Optimal Contract of P2P Content Distribution

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Abstract

A Peer-to-Peer (P2P) network becomes an increasingly popular content distribution channel. Utilizing the principal-agent model from incentive theory, this paper provides a contract model for a business P2P file sharing networks, in which contracted P2P participants compete for the provision service compensation. Optimal compensation scheme and corresponding capacity effort is presented. It is shown that monopolistic service compensation increases with the dispersion of peer positions and file size, but decreases with the network size and the content availability.

Keywords: P2P networks, content distribution, optimal contract, principal-agent model, tournaments

1. Introduction

A Peer-to-Peer (P2P) network is a social network for pooling resources, such as computing cycle, hard disk storage, network bandwidth, and content, at numerous edge nodes. Each member participating in various dedicated P2P communities leverages the aggregated commons by resource exchanging and information sharing. Business applications of P2P applications include grid computing, instant messaging, collaborating, and file sharing.

Among the various P2P applications, file sharing is probably the most successful and prevalent. However, as a decentralized system, a P2P file sharing network has similar problems occurring in traditional public goods: under-provision and over-consumption on the commons. This phenomenon has been observed and analyzed (Adar and Huberman 2000, Krishnan et al. 2004, Li et al. 2004), and many incentive mechanisms have been proposed to conquer this free-riding problem (Golle et al. 2001, Lai et al. 2003, Antoniadis et al. 2004, Feldman et al. 2004). These existing literatures mainly focus on network efficiency (socially optimum) from the perspective of the value-maximization organization or a network regulator. Regarding P2P market, Antoniadis and Courcoubetis (2002) propose a market model in which peers buy and sell contents competitively within the community, considering variable content transport costs and asymmetric information. Lan and Vragov (2005) develop monopolistic pricing model to compare the profitability between P2P and client server architecture.

In business context, these participating peer nodes and the P2P provider become integrated but independent business units of a digital content supply chain. However, because of the decentralized characteristics of the network, it is difficult to observe the effort of the participating peer nodes, such as the content provision (upload) service. These peer nodes will select to shrink to avoid the cost incurred during file transfer. In order to conquer the hidden action (or moral hazard) problem, utilizing principal-agent model from incentive theory, we propose business contracts between the P2P provider (as the principal) and P2P participants (as the agents). The class of principal-agent problem with moral hazard has been widely used as a representation of various standard economic relations, for example, in the theory of insurance under moral hazard (Arrow 1970, and Spence and Zeckhauser 1971), and in efficiency wage theory (Shapiro and Stiglitz 1984). Utilizing a specific principal-agent model, the tournaments model (Lazear and Rosen 1981, Green and Stokey 1983, and Gibbons 1992), in this proposed contract model, a customer (content request node) should pay the P2P provider content download service fee, whereas the P2P provider needs to pay upload service compensation to the peer node(s) that actually execute(s) the file upload.

The remainder of the paper is organized as follows. Section 2 presents a formal description of the network and contracting models. In Section 3, we present the optimal contract for a monopolistic P2P network. In Section 4, we discuss the optimal network size decision of profit maximization. Section 5 extends the model to a competitive market setting. Section 6 concludes our findings and presents future research directions.

2. The Model

We consider a content-sharing P2P network in which profit-seeking P2P providers (firms) develop a contract (price for a content file download service and compensation for a content file upload service) to support the operations of the online file exchange business. After a content request is initiated, P2P provider searches the content catalog (through central index service or distributed search on the peer nodes), and provides download information (transfer delay estimation) of candidate (satisfied) provision nodes.

2.1. P2P Dynamics and Operating Policies

The operations of a typical P2P file sharing network is simplified as three main procedures: First, a peer node initiates a content request. Then, after searching the profiles of peer nodes, the P2P provider recommends a provision node that has the desired file and is "close" to the request node (determined by the expected file transfer latency between these two nodes). Finally, once this information is passed on to the requesting and provision nodes, download occurs directly between these two nodes. P2P software offers a list of satisfied peer nodes ranked according to estimated transfer speed and approximate delay. The network dynamics and operating policy are specifically described as follows.

Content Provision. Assume there are n active peer nodes and M same-size varieties of content files. Because of the limit of storage capacity and the uncertainty of content availability at the peer nodes, we introduce binary random variables, $x_{i,m}$, to indicate the availability of file F_m *stored* on node i. Explicitly,

$$x_{i,m} = \begin{cases} 1, & \text{if node } i \text{ has file } F_m; \\ 0, & \text{otherwise,} \end{cases} \quad \forall\, i \in \{1,\cdots,n\}, m \in \{1,\cdots,M\}. \tag{1}$$

Let $\beta_{i,m} = E(x_{i,m})$, then they denote the probability that node i has file F_m.

Transfer Delay. P2P technologies utilize the aggregate bandwidth from edge nodes for content transmission to avoid the congestion at dedicated servers. Therefore, the effective bandwidth is scalable with the number of active users. *Transfer delay* in a P2P content distribution network constitutes *provision delay* (denoted as D), and *transmission delay* (denoted as T). Provision delay occurs at the end edge of a provision node. Thus, the content provision performance (upload speed) at a peer node can be improved if he can increase its bandwidth capacity. We denote the effective provision delay at a node j as d_j, which is endogenously decided by node j. Assume the size of a file is f_0 byte and bandwidth capacity is b_j byte/sec, the provision delay at peer node j is calculated as $D_j = f_0 / b_j$. The transmission delay is estimated by comparing the "transmission distance" from locations of the provision node to the request node. Because uptime and location of participating peer nodes are stochastic, the transmission delay between content request node i and provision node j, $T_{i,j}$, is assumed to be an *i.i.d.* random variable with value drawn from a transmission delay density function $f(T_{ij})$. Obviously, the transmission delay for a file is increasing with the file's size and assumed to be linear.

Provision Policy. If more than one node can provide a file, the node with the minimum download delay to the request node will be selected as the provision node. That is, when node i requests file F_m, the P2P provider suggests the optimal provision node j^*, where,

$$j^* = \arg\min_j \left(D_j + T_{i,j}\right) \text{s.t. } x_{j,m} = 1. \quad (2)$$

Here, the request peer node is assumed to be rational and chooses the provision node with the highest quality (fastest transfer speed), according to the information provided by the P2P software.

For the purpose of analytical convenience, we assume the peer nodes are symmetric and all the files have the same popularity $\beta_{i,m} = \beta$, $\forall j \in \{1,\cdots,n\}, m \in \{1,\cdots,M\}$. The value of variable T_{ij} is uniformly–distributed on $[0, f_0\tau]$, where parameter τ is the upper bound of transmission delay per byte. Higher value of τ could be interpreted as larger position dispersion of these uptime peer nodes or traffic congestion on the *public* network domain.

2.2. The Multilateral Contracting Model

P2P networks are self-organizing and operated by independent parties: a P2P provider and many peer nodes. Thus, the service contracting problem can be formulated as a multilateral contracting problem: the principal (the P2P provider) hire many agents (peer nodes) to perform a task (file transfer).

Service Price and Compensation. In order to improve the revenue, the P2P provider has to offer the provision nodes sufficient reward to induce higher effort (i.e. provide higher bandwidth capacity). The rewards include the basic participation compensation, w_0, and service compensation, w_d. All contracted peer nodes will receive w_0 once he accepts the contract, however, only one provision node (with fastest transfer speed) will be chosen to serve the content file uploading, and receives w_d. Thus, the peer nodes do bandwidth capacity competition in order to win the service compensation if it is attractive to the peer nodes.

Stages of the Contracting Game. The time stage of the contracting game is modeled as follows: In the first stage, the P2P provider offers a compensation scheme (w_0, w_d) for content provision service, and advertise the content download service price p. In the second stage, the P2P participants observe the offer, and decide whether to accept the offer or not. If they accept the offer, then they make decision of provision delay quality (bandwidth capacity), and receive the participation compensation w_0 from the P2P provider. In the third stage, the chosen provision node receives the service compensation w_d if file transfer is completed successfully. In the fourth stage, the request node pays the P2P provider content download service fee p.

3. Optimal Contract

In this section, we develop the optimal contract for a monopolistic P2P network, following a specific kind of principal-agent model, a tournaments model (Lazear and Rosen, 1981).

3.1. The Agents' (P2P participant's) Problem

In this section, we analyze the best response capacity function of a peer node, given the compensation scheme offered by the P2P provider. Denote compensation scheme as $\left(w_0*, w_d^*\right)$, and the best provision delay choices of the other peer nodes as $D_j^*, \forall j \neq i$.

Cost of Effort. The participating (sharing) cost for a peer node is defined as opportunity cost of allocating bandwidth capacity for P2P uploading service. Assume the cost of bandwidth capacity is c_b per byte/sec, the participating cost of peer node i is formulated as,

$$C(D_i) = c_b f_0 / D_i \tag{3}$$

.*Reward of Effort.* The expected overall compensation that a typical peer node *i* will earn is written as

$$W(D_i) = w_0^* + \Pr ob\{j^* = i \mid D_i\} w_d^*, \tag{4}$$

where $\Pr ob\{j^* = i \mid D_i\}$ denotes the probability that peer node *i* will be selected as the provision node if provision delay level D_i is chosen, and is explicitly written as

$$\Pr ob\{j^* = i \mid D_i\} = \beta \binom{n-1}{0} (1-\beta)^{n-1} \tag{5}$$

$$+\beta \sum_{k=1}^{n-1} \left(\binom{n-1}{k} \beta^k \cdot (1-\beta)^{n-1-k} \cdot \Pr ob\{D_i + T_{ir} < D_j^* + T_{jr}, \forall j \neq i, |j| = k\} \right).$$

The first term in the right hand side of the equation is the probability that peer node *i* is the only satisfied peer node. The probability function in the second term describes the probability that peer node *i* is the provision node with the fastest transfer speed, given *k* other peer nodes ($k \geq 1$) having the same content file. Thus, this probability function can be further expressed as

$$\Pr ob\{D_i + T_{ir} < D_j^* + T_{jr}, \forall j \neq i, |j| = k\} \tag{6}$$

$$= \int_{T_{ir}} \Pr ob\{T_{jr} > D_i + T_{ir} - D_j^*, \forall j \neq i, |j| = k \mid T_{ir}\} f(T_{ir}) dT_{ir}$$

$$= \int_{T_{ir}} \prod_{j \neq i}^{k+1} \left(1 - F\left(D_i + T_{ir} - D_j^*\right)\right) f(T_{ir}) dT_{ir}$$

, where $f(T_{ir})$ and $F(T_{ir})$ are the PDF and CDF for the transmission delay, which has a uniform distribution. Thus, the probability to be selected as the provision node is determined by not only provision delays of all the participating peer nodes, but also uncertain transmission delay incurred in the public network domain.

Optimal Effort. The tradeoffs facing a P2P participant are the raising of the probability to win the service compensation and corresponding cost of capacity increment. Thus, the utility maximization problem for a typical P2P participant *i* is to select optimal (minimum) provision bandwidth capacity b_i (the maximum provision delay D_i) to achieve the maximum overall compensation. The objective function for participant *i* is formulated as

$$\max_{D_i} U_i = W(D_i) - C(D_i). \tag{7}$$

Given other participants' delay selection, $D_j^*, \forall j \neq i$, P2P participant *i*'s best choice of provision delay D_i^* is determined by solving

$$\frac{\partial U_i}{\partial D_i} = \beta \sum_{k=1}^{n-1} \left(\binom{n-1}{k} \beta^k (1-\beta)^{n-1-k} \cdot \frac{\partial}{\partial D_i} \left(\int_{T_{ir}} \prod_{j \neq i}^{k+1} \left(1 - F\left(D_i + T_{ir} - D_j^*\right)\right) f(T_{ir}) dT_{ir} \right) \right) \cdot w_d^*$$

$$+ \frac{c_b f_0}{D_i^2} = 0. \tag{8}$$

Because the peer nodes are assumed to be symmetric (i.e. $D_i^* = D^*, \forall i$), in Nash equilibrium, we have

$$\frac{\partial}{\partial D_i} \left(\int_{T_{ir}} \prod_{j \neq i}^{k+1} \left(1 - F\left(D_i + T_{ir} - D_j^*\right)\right) f(T_{ir}) dT_{ir} \right) \tag{9}$$

$$= -\int_{T_{ir}} k\left(1 - F\left(T_{ir}\right)\right)^{k-1} f(T_{ir})^2 dT_{ir} = -\frac{1}{f_0 \tau}.$$

Hence, the optimal provision delay of a peer node i is given by the satisfying the following equation,

$$\frac{\beta H(n\text{-}1) w_d^*}{f_0 \tau} = \frac{c_b f_0}{D_i^2}, \forall i, \tag{10}$$

where $H(n\text{-}1) = 1 - (1-\beta)^{n-1}$.

Finally, given the service compensation w_d^*, the best response provision delay and bandwidth capacity of peer node i are derived as,

$$D_i^*\left(w_d^*\right) = f_0 \sqrt{\frac{c_b \tau}{\beta H(n\text{-}1) w_d^*}}; \tag{11}$$

$$b_i^*\left(w_d^*\right) = \sqrt{\frac{\beta H(n\text{-}1) w_d^*}{c_b \tau}}, \forall i. \tag{12}$$

3.2 Principal's (P2P provider's) Problem

Expecting the best response provision delay function $D_i^*\left(w_d^*\right)$, the P2P provider's problem is to choose the optimal compensations w_0 and w_d so as to maximize its profit.

Optimal Compensation. Assume the content value is v, then the highest price a peer node is willing to pay is $p = v - \gamma\left(D+T\right)$, where D and T are the expected provision delay and transmission delay respectively, and γ catches the sensitivity of delay (i.e. the value of time per second). Suppose also that reservation utility for a peer node is U_0, which can be interpreted as the utility a peer node will achieve if he chooses to do other activities, instead of participating in content provision. The profit maximization function of the P2P provider is formulated as

$$\max_{w_0, w_d} \ \pi_m = H\left(n\right) p - n w_0 - H\left(n\right) w_d \tag{13}$$

s.t. $U_i \geq U_0$.

At the optimum, the participation constraint holds with equality:

$$w_0 + H\left(n\right) w_d / n = C\left(D\right) + U_0. \tag{14}$$

Here, the objective function then becomes

$$\max_{D} \ \pi_m = H\left(n\right)\left(v - \gamma\left(D+T\right)\right) - nC(D) - nU_0, \tag{15}$$

so we obtain the profit maximizing provision delay

$$D^* = \sqrt{\frac{n c_b f_0}{\gamma H(n)}}. \tag{16}$$

Thus, the optimal compensation scheme is achieved:

$$w_{0(m)}^* = \sqrt{\frac{c_b \gamma f_0 H(n)}{n}} - \frac{\gamma f_0 \tau H(n)^2}{n^2 \beta H(n-1)} + U_0; \tag{17}$$

$$w_{d(m)}^* = \frac{\gamma f_0 \tau H(n)}{n \beta H(n-1)}. \tag{18}$$

Proposition 1. (Optimal compensation scheme) Service compensation w_d^* increases with the dispersion of peer positions/congestion of the public network and file size (heavy content), but decreases with the network size and the content availability (cache capacity).

The outcome of the subgame perfect Nash equilibrium is the P2P provider offer compensation scheme (w_0^*, w_d^*), then the peer nodes accept the contract and choose optimal bandwidth capacity

$$b_m^* = \sqrt{\frac{\gamma f_0 H(n)}{nc_b}}. \tag{19}$$

Proposition 2. (Optimal provision bandwidth capacity) Provision bandwidth capacity pf a peer node, b_m^* increases with file size (heavy content) and content availability (cache capacity), but decreases with the network size.

It is noteworthy that the configuration of public network (τ) has no impact on the equilibrium provision bandwidth capacity. If time becomes more important, the P2P provider will pay P2P participants higher service compensation to reduce provision delay.

Optimal Quality and Price. Quality of service is evaluated based on the transfer delay a request peer node expects to endure. As defined, transfer delay includes provision delay and transmission delay. Here, we analyze the expected transmission delay. Denote the expected minimum transmission delay among *k* nodes by $T_{\min(k)}$. Using order statistics, we have,

$$T_{\min(k)} = \int_0^{f_0\tau} T_{ij} \cdot k \cdot \left(1 - F(T_{ij})\right)^{k-1} \cdot f(T_{ij}) \cdot dT_{ij} = f_0\tau/(k+1). \tag{20}$$

Next, $T(n)$, the expected transmission delay for a file in the network with *n* nodes can be evaluated as

$$T(n) = E(T_{\min(k)} \mid \text{requested file is available}) = \sum_{k=1}^{n} T_{\min(k)} \binom{n}{k} \beta^k (1-\beta)^{n-k} / H(n).$$

After some simplifications, we have,

$$T(n) = \frac{\left(H(n+1) - n\beta\left(1 - H(n)\right)\right) f_0\tau}{(n+1)\beta H(n)}. \tag{21}$$

Next, we have overall file transfer delay,

$$D(n) + T(n) = \sqrt{\frac{nc_b f_0}{\gamma H(n)}} + \frac{\left(H(n+1) - n\beta\left(1 - H(n)\right)\right) f_0\tau}{(n+1)\beta H(n)}. \tag{22}$$

Then, the P2P provider sets the price of a content download as

$$p_m^* = v - \sqrt{\frac{nc_b\gamma f_0}{H(n)}} - \frac{\left(H(n+1) - n\beta\left(1 - H(n)\right)\right)\gamma f_0\tau}{(n+1)\beta H(n)}, \tag{23}$$

Finally, we obtain profit of the P2P provider,

$$\pi_m^* = H(n)v - 2\sqrt{nc_b\gamma f_0 H(n)} - \frac{\left(H(n+1) - n\beta\left(1 - H(n)\right)\right)\gamma f_0\tau}{(n+1)\beta} - nU_0. \tag{24}$$

Proposition 3. (File transfer quality) Provision delay increases with network size ($\partial D(n)/\partial n > 0$), whereas transmission delay decreases with network size ($\partial T(n)/\partial n > 0$).

The effect of network size on these two kinds of delay can be explained as follows: the probability of wining the service compensation becomes smaller as the network becomes larger;

therefore, a peer node has less incentive to provide higher provision capacity. When more peer nodes join the networks, it is more likely to find a closer provision node which results in the reduction of transmission delay.

4. Optimal Network Size

According to the profit function, the P2P provider faces a problem of deciding an appropriate network size to balance the tension between provision delay and transmission delay so as to minimize overall transfer delay. In this section, we examine the optimal network size (optimal number of provision nodes) that maximizes the profit of the monopolistic P2P provider. We first analyze the impact of scale effect on the resulting provision delay and transmission delay. We examine the optimal number of provision nodes that have the requested file, and compete for the upload service. Notice that given a content request, the peer nodes are categorized as satisfied peer nodes and unsatisfied peer nodes. Here, we assume only the satisfied peer nodes are admitted to make provision capacity decision to compete for the service compensation. Thus, we substitute $\beta = H(n) = 1$ in the results derived above, and rewrite the provision delay and transmission delay as,

$$D(n) = \sqrt{nc_b f_0 / \gamma} \text{ , and } T(n) = \frac{f_0 \tau}{(n+1)\beta}. \tag{25}$$

The profit function of the P2P provider becomes

$$\pi_m^*(n) = v - 2\sqrt{nc_b \gamma f_0} - \frac{\gamma f_0 \tau}{n+1} - nU_0. \tag{26}$$

The optimal number of provision nodes n_m^* is given by solving $\partial \pi_m^* / \partial n = 0$. We have the following observations according to the calculus rule that the impact (i.e. comparative statistics) of the system parameter y on the optimal number of provision nodes is determined by the sign of $\partial^2 \pi / \partial n \partial y$.

Proposition 4. (Optimal network size) The optimal number of provision nodes that maximizes a P2P provider's profit is (a) increases with file size, dispersion of peer positions/congestion of the public network, bandwidth capacity, and value of time (b) decreases with reservation utility (the value of alternative opportunity).

Specifically, when the network size is sufficiently large, we can assume $n+1 \approx n$. If the reservation utility is neglectable (i.e. $U_0 \approx 0$), we obtain the an approximate optimal number of provision nodes,

$$n_{m\ (U_0=0)}^* \approx \sqrt[3]{c_b \gamma^3 f_0^{\ 3} \tau^2}. \tag{27}$$

5. Competitive P2P Networks

It is common that there exist several P2P networks in the market. In this section, we consider two symmetric P2P networks competing for the content distribution service. Our analysis can be naturally extended to a larger number of competing P2P networks. Let n_0 is the total number of P2P participants that have the requested file (satisfied peer nodes), and n^* the optimal number of satisfied peer nodes in a single P2P network. Since the manager of P2P networks control the admission of the satisfied to compete for provision service, only the admitted satisfied peer nodes make provision capacity decision. As we will find, the resulting equilibrium contract is sensitive to total number of the content replicas in the network.

(1) If $n_0 > 2n_m^*$ then both P2P providers will admit n_m^* satisfied peer nodes to join his network since both providers' profits are maximized. Thus, we obtain Pareto Nash equilibrium results:
The P2P provider determines the optimal compensation scheme

$$w_{0(c_1)}^* = \sqrt{c_b \gamma f_0 / n_{c_1}} - \gamma f_0 \tau / n_{c_1}^2 + U_0; \quad (28)$$

$$w_{d(c_1)}^* = \gamma \tau / n_{c_1}, \text{ where } n_{c_1} = n_m^*, \quad (29)$$

and the optimal price of content download

$$p_{c_1}^* = p_m^* = v - \sqrt{n_{c_1} c_b f_0 \gamma} - \frac{\gamma f_0 \tau}{n_{c_1} + 1}. \quad (30)$$

Next , P2P participants' decide the optimal bandwidth capacity

$$b_{c_1}^* = \sqrt{\frac{\gamma f_0}{n_m^* c_b}}. \quad (31)$$

(2) If $n_0 < 2n_m^*$, then both competitive P2P providers have incentive to raise the compensations to attract the provision nodes of his opponent's networks to switch to his network. Similar to the outcome of Bertrand pricing competition of homogeneous products, a P2P networks will attract all satisfied peer nodes if his offer of compensation is slightly higher than his opponent. In symmetry, his opponent will use the same strategy. Consequently, the (participation) compensation is raised until both firms' profits become zero. The corresponding equilibrium compensation scheme is derived as follows. Plugging the service compensation $w_d = c_b f_0^2 \tau / D^2$ into the profit function of a competitive P2P provider, we have the objective function,

$$\max_{D} \ \pi_{c_2} = v - \gamma (D + T) - c_b f_0^2 \tau / D^2 - n_{c_2} w_0. \quad (32)$$

Then, solving $\partial \pi_{c_2} / \partial D = 0$, we get optimal provision delay $D = \sqrt[3]{2 c_b f_0^2 \tau / \gamma}$, and the resulting service compensation offered by each competitive P2P network,

$$w_{d(c_2)}^* = \sqrt[3]{\gamma^2 c_b \tau f_0^2 / 4}. \quad (33)$$

In order to attract more provision nodes to join the network, both competitive P2P providers will raise the participation compensation w_0, As a result, both providers get zero profit ($\pi_{c_2} = 0$) and attract $n_{c_2} = n_0 / 2$ satisfied provision peer nodes, in symmetric equilibrium. Consequently, we have equilibrium participation compensation,

$$w_{0(c_2)}^* = \frac{v - \left(\sqrt[3]{2} + \sqrt[3]{1/4} \right) \sqrt[3]{\gamma^2 c_b f_0^2 \tau}}{n_{c_2}} - \frac{\gamma f_0 \tau}{n_{c_2} \left(n_{c_2} + 1 \right)}, \text{ where } n_{c_2} = n_0 / 2 \quad (34)$$

, and the price of content download

$$p_{c_2}^* = v - \sqrt[3]{2 \gamma^2 c_b f_0^2 \tau} - \frac{\gamma f_0 \tau}{n_{c_2} + 1}. \quad (35)$$

Then, given the compensation scheme, these contracted peer nodes will choose bandwidth capacity,

$$b_{c_2}^* = \sqrt[3]{\frac{\gamma f_0}{2 c_b \tau}}. \quad (36)$$

Proposition 5. (Competitive P2P networks) In duopolistic market, if potential network size is sufficiently large ($n_0 > 2n_m^*$), the equilibrium service compensation and bandwidth capacity decreases with the admitted number of provision nodes. Otherwise, the admitted number of provision nodes has no impact on equilibrium service compensation and bandwidth capacity.

Notice that in competitive market setting, if each P2P networks includes n_m^* provision nodes, the configuration of public network, τ , has no effect on the equilibrium provision bandwidth capacity. The capacity decreases as the position dispersion of peer nodes becomes sparser if the number of admitted provision nodes is smaller than n_m^* .

6. Conclusion

This paper has presented a contract model for business P2P file-sharing networks. This contract allows a P2P provider to induce peer nodes to provide appropriate provision capacity, and the file transfer service quality and profitability are maximized. In this contract, each peer node is given a participation compensation, and receives a service reward after content upload is completed. The linking of technological protocol and economic mechanism operated in a typical P2P network are addressed. In addition to the contract design, we examine the optimal network size for quality service and profitability. Tournaments among peer nodes and competition between duopolistic P2P networks are analyzed.

Our model shows that upload service compensation increases with dispersion of peer positions/congestion of the public network and file size, but decreases with the network size and the content availability. In a duopolistic market, the equilibrium is closely associated with the total number of peer nodes. If potential network size is large, equilibrium service compensation and bandwidth capacity decreases with the admitted number of provision nodes; otherwise, admitted number of provision nodes have no impact on equilibrium service compensation and bandwidth capacity.

The players (P2P participants and P2P providers) in this model are assumed to be symmetric. Examining the impact of heterogeneity of the players (e.g. heterogeneous capacity and security cost structures) on the equilibrium results is a planned future extension. Here, the transmission delay is assumed to be uniform distribution. It is interesting to investigate the corresponding contracts under various distribution functions. Another interesting topic is to study the contract design under asymmetric information scenario in which both adverse selection and moral hazard problems are jointly examined.

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