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Abstract

In this paper, for solving the moral hazard problem of super nodes in VOIP network and achieving better communication quality, we establish a reward mechanism based on classical efficiency-wage models. In the reward mechanism, the function of reward is to encourage super nodes to contribute their bandwidth and cover their effort costs, whereas the function of fine is to prevent opportunistic super nodes from shirking. We consider that network quality and idle bandwidth are the essential criterions for selecting qualified super nodes. Once all super nodes can satisfy specific conditions, the required reward can be derived so as to improve the VoIP platform's revenue. Moreover, we also suggest several targets both in technical and economic view that the platform provider can strive in order to boost his/her market share. In addition, the case of Skype is discussed in this study and we also examine its current pricing strategy.

Keywords: Efficiency-Wage Model, Incentive, Supernode, Skype, VoIP

1 INTRODUCTION

A Peer-to-Peer (P2P) network which is a social network for pooling resources, such as computing cycle, hard disk storage, network bandwidth, and content has been successfully applied in Internet telephone or Voice over Internet Protocol (VoIP). Not only VoIP technology has been investigated from different perspective (Markopoulou et al. 2003, Nguyen & Zakhor 2003, Tao et al. 2005), but also P2P technology has quickly emerged in Internet telephony, where P2P is used for both searching clients and relaying voice packets. The use of a relay allows two nodes that could not otherwise communicate to do so, and can improve the quality of the communication between two nodes by avoiding congested or faulty paths (Feamster et al. 2003). All participants are peers and communicate in the distributed environment to achieve a certain objective such as file sharing or network bandwidth sharing.

The reason for what tremendous people are enthusiastically using VoIP platforms is that people can make free calls over the Internet to other people on the same platforms. Skype, an application of Kazza architecture (http://www.skype.com, http://www.kazaa.com), is the first and successful commercial platform that uses P2P technology in both searching nodes and transmitting voice packets and threatens existing telecommunication operators (GONÇALVES & RIBEIRO 2005). The relayed traffics of Skype (Suh et al. 2006) characterize many different metrics such as start and end time differences, byte size ratio, and maximum cross correlation between two relayed packets. Skype's decentralized structure can automatically appoint super nodes to serve as routers and solve the problem of transmission paths by switching to better paths as the quality degrades in the current path (Guha et al. 2006). It seems to work well; nevertheless, the voice quality of Skype is no better than traditional VoIP platform (Gao & Junzhou 2006).

Any node in the Internet with a public IP address which installs Skype platform may be chosen as a super node by Skype. It is worthy to notice that the role of a super node on the Skype network is critical. First, it solves the problem (Baset & Schulzrinne 2006) that the nodes behind NAT (network address translation) and firewall can't be identified and connected by other outside nodes directly. Second, they form a decentralized network by switching messages to each other and enhance communication quality by offering routing services. However, there exist several problems that remain to be solved. First, once a machine becomes a super node, then its bandwidth, which is extremely expensive, will be used to carry irrelevant traffic. Second, because Skype bypasses network security, such as NAT and firewalls, it poses a security risk and becomes the target for hackers. Moreover, Xie and Yang (2007) point out that the overall VoIP quality of Skype degrades significantly and a large percentage of VoIP sessions will have unacceptable quality when super nodes have limited bandwidth available. In addition, the super nodes that follow an autonomous system policy may refuse to relay traffic for its providers. When the call over the Internet becomes frequent and more users know how to disable the super node setting, the platform provider should propose a mechanism to solve the problem of super nodes in VOIP network.

In this study, we design a reward mechanism based on classical efficiency-wage models to deal with the issue of super nodes. It is obvious that a self-interested node would manage to disable the super node function or restart its computer to avoid relaying large traffic. Therefore, we focus on the following questions and give useful suggestions in this paper. First, how should the reward and fine be set to make each super node behave cooperatively? That is, each node under the reward mechanism would be willing to contribute its bandwidth. Second, in addition to setting a fixed fee which is charged for users, how can a VoIP platform provider boost his/her market share by other approaches? Third, what is the managerial implication in the efficiency-wage model for a competitive VoIP market? The remainder of this paper is organized as follows. In the next section, we review prior research and highlight what influence our study deeply. In section 3, a reward mechanism based on classical efficiency-wage models is introduced. Finally, we conclude our research and provide possible future directions in section 4.

2 LITERATURE REVIEW

In this paper, we design a reward mechanism to eliminate the effect of Moral hazard in VOIP network. Here, the effect of moral hazard in VOIP network refers to the problem of inducing agents (super nodes) to supply proper amounts of bandwidth "when their actions cannot be observed and contracted for directly" (Holmstrom 1982). Prior study has widely used principal-agent models as the solution to induce agents not to shirk work. For example, Feldman et al. (2007) consider a hidden-action problem in network routing where the principal is a pair of communication endpoints that wishes to switch packets over a multi-hop network, and the agents are the links that lie on the path between the endpoint. Each agent may forward the packets at a high priority or not forward them at all; however, the principal can't know whether each agent transits the packet or drops it. If the principal can make an individual *take-it-or-leave-it* offer to each agent and the agents who accept the contract can choose their actions to maximize their expected payoffs based on the payment schedule of the contract, they show that the hidden-action problem can be overcome through appropriate design of contracts by using the model. The phenomenon of moral hazard can also be found in e-commerce trading platforms. For example, although reputation systems can help establish trust and induce cooperation among buyers and sellers in trading platforms, participants in the platforms may report false feedback to the systems. Dellarocs (2005) offers a systematic exploration of reputation mechanism that provides agents with incentives to participate in the mechanism as well as to rate truthfully. His research shows if there is no uncertainty about the seller's type, eBay's mechanism can achieve the maximum possible efficiency. In addition, moral hazard also exists in contract software development. For example, an IT consulting firm may place less-skilled staffs on a project than originally promised and charge its customers at the same hourly rates (Clemons and Hitt 2004).

In order to encourage cooperation or contribution in e-commerce environments, many studies have been proposed to better understand the relevant optimal conditions by conducting relevant economic experiments. Ba et al. (2003) address online auction transaction by assigning a digital certificate to each participant and all participants would behave honestly under their setting. Fan et al. (2005) evaluate and analyze existing mechanisms of online reputation systems based on cooperative feedbacks of past transaction information. They find that existing popular feedback systems do not offer competent incentives for sellers to behave honestly over time. Feldman et al. develop a model (2006) to study the phenomenon of free-riding in peer-to-peer systems. Their results show that penalty imposed on all newcomers is a feasible option in order to avoid whitewashing when the turnover rate among users is not so high. Ma et al. (2007) solve the agency problem between the supplier and the retailer where the downstream enterprises provide financial support for upstream enterprises of a supply chain. They apply comparative static analysis to understand how different parameters, such as the risk aversion degree and the effort cost, influence the expected revenue of the retailer.

One of the most important questions for VOIP platforms, such as Skype, is how to select a subset of the nodes with public IP address to serve as super nodes. The best super node (Lo et al. 2005) would be well-dispersed throughout the peer-to-peer overlay network and can exert additional effort such as load balance, resource needs, adaptability to churn, and heterogeneity. Cicco et al. (2007) find that Skype flows are elastic because it employs some sort of congestion control when sharing the bandwidth with unresponsive flows. However, they also confirm that when more connections are established on the same link, there exists the risk of network congestion collapse. Sat and Wah (2006) also show that Skype has noticeable quality degradations because it only applies a fixed jitter control and ignores the issue of out-of-order arrivals. Therefore, providing incentive for sharing bandwidth becomes an important strategy to improve communication quality.

Indeed, the agents in the principal-agent models can sign a compensation contract that is contingent on outcome, so as to induce effort. However, "it is may be difficult for a court to enforce them, perhaps because the appropriate measure of output includes the quality of output, unexpected difficulties in the conditions of production, and so on" (Gibbons 1992). In fact, even if some form of monitoring mechanism allows the endpoint to detect the location of the failure, some external factors beyond its control, such as network congestion, channel interference, or data corruption, may result in a failure (Feldman et al. 2007). Therefore, the reward in this study is paid to agents in advance to avoid clarifying the responsibility of a failure transmission; meanwhile, if all agents are willing to cooperate at the next stage, they have to pay a fine when a transmission failure occurs at the current stage. Otherwise, they are enforced to exit the platform forever. Our model is similar to traditional efficiency-wage models (Shapiro and Stiglitz 1984). In the efficiency-wage models, firms induce their staffs to work hard by paying high salary and threatening to fire the staffs caught shirking. By using the mechanism, we show that once all super nodes can satisfy specific conditions, the required reward can be derived so as to improve the VoIP platform's revenue.

3 MODEL

We assume that each user may make a phone call over PSTN (public switched telephone network) or make a call over the Internet on a specific platform, such as Skype, to a PSTN telephone number (see figure 1). The phone call offered by a traditional telephone service provider comprises a long-distance call (e.g., an oversea call) and a short-distance call (e.g, a domestic call). At any single slice of time, each user can receive benefit V from using communication services when he/she pays a connection fee to the telephone service provider. The telephone service provider charges p_m and p_l for a short-distance access and long-distance access, respectively. That is, each user's utility is given by $V - p_m - p_l$ at a single slice of time. However, because of P2P, the same function offered by a VoIP platform provider can make a call over the Internet plus a short-distance call so as to save user's expenditure. Although Internet telephone can save user's cost, it also incurs lower or unsettled communication quality resulting from network uncertainty, such as bandwidth, delay, jitter, and packet loss. We denote the network quality as q and the parameter is a measure that describes the possibility of a high quality connection. In other words, the communication quality may be bad with probability $1-q$ when all nodes which constitute a P2P network contribute their bandwidth at a single slice of time. When the communication quality is bad, the sound would be fuzzy and not clear. Also, the connection from a computer to a telephone may be broke. We assume that the sensitivity of communication quality θ is uniformly distributed within an interval $[0,1]$; thus, the value derived from using Internet telephone can be defined by $v_i \equiv V - \theta_i (1-q)\gamma$ where γ measures the loss of value which results from bad communication quality.

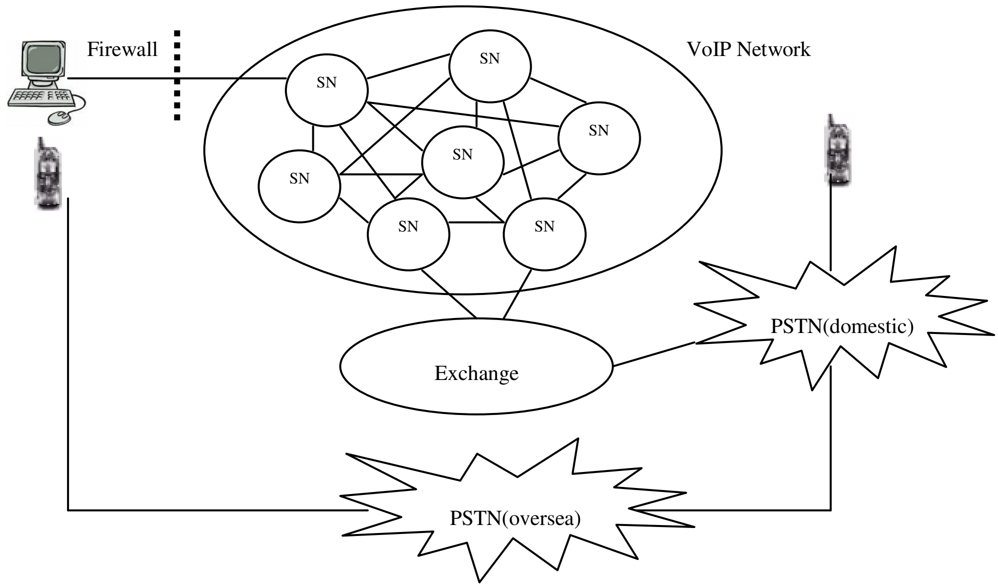

Figure 1

3.1 How does reward mechanism work?

In the P2P network architecture, in addition to coordinating the decentralized communication structure, some nodes, also known as supernodes, own public IP addresses may be forced to play the role of a router to relay packets to other nodes. We assume that most of the nodes are self-interest; therefore, in order to keep the level of communication quality, the VoIP platform provider should offer a reward for these supernodes to encourage their contribution. Consider the following stage game. First, the VoIP platform provider offers the supernode a reward, p_e. Second, the supernode accepts or rejects the platform provider's offer. If the supernode rejects the contract, then the supernode can receive payoff w_i by offering other services at the i slice of time (i.e., self-employed). We assume that w_i's are independently identically distributed random variables with the common distribution of w's.

If the supernode accept p_e, then the supernode chooses either to supply effort (i.e., relay packets) or to shirk (i.e., discard packets). The supernode would entail disutility e when it exerts effort or entail no disutility when it shirks. Here, we assume that supernodes can't offer other services when they do exert effort. These supernodes' effort decisions are not observed by the VoIP platform provider, but the communication quality is observed by both the platform provider and supernodes. When any of the supernodes which comprises a transmission path shrinks, the communication quality must be bad. In order to avoid charlatanism, the platform also asks each supernode which agrees to offer bandwidth to pay a fine F when the communication quality is bad. For the sake of comparison, the fine is defined as $F \equiv k \cdot p_e$. If supernodes refuse to pay the fine when bad communication quality is detected by the

VoIP platform provider, then they would be self-employed always. Otherwise, the VoIP platform provider would believe that the bad communication quality is caused by network uncertainty and then pay rewards for these supernodes at the next slice of time. In the following, we define $\delta \equiv 1/(1+\sigma)$ as the discount factor which reflects the time-value of money, where $\delta \in (0,1)$ and σ is the interest rate.

Lemma 1. When all supernodes adopt a cooperation strategy (i.e., exert effort), the present value of each supernode's payoffs is given by $U_e = \dfrac{(p_e - e) - \delta(1-q)F}{1-\delta}$.

Proof. If all nodes adopt a cooperation strategy, then the probability of bad communication quality is given by $(1-q)$ and the expected value of a fine is given by $(1-q)F$. Because the fine which results from bad communication quality at the current slice of time is paid at the next slice of time, the present value of each supernode's payoff is given by $U_e = (p_e - e) + \delta(U_e - (1-q)F)$, which completes the proof.

Lemma 2. When $k \geq 1$, the supernode adopting a fraud strategy won't pay the fine and its payoff is given by $U_s = p_e + E[w]/(1-\delta)$.

Proof. Not like people employed by a firm, each node adopting a fraud strategy can be self-employed (e.g., receives benefit from offering download services) even if it takes the reward. Because disconnection must be detected by the VoIP platform provider, it faces a fine at the next slice of time. When $k \geq 1$, the node has no incentive to pay the fine and then it would be self-employed always. That is, the present value of its payoff is given by $U_s = p_e + E\left[w_0 + \delta w_1 + \delta^2 w_2 + \cdots\right] = p_e + E[w]\sum_{t=0}^{\infty}\delta^t$, where $E[w]$ is the expectation of w.

The value of k is critical because nobody would prefer cooperation when k is sufficiently large and opportunistic supernodes would take the reward and shirk at each slice of time when k is sufficiently low. The following proposition gives the conditions under which supernodes won't implement a cooperation strategy.

Proposition 1. When $p_e < \dfrac{e}{1-\delta(1-q)k}$, nobody would adopt the cooperation strategy.

Proof. From Lemma 1, it is intuitive that nobody would adopt the cooperation strategy when $U_e < 0$. The inequality $U_e < 0$ implies that $(p_e - e) - \delta(1-q)F \leq 0$.

In fact, $p_e \geq \dfrac{e}{1-\delta(1-q)k}$ is also know as incentive rationality conditions, this constraint ensures that a user would adopt the cooperation strategy if no action is better than exerting effort. From this proposition, we find that the reward increases with the cost of exerting effort, discount factor, and fine and decreases with network quality. When the network environment is of high quality, such as optical fiber network, the function of reward is to cover user's effort cost. Even if the fine is sufficiently high, the reward is still small as long as the network quality is excellent. However, when the network quality is poor, the user who adopts the cooperation strategy would hope to receive a higher reward to cover the expected future loss due to the fine and interest rate. Based on the viewpoint of cost, this proposition suggests that one of the successful factors for implementing the reward mechanism is to choose supernodes in a high quality network environment as more as possible.

Proposition 2. When $p_e \geq \frac{e+E[w]}{\delta(1-(1-q)k)}$, adopting a cooperation strategy is better than a fraud strategy.

Proof. From Lemma 1 and Lemma 2, what a cooperation strategy is better than a fraud strategy means that U_e is higher than U_s. Therefore, we complete the proof by resorting the inequality, $\frac{(p_e-e)-\delta(1-q)F}{1-\delta} \geq p_e + \frac{E[w]}{1-\delta}$.

This constraint, $p_e \geq \frac{e+E[w]}{\delta(1-(1-q)k)}$, also known as incentive compatibility conditions, prevents opportunistic supernodes from adopting a fraud strategy. Comparing Proposition 2 with Proposition 1, we find that the incentive compatibility condition is more rigid than the incentive rationality condition. Furthermore, we find that the discount factor plays an important role in the incentive compatibility condition. First, when the discount factor is sufficiently small, the VoIP platform provider has to offer more reward to make opportunistic supernodes give up shirking. The function of a higher reward is as a signal to let opportunistic supernodes know that it is not smart to put reward in the bank to earn interest. In the real world, the interest rate is so low as to result in high discount factor; therefore, the key factor should be $E[w]$. In other words, the expected present value that surpernodes can acquire by offering other services after using a fraud strategy influences the level of the reward. In a competitive market, in order to implement the reward mechanism, all VoIP platform providers should set a lower job acquisition rate so as to reduce the value of $E[w]$. That is, because of low job acquisition rate, a stable long-time reward becomes alluring and then opportunistic supernodes would exert effort to keep the job. On the other hand, altruist nodes also play a critical role in the reward mechanism. When the number of altruist nodes is large, the demand of effort exerted by self-interest nodes would be so small as to decrease the job acquisition rate.

Lemma 3. In the reward mechanism, the fine is given by $p_e \leq F < \frac{p_e}{1-q}$.

Proof. Indeed, when the fine is smaller than the reward, then the opportunistic supernodes would pay the fine and receive a positive benefit at each slice of time and gain an extra payoff by offering other services. On the other hand, when the find is larger than $\frac{p_e}{1-q}$, no matter which strategy the supernodes adopts, there exists no such a reward that can make sueprnodes receive positive payoff. Therefore, they become self-employed when the fine is sufficiently high.

3.2 Whether it is a smart strategy to charge a fixed fee?

Now, we have derived the key conditions such that the supernodes are willing to play the cooperation strategy. Next, we stand on the viewpoint of users and derive an equilibrium results. First, because the telephone service provider offers a high quality service, they can charge a higher fee to maximize their profit. On the contrary, the VoIP platform provider should set a lower fee to attract users who doesn't care about quality. In practice, the platform often charges a fixed fee p_c when a phone call connection over the Internet is established. On the other hand, the reward paid to supernodes can in turn be passed on to users who use the Internet telephone. However, in order to avoid congestion and improve communication quality, the platform provider can use a complex algorithm to allocate routing paths dynamically. That is, at each slice of time, the transmission path may not be the same and the number of supernodes changes with time. Therefore, we denote n_i as the number of supernoes at the i slice of time and assume that n_i 's are independently identically distributed random variables with the common distribution of n 's.

Proposition 3. For a user with the network quality sensitivity θ_i , if he is willing to use Internet telephone, his/her value v_i derived from the communication service offered by the VoIP platform provider should be higher than $(1-\delta) p_c + p_m + E[n] p_e$.

Proof. In an infinite repetition of a stage game, a player's time-weighted average payoff can be defined as $\overline{u} = (1-\delta)U$ where $U = \sum_{t=0}^{\infty} \delta^t u_t$. Because of $\sum_{t=0}^{\infty} \delta^t u_t = U = \sum_{t=0}^{\infty} \delta^t \overline{u}$, maximizing U is equivalent to maximizing $\overline{u}$ (Ba et al. 2003). Therefore, for a user with the network quality sensitivity θ_i , his/her expected lifetime average payoff is:

$$\overline{v}_i = -(1-\delta) p_c + (1-\delta) E\left[(v_i - n_0 \cdot p_e - p_m) + (v_i - n_1 \cdot p_e - p_m)\delta + (v_i - n_2 \cdot p_e - p_m)\delta^2 + \cdots\right]$$

$$= -(1-\delta) p_c + (1-\delta)(v_i - p_m - E[n] p_e)\sum_{t=0}^{\infty} \delta^t$$

$$= -(1-\delta) p_c + (v_i - p_m - E[n] p_e)$$

as $t \to \infty$. Actually, what the number of stages is infinite is impossible; however, when the slice of time is tiny, the number of the stages can be viewed as infinite. Therefore, by $\overline{v}_i > 0$ we complete the proof.

In Proposition 3, we find that the platform provider charges a fixed fee p_c is a smart strategy because the fee is nothing when the discount factor is sufficiently high. In addition, the higher number of supernodes can help the platform provider gain more profit. First, the increasing number of altruist nodes can reduce the expected number of supernodes which should be paid the reward. Second, if the platform can steal bandwidth from supernodes without signing the contract and these supernodes are hard to find that it is being forced to offer routing services, the platform provider can make maximal profit by this way. Because the traffic is shared by all supernodes, when the number of supernodes is sufficiently high, even if they restart their computers when they do find that their network performance is not normal, the connection can be taken over by other supernodes instantaneously.

Theorem 1 As long as $\overline{\theta} > 0$ and the following conditions are satisfied, the users with the network quality sensitivity $\theta_i < \overline{\theta}$ use VoIP services, whereas the users with the network quality sensitivity $\theta_i > \overline{\theta}$ use the traditional telephone services:

$$\frac{e + E[w]}{\delta(1-(1-q)k)} \le p_e \le F < \frac{p_e}{1-q}, \text{ and} \tag{1}$$

$$\overline{\theta} = \frac{p_l - (1-\delta) p_c - E[n] p_e}{(1-q)\gamma}, \text{ and} \tag{2}$$

Proof. In addition to $\overline{\theta}$, Theorem 1 is based on the above Propositions and Lemmas. From the proof of Proposition 2 and the proof of Lemma 3, we obtain condition (1). The value of $\overline{\theta}$ is given by solving $V - p_m - p_l = -(1-\delta) p_c + v_i - p_m - E[n] p_e$; in other words, the user with $\theta_i = \overline{\theta}$ is indifference between using Internet telephone and general telephone. Therefore, the average payoff per period for each supernode is given by $\left(p_e - e\right) - \delta\left(1-q\right)F$ and the average utility per period for each user is given by $v_i - p_m - E\left[n\right]p_e - \left(1-\delta\right)p_c$.

3.3 Implication discussion

In practice, the roles of the traditional telephone service provider and VoIP platform provider are the incumbent and entrant, respectively. This equilibrium result offers some useful implications. First, when the network quality is perfect, the telephone service provider would face the most serious challenging which stems from the Internet telephone. However, although the telephone service provider may lose the market of long-distance access, he/she still make profits from short-distance access because each call over the Internet on the platform to a PSTN telephone number still needs the short-distance access. That is, because of the advantage of first mover, the traditional telephone service provider locks most users in the world in. On the other hand, the faction that people use the VoIP platform also influences both providers' profits. Therefore, free platform policy becomes a useful strategy for the VoIP platform provider to take the communication market share. On the other hand, because reducing user's loss of value which results from bad communication quality can increase VoIP's market share, the VoIP platform provider has several targets which is worthy to strive. First, the VoIP platform provider can enhance its voice compression algorithm so as to reduce the impact of network quality on communication quality. Second, in the current IPv4 architecture (Internet Protocol version 4), all nodes adopts best effort strategy and compete bandwidth with others. Therefore, IPv6 architecture, the next generation IP protocol, should be promoted intensively because it has been designed with network-layer QoS functions. Third, communication quality, sometimes, is determined by the quality of client's network environment, not the quality of backbone network. Thus, the VoIP platform provider may charge different connection fees based on user's network environment. Finally, from the viewpoint of economics, the payment collected from the fine can be served as compensation to users for disconnection without warning or bad communication quality.

4 CONSLUSION

In this paper we establish a reward mechanism based on classical efficiency-wage models for solving the problem of super nodes and achieving higher communication quality. In the reward mechanism, the function of reward is to encourage super nodes to contribute their bandwidth and cover their effort cost, whereas the function of fine is to prevent opportunistic super nodes from shirking. In order to guiding self-interested super nodes to exert effort, a VoIP platform may select qualified super nodes based on the following suggestions. First, a super-node candidate is characterized by superior network quality. Excellent network quality not only reduces the payment of reward, but also boosts VoIP platform's market share. Second, a super-node candidate should has a smaller opportunity cost. That is, the super-node candidate should have lots of idle bandwidth usually. The super-node candidate would lose the opportunity of gaining a reward periodically once it adopts a fraud strategy; thus, it would always contribute bandwidth as long as its expected self-employed payoff is not so high. Moreover, we also offer a managerial insight about a competitive VoIP market. In a competitive VoIP market, these VoIP platform providers should achieve a common consensus of setting a lower job acquisition rate. Higher job acquisition rate is equal to encourage these super nodes which sign contracts violate the contracts because they have incentive to shirk while they can acquire new job easily. Moreover, we also suggest several targets both in technical and economic view that platform provider can strive in order to boost its market share.

In our setting, the prices of traditional telephone service are exogenous; thus, there exists a dynamic competition issue in the communication industry. Actually, the reward mechanism we propose can maintain a cooperative relationship between the VoIP platforms and super nodes. However, if the VoIP platforms can steal bandwidth from its super nodes and switch transmission paths as current communication quality degrades, what is the key that make the VoIP platforms consider utilize a reward contract to achieve stable and even excellent communication quality? Therefore, one of the future studies is to better understand the condition under which the VoIP platform provider can make more profit by offering a higher communication quality. Moreover, once the relation between the number of super nodes and communication quality is established, how does the reward and fine change? In the further work, we would discuss the relationship and understand the dynamic rule behind the model.

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