A Study of Non-Neutral Networks with Usage-based Prices

Eitan Altman[1], Pierre Bernhard[1], Stephane Caron[2], George Kesidis[⋆2], Julio Rojas-Mora[3], and Sulan Wong[4]

[1] INRIA. 2004 Route des Lucioles. 06902 Sophia-Antipolis, France.
{eitan.altman,pierre.bernhard}@sophia.inria.fr
[2] CS&E and EE Depts, Pennsylvania State Univ. University Park, PA, 16802
spc15@psu.edu, Kesidis@engr.psu.edu
[3] Fac. of Econ. and Bus. Sci., Univ. of Barcelona. 08034 Barcelona, Spain.
jrojasmo7@alumnes.ub.edu
[4] Fac. of Law, Univ. of Coruña. 15071 A Coruña, Spain. swong@udc.es

Abstract. Hahn and Wallsten [1] wrote that network neutrality "usually means that broadband service providers charge consumers only once for Internet access, do not favor one content provider over another, and do not charge content providers for sending information over broadband lines to end users." We study the implications of non-neutral behaviors under a simple model of linear demand-response to *usage-based* prices. We take into account advertising revenues for the content provider and consider both cooperative and non-cooperative scenarios. We show that by adding the option for one provider to determine the amount of side payment from the other provider, not only do the content provider and the internaut suffer, but also the Access Provider's performance degrades.
Keywords: Network neutrality, game theory.

1 Introduction

Network neutrality is an approach to providing network access without unfair discrimination among applications, content or traffic sources. Discrimination occurs when there are two applications, services or content providers that require the same network resources, but one is offered better quality of service (shorter delays, higher transmission capacity, *etc.*) than the other. How to define what is "fair" discrimination is still subject to controversy[5]. A preferential treatment

⋆ The work by George Kesidis is supported in part by NSF CNS and Cisco Systems URP grants.

[5] The recent decision on Comcast v. the FCC was expected to deal with the subject of "fair" traffic discrimination, as the FCC ordered Comcast to stop interfering with subscribers' traffic generated by peer-to-peer networking applications. The Court of Appeals for the District of Columbia Circuit was asked to review this order by Comcast, arguing not only on the necessity of managing scarce network resources, but also on the non-existent jurisdiction of the FCC over network management practices. The Court decided that the FCC did not have express statutory authority

of traffic is considered fair as long as the preference is left to the user[6]. Internet Service Providers (ISPs) may have interest in traffic discrimination either for technological or economic purposes. Traffic congestion, especially due to high-volume peer-to-peer traffic, has been a central argument for ISPs against the enforcement of net neutrality principles. However, it seems many ISPs have blocked or throttled such traffic independently of congestion considerations.

ISPs recently claimed that net neutrality acts as a disincentive for capacity expansion of their networks. In [2], the authors studied the validity of this argument and came to the conclusion that, under net neutrality, ISPs invest to reach a social optimal level, while they tend to under/over-invest when neutrality is dropped. In their setting, ISPs stand as winners while content providers (CPs) are left in a worse position, and users who pay the ISPs for preferential treatment are better off while other consumers have a significantly worse service.

In this paper, we focus on violations of the neutrality principles defined in [1] where broadband service providers charge consumers more than "only once" through usage-based pricing, and charge content providers through side-payments. Within a simple game-theoretic model, we examine how regulated[7] side payments, in either direction, and demand-dependent advertising revenues affect equilibrium usage-based prices. We also address equilibria in Stackelberg leader-follower dynamics. We finally study the impact of letting one type of provider determine the amount of side payment from the other provider, and show that this results in bad performance to both providers as well as internauts.

The rest of the paper is organized as follows. In Section 2, we describe a basic model and derive Nash equilibria for competitive and collaborative scenarios. We consider potentially non-neutral side-payments in Section 3 and advertising revenues in Section 4, analyzing in each case how they impact equilibrium revenues. In Section 5, we study leader-follower dynamics. In Section 6 we study the results of allowing one provider to control the amoount of side payments from the other one. We conclude in Section 7 and discuss future work.

---

over the subject, neither demonstrated that its action was "reasonably ancillary to the [...] effective performance of its statutorily mandated responsibilities". The FCC was deemed, then, unable to sanction discriminatory practices on Internet's traffic carried out by American ISPs, and the underlying case on the "fairness" of their discriminatory practices was not even discussed.

[6] Nonetheless, users are just one of many actors in the net neutrality debate, which has been enliven throughout the world by several public consultations for new legislations on the subject. The first one was proposed in the USA, the second one was carried out in France and a third one is intended to be presented by the EU during summer 2010. See [5, 3, 4].

[7] In the European Union, dominating positions in telecommunications markets (such as an ISP imposing side-payments to CPs at a price of his choice) are controlled by the article 14, paragraph 3 of the Directive 2009/140/EC, considering the application of remedies to prevent the leverage of a large market power over a secondary market closely related.

2 Basic model

Our model encompasses three actors, the internauts (users), collectively, a network access provider for the internauts, collectively called ISP1, and a content provider and its ISP, collectively called CP2. The two providers play a game to settle on their (usage-based) prices. The internauts are modeled through their demand response. They are assumed willing to pay a usage-based fee (which can be \$0/byte) for service/content that requires both providers.

Denote by $p_i \geq 0$ the usage-based price leveed by provider i (ISP1 being $i = 1$ and CP2 being $i = 2$). We assume that the demand-response of customers, which corresponds to the amount (in bytes) of content/bandwidth they are ready to consume given prices p_1 and p_2, follows a simple linear model:

$$D = D_0 - d(p_1 + p_2). \tag{1}$$

With such a profile, we are dealing with a set of homogeneous users sharing the same response coefficient d to price variations. Parameter D_0 corresponds to the demand under pure *flat-rate* pricing ($p_1 = 0 = p_2$).

Demand should be non-negative, *i.e.*,

$$p_1 + p_2 \;\leq\; \frac{D_0}{d} \;=:\; p_{\mathsf{max}}.$$

Provider i's usage-based revenue is given by

$$U_i \;=\; Dp_i. \tag{2}$$

2.1 Competition

Suppose the providers do not cooperate. A Nash Equilibrium Point (NEP) (p_1^*, p_2^*) of this two-player game satisfies:

$$\frac{\partial U_i}{\partial p_i}(p_1^*, p_2^*) = D^* - p_i^* d = 0 \quad \text{for } i = 1, 2,$$

which leads to $p_1^* = p_2^* = D_0/(3d)$. The demand at equilibrium is thus $D^* = D_0/3$ and the revenue of each provider is

$$U_i^* = \frac{D_0^2}{9d}. \tag{3}$$

2.2 Collaboration

Now suppose there is a coalition between ISP1 and CP2. Their overall utility is then $U_{\mathsf{total}} := U_1 + U_2 = Dp$, and an NEP (p_1^*, p_2^*) satisfies

$$\frac{\partial U_{\mathsf{total}}}{\partial p_i}(p_1^*, p_2^*) \;=\; D^* - d(p_1^* + p_2^*) \;=\; 0 \quad \text{for } i = 1, 2,$$

which yields $p^* := p_1^* + p_2^* = D_0/(2d)$. The demand at equilibrium is then $D^* = D_0/2$, greater than in the non-cooperative setting. The overall utility $U^*_{\mathsf{total}} = D_0^2/(4d)$ is also greater than $D_0^2/(4.5d)$ for the competitive case. Assuming both players share this revenue equally (trivially, the Shapley values are $\{1/2, 1/2\}$ in this case), the utility per player becomes

$$U_i^* = \frac{D_0^2}{8d}, \tag{4}$$

which is greater than in the competitive case. So, both players benefit from this coalition.

3 Side-Payments under Competition

Let us suppose now that there are *side payments* between ISP1 and CP2 at (usage-based) price p_s. The revenues of the providers become:

$$U_1 = D\,(p_1 + p_s)\ ;\ U_2 = D\,(p_2 - p_s) \tag{5}$$

Note that p_s can be positive (ISP1 charges CP2 for "transit" costs) or negative (CP2 charges ISP1, *e.g.*, for copyright remuneration[8]). It is expected that p_s is *not* a decision variable of the players, since their utilities are monotonic in p_s and the player without control would likely set (usage-priced) demand to zero to avoid negative utility. That is, p_s would normally be *regulated* and we will consider it as a fixed parameter in the following (with $|p_s| \leq p_{\mathsf{max}}$).

First, if $|p_s| \leq \frac{1}{3}p_{\mathsf{max}}$, the equilibrium prices are given by

$$p_1^* = \frac{1}{3}p_{\mathsf{max}} - p_s\ ;\ p_2^* = \frac{1}{3}p_{\mathsf{max}} + p_s$$

but demand $D^* = D_0/3$ and utilities

$$U_i^* = \frac{D_0^2}{9d}$$

are exactly the same as (3) in the competitive setting with no side payment. Therefore, though setting $p_s > 0$ at first seems to favor ISP1 over CP2, it turns out to have no effect on equilibrium revenues for both providers.

[8] In France, a new law has been proposed recently to allow download of unauthorized copyright content, and in return be charged *proportionally* to the volume of the download [9]. A similar law had been already proposed and rejected five years ago by the opposition in France. It suggested to apply a tax of about five euros on those who wish to be authorized to download copyrighted content. In contrast, the previously proposed laws received the support of the trade union of musicians in France. If these laws were accepted, the service providers would have been requested to collect the tax (that would be paid by the internauts as part of their subscription contract).

Alternatively, if $p_s \geq \frac{1}{3}p_{\mathsf{max}}$, a boundary Nash equilibrium is reached when $p_1^* = 0$ and $p_2^* = \frac{1}{2}(p_{\mathsf{max}} + p_s)$, which means ISP1 does not charge usage-based fees to its consumers. Demand becomes $D^* = \frac{1}{2}(D_0 - dp_s)$, and utilities are

$$U_1^* = \frac{(D_0 - dp_s)dp_s}{2d}\ ;\ U_2^* = \frac{(D_0 - dp_s)^2}{4d}$$

Though $p_1^* = 0$, U_1^* is still strictly positive, with revenues for ISP1 coming from side-payments (and possibly from flat-rate monthly fees as well). Furthermore, $p_s \geq \frac{1}{3}p_{\mathsf{max}} \Leftrightarrow dp_s \geq \frac{1}{2}(D_0 - dp_s)$, which means $U_1^* \geq U_2^*$: in this setting, ISP1's best move is to set his usage-based price to zero (to increase demand), while he is sure to achieve better revenue than CP2 through side-payments.

Finally, if $p_s < -\frac{1}{3}p_{\mathsf{max}}$, the situation is similar to the previous case (with $-p_s$ instead of p_s). So, here $p_2^* = 0$ and $p_1^* = \frac{1}{2}(p_{\mathsf{max}} - p_s)$, leading to $U_2^* \geq U_1^*$.

To remind, herein revenues U_i are assumed usage-based, which means there could also be flat-rate charges in play to generate revenue for either party. Studies of flat-rate compare to usage-based pricing schemes can be found in the literature, see, *e.g.*, [6].

4 Advertising revenues

We suppose now that CP2 has an additional source of (usage-based) revenue from advertising that amounts to Dp_a. Here p_a is not a decision variable but a fixed parameter.[9]

4.1 Competition

The utilities for ISP1 and CP2 are now:

$$U_1 = [D_0 - d \cdot (p_1 + p_2)]\,(p_1 + p_s) \tag{6}$$

$$U_2 = [D_0 - d \cdot (p_1 + p_2)]\,(p_2 - p_s + p_a) \tag{7}$$

Here, the Nash equilibrium prices are:

$$p_1^* = \frac{1}{3}p_{\mathsf{max}} - p_s + \frac{1}{3}p_a\ ;\ p_2^* = \frac{1}{3}p_{\mathsf{max}} + p_s - \frac{2}{3}p_a$$

The cost to users is thus $p^* = \frac{2}{3}p_{\mathsf{max}} - \frac{1}{3}p_a$ while demand is $D^* = \frac{1}{3}(D_0 + dp_a)$. Nash equilibrium utilities are given by

$$U_i^* \;=\; \frac{(D_0 + dp_a)^2}{9d} \quad \text{for } i = 1, 2, \tag{8}$$

which generalizes equation (3) and shows how advertising revenue quadratically raises players' utilities.

[9] One may see p_a as the result of an independent game between CP2 and his advertising sources, the details of which are out of the scope of this paper.

4.2 Collaboration

The overall income for cooperating providers is

$$U_{\mathsf{total}} = (D_0 - dp)(p + p_a). \tag{9}$$

So, solving the associated NEP equation yields

$$p^* = \frac{p_{\mathsf{max}} - p_a}{2}. \tag{10}$$

The NEP demand is then $D^* = (D_0 + dp_a)/2$, and the total revenue at Nash equilibrium is $U^*_{\mathsf{total}} = (D_0 + dp_a)^2/(4d)$. Assuming this revenue is split equally between the two providers, we get for each provider the equilibrium utility

$$U^*_i = \frac{(D_0 + dp_a)^2}{8d}, \tag{11}$$

which generalizes equation (4). As before, providers and users are better off when they cooperate.

Thus, we see that $p_a > 0$ leads to lower prices, increased demand and more revenue for *both* providers (*i.e.*, including ISP1).

5 Stackelberg equilibrium

Stackelberg equilibrium corresponds to asymmetric competition in which one competitor is the leader and the other a follower. Actions are no longer taken independently: the leader takes action first, and then the follower reacts.

Though the dynamics of the games are different from the previous study, equations (6) and (7) still hold, with fixed $p_a \geq 0$ and regulated p_s. In the following, we need to assume that

$$p_s \leq \frac{1}{2}p_{\mathsf{max}} + \frac{1}{2}p_a \,;\, p_a \leq \frac{1}{3}p_{\mathsf{max}} + \frac{1}{4}p_s$$

so that NEPs are reachable with positive prices.

If ISP1 sets p_1, then CP2's optimal move is to set

$$p_2 \;=\; \frac{1}{2}(-p_1 + p_{\mathsf{max}} + p_s - p_a).$$

This expression yields $D = \frac{d}{2}(p_{\mathsf{max}} - p_1 - p_s + p_a)$ and $U_1 = \frac{d}{2}(p_{\mathsf{max}} - p_1 - p_s + p_a)(p_1 + p_s)$. Anticipating CP2's reaction in trying to optimize U_1, the best move for ISP1 is thus to set

$$p^*_1 \;=\; \frac{1}{2}p_{\mathsf{max}} - p_s + \frac{1}{2}p_a \;\rightarrow\; p^*_2 = \frac{1}{4}p_{\mathsf{max}} + p_s - \frac{3}{4}p_a.$$

Therefore, when ISP1 is the leader, at the NEP demand is $D^* = \frac{1}{4}(D_0 + dp_a)$ and utilities are:

$$U^*_1 = \frac{1}{8d}(D_0 + dp_a)^2 \,;\, U^*_2 = \frac{1}{16d}(D_0 + dp_a)^2. \tag{12}$$

Suppose now that CP2 is the leader and sets p_2 first. Similarly, we find:

$$p_2^* = \frac{1}{2}p_{\mathsf{max}} + p_s - \frac{1}{2}p_a \,;\, p_1^* = \frac{1}{4}p_{\mathsf{max}} - p_s + \frac{1}{4}p_a$$

These values yield the same cost p^* and demand D^* for the internauts at the NEP, while providers' utilities become:

$$U_1^* = \frac{1}{16d}(D_0 + dp_a)^2 \,;\, U_2^* = \frac{1}{8d}(D_0 + dp_a)^2. \tag{13}$$

Therefore, in either case of leader-follower dynamics, the leader obtains twice the utility of the follower at the NEP (yet, his revenue is not better than in the collaborative case).

6 Further abandoning neutrality

Throughout we assumed that the side payments between service and content providers were regulated. If p_s is allowed to be determined unilaterally by the service provider or by the content provider (as part of the game described in Section 3 or 4) then the worst possible performance is obtained at equilibrium. More precisely, the demand at equilibrium is zero, see [8]. The basic reason is that if the demand at equilibrium were not zero then a unilateral deviation of the provider that controls the side payment results in a strict improvement of its utility. (Note that the demand is unchanged as it does not depend on p_s.)

More generally, assume that an ISP is given the authority to control p_s and that its utility can be expressed as $U = f(D) \times (g(p_s) + h)$ where f is any function of the demand (and possibly also of prices other than p_s) g is a monotone strictly increasing function of p_s, and h does not depend on p_s. Then at equilibrium, necessarily $f(D) = 0$, otherwize U can be further increased by the provider by increasing (unilaterally) p_s.

The same phenomenon holds also in case the CP is given full control over p_s.

7 Conclusions and on-going work

Using a simple model of linearly diminishing consumer demand as a function of usage-based price, we studied a game between a monopolistic ISP and a CP under a variety of scenarios including consideration of: non-neutral two-sided transit pricing (either CP2 participating in network costs or ISP1 paying for copyright remuneration), advertising revenue, competition, cooperation and leadership.

In a basic model without side-payments and advertising revenues, both providers achieve the same utility at equilibrium, and all actors are better off when they cooperate (higher demand and providers' utility).

When regulated, usage-based side-payments p_s come into play, the outcome depends on the value of $|p_s|$ compared to the maximum usage-based price p_{max} consumers can tolerate:

– when $|p_s| \leq \frac{1}{3}p_{\mathsf{max}}$, providers shift their prices to fall back to the demand of the competitive setting with no side-payments;
– when $|p_s| \geq \frac{1}{3}p_{\mathsf{max}}$, the provider receiving side payments sets its usage-based price to zero to increase demand, while it is sure to be better off than his opponent.

When advertising revenues to the CP come into play, they increase the utilities of *both* providers by reducing the overall usage-based price applied to the users. ISP1 and CP2 still share the same utility at equilibrium, and the increase in revenue due to advertising is quadratic.

Under leader-follower dynamics, the leader obtains twice the utility of his follower at equilibrium; yet, he does not achieve a better revenue than in the cooperative scenario.

We finally showed that by adding the option for one provider, say the service provider, to determine side payments from the other provider, not only do the content providers and the internauts suffer, but also the Access Provider's performance degrades.

Acknowledgements:

The work by Penn State is supported in part by the National Science Foundation under grant 0916179 and by a Cisco Systems URP gift.

References

1. R. Hahn and S. Wallsten, "The Economics of Net Neutrality", *Economists' Voice*, The Berkeley Economic Press, **3**(6), pp. 1-7, 2006.
2. K. Cheng, S. Bandyopadhyay, and H. Gon, "The debate on net neutrality: A policy perspective", *Information Systems Research*, June 2008. Available at SSRN: `http://ssrn.com/abstract=959944`.
3. "Consultation publique sur la neutralité du net", du 9 avril au 17 mai 2010. `http://www.telecom.gouv.fr/fonds_documentaire/consultations/10/consneutralitenet.pdf`
4. "Neelie Kroes Vice President of the European Commission, Address at TEFAF ICT Business Summit", `http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/10/87` *Press release RAPID*, April 2010.
5. "Notice of proposed rulemaking (FCC 09/93)", October 2009–April 2010.
6. G. Kesidis, A. Das, G. de Veciana, "On Flat-Rate and Usage-based Pricing for Tiered Commodity Internet Services", in *Proc. CISS*, Princeton, March 2008.
7. G. Kesidis, "Congestion control alternatives for residential broadband access by CMTS", in *Proc. IEEE/IFIP NOMS*, Ōsaka, Japan, Apr. 2010.
8. Eitan Altman, Pierre Bernhard, George Kesidis, Julio Rojas-Mora , Sulan Wong, "A study of non-neutral networks". INRIA Research report Number 00481702, May 2010.
9. Michael Zumkleller, "Proposition de loi sur la création d'une licence globale á palier, visant á financer les droits d'auteur dans le cadre d'échanges de contenus audiovisuels sur internet (travaux préparatoires), nro 2476, déposée le 29 avril 2010".