P_1^{(j)}, P_2^{(j)}, \ldots, P_{N_s}^{(j)}].$$

Where $P_i^{(j)}$ is the power that the secondary buyer *j* plan to purchase from subscriber . With multiple secondary buyers, each subscriber may receive several power purchase orders from different secondary buyers.

B. Mixed-Strategy Equilibrium

The deterministic way to find the optimal strategy is to model the competition among secondary buyers as an auction problem. However, in a fast-changing mobile network, secondary buyers may not have enough interactions to learn how much others value the transmission power and the video bit stream. Also, without a central authorization, the final bided price may not be revealed to all subscribers. Instead, we focus on finding the optimal probability distribution over possible strategies and find the mixed-strategy equilibrium of the game. We will use backward
induction to find the equilibrium. Backward induction first considers any decision that is made just before the end of the game, i.e., after each move stemming from this decision, the game ends. If the player who makes such a decision rationally acts, he/she will choose the best move for himself/herself.
We use an iterative best response algorithm for the secondary buyers to find the probability distribution { $f_m(P^{(m)}$}m€ N_b below.

1) First, calculate the equilibrium power $\mathbf{P}^{(j)*}$ of each secondary buyer B_j based on (12) as a single secondary buyer. Also, let $f_j(\mathbf{P}^{(j)}) = \delta(\mathbf{P}^{(j)} - \mathbf{P}^{(j)*})$ for all $\mathbf{P}^{(j)} \neq \mathbf{P}^{(j)*}$.
2) For each $j \in N_b$, given $\{f_m(\mathbf{P}^{(m)})\}_{m\in N_b, m\neq j}$, solve (24), and update $f_j(\mathbf{P}^{(j)})$.
3) Repeat the aforementioned step until the solutions converge.

Algorithm 1: Probability Distribution

C. Simulation Results

1) Single Secondary Buyer: In our simulations, the secondary buyer is located at the origin (0,0), and the subscribers are initially uniformly distributed in a rectangle of size 100 m by 100 m centered around the origin. The pricing game is played 100 times, and each subscriber changes its location each time the game restarts. For each subscriber, the location change is normally distributed with zero mean and unit variance. The direction of each subscriber's location change follows the uniform distribution

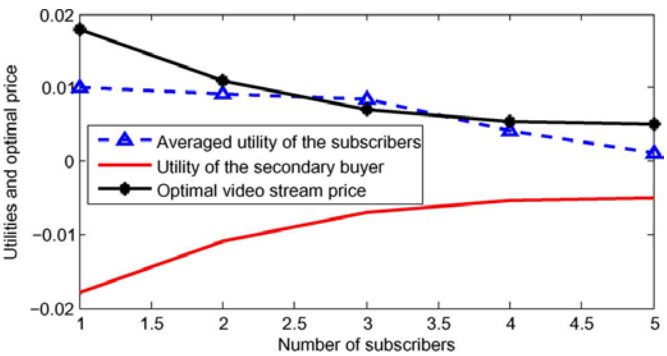

Fig. 3: Utilities of the users and the optimal video-stream price versus different number of subscribers.

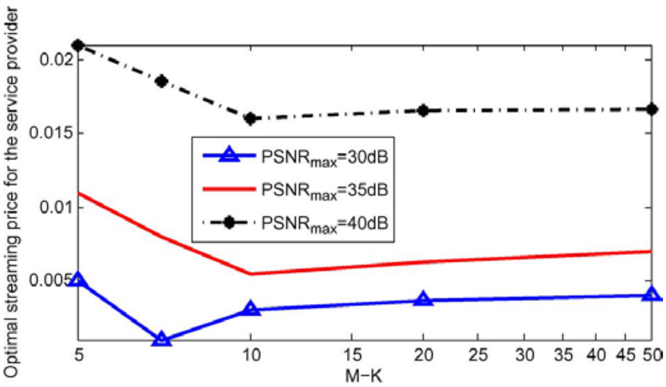

Fig. 4: Optimal video-stream price versus qualities of network and streaming service.

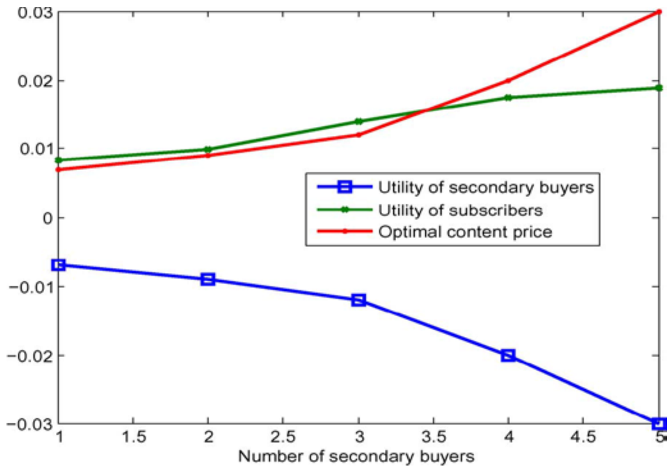

Fig. 5: Utilities of the users and the optimal video-stream price versus different number of secondary buyers with three subscribers.

V. CONCLUSION

The optimal pricing for mobile video data by analyzing the video redistribution network between data-plan subscribers and nonsubscribers. We have first analyzed the equilibrium price of the video stream redistributed by the subscribers given the number of subscribers and secondary buyers. onsequently, the results provide a guideline for the content owner to prevent the redistribution behavior and to maximize the service provider's payoff. The redistribution behavior has been modeled as a Stackelburg game, and we have analyzed the optimal strategies of both subscribers and secondary buyers.

From the simulation results, a secondary buyer will tend to buy more power from subscribers with better channel to maximize his/her utility. If the total number of the subscribers increases, a secondary buyer can obtain a larger utility value, and the payment to each subscriber is reduced due to a more severe competition among the subscribers. Also, when the mobile phone network is crowded, a secondary buyer tends to purchase the video stream from fewer subscribers, and the price for the streaming service can be higher. Nevertheless, the service provider should always offer high-quality video stream to prevent the illegal redistribution of video via such redistribution networks.

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 users' behavior and have derived the evolutionarily stable equilibrium, which leads to the optimal price for the content owner to maximize his/her total income.

VI. REFERENCES

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