On the Interaction between ISP Revenue Sharing and Network Neutrality

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ABSTRACT

Flows typically pass through multiple networks owned and managed by different ISPs (Internet Service Providers). Users pay usage fee to the traversed networks, and each ISP typically applies different charging rules, depending on their own economic interests and business policies. The revenue sharing rule among ISPs, i.e., how users' fee is shared among them has been known to have large impacts on evolution of the networks, e.g., incentives to upgrade the networks. Related to revenue sharing is network neutrality, where we are particularly interested in the way of sharing the network operation cost between EUs (End-User) and CPs (Content-Providers). This paper studies the interaction between ISP revenue sharing and neutrality-compatible pricing between EU and CP. We study the cases (i) when ISPs charge users/CPs selfishly and (ii) when they coordinate towards fairness of ROI (Return-On Investment). We discuss different engineering and economic implications using the analytical results for two revenue sharing policies coupled with neutrality in the network.

1. INTRODUCTION

Internet consists of multiple ISPs, where users' flows typically traverse the networks owned by multiple, different organizations. Each ISP adopts its own economic polices (such as pricing scheme) to maximize the profit, and such economic heterogeneity existing in ISPs may have huge, macroscopic impact on many things, e.g., users' incentive to use the Internet as well as providers' incentive to invest [3]. ISPs either behave selfishly or cooperate, each of which differently determines the way of sharing the money, called *revenue sharing*, which users pay for the Internet access.

In classifying "users" into EUs and CPs, depending on their objective of connecting to the Internet and the amount of generated data volume, an important, yet controversial issue, *network neutrality*, emerges. Network neutrality adds more challenges to understanding of the economic phenomena in the Internet and describes an intrinsic characteristic of the Internet, essentially dealing with discrimination of flows and/or users (in terms of QoS and pricing) by ISPs. Network neutrality covers a broad collection of issues, of which we consider the issue of how much the heavy users generating a large volume of traffic (e.g., CPs) should be responsible for the overall network operation cost. An example of non-neutral case is that a CP is responsible for the EUs' Internet access fee directly (e.g., via provision of subsidy) or indirectly (paying more than the neutral case to his access ISP which would share the money with EUs' access ISPs).

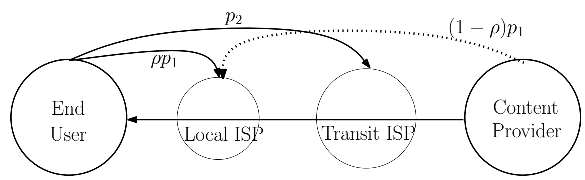

Figure 1: Two sided market model with neutrality-pricing factor ρ.

The authors in [3] studied the impact of revenue sharing on the network-upgrade incentives. The research on the relation between network neutrality and pricing has also been made in e.g., [1, 2, 4]. However, the interaction between revenue sharing and neutrality are largely under-explored, which is the focus of our paper. We model the system with a standard two-sided market. We introduce a notion of *neutrality-pricing factor* that models a degree of responsibility of heavy users for the entire network operation cost (see Figure 1). Two revenue sharing policies are considered here: cooperative and non-cooperative. The questions that we address in this paper are: *(i)* How does the incentive of network-upgrade incentive change for different neutrality-pricing factors and revenue sharing policies?, *(ii)* Can we provide the upgrade incentive for both revenue sharing policies? *(iii)* If no, when and how does the ISPs lose the upgrade incentive for varying neutrality-pricing factor? *(iv)* If yes, what are exact revenue sharing policies?

2. MODEL

We consider a system with one EU and one CP as users,

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and two ISPs, where one is a local ISP and another is a transit ISP. We adopt this simple model for tractable analysis. Local ISP is an access ISP for the EU, and we assume that the CP is directly connected to the transit ISP. We assume usage-based pricing, where let p_1 and p_2 be the prices per unit volume of data charged by the local and transit ISP, respectively. This simple model is not artificial and made based on the assumption that the CP's access ISP charges access fee to the CP, which is same as the network operation cost. Note that this cost includes the money that the CP's access ISP pays to the transit ISP. Note that p_1 and p_2 are the prices that are normalized by the aforementioned assumptions (see [3] which we refer to the readers for more backgrounds about this simple model).

We denote by $\rho \in [0,1]$ the neutral-pricing factor representing the portion that the CP as a heavy user is responsible for the network operation cost. Let $p_1^E = \rho p_1$ and $p_1^C = (1-\rho)p_1$. Again, the additional revenue $(1-\rho)p_1$ may be to compensate local ISP's burden for dealing with congestion of the EU's access link due to the heavy CP. We assume that the local ISP's link capacity C to the EU is a bottleneck, and denote by M_1 and M_2 the operation costs of the local and the transit ISPs, respectively. We assume a linear demand function, meaning that the EU demands data from a CP at the rate of $d(p) = a - p$ for the given EU price p, where a is some constant corresponding to the price that leads to no data demand of EU. In our case, $p = \rho p_1 + p_2$. We omit other parts of the model such as revenue maximization by the local and transit ISPs due to space limitation.

3. MAIN RESULTS

3.1 Selfish Revenue Sharing

We first analyze a revenue sharing strategy where each ISP *selfishly* decides his price p_1 and p_2 to maximize his own revenue, for a given neutrality-pricing factor ρ. We let such selfish optimal solution for the prices be $(p_1^\star, p_2^\star)$. From this solution, we compute the fairness and the upgrade incentive of this non-cooperative revenue sharing scheme as follows: First, for fairness, which we denote by α, we consider the ROI (Return On Investment) fairness using Jain's index. Regarding the upgrade incentive, we study $\partial R(C)/\partial C$, where $R(C)$ is the local ISP's revenue (obtained from the selfish optimization) for the given capacity C.

THEOREM 1.

(i) The ROI fairness is maximized when $\rho = \rho^\star \triangleq \min\{\frac{M_2(a-M_2-2C)}{M_1(C+M_2)}, 1\}$.

(ii) $\alpha = 1$, *if* $M_1 > \frac{M_2(a-M_2-2C)}{C+M_2}$ *and* $\alpha < 1$, *otherwise.*

(iii) $\partial R(C)/\partial C > 0$, *if* $C < \frac{1}{4}(a - \rho M_1 - M_2)$, *and* $\partial R(C)/\partial C \leq 0$, *otherwise.*

Theorem 1 shows the condition of optimal ROI fairness in non-cooperative revenue sharing. It implies that only for a limited case, the fairness becomes optimal, i.e., Jain's index$=1$. Theorem 1 also implies that in non-cooperative revenue sharing there exists an upper-bound beyond which there is no incentive of upgrading the network by investing for capacity increase. We also observe that there exists a tradeoff between neutrality and the upgrade incentive in the sense that as the network becomes less neutral (i.e., as ρ decreases), the maximum allowable capacity guaranteeing the positive upgrade incentive grows.

3.2 Cooperative Revenue Sharing

We now propose a new revenue sharing policy controlled by the neutrality-pricing factor ρ, which guarantees the optimal fairness as well as the incentive to upgrade irrespective of C. A new revenue sharing policy is determined by the solution of the following optimization problem:

$$\max_{p_1,p_2 \geq 0} \sum_{i=1,2} w_i \log(R_i)$$

where $w_1 = \rho M_1, w_2 = M_2$, and $R_i,\ i = 1,2$ is the revenue earned by the local or transit ISP, i.e., $R_i = (p_i - M_i)d(p_1^E + p_2)$. This optimization-based revenue sharing aims at maximizing the weighted sum of ISP revenues. Note that the similar approach has been adopted in [3]. However, the key difference is how we should choose the weights $w_i, i = 1, 2$, depending on ρ. We designed this cooperative policy, such that the local ISP's w_i should be the ρ-fraction of the original network operation cost.

The above optimization is a form of weight proportional fairness, where the weight w_i is interpreted as the bargaining power of the ISP i. In economics, the bargaining power is known to be proportional to the cost.

THEOREM 2. *For all* $\rho \in [0,1]$, *the ROI fairness becomes 1, and* $\partial R(C)/\partial C > 0$, *for all* $C > 0$.

Theorem 2 shows that when CP is "ρ-portion responsible" for congestion in EU's access network, by adopting a revenue sharing policy characterized by the weight proportional fair, where the weight is ρM_1 (i.e., ρ-portion of the cost of EU's access network), then the ROI fairness and the incentive to network-upgrade is ensured.

4. FUTURE WORK

We presented preliminary results on the interaction between revenue sharing among ISPs and network neutrality quantified as the amount of money that heavy users should give to EU. A lot of future work remains for further study. Examples include the study of other pricing schemes such as flat pricing or two-part pricing and generalization of the results to a more complex network.

5. REFERENCES

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