

Net Neutrality and Quality of Service

Eitan Altman¹, Julio Rojas^{1,2}, Sulan Wong^{1,3},
Manjesh Kumar Hanawal^{1,4}, and Yuedong Xu⁴

¹ INRIA Sophia Antipolis, 2004 Route des Lucioles, France

² Dept. of Econ. and Bus. Sci. at Univ. of Barcelona, 08034 Barcelona, Spain

³ Dept. of Law, Univ. of Coruña, 15071 A Coruña, Spain

⁴ LIA, University of Avignon, 339, chemin des Meinajaries, Avignon, France
{eitan.altman,mhanawal}@inria.fr, yuedong.xu@gmail.com,
jrojasmo7@alumes.ub.edu, swong@udc.es

Abstract. 2010 has witnessed many public consultations around the world concerning Net neutrality. A second legislative phase that may follow, could involve various structural changes in the Internet. The status that the Internet access has in Europe as a universal service evolves as the level of quality of service (QoS) to be offered improves. If guarantees on QoS are to be imposed, as requested by several economic actors, it would require introducing new indicators of quality of services, as well as regulation legislation and monitoring of the offered levels of QoS. This tendency in Europe may change the nature of the Internet from a best effort network to, perhaps, a more expensive one, that offers guaranteed performance. This paper presents an overview of the above issues as well as an overview of recent research on net-neutrality, with an emphasis on game theoretical approaches.

1 Introduction

Several public consultations on network neutrality policies have taken place in 2010. From them, regulation was introduced by the FCC in the USA [11], while the European authorities feel there is no need for it [12, p. 3] at this moment. France’s Assembly, meanwhile, is discussing a bill on net neutrality [13]. The growing economic and social role of the Internet along with the fast evolution of its performance and of the services it offers, have triggered evolution of the legal status of the access to the Internet. Already on 2002, access to the Internet has become an universal service in the EU, which should imply guarantees on QoS. Even if data connections “should be capable of supporting data communications at rates sufficient for access to online services such as those provided via the public Internet”, the European Parliament understands that due to the heterogeneous nature of the Internet “it is not appropriate to mandate a specific data or bit rate at Community level”, leaving Member States with the responsibility of monitoring if the data rates provided by ISPs are “sufficient to permit functional Internet access” [15, Whereas 5]. Nonetheless, this guarantee only covers access to the narrowband Internet service, while the definition of the broadband Internet service as a universal service is currently in discussion [14].

From the debate on network neutrality we learn that new indicators of QoS are sought, and that we should expect an intensive work of regulating and standardization bodies on defining requested minimum values of performance measures. By actually requiring QoS to be guaranteed to the end user's actual experience (see e.g. [2] page 19), we may expect new legislation to create a new reliable and yet more expensive Internet, that would be different than the best effort type network that we have known.

This issue of a best effort versus a guaranteed performance network was not only present in the debate on network neutrality, but could be central in the legislation that would follow that debate. Another new comer issue is that of imposing taxes on content providers by the government. We provide more details on both issues in the next section.

The paper is organized as follows. The next section provides an overview on (i) the Internet as a universal service, (ii) the legislation concerning QoS, and on (iii) economic issues that arise in the debate on network neutrality. The following section provides a brief non exhaustive overview on mathematical models related to the neutral net question, with special focus on game theoretical models.

2 Overview

The Economic Aspects. The information and communication technologies have a central economic role. Indeed, "The information and communication technologies sector already generates revenue of 2,700 billion euros, or close to 7% of global GDP, and could account for 20% of GDP within the next 10 years" [2]. The latter reference specifies moreover: "Pyramid Research and Light Reading predict a rise in annual worldwide revenue for voice and data services of around 2.5% and 12.8%, respectively, between 2010 and 2013, while data traffic is forecast to increase by 131% during that same period. To give an example, in December 2009 ComScore reported that 5.4 billion videos had been watched in France that year (a 141% increase over the year before), of which 1.8 billion on YouTube.com between January and September".

In Europe, 5% of its GDP, i.e. 660 billion annually, comes from the IT sector, with 250 million daily Internet users and a penetration of the mobile market close to 100% [16].

Internet as a Tool for Exercising the Freedom of Speech. In 2009, France passed a law against non-authorized downloading of copyrighted material. Measures against file-sharing included disconnection from the Internet through an administrative order. The Constitutional Council went back to the **Declaration of the Rights of Man and of the Citizen** (from the time of the French revolution, two hundred years before the Internet was born) to conclude that freedom of speech could not be trusted to a new nonjudicial authority in order to protect holders of copyrights and neighboring rights. In their judgement, it recognized that the Internet is an instrument for exercising the freedom of speech. Similar relations between the Internet and the American constitution (and amendments) have also been made in the USA, see [3] for more details.

Recent events in the Arab world have shown us that people use Internet as a source not only to express their opinion on governments, but also to coordinate actions that allows overthrowing them. Governments have reacted, predictably, by blocking not only the Internet but also the mobile phone service. However, the effectiveness of these measures has been compromised with the release in media outlets throughout the world, of videos recorded in those countries.

Internet Access as a Universal Service. Directive 2002/22/EC of the European Union established the access to the Internet as a universal service, i.e. a global service guaranteed to all end users, regardless of their geographical location, at reasonable quality and reliability and at affordable price. Directive 2009/136/CD did not only request that access has a reasonable guaranteed service quality, it further complemented this request by giving ANRs the power to define the minimum QoS levels, in order to avoid service degradation, throttling and blocking.

To apply the law, one needs to constantly monitor the QoS in order to check if the targets values are indeed met. It is our conviction that this monitoring should involve not only those who offer the services and access to the Internet but also scientists that come from the public sector (research institutes and universities) who do not have direct economic interests.

2.1 New Indicators of Quality of Service Needed

Since 2002, there has been an exponential increase in the internet traffic, with new services and applications that appeared. In view of this huge growth, it has become clear that levels of QoS that have been appropriate for 2002 are no more sufficient, and moreover, there is a need in new indicators of QoS.

On the legislation side, there is a need to redefine the quality of services which the European universal service should offer. This can be done also in legislation at a state level. The first such initiative has been taken by Finland where already on October 2009 [18], followed by Spain in February 2010 [17, Art. 53]. Both of them require from providers a minimum guaranteed rate of 1 Mbps, a rate that makes difficult to see how the new multimedia services that are available through Internet could be provided.

Not surprisingly, we find the issue of QoS of today's and of future Internet in the center of the debate on network neutrality.

In [2], ARCEP (the French regulation body of Electronic Communications Markets) proposes six general policy directions for the network neutrality policy. The third one concerns QoS and it is summarized by: "3rd direction: A connection to the Internet must be provided with a sufficient and transparent QoS. To guarantee this, the Authority is launching sector-specific efforts to qualify the minimum QoS parameters for Internet access, and is working to implement specific indicators."

The document further specifies: "End users must be contractually informed of the technical properties of their Internet access, so that they can know the resources that have been assigned to them and the performance they can expect

under "normal conditions" (i.e. "best effort" operations)... Work also needs to be done on the contribution of other players in the equation (ISPs¹, equipment manufacturers, software providers, etc.)".

How should one proceed to determine the required indicators of QoS as well as their minimum value?

In the paragraph on QoS (related to the third proposed policy direction in [2]), ARCEP first invites "operators and the associations that represent them to engage in sector-specific work devoted to setting minimum QoS parameters for "Internet access" (availability, bandwidth, latency, packet loss, jitter, etc.)".

They then propose that "this work could be the basis of exchanges with consumer associations and be enhanced by close collaboration with other relevant players, and particularly with ISPs since, as the designers of services and applications, they are particularly well suited to analyze user's qualitative experience."

Would it indeed be enough to put together the operators with the consumer associations in order to come up with indicators and minimum levels of QoS?

Do the consumer associations have the experts to understand the impact of choices of minimum values of quality of services, and of proposed indicators, on the quality they would perceive? Do the legislators have these?

We recommend to involve in this work a third actor, such as research institutes and universities etc., that has the required experts in answering these questions and has the commitment of contributing to progress of the society.

2.2 The Involvement of End-Users in Determining Policies in France

2010 has experienced dramatic events related to network neutrality question. Exceptional legislation initiatives have been taken, that may pave the way to shape a different future Internet. 2010 saw the first country, Chile, adopting a legislation that establishes network neutrality. At the same year, a USA Court shook the foundation of the Net neutrality in USA by denying the USA telecom regulation body, the FCC, the authority to take decisions and actions on that topic. In preparation to legislation on the topic, public consultations were launched in USA, France and the European Union (EU).

There is a huge difference in the number of participants between the American consultation, on one side, and the French and European ones, on the other. In total there are more than 89,000 filings in the American one, where as the French consultation was answered by only 121 stake holders [5] and the European one was answered 318 times [12]. As can be seen in the FCC web site, the vast majority of the answers to the consultation in USA came from individuals who used a web tool provided by the platform `savetheinternet.com` for the automation of this process. This tool had a very basic template with a short standard text in favor of net neutrality, in which the interested individual provided his name.

If the level of participation seems low for France, a country with close to 65 million people of which 68.9 % have access to Internet [6], we were shocked by

¹ Internet Service Providers.

the number of responses that the European one attracted, as the EU has an estimated two thirds more population than the USA.

Among the 121 responses made by stake holders [5] in the French consultation, eight came from ISPs, four from networking vendors, six from content production corporations, three from copyright collecting societies, eleven from software and content providers, six from user associations, three from public initiative networks, four from other kinds of professional associations, two from a group of experts gathered by Nathalie Kosciusko-Morizet², five from researchers, and 67 from individual citizens.

The European call also showed low level of interest among stake holders, attracting a total of 318 responses [12]. Of this relatively small participation, 34 answers came from ISPs, seven from infrastructure providers, two from mobile phone manufacturers, 16 from national and regional authorities, 38 from Internet-related organizations, 18 from media-related organizations, six from content providers, 42 from industrial organizations, social, consumer and non-governmental organizations, seven from other companies, ten from academic institutions, three from political parties, and 145 from individual citizens.

We can compare these figures with the consultation process in Canada that was initiated by the CRCT. It provided around three months for sending comments to the commission. In addition it had several days of hearing. The commission which received “437 initial comments, 35 reply comments, and 34 final replies from parties (companies and advocacy groups) and individuals. In addition, an online campaign resulted in over 13,000 email submissions to the Commission from individuals. At the oral hearing in July 2009, 26 presentations were made. Finally, an online consultation initiated by the Commission resulted in 1,400 additional individual comments” [7, §10]. Thus the response to both, the French and the European consultations, are also much lower than the one for the Canadian consultation.

2.3 Duration and Timing

Of the three public consultation processes, the French was the shortest, running for 39 days (April 9 to May 17, 2010), followed by the European, that extended for 93 days (June 30, 2010 to September 30, 2010), and then the longest is the American, which ran for 187 days (October 22, 2009 to April 26, 2010)³. The French consultation is not only much shorter than the American. The timing for the consultation was chosen to overlap the two weeks vacation period of the Eastern holidays in France, in which many French spending vacations with their families are disconnected from the politics. Since both the duration and the timing of the consultation are under the control of the government, it seems natural to speculate that the French government was not interested in having a large participation. The European consultation was not only half as long as the

² French State Secretary for the Digital Economy.

³ Due to the “Comcast” decision[8], the FCC extended the deadline for filing reply comments in response to the NPRM from March 5 to April 26.

American one, it also had the same problem of the French one, as it ran over the summer holidays that usually spread from mid-July to mid-September, a period of almost 60 days of very little activity by the consultees.

2.4 The Impact of the Government Position

As both, the U.S. government led by President Obama and the FCC headed by the Commissioner Genachoswki, have been strong proponents of the consecration of the principle of net neutrality, either by an amendment of the Telecommunications Act, or by an administrative mandate issued by the FCC itself, the debate on net neutrality has been re-launched, achieving a media presence that is usually very difficult to reach for such a complex issue that weaves together three different areas of knowledge. In December 2010, the FCC issued a Report and Order [11] as the conclusive and regulatory document obtained from the NPRM. In it, the FCC keeps maintaining its authority to adopt rules on the open Internet [11, Part IV], but not unanimously, as two of its members believe that it does not so [11, p. 148-150, 188-193].

The European Union, both through the statement issued by the Commission under the Telecom Package⁴ as well as through Commissioners Reding and Kroes, made it clear that the intention of the European government is to protect the neutrality of the network.

We recall that in France, the conditions chosen to launch the consultation seem to indicate that the government was not interested in receiving a large number of responses. Minimizing the dimensions of the public debate associated with the consultation may also be useful in order to avoid the French citizens questioning other aspects of the government policy on the Internet. In particular, the government was probably aware that public discussions on the HADOPI law⁵ could be triggered by the fact that the questionnaire of the French consultation includes an important link between the HADOPI law and the proposed net neutrality. The relatively limited interest in France in getting feedback from end users should not be interpreted as a disinterest in the opinion of the various economic actors. Indeed, as we have already seen, there was a conference held by the ARCEP in which important economic actors participated⁶.

2.5 Taxation Issues

Among the issues that Net neutrality is concerned with are relations between access and content providers along with related pricing issues, as well as the

⁴ The Commission acknowledges in a declaration attached to the Telecom Package that net neutrality is “a policy objective and regulatory principle to be promoted by national regulatory authorities” [19].

⁵ Adopted in France last year and which bans downloading unauthorized copyrighted content.

⁶ We were surprised not to see among the participants speakers from French universities or research institutes. In fact, the only two talks from Professors from universities are from the USA. In addition, one can find video interviews of many stake holders in the conference’s home page: <http://www.arcep.fr/index.php?id=10370>.

possibility of an access provider to have exclusive agreement with some content provider or some service provider.

In Europe, these issues take another dimension, due to the fact that many large content providers (such as google, facebook etc) are non-european: these are mainly American companies. These companies make large benefits from advertisement.

It is known that google pays very little taxes on this income, in contrast to what google pays in the USA. In a context where all other actors related to the Internet do pay taxes, applying network neutrality would mean favoring or subsidising these providers that do not pay. To be more precise, Google managed to cut 3.1 billion American dollars of taxes in the three last years by declaring its foreign profits (made in Europe) in Bermuda. This enabled Google to reduce its overseas tax rate to 2.4% . This is done using Irish law that allows to legally shuttle profits into and out of subsidiaries there, thus escaping the Irish 12.5 % tax. Facebook is preparing a similar strategy to shift declared benefits from Ireland to Caymans. For details, see [4].

The so-called “Zelnick Report” [9], which came out in France in January 2010, proposed to impose a tax on advertising revenue generated by the use of online services from France. According to estimates put forward by the authors, between 10 to 20 million euros would be collected mainly from U.S. content providers (Google, Microsoft, AOL, Yahoo and Facebook). It is pertinent to note that the report expresses concerns about the drop in advertising revenues of the French content providers, citing the poor state of competition in the French market for search engines, and certain behaviors (never clarified in the text) of Google. Later, French President Nicolas Sarkozy supported this proposal in a speech where he presented a set of policies to support the sector of cultural content creation.

The French position concerning google had perhaps some impact. In September 2010, Google CEO Eric Schmidt met with the French president Sarkozy to discuss the opening in Paris of a Google research center and the creation of a European cultural institute[10]. Schmidt said that the only reason for this initiative is economic, since it considers the French market for online searches as very dynamic. He added that in the meeting, the so-called “Google tax” was not discussed and that he has not met with the French competition authority.

2.6 Incentives for Investments

One of the issues in the debate on Network Neutrality has been incentives for investments in the infrastructure. Some argue that neutrality would create the incentives and some argue that only a non-neutral net would guarantee that. This problem has been partly resolved in the European Union when Internet access was declared as a universal service. Indeed, there are several possible ways to finance the cost of Providing communications services to all end-users comes. The Universal Service Directive allows providers to be compensated either from public funds or through a cost-sharing arrangement between providers if it

is demonstrated that by complying with the universal service obligations they incur a loss or suffer net costs that exceed normal commercial standards [1].

The latter reference further says: "Member States are free to go beyond the minimum requirements laid down in the Directive, the only stipulation being that any additional obligation cannot be funded by a Levy on telecom providers."

We note however that in order to guarantee that the development of infrastructure would continue, it may be necessary to upgrade also the legislation on the universal service in order to apply it not just for the Internet access but also to broadband Internet services, which has not yet been declared universal service by the European community.

3 Mathematical Modeling of Network Neutrality Issues

3.1 Conclusions of the Models at a Glance

There is one particular economic issue that is at the heart of the conflict over network neutrality. Hahn and Wallsten [26] write that net 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." This motivates the recent studies on the implications of being non-neutral and of charging the content providers (CP).

Two central questions in the context of a possibly non-neutral Internet which many researchers have tried to answer are [37]: i) who would gain or loser in the absence of neutrality; ii) will ISPs or CPs have more incentives to invest on the network infrastructure. The heated debate on these questions involve legal, economic and technological aspects, see e.g. [36]. There have not been much work which involves all these expertise. Moreover, some of the existing works draw contradictory conclusions due to their differences in the market modeling.

We first take a glance at the state of the art research before diving into the details. We concentrate on the profits of the economic actors as well as the incentive of investment when the network neutrality is abandoned. The main results of existing work are summarized in Table 1. The first column lists the recent work as well as the year of publication. The second column highlights the power of ISPs in an Internet market. The charging of CPs may have different impacts on network utility in the competing and the monopoly ISP markets. The symbol \checkmark denotes that the performance metric is better off with network non-neutrality. On the contrary, the symbol \times represents a disadvantage in the non-neutral networks. For the two questions raised above, only part of existing works present definite answers. We use the symbol \star to denote the case where the authors provide a more complex result: they provide some conditions under which the network non-neutrality is beneficial and others for which it is harmful. The symbol \emptyset means that the authors have not studied that specific metric. From this table, we can conclude that the available models do not seem to agree with each other. However, the ISPs have more incentives to invest if they are better off with no regulation, according to these studies (including [23,32]).

Table 1. Comparisons of Existing Work on Net non-neutrality

	Market	ISP Surplus	CP Surplus	User Surplus	Social Surplus	ISP Investment
ET[38]	One ISP	✓	×	✓	×	∅
ET[38]	Two ISPs	×	×	✓	×	∅
NOSW[34]	Two ISPs	✓	✓	✓	✓	✓
CBG[37]	One ISP	✓	×	✓	✓	×
JL[44]	One ISP	∅	∅	∅	✓	✓
MSW[32]	More ISPs	*	*	*	*	*
ALX[23]	One ISP	*	*	*	*	*
HCCR[39]	One ISP	*	*	✓	✓	∅
HCCR[39]	More ISPs	*	*	✓	*	∅

Game theoretic modeling of neutral or non-neutral networks may consider as actors that are involved in strategic interactions not only service providers and content providers but also the users as well as the advertisement sector that often represents a major source of revenue to the content providers. Not all game theoretic models studied the net neutrality problem from a non-cooperative point of view. When considering the relation between service providers and content providers, some researchers have considered cooperative mechanisms to regulate the price that one provider pays to the other. The Nash bargaining solution was considered in [31,22,23] where as the Shapley value was considered in [27,28].

The Nash bargaining paradigm is also known as the proportional fair rate allocation in the traffic engineering [30]. It is the unique way of transferring utilities that satisfies a well known set of four axioms [29] related to fairness. In [27]-[28] the Shapley value (which is known to have some fairness properties [25]) has been used for deciding how revenues from end users should be split between the service and the content providers. Interestingly, it is the service provider that is seen to be the one that has to pay the content provider, which reflects the fact that the benefits of the service providers are obtained thanks to the presence of the content provider (assuming that users subscribe to the ISP in order to access the content of the CPs).

3.2 Literature Survey

We classify the existing work mainly based on types of game models that are used, i.e. noncooperative and the cooperative games. For the models concentrated on noncooperative price competition, we subdivide them into two classes. One of them assumes the same QoS for the packets of all content providers. The other, on the contrary, allows an ISP to provider premier QoS for the content providers that agree to pay to the ISP. Beside the game oriented studies, we further describe a work that considers the neutrality issue in network utility maximization.

Noncooperative Game without Considering QoS Differentiation. Economides and Tag [38] proposed a model of two-sided market in which the ISPs play the role of platform, collecting revenues from both the end users and the non-competing content providers. The quantities of content providers and end users are assumed to be normalized continuums. In the monopoly market, the demand generated by end users is increasing with regard to the quantity of the CPs, while decreasing along with the access price of the ISP. A CP has a positive externality of revenue from advertisers, at the cost of payment to the ISP. According to their analysis, the ISP and the users are better off, but the CPs' surplus as well as the social surplus are worse without network neutrality. In a duopoly market with two ISPs and multi-homing CPs, the quantity of end users subscribing to one ISP depends on not only the strategy of this ISP, but also that of its opponent. By using non-cooperative game tool, the authors find that the total surplus as well as the surplus of the CPs and the ISPs are better off at the equilibrium under the neutral regulation. This is opposite to the monopoly ISP market.

Musacchio, Schwartz and Walrand [32] investigate a two sided market where the CPs and the ISPs invest jointly on the network infrastructure. Each ISP is a monopoly over its end users and the CPs can be contacted by all the users. The total click rate (or flow rate equivalently) to the CPs is strictly increasing with regard to the investment of all the CPs and the ISPs. For a CP, a larger investment will attract more clicks, hence bringing more revenues from the advertisers. The major performance measure studied in this work is the social surplus. The authors indicate that the ratio between parameters characterizing advertising rates and end user price sensitivity plays a key role in choosing the one-sided or the two-sided pricing. If this ratio is either low or high, the two-sided pricing is more favorable, and vice versa.

In [40], Zhang et al. study the competition and innovation of the service-oriented Internet. This service-oriented Internet can be regarded as a two sided market composed of two CPs and two ISPs. The CPs charge end users based on their usage, while the ISPs charge them flat rate fees. The CPs engage in a Cournot competition where the price is determined by the total demand from the users. The ISPs engage in a Bertrand game so that they compete over the side payment from the CPs (while not the end users). The Cournot and the Bertrand competitions are tied together in a two-stage Stackelberg game. The authors indicate that the update of an ISP becomes profitable only when the increase of the marginal cost is upper bounded by an appropriate gain in its market share.

Motivated by [26], the authors of [21] investigate network non-neutrality with a monopoly ISP, one CP and a number of end users. The sources of income (other than side payments) are payments of end users (to both the ISP and the CPs), and some third party payments (e.g. publicity income) that the content providers receive. We formulate the price competition as a noncooperative game. The CP's strategy is its charging to the users, and the ISP's strategy is the charging from both the CP and the end user. In [21] we find that if the ISP has the power to decide the side payment, not only do the CP and the end users suffer, but also the ISP's utility degrades. More precisely, we show that the only possible equilibrium

would be characterized by prices that will induce zero demand from the users. This phenomenon does not occur if the CP's payment is fixed by some regulators, or the ISP determines the payments from the CP and the users sequentially.

We extend [21] to incorporate the QoS of users provided by the ISP in the non-neutral model [23]. This QoS measure is different from those in [37,43] where more demands lead to a reduced QoS. We connect the QoS with the incentive of ISP's investment. A larger demand from the users means a larger revenue, resulting in a larger bandwidth provision of the ISP and a better QoS. The authors introduce a parameter called *relative price sensitivity* to model the difference of demand sensitivities to the price of the ISP and that of the CP. When the price paid by the CP to the ISP for per-unit of traffic is a constant, the qualitative impact of being non-neutral is decided by the *relative price sensitivity*. If this relative sensitivity is greater than 1, the users value the service of the ISP more than that of the CP. We show that a positive payment of the CP to the ISP leads to worse surplus of all parties involved and worse QoS of end users. Our analysis reveals an implication that the ISP may pay to the CP of high price sensitivity so that the CP is able to reduce its service price. This type of reverse payment is rarely discussed in the literature of network non-neutrality.

In [24], we explore the effects of content-specific (i.e. not *application* neutral) pricing, including multiple CPs providing different types of content. Also, we consider competition among multiple providers of the same type, including different models consumer stickiness (inertia or loyalty). In an on-going work, we are also considering providers' infrastructure and operating costs (as in, e.g. [32]), more complex models of end-user demand and their collective social welfare, and the effects of different options for flat-rate pricing (e.g. [33,35]).

Noncooperative Game with QoS Differentiation. Hermalin and Katz [41] consider the two sided market with a monopolistic ISP and continuum of CPs and end users. They compare the levels of profit, social welfare under neutral and non-neutral regime. In the non-neutral regime they assume that the ISP can offer a range of differentiated quality of connection qualities (e.g., an ISP can offer different combinations of bandwidth, latency, and packet loss rate) to the CPs and charges them depending on the type of quality of connections they opt for. Their analysis suggests that any restriction on the ISP's choice to offer differentiated services will often result in poor social welfare and it improves social welfare only under few conditions. They further observe that the small scale content providers—the ones who are intended to benefit from regulations—are almost always harmed by the regulations. They extend the analysis of non-neutral regime to a Hotelling duopoly ISP model and observe that welfare results of monopoly ISP carry over.

Economides and Hermalin [42] study a two sided market similar to the one in [41] by considering the affect of network congestion. They allow the amount of information purchased by the users to vary. Their work shows restriction on granting or selling of priority services, i.e., neutral regime leads to superior social welfare. Further they show that the incentive to invest is ambiguous under non neutral regime. The investment by the ISP helps to improve the overall quality of

the network and thus reducing to some degree the difference among the services offered at discriminated prices, thus reducing the ISP's income.

Cheng et al. [37] study a market with one ISP, two competing content providers and a finite number of end users. The monopoly ISP provides two type of services, the preferential and the non-preferential delivery. The content providers can pay the ISP a fixed fee for preferential service, which implies a non-neutral network. The authors model the QoS by the M/M/1 queueing delay, and the competition of the CPs by a hotelling framework. In this paper, the principle with no regulation is beneficial to the surplus of the ISP, while harmful to those of the CPs. The social benefit is improved when one of the CP pays to the ISP, but remains unchanged when both CPs join the preferential service. The non-neutrality might lead to better QoS for a majority of users and worse QoS of the others if the social surplus is better. The authors also observe that the ISP has less incentive for capacity expansion in a non-neutral network. This is because if the bandwidth is upgraded, more users experience less congestion and switch to the non-preferential service. Thus, the difference of aggregate surplus of the ISP before and after capacity expansion becomes smaller in a non-neutral regime than in a neutral regime, resulting in less incentives to invest.

Choi and Kim [43] study the investment incentives with and without network regulation. They consider a monopolist ISP and two CPs. Prioritization of delivery of packets by assigning "fast lane" to one of the CPs who agree to pay to the ISP is considered as the main mode of the non neutrality. The congestion is taken into account by modeling the network as M/M/1 queue. They study the neutral and non neutral regime by comparing the market equilibrium in the short run (fixed capacity) and investment incentives in long run. They observe that in the short run the CPs will face the prisoner's dilemma to get access to the fast lane and will be worse off. The social welfare improves in the non-neutral network when there is significant asymmetry across the content providers. In the long run they argue that contrary to ISP's claim that net neutrality regime will have adverse affect on their expansion, they may not have investment incentive in the non-neutral regime. The CPs also may not have investment incentives as they may fear that the ISP can expropriate some of the benefits made by them. Their analysis yields ambiguous conclusions on investment incentives.

Njoroge et al. [34] consider a network where two interconnected ISPs compete for the users and the CPs over the quality and the price. The definition of "neutrality" is different from that of [38]. In a neutral model, a CP pays to one ISP for Internet access, but does not pay to the other ISP without direct connection. In a non-neutral model, a CP has to pay to the ISP without direct connection in order to be reachable by its end users. The inter-ISP link is bandwidth limited so that the quality of a user-CP connection is decided by this bottleneck. The authors model the price and quality competition as a six-stage sequential game and solve it using backward induction. They show that the non-neutrality is able to improve the surplus of the ISPs, the CPs and the users. The social surplus is also better, and the ISPs have higher incentives of investment.

Regulation Mechanisms Based on Cooperative Games. Giving the full control of a market, an ISP can charge an arbitrary price from CPs for the delivered contents. However, there does not exist such a “dictatorship” status in reality. Recent work introduces cooperative game tools, such as Nash bargaining game and Shapley value, to study the revenue splitting issues among the players.

Shapley value is a well known concept in cooperative game theory that provides a way of splitting revenues obtained by the cooperating players⁷. It satisfies important properties like fairness, efficiency, symmetry, additivity, etc. In [27] Ma et al. explore Shapley pricing mechanism [45] to share the revenues from Internet subscribers among the service providers that peer each others’ traffic. The authors show that if Shapley value based revenue sharing is enforced at the global level the selfish ISPs, at the Nash equilibrium point, will opt for strategies that will maximize the aggregate network profits. Further extending their work, in [28] the authors consider three type of ISPs: content ISPs, eye ball ISPs and transit ISPs. They obtain closed form expressions of the ISPs’ revenues for the bipartite topologies (each type of ISP nodes can be separated) and give dynamic programming procedures to calculate the Shapley revenues for the general internet topologies. With the Shapley value solution they suggest the appropriate pricing structure for the differentiated services (non-neutral regime) that improves social welfare.

Saavedra in [31] initially uses Nash bargaining game to study joint investment in a non-neutral regime with one CP and two ISPs. The CP is able to negotiate with one or the both ISPs via contracts. The author highlights the impact of the CP’s bargaining power on QoS agreements. If the ISPs allow lower quality of services in the non-neutral regime, the CPs with low bargaining power can enter into the exclusive contract with ISP and improve their bargaining position. Building upon [31], Altman et al. focus In [22] on mechanisms of setting the price that one provider would pay to another based on the Nash bargaining paradigm. The authors address a problem and a model that differ however, from [31]. Two bargaining concepts, the *pre-bargaining* and the *post-bargaining* are presented to characterize the exact sequence of decisions that determine the side payment as well as the other prices. The first concept is used when bargaining over the side payment takes place before the user prices are determined. The second one models the occurrence of bargaining after the user price competition. The authors point out under what situations the *pre-bargaining* or the *post-bargaining* is preferable. They further study another aspect of non-neutral behavior which is the possibility for an ISP and a CP to collude together which could result in better performances for them but a worse performance for other competing CPs.

Network Neutrality in Network Utility Maximization Issues. In this survey, we do not restrict to the papers that use game theoretic models. We

⁷ On the usefulness of this concept to split profits or costs we can learn from [46] where K Binmore writes [46]: “I was once summoned urgently to London to explain what the French government was talking about when it suggested that the costs of a proposed tunnel under the English Channel be allocated to countries in the European Union using the Shapley value”.

mention one more reference whose model includes some aspects of competition. Hande et al. [39] consider the two-sided market in a quite different context. Instead of using the predefined price-demand curve, they look into the network utility maximization with the participation of the CPs. This model mitigates the key drawback of economic studies that does not deal with the engineering aspect of rate allocation. They define the utility of users as a function of flow rates. The concept “non-neutrality” refers to the restriction on the maximum price that the ISPs can extract from the CPs. This price restriction exhibits different impacts on the profits concerning the power of the ISPs. In a market of competitive ISPs, the users’ benefit and the social benefit increase as the price restriction is relaxed. If we understand neutrality as zero payment for per-unit of delivered content, the non-neutral regime is always favorable in terms of the social profit and the users’ profits.

4 Conclusion

We summarized some recent aspects in the development of the Internet as well as in the debate on its neutrality. We cover both legal aspects, economic ones as well as technological issues. We then present an overview of research papers on the net non-neutrality problem. We focus in particular on issues related QoS. As a universal service, the Internet is required to guarantee certain QoS levels. We related this to the legislation over network neutrality and to the question of the incentives for investing in the infrastructure. We then provided an overview of the research studies on network neutrality issues with an emphasis on using game theoretical tools.

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