Dynamic Pricing Strategies Based on Adaptive Terminals for Wireless Service Providers

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Keywords: Dynamic pricing; Adaptive Terminals; Markov Decision Process, Mobile Edge Computing (MEC).

Abstract: Low latency, low energy consumption and high security make the mobile edge computing (MEC) receive a lot of attention and good comments from art industry in the past few years. However, with task offloading, pricing of data is always a difficulty in MEC. In this paper, dynamic pricing schemes based on adaptive terminals are studied for wireless service providers. Adaptive terminals (ATs) use computational and machine learning technologies to analyze and induce the historical cosmetology records for self-decision making. In the considered model, there is a wireless marketplace monopolized by two competing operators who offer differentiated wireless service to users and price wireless service in different periods. Each user has a valuation on quality of wireless service. ATs will adjust automatically the valuation and make it most suitable for the owners' psychological expectation, then it can help the users determine when to connect to which base station (BS) for maximum individual benefit. Toward this end, the problem is modeled as a Markov decision process. This paper aims at designing an algorithm for finding the two operators' optimal pricing strategies in a competing version.

1. Introduction

In recent years, MEC becomes the emerging trend research topic in most countries for its low latency, low energy consumption and high security and so on [1-2]. The authors in [3] define that MEC is an emergent architecture where cloud computing services are extended to the edge of networks leveraging mobile base stations.

Most research in MEC focuses on task offloading, resource allocation and management, and lowering latency [4-7]. In addition, the authors in [8] develop an user level online offloading framework for MEC, offloading up to 73 percent of computations, and improving the execution time by 50 percent while at the same time significantly reducing the energy consumption of mobile devices; The authors in [9] develop a novel online small-cell base stations peer offloading framework for maximizing the long-term system performance while keeping the energy consumption of small-cell base stations below individual long-term constraints. The authors in [10-11] proposes the edge computing architecture with low energy consumption. Indeed, the authors in [12] proposes human-enabled edge computing that exploits the crowd as a dynamic extension of MEC. However, the traffic accounting were not mentioned for MEC.

In our paper, we will design an algorithm in terms of traffic accounting for operators. The BSs collect the relative data information about adaptive terminals and other competitors and upload them to the MEC server. Then, the server uses the algorithm to calculate the pricing strategies for operators. The application of MEC greatly reduce the energy consumption and network congestion.

2. The optimal strategies studied for multi-period access model

2.1 The multi-period access model

Consider an area monopolized by two competing operators, O_H and O_L. They provide ATs with differentiated quality of data download service (DDS), characterized by data rate, R_H and R_L, respectively. Duration of the whole game is divided into T consecutive periods. Both operators price DDS simultaneously at the beginning of each period. Specifically, the price of DDS offered by O_i (i=H,L) in period t (t=1,2,...,T) is denoted by $p_{t,i}$. We assume the cost is proportional to the quality of DDS, so if the unit cost of DDS offered by O_H is c, that offered by O_L is $c*R_H/R_L$.

The total number of ATs is normalized to 1. Each AT has a valuation, denoted by θ, on the quality of DDS, where θ is supposed to follow a Uniform distribution on [0,1]. If an AT with valuation θ choose O_i (i=H,L) at price $P_{t,i}$ in period t, its surplus is θ- $P_{t,i}$; If it doesn't choose any operator, it earns zero surplus. Suppose that ATs are inter-temporal utility maximizers and receive DDS at most once over the entire game.

We consider the number of remaining ATs having not yet received DDS as the state variable of the current period. If an AT with valuation θ choose O_i (i=H,L) in period t, all ATs with valuations higher than θ must also choose O_i in period t or earlier periods because ATs discount future utilities of DDS, which is characterized by the per-period delay discount coefficient (PDDC) for users, denoted by γ. Therefore, the remaining ATs in period t can be characterized by an interval $[0,\theta_t]$, where θ_t is both the state of period t and the marginal valuation at which an AT is indifferent between receiving DDS in period t-1 and receiving DDS in period t.

The system model is shown in FIG.1.

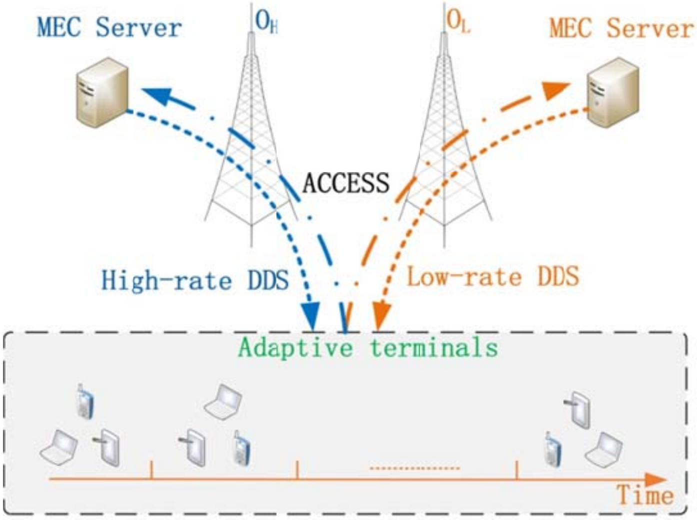

Fig. 1. The Multi-period Access Model.

2.2 Strategy analysis

The problem is modeled as a Markov decision process, whose optimum solution is the Markov perfect equilibrium (MPE). MPE is a subgame perfect equilibrium in Markov strategies. Therefore, we can use backward induction to solve the equilibrium.

2.2.1 Analysis for the Last Period

Given the state variable θ_T and the price pair $P_T=(P_{T,H}, P_{T,L})$, an AT with valuation θ gets surplus $\theta-P_{T,H}$ if it chooses O_H and $R_L/R_H*\theta-P_{T,L}$ if it chooses O_L. Then, we can calculate the middle valuation $\theta_{T,M}$, equal to $R_H*(P_{T,H}- P_{T,L})/(R_H-R_L)$, at which an AT is indifferent between choosing O_H and choosing O_L in the current period. To ensure non-zero profit for both operators, it must be satisfied that $\theta_{T,M} \leq \theta_T$ and $P_{T,L} \leq R_L* P_{T,H}/R_H$. The utility function of both operators in the last period is given by

$$r_{T,H}(\theta_T, P_T) = (P_{T,H} - c)(\theta_T - \theta_{T,M}), r_{T,L}(\theta_T, P_T) = (P_{T,L} - \frac{R_L}{R_H} c)(\theta_{T,M} - \frac{R_H}{R_L} P_{T,L}). \tag{1}$$

Obviously, there exists an unique Nash equilibrium in the last period, then we can get the equilibrium solution by the first derivative. The equilibrium pricing strategy profile is given by

$$\begin{aligned} &P^*_{T,H}(\theta_T) = A_{T,H}(\theta_T - c) + c, P^*_{T,L}(\theta_T) = A_{T,L}(\theta_T - c) + \frac{R_L}{R_H} c, \\ &r^*_{T,H}(\theta_T) = B_{T,H}(\theta_T - c)^2, r^*_{T,L}(\theta_T) = B_{T,L}(\theta_T - c)^2. \end{aligned} \tag{2}$$

Where

$$A_{T,H} = \frac{2R_H - 2R_L}{4R_H - R_L}, A_{T,L} = \frac{R_L}{2R_H} A_{T,H}, B_{T,H} = \frac{2R_H}{4R_H - R_L} A_{T,H}, B_{T,L} = \frac{R_L}{8R_H - 2R_L} A_{T,H}. \tag{3}$$

2.2.2 Analysis for the former t-1 periods

In the multi-period game, there exists a mixed-strategy MPE where the surplus of choosing O_L in the current period might be equal to the surplus of choosing O_H in the next period. Fortunately, we can establish a simple condition that $R_L/R_H \geq \gamma$, under which there exists a pure-strategy MPE. The condition is a natural one because it indicates that ATs prefer choosing low-quality operator now than choosing high-quality operator in the next period if these two options are equally priced.

Consider the game in period t with state θ_t. Suppose the Markov equilibrium in period t+1 is a pure strategy with

$$\begin{aligned} &P^*_{t+1,H}(\theta_T) = A_{t+1,H}(\theta_{t+1} - c) + c, P^*_{t+1,L}(\theta_{t+1}) = A_{t+1,L}(\theta_{t+1} - c) + \frac{R_L}{R_H} c, \\ &r^*_{t+1,H}(\theta_{t+1}) = B_{t+1,H}(\theta_{t+1} - c)^2, r^*_{t+1,L}(\theta_{t+1}) = B_{t+1,L}(\theta_{t+1} - c)^2. \end{aligned} \tag{4}$$

To ensure that only a pure-strategy MPE exists and both operators have positive demand, it must be satisfied that $R_L/R_H-\gamma(1- A_{t+1,H})-2B_{t+1,L}\geq 0$ and $B_{t+1,H}- B_{t+1,L}\leq(R_H-R_L)/2R_H$. Then, the equilibrium in period t can be characterized by

$$\begin{aligned} &P^*_{t,H}(\theta_T) = A_{t,H}(\theta_{t+1} - c) + c, P^*_{t,L}(\theta_t) = A_{t,L}(\theta_t - c) + \frac{R_L}{R_H} c, \\ &r^*_{t,H}(\theta_t) = B_{t,H}(\theta_t - c)^2, r^*_{t,L}(\theta_t) = B_{t,L}(\theta_t - c)^2. \end{aligned} \tag{5}$$

To simplify notations, define $M_{t+1}=R_L/R_H-\gamma(1-A_{t+1,H})$ and $N_{t+1}=3M_{t+1}^2+4(1-R_L/R_H)(M_{t+1}-B_{t+1,L})$. The symbols of (4) are specified by

$$A_{t,H} = \frac{(R_H - R_L)(M^2_{t+1} + N_{t+1})}{2R_H N_{t+1}}, A_{t,L} = \frac{(R_H - R_L)M^2_{t+1}}{R_H N_{t+1}}, \tag{6}$$

$$\begin{aligned} &B_{t,H} = \frac{(R_H - R_L)((M^2_{t+1} + N_{t+1})^2 R_H + 4(R_H - R_L)B_{t+1,H} M^2_{t+1})}{(2R_H N_{t+1})^2}, \\ &B_{t,L} = \frac{(R_H - R_L)M^2_{t+1}(N_{t+1}R_H - M^2_{t+1}R_H - 2(R_H - R_L)(M_{t+1} - B_{t+1,L}))}{2(R_H N_{t+1})^2}. \end{aligned} \tag{7}$$

When $R_L/R_H \geq \gamma$, a unique pure-strategy MPE exists and can be characterized by explicit recursive equations. We can solve the equilibrium by these recursive equations. $A_{T,H}$, $A_{T,L}$, $B_{T,H}$ and $B_{T,L}$ have been given in (3), the sequence of price and profit coefficients, $\{A_{t,i}\}$ and $\{B_{t,i}\}$(t=1,2,…,T-1, i=H,L) can be calculated backwards according to (6) and (7). Noted that $\theta_1=1$, the sequence of states, $\{\theta_t\}$(t=2,3,…,T), are determined forward, based on the equilibrium price (P_{t-}

$_{1,H}$, $P_{t-1,L}$) in the last period.

3. Conclusion

We consider the dynamic pricing strategies based on ATs for two competing operators with differentiated quality of wireless service. An mixed-strategy MPE exists in the game. Furthermore, we give a simple condition for the existence of a unique pure-strategy MPE, which admits explicit recursive expressions. In the competing version, two operators only need to collect relative data information about ATs and another competitor, then send them to the MEC server. The server can calculate the optimal price in each period for the operator by our algorithm, which will contribute to pricing of data in MEC. In the future, we will study a version of the model where one operator unilaterally commits to static pricing and the situation that there are more than one competitor.

Acknowledgments

First and foremost, I would like to show my deepest gratitude to my supervisor, Dr. Huang Bo, a responsible and resourceful scholar, who has provided me with valuable guidance in every stage of the writing of this thesis. I shall extend my thanks to Dr. Li Dapeng for all his kindness and help. Last but not least, I'd like to thank all my friends, especially my roommates, for their encouragement and support.

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