A User-Influenced Pricing Mechanism for Internet Access

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Abstract. Proper pricing schemes are vital components to the continuing success of the Internet. In this paper, we propose a new pricing scheme for Internet access called user-influenced pricing. Our main contribution is threefold: first, we show how user-influenced pricing can provide the ISP with calculable revenues, while giving the users a chance to lower their costs via voting for their preferred pricing scheme. Second, we develop a cooperative weighted voting game which models the decision-making process, and we derive equilibrium solutions to analyze possible outcomes of the vote. Third, we investigate the distribution of power and we show that users with medium generated traffic volume are pivotal to the outcome. Finally, we discuss the practical feasibility of the proposed mechanism regarding user population, revenue planning and charging.

1 Introduction

Advances in networking technology and affordable service prices are continuing to make the Internet a success story both for users and network providers. However, the recently emerged net neutrality debate has shed light on some problems of Internet Service Providers (ISPs) [1]. Since flat-rate billing is dominant and user traffic keeps on growing [14], ISPs get lower profits per data unit carried. An increasing number of news and studies report on the techniques ISP are beginning to look at and use to keep themselves profitable: these include traffic discrimination, introducing download caps and experimenting with alternative pricing schemes (e.g., usage-based pricing, three-part tariffs and charging content providers) [2]. In parallel, there is an ongoing global economic crisis of unseen proportions folding out in the recent months. This downturn makes people think twice about spending more than they absolutely have to. Consequently, ISPs may have to face the fact of decreasing popularity of their services among users. Since economic analysts cannot really predict the length of the global crisis, ISPs have to prepare for a user demand-driven market resulting in diminishing profits, and similarly, customers have to minimize their Internet access costs for an extended period of time.

There is extensive research work dedicated to pricing network services. Some of the papers propose sophisticated pricing models for ISPs to extract consumer

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surplus [4] [5] [7]. Others argue that simple pricing plans are the only viable ones, since there is a clear user preference towards them [3] [6]. In [8] authors establish the "Price of Simplicity" (PoS) referring to the difference in revenues between a simple pricing scheme (flat-rate) and the maximum achievable revenue. Furthermore, they characterize a range of environments, where PoS is low, i.e., flat-rate pricing is efficient. The authors of [9] show how ISPs can charge content providers for terminating their traffic at their users creating extra income if no net neutrality is enforced.

We take a different approach: our goal is to give ISPs the benefit to plan their revenues, while giving a freedom of choice to the users to shape their own monthly cost. In a certain sense this approach has something in common with packet auctions [5] [7]: we involve users in the pricing process. On the other hand, we do not use a sophisticated auction scheme which makes it harder both for ISPs and users to plan/estimate their revenues and costs, respectively [3]. We also note that in these economically hard times users generating a low traffic volume have a strong incentive to be billed proportionally to traffic volume, contradicting the findings of [6]. Heavy users, of course, prefer sticking to flat rates.

In this paper we propose a user-influenced pricing scheme for ISPs. First, the ISP determines the amount of income it wants to collect in the next billing period, and announces it to the forum of its users. At the same time, it announces the pricing schemes the users can choose from. In this paper we restrict the selection to simple flat-rate and usage-based schemes due to space constraints and tractability. Second, users vote for their preferred pricing scheme. Simple majority decides the outcome of the vote. Finally, the ISP implements the chosen billing method and bills its service accordingly. This simple scheme enables ISPs to get a fixed revenue that can be planned in advance, and gives incentive to users of the same traffic category to cooperate in order to achieve lower monthly costs. We analyze the possible outcomes of the vote in the presence of different user distributions, where different class of users dominate the population.

The remainder of this paper is structured as follows. We introduce the concept of user-influenced pricing in Section 2. A game-theoretical model of the voting process is proposed in Section 3. We study the equilibrium solutions in Section 4. The distribution of voting power is derived using the Shapley value approach in Section 5. Section 6 discusses practical issues, and finally, Section 7 concludes the paper.

2 User-Influenced Pricing

Here we describe how a service provider can use user-influenced pricing to bill its customers. As a first step, the ISP has to set a goal for the next billing cycle (e.g., one month), how much revenue R it wants to collect. This depends on a number of factors. From Section 3 in this paper we do not consider multiple ISPs competing for the same set of users, rather a single ISP in a monopolistic setting. Nevertheless, here we mention that choosing a very high R would certainly drive users away, so there is an incentive to keep the expectations reasonable.

Second, the ISP announces R to its users along with the possible billing options: flat-rate (F) and usage-based (U). Then users vote for the billing scheme they like. We assume that voting is mandatory, non-voting users are punished to pay according to the pricing scheme that is worse for them (e.g., usage-based for non-voting heavy users). The ISP summarizes the votes and announces the chosen pricing scheme for the upcoming billing cycle. During the vote, users can motivate other users to vote with them. We assume that users can utilize financial incentives (side-payments) to sweeten the deal for others, while still profiting from the outcome of the vote.

Third, users use their subscription and pay according to the implemented pricing scheme chosen by the user community. We assume that the decision on the applied billing method does not affect user behavior during the billing cycle. Note that in the rest of the paper we put the voting at the beginning of the billing period because of conformity; however, putting it at the end of the billing period would anneal the need for the above assumption on user behavior.

3 The Game

This section presents a game-theoretical representation of the user-influenced pricing game. Suppose that there is a single ISP on the Internet access market selling a single-tier service. There are n customers, each of them with a fixed monthly traffic amount τ_i measured in bytes. The ISP's goal is to get a monthly revenue of R while serving a traffic volume of T, and it does not care about how users share this total cost. The ISP lets the users decide on the applied pricing scheme: it can be either flat-rate (F) or usage-based (U). The simple majority wins and their preferred pricing scheme will be used to bill all customers. We use a cooperative game with transferable payoffs to model this decision-making process.

3.1 Players

Today's typical ISP has a very diverse set of users. Some users download massive amounts of data via peer-to-peer file sharing systems such as BitTorrent, watch streaming videos frequently through sites like YouTube and play multiplayer online games (e.g., World of WarCraft). Those customers are considered heavy users, they can impose a monthly traffic amount of several hundred of gigabytes on the ISP's network. An other category consists of light users: they just browse the Web and send a couple of e-mails. Light users usually have a monthly traffic amount around 5-10 gigabytes. Somewhat forgotten, between the above categories are people who use their Internet access in an "average" sense. That means an occasional movie download, contacting their relatives via some VoIP application (e.g., Skype), using one or two social networking sites, such as Facebook or MySpace, to keep in touch with friends and colleagues. Those customers are referred to as medium users.

These three groups have different interests when it comes to pricing schemes applied. Obviously, heavy users want to pay a fixed monthly rate, since their traffic volume is high, so paying per byte would result in huge bills for them. Conversely, light users are interested in paying on-the-go. Since it is likely that they never really consume the bandwidth equivalent of the flat-rate price, they prefer to pay proportionally to their traffic volume. We assume that medium users are indifferent: they pay more or less the same price regardless of the applied pricing scheme.

To reduce the complexity of the game and to provide intuitive results, we model this voting as a three-player game [10]. Player 1 represents the heavy users preferring flat-rate pricing. Let the ratio of heavy users among all consumers be $0 \leq w_1 \leq 1$. Similarly, the ratio of the whole monthly traffic volume imposed on the ISP by heavy users is $0 \leq t_1 \leq 1$.

Player 2 stands for the class of medium users. Their ratio compared to the whole customer population is $0 \leq w_2 \leq 1$. They generate a traffic ratio of $0 \leq t_2 \leq 1$.

Player 3 represents the class of light users preferring usage-based pricing. Their ratio among all users is $0 \leq w_3 \leq 1$, while their traffic ratio is $0 \leq t_3 \leq 1$.

Note that we classify every user as heavy, medium or light, therefore $w_1 + w_2 + w_3 = 1$ (all users are represented), furthermore $t_1 + t_2 + t_3 = 1$ (all traffic is accounted for). An interesting question is how the actual values of parameters w_i and t_i should be chosen. We do not make any further assumptions in our analysis to maintain the generality of our model, but we discuss realistic parameters in Section 6.

Certainly, we lose some behavioral details by introducing our assumptions and simplifications, e.g., by assuming that medium users are indifferent to the actual pricing scheme. Therefore, our results are intended to be qualitative, i.e., we concentrate on the rough behavior of the pricing mechanism and the players.

3.2 Strategies and the Characteristic Function

We treat the user-inferred pricing problem as a majority voting game. In our case there is one significant difference to a general cooperative game: the strongly opposed interests of two players, i.e., heavy and light users, induce some non-cooperative aspects referred to as *quarreling*.

The possible coalitions in a general three-player cooperative game are: $\{\{1\}, \{2\}, \{3\}, \{12\}, \{13\}, \{23\}, \{123\}\}$. In our game, heavy users (Player 1) and light users (Player 3) are strategically opposed, thus they will never be a part of the same coalition. Additionally, since there are only two pricing methods offered by the ISP, medium users (Player 2) will always cast a vote, either for flat-rate or usage-based pricing. These constraints eliminate the chance of forming a *grand coalition*, the coalition of $\{2\}$ and also the coalition of the two extremists. The remaining possible coalitions are: $\{\{1\}, \{3\}, \{12\}, \{23\}\}$.

Heavy users clearly choose flat-rate pricing (F), on the other hand, light users always prefer usage-based pricing (U). Since Player 2 is indifferent in choosing either side, the other two players have to give him some incentive to join forces. We model this as a side-payment, which reduces the costs of Player 2. Giving a large side-payment can be crucial to winning the voting game, nevertheless none of the two quarreling players can pay more for the vote of Player 2 than their payoff expected from the ISP implementing their preferred pricing scheme. Heavy users can offer a side-payment s_1 in the range $[0,(t_1-w_1)R) \equiv S_1$, where S_1 is the strategy set of Player 1 in the voting game. It is easy to see that the upper limit of the side-payment corresponds to Player 1's profit due to flat-rate pricing. Similarly, the side-payment offered by Player 3 is $s_3 \in [0,(w_3-t_3)R) \equiv S_3$, where the upper limit is Player 3's profit due to usage-based pricing and S_3 is the strategy set of Player 3. Considering Player 2, we assume that the vote and the side-payment are exchanged at the same time ensuring that Player 2 can only accept one side-payment and it has to vote accordingly. So Player 2's strategy set is $S_2 \equiv \{F,U\}^{S_1 \times S_3}$, i.e., all functions mapping side-payments to votes.

We can now define the payoffs of each player formally. The payoff of heavy users (Player 1) is:

$$\Pi_1(s_1,s_2,s_3) = (t_1-w_1)RI_1 - s_1 I_2 \tag{1}$$

where

$$I_1 = \begin{cases} 1 & \text{if Player 1 wins} \\ 0 & \text{otherwise} \end{cases}$$

and

$$I_2 = \begin{cases} 1 & \text{if } s_2 = F \\ 0 & \text{if } s_2 = U \end{cases}$$

The payoff of light users (Player 3) is:

$$\Pi_3(s_1,s_2,s_3) = (w_3-t_3)R(1-I_1) - s_3(1-I_2) \tag{2}$$

Note that indicator variables are complemented due to opposing conditions.

Player 2's payoff is the following:

$$\Pi_2(s_1,s_2,s_3) = \begin{cases} s_1 & \text{if } s_2 = F \\ s_3 & \text{if } s_2 = U \end{cases} \tag{3}$$

Now we formulate the characteristic function using the standard approach, keeping in mind that certain coalitions of players are not reasonable because of quarreling. Those coalitions receive zero utility, formally:

$$\nu(H) = 0 \quad | \quad C \notin \{\{1\},\{3\},\{12\},\{23\}\} \quad \text{and} \quad H \in 2^N. \tag{4}$$

For the reasonable coalitions the corresponding utilities are:

$$\begin{aligned}
\nu(\{1\}) &= \max_{s_1} \min_{s_2,s_3} \Pi_1(s_1,s_2,s_3) \\
\nu(\{3\}) &= \max_{s_3} \min_{s_1,s_2} \Pi_3(s_1,s_2,s_3) \\
\nu(\{12\}) &= \max_{s_1,s_2} \min_{s_3} [\Pi_1(s_1,s_2,s_3) + \Pi_2(s_1,s_2,s_3)] \\
\nu(\{23\}) &= \max_{s_2,s_3} \min_{s_1} [\Pi_2(s_1,s_2,s_3) + \Pi_3(s_1,s_2,s_3)]
\end{aligned} \tag{5}$$

Table 1. Characteristic function for the user-influenced pricing game (w_1 and t_1 are the population ratio and traffic ratio of heavy users, while w_3 and t_3 are those of the light users, respectively)

Characteristic function	Heavy user regime ($w_1 > 1/2$)	Balanced regime ($w_1 < 1/2, w_3 < 1/2$)	Light user regime ($w_3 > 1/2$)
$\nu(\{1\})$	$(t_1 - w_1)R$	0	0
$\nu(\{3\})$	0	0	$(w_3 - t_3)R$
$\nu(\{12\})$	$(t_1 - w_1)R$	$(t_1 - w_1)R$	0
$\nu(\{23\})$	0	$(w_3 - t_3)R$	$(w_3 - t_3)R$
$\nu(H)$ for all other $H \in 2^N$	0	0	0

Using Equations 4 and 5 we compile the characteristic functions presented in Table 1. Different columns represent different user distributions in the population. If heavy users are a majority ($w_1 > 1/2$) they will dominate voting (heavy user regime). If light users are a majority ($w_3 > 1/2$) they will be the dominant player (light user regime). If neither of the above are true ($w_1 < 1/2, w_3 < 1/2$, but due to constraints of w_i, $w_1 + w_2 > 1/2, w_2 + w_3 > 1/2$), the players enter a balanced regime, where the outcome of the pricing game will be decided by the offered side-payments.

4 Equilibrium Solutions

Here we derive the equilibrium solutions for the user-influenced pricing game G. Since G includes players that will never form a coalition, we employ the notion of ψ-allowable coalition structures [12]. Let P be a partition of N, called a *coalitional structure*. The possible partitions are: $\{\{1\},\{2\},\{3\}\}, \{\{12\},\{3\}\}, \{\{1\}, \{23\}\}, \{\{123\}\}$. Then we define the set of *allowable coalitional structures* ($\psi(P)$) that satisfy the constraints imposed by quarreling. For G

$$\psi(P) = \psi = \{(\{12\},\{3\}),(\{1\},\{23\})\}. \tag{6}$$

For a given $P \in \psi$, let $X(P)$ be the set of imputations as follows:

$$X(P) = \{(x_1, x_2, x_3) \in R^3 \mid \sum_{i \in H} x_i = \nu(H) \text{ for all } H \in P \text{ and } x_i \geq \nu(\{i\}) \text{ for } i = 1, 2, 3\} \tag{7}$$

Intuitively an imputation is a distribution of the maximum side-payment such that each player receives at least the same amount of money that they can get if they choose to stay alone (individual rationality), and each coalition in the structure P receives the total side-payment they can achieve (group rationality).

Now, we restrict the set of imputations to the *core* $C(P)$. The core is defined to be the set of undominated imputations. To put it differently, the core is the set of imputations under which no coalition has a value greater than the sum of its members' payoffs. Formally:

$$C(P) = \left\{ (x_1, x_2, x_3) \in X(P) | \sum_{i \in H} x_i \geq \nu(H) \text{ for all } H \in \bigcup \{J \in P \mid P \in \psi\} \right\} \tag{8}$$

Considering our game G, Equation 8 is equivalent to the standard core (since $\nu(H) = 0$ for unreasonable coalitions), so

$$C(P) = \left\{ (x_1, x_2, x_3) \in X(P) \mid \sum_{i \in H} x_i \geq \nu(H) \text{ for all } H \in 2^N \right\} \tag{9}$$

As it can be noticed the core is dependent on a certain coalitional structure P. For us to determine which structure will emerge when playing the game, we define a ψ-stable pair $[\overline{x}, P]$:

$$[\overline{x}, P] \mid \overline{x} \in C(P), P \in \psi \tag{10}$$

Now applying this solution to the characteristic function $\nu(H)$ in Table 1, we have three different cases depending on user regimes.

4.1 Heavy User Regime

In this case heavy users are dominant in the population, thus $w_1 > 1/2$. The only possible imputation is $\overline{x} = ((t_1 - w_1)R, 0, 0)$ hence there are two ψ-stable pairs:

$$[((t_1 - w_1)R, 0, 0), \{\{12\}, \{3\}\}] \text{ and } [((t_1 - w_1)R, 0, 0), \{\{1\}, \{23\}\}]$$

Note that both coalitional structures are possible, since it does not matter which side medium users take.

In words, this means heavy users dominate the voting, no side-payment is transferred. Considering the individual user's point of view, let c_i denote the cost of a single user i. Flat-rate pricing is implemented by the ISP, Internet access costs are shared per capita, hence the cost for a single user is independent of his traffic and equal for every user is

$$c_i = \frac{R}{n} \text{ for all } i \in N \tag{11}$$

4.2 Light User Regime

Here light users have the absolute majority across the population ($w_3 > 1/2$). Following the same line of thought as in Section 4.1 we derive the ψ-stable pairs for this case:

$$[(0, 0, (w_3 - t_3)R), \{\{1\}, \{23\}\}] \text{ and } [(0, 0, (w_3 - t_3)R), \{\{12\}, \{3\}\}]$$

As expected light users dominate the voting, no side-payment is made to medium users. From a single user's perspective, let τ_i denote the traffic volume of user i. Since usage-based pricing is implemented by the ISP, Internet access costs are shared proportionally to traffic volume. Therefore the access cost for user i is

$$c_i = \frac{\tau_i}{T} R \text{ for all } i \in N. \tag{12}$$

4.3 Balanced Regime

In this case cooperation is explicitly needed to form a winning coalition, since $w_1 < 1/2, w_3 < 1/2$, and $w_1 + w_2 > 1/2, w_3 + w_2 > 1/2$. Side-payments determine the outcome of the voting game. For easier analysis let $s_1^{\max} = (t_1 - w_1)R$ and $s_3^{\max} = (w_3 - t_3)R$ be the maximum reasonable side-payment possibly offered by Player 1 and Player 3, respectively. The imputations and the core for any $s_1^{\max}, s_3^{\max}$ are :

$$X(\{1\},\{23\}) = \{(x_1, x_2, x_3) \in R^3 \mid x_1 = 0, x_2 \geq 0, x_3 \geq 0, x_2 + x_3 = s_3^{\max}\}$$

$$C(\{1\},\{23\}) = \begin{cases} \emptyset, & \text{if } s_1^{\max} > s_3^{\max} \\ (0, s_1^{\max} + \epsilon, s_3^{\max} - s_1^{\max} - \epsilon), & \text{if } s_3^{\max} \geq s_1^{\max} \end{cases}$$

where $0 \leq \epsilon \leq s_3^{\max} - s_1^{\max}$. Furthermore:

$$X(\{12\},\{3\}) = \{(x_1, x_2, x_3) \in R^3 \mid x_1 \geq 0, x_2 \geq 0, x_3 = 0, x_1 + x_2 = s_1^{\max}\}$$

$$C(\{12\},\{3\}) = \begin{cases} \emptyset, & \text{if } s_1^{\max} < s_3^{\max} \\ (s_1^{\max} - s_3^{\max} - \epsilon, s_3^{\max} + \epsilon, 0), & \text{if } s_1^{\max} \geq s_3^{\max} \end{cases}$$

where $0 \leq \epsilon \leq s_1^{\max} - s_3^{\max}$.

Let us first study the coalitional structure $(\{1\},\{23\})$. The core is empty if the maximum side-payment of Player 3 is smaller than that of Player 1. This is due to the fact that Player 2 wants to form a coalition with Player 1 and get more money than $s_3^{\max}$, but the constraint on imputations prevents this. On the other hand, if the maximum side-payment of Player 3 is greater than Player 1's, than the core is non-empty with Player 3 (the light users) winning, and the game G is *balanced*. Player 3 pays $s_1^{\max} + \epsilon$ to Player 2 and retains $s_3^{\max} - s_1^{\max} - \epsilon$. A similar (but opposing) explanation applies for the coalitional structure $\{\{12\},\{3\}\}$.

The solution of the user-influenced pricing game is given as ψ-stable pairs in Table 2. Note that the ψ-stable concept does not restrict the possibilities. In the first row of the table heavy users win (flat-rate pricing is chosen), but a side-payment of at least $s_3^{\max}$ has to be paid. According to the third row, light users win by paying at least $s_1^{\max}$ to medium users. If the maximum side-payments are equal, the outcome is indeterminate.

Now, let us take a look at how individual users can share the burden of side-payments in the balanced regime. Let $H, M, L \subset N$ be the set of heavy, medium and light users.

Table 2. ψ-stable pairs in the balanced regime

Side-payment parameters	Core solution	Coalitional structure
$0 < s_3^{\max} < s_1^{\max}$	$(s_1^{\max} - s_1, s_1, 0)$	$(\{12\}, \{3\})$
$0 < s_3^{\max} = s_1^{\max}$	$(0, s_1^{\max}, 0)$	$(\{12\}, \{3\})$ or $(\{1\}, \{23\})$
$0 < s_1^{\max} < s_3^{\max}$	$(0, s_3, s_3^{\max} - s_3)$	$(\{1\}, \{23\})$

Flat-rate pricing. Suppose that $s_3^{\max} < s_1^{\max}$, hence heavy and medium users team up to implement flat-rate pricing. A suitable division of side-payments among heavy users would be to share the additional cost equally, resulting in a payment of $\frac{s_1}{|H|}$ for each heavy user i. Also by choosing the flat-rate approach, medium users share the profit from the side-payments equally, each medium user getting $\frac{s_1}{|M|}$.

Now we can give the monthly cost of a single user:

$$c_i = \begin{cases} \frac{R}{N} + \frac{s_1}{|H|} & \text{if } i \in H \\ \frac{R}{N} - \frac{s_1}{|M|} & \text{if } i \in M \\ \frac{R}{N} & \text{if } i \in L \end{cases} \tag{13}$$

Usage-based pricing. Suppose that $s_1^{\max} < s_3^{\max}$, therefore light and medium users join forces to achieve usage-based pricing. A suitable division of side-payments among light users would be to share the the additional cost proportional to traffic volume, resulting in a payment of $\frac{s_3 \tau_i}{t_3 T}$ for each light user i. Also by choosing the usage-based approach, medium users can agree to benefit from the side-payments proportionally to their traffic volume, so each medium user j user gets $\frac{s_3 \tau_j}{t_2 T}$.

Now we can give the monthly cost of a single user:

$$c_i = \begin{cases} \frac{R\tau_i}{T} & \text{if } i \in H \\ \frac{R\tau_i}{T} - \frac{s_3 \tau_i}{t_2 T} & \text{if } i \in M \\ \frac{R\tau_i}{T} + \frac{s_3 \tau_i}{t_3 T} & \text{if } i \in M \end{cases} \tag{14}$$

5 Distribution of Power

This section reveals the distribution of voting power in the game G. The usual approach is to calculate the *Shapley value*:

$$\phi_k[\nu] = \sum_{S \subset N} \gamma(n, s) V_k(S) \tag{15}$$

with

$$\gamma(n, s) = \frac{(s-1)!(n-s)!}{n!}, \text{ and } V_k(S) = \nu(S) - \nu(S \setminus \{i\}) \tag{16}$$

where $s = |S|$ and $n = |N|$.

Here, the existence of quarreling players prevents us to use the original Shapley value. Fortunately, a *modified Shapley value* incorporating quarreling has been developed in [11]. This modified value represents an expected distribution of side-payments (x_1, x_2, x_3) in G, when the players arrive in random fashion to join coalitions, and receive their marginal worth to the coalition. The modified Shapley value employs the constraint of a quarreler not joining a coalition where an other quarreler is already present: then he receives no payoff. Formally for Player j:

$$\phi_j^\star[Q,\nu] = \sum_{S \cap Q = j} \gamma(n,s) V_j(S) + \frac{q-1}{q}\nu(j), \;\; j \in Q \tag{17}$$

and

$$\phi_j^\star[Q,\nu] = \sum_{S \cap Q = \emptyset} \gamma(n,s) V_j(S) + \sum_{|S \cap Q| = 1} \frac{\gamma(n-q, s-1) - \gamma(n, s-1)}{q} V_j(S), \; j \notin Q \tag{18}$$

where Q is the set of quarrelers and $q = |Q|$.

Now, we can calculate the modified Shapley values. For Player 1:

$$\begin{aligned} \phi_1^\star &= \frac{1! \cdot 2!}{3!}\nu(\{1\}) + \frac{1! \cdot 1!}{3!}(\nu(\{12\}) - \nu(\{2\})) + \frac{1}{2}\nu(\{1\}) = \\ &= \frac{5\nu(\{1\}) + \nu(\{12\}) - \nu(\{2\})}{6} \end{aligned} \tag{19}$$

Similarly for Player 3:

$$\phi_3^\star = \frac{5\nu(\{3\}) + \nu(\{23\}) - \nu(\{2\})}{6} \tag{20}$$

Finally, for non-quarreling Player 2:

$$\phi_2^\star = \frac{\nu(\{12\}) + \nu(\{23\}) + \nu(\{2\}) - \nu(\{1\}) - \nu(\{3\})}{3} \tag{21}$$

Evaluating the modified Shapley values for the different regimes depending on the relation of $s_1^{\max}$ and $s_3^{\max}$, we get the distributions of power based on Table 1.

Under the heavy user regime the modified Shapley value is $(s_1^{\max}, 0, 0)$, heavy users have all the power. Similarly for the light user regime, the value is $(0, 0, s_3^{\max})$, light users are in total control. In the balanced regime the power is shared with a modified Shapley value of $(\frac{s_1^{\max}}{6}, \frac{s_1^{\max}+s_3^{\max}}{3}, \frac{s_3^{\max}}{6}$. Note that for $s_1^{\max} > s_3^{\max}$ heavy users have more power than light users, and for $s_3^{\max} > s_1^{\max}$ the opposite is true. Most importantly, irrespective of the maximum offered side-payments, Player 2 is the most powerful since he is a *pivotal* player. His power grows twice as fast as the other players if side-payments begin to grow.

An other measure of power is the *Shapley-Shubik index* [13]. Suppose that voters arrive in a random order, until a pivotal player turns a losing coalition into a winning one. The Shapley-Shubik index is then the proportion of orders where the player is pivotal, formally:

$$\phi_i^{SS} = \frac{p_i}{n!} \tag{22}$$

where p_i is the number of occasions where Player i is pivotal. Note that we restrict possible coalitions to those where quarreling players are not together. It is easy to see that under the heavy user and light user regimes the Shapley-Shubik power index is $(1, 0, 0)$ and $(0, 0, 1)$, respectively. In the balanced regime, side-payments determine the outcome: if $s_1^{\max} > s_3^{\max}$ the index is $(0.5, 0.5, 0)$; symmetrically if $s_1^{\max} < s_3^{\max}$ the index is $(0, 0.5, 0.5)$. To put in words, the Shapley-Shubik index shows the importance of a player in a winning coalition: medium users are just as important as heavy users if flat-rate pricing is voted for, and they have the same importance as light users if usage-based pricing prevails.

6 Discussion on Feasibility

Here we give an outlook at the practical issues that can be raised by the actual implementation of the proposed pricing scheme.

Composition of user population. During our analysis in Section 3 to 5 we have not assumed any particular composition of the user population, and we studied the entire parameter space. In practice though, the composition can decide the outcome by itself, hence the notions of heavy and light user regimes. Of course, a lot depends on how different user classes are defined. An exact definition is out of scope for this paper, but a rule of thumb is presented in Section 3. Note that heavy-hitters still dominate overall traffic, but their shares are decreasing, while other users are catching up due to multimedia content, resulting in a more balanced user distribution based on generated traffic volume [14]. In other words, the existence of a balanced regime is highly likely.

Planning income. First of all, can an ISP efficiently estimate its future revenues? It is common sense that companies do plan their revenues and expenses in advance. The difference here is that the ISP actually gets the exact amount of money they planned for. Coming up with a single number every month is not straightforward; a small provider has some advantage over its larger counterpart in this sense, since smaller ISPs tend to have a simpler business and service structure.

Voting and charging. How can the announcement process be implemented? Also, is there a reasonable method to distribute side-payments among the users? We believe if an ISP uses the proposed method, it is in its best interest to provide for the announcement, negotiations and the voting process. The voting process can be entirely web-based. This requires strong identities and a secure infrastructure. Since such infrastructures already exist, it is reasonable to assume that the ISP can fulfill all the requirements. It is important to emphasize that users do not have to explicitly administer side-payments: the ISP can calculate and incorporate side-payments into their monthly bill.

Future work. We see the presented mechanism as a first step towards a user-controlled pricing system. We plan to plug slightly more complicated schemes, such as three-part tariffs, to the framework of user-influenced pricing introducing further benefits both for the user and the provider. Also, we plan to conduct a simulation study on a competitive market setting where multiple ISPs are present. This will enable us to evaluate the proposed scheme without the limitations introduced by the analytical model.

7 Conclusion

In this paper we presented results on a novel pricing mechanism for Internet Service Providers called user-influenced pricing, where users can vote for the exact pricing scheme implemented in the next billing cycle. Our assumptions were that ISPs want plannable revenues, while users want to keep their costs low. We showed that under user-influenced pricing, users of different traffic volumes (heavy, medium, light) can cooperate to achieve lower costs utilizing side-payments. We modeled this process as a weighted cooperative voting game, and derived the equilibrium solutions and payoffs on the individual user and group level. We showed how the ratio of different users and maximum reasonable side-payments affect the outcome of the voting game. We also derived the distribution of power in various regimes of the game. Results indicate that medium users are pivotal in the decision-making process.

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