Chapter 2
Perspectives on Net Neutrality and Internet Fast-Lanes

"Net neutrality" and Internet "fast-lanes" have been the subject of raging debates for several years now, with various viewpoints put forth by stakeholders (Internet Service Providers, Content Providers, and consumers) seeking to influence how the Internet is regulated. In this chapter we summarize the perspectives on this debate from multiple angles, and propose a fresh direction to address the current stalemate. Our first contribution is to highlight the contentions in the net neutrality debate from the viewpoints of technology (what mechanisms do or do not violate net neutrality?), economics (how does net neutrality help or hurt investment and growth?), and society (do fast-lanes disempower consumers?). Our second contribution is to survey the state-of-play of net neutrality in various regions of the world, highlighting the influence of factors such as consumer choice and public investment on the regulatory approach taken by governments. Our final contribution is to propose a new model that engages consumers in fast-lane negotiations, allowing them to customize fast-lane usage on their broadband link. We believe that our approach can provide a compromise solution that can break the current stalemate and be acceptable to all parties.

2.1 Introduction

Network neutrality, often abbreviated as "net neutrality", is a phrase introduced by Tim Wu in [1], and refers to the principle that all legal content flowing on the public Internet should be treated equally (i.e. fairly) by Internet Service Providers (ISPs) and other responsible agencies [2, 3]. Specifically, this requires that ISPs should not indulge in "preferential treatment" of data based on its type (i.e. voice, video, gaming, etc.), the site hosting the content, the network carrying the traffic, the end-user viewing the content, or the charges paid by end-users to ISPs for accessing the content over the Internet. Breaching any of these principles amounts to violating the notion of net neutrality.

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The beginnings of net neutrality can be traced back to the late 90 s when questions were raised [2, 4, 5] over the implementation of certain mechanisms that seem to violate the end-to-end design philosophy of the Internet [6]. For example, introducing network-level approaches to identifying and preventing attacks from untrusted end-hosts, providing ISP differentiated services, or enabling multi-party interaction such as video conferencing, each of which require embedding intelligence "in" the network, were perceived to be a departure from the traditional end-to-end design philosophy of the Internet. The work in [7] gives an interesting perspective on different factors forcing a rethink of this design paradigm up until the start of this millennium.

2.2 Technology, Economic, and Societal Perspectives

The rapid growth of new technologies employed in the Internet, the development of new Internet business models, and the growing role of the Internet in society, are all exposing an increasing number of contentious aspects relating to net neutrality. We provide a brief overview of these perspectives.

2.2.1 Technology Aspects

The popular perception on how net neutrality gets violated is that the ISP blocks or throttles content from certain sites or applications. There are however other ways in which an ISP can give differential experience to consumers for different content:

Sponsored Data: It is common practise for many ISPs around the world to offer "sponsored data", also known as "zero-rating" or "unmetered content". Essentially what this means is that end-users are given access to content from specific Content Providers or CPs (such as Facebook, Twitter, etc.) at no additional cost (beyond their regular monthly Internet access fee) [8]. The data coming from these CPs is considered in-network and does not count towards the user's quota. CPs enter into specific financial arrangements with ISPs to offer this service, enabling them to attract more traffic from end-users, while ISPs benefit by attracting and retaining customers. The scheme is offered in several countries including the US, Australia, and India, while it is explicitly prohibited in countries such as Chile and the Netherlands [9–11]. While proponents of net neutrality lament that sponsored data discriminates against content that is not zero-rated by the ISP, opponents argue that it could increase demand for Internet connectivity, enabling more investment into the broadband infrastructure [8].

Content Distribution Networks (CDNs): Major CPs such as Google and Netflix use their own content delivery platforms, while several other CPs rely on third-party CDNs like Akamai to distribute their content. These caching sites are often collocated within an ISP's premises (close to the end-users) [12], permitting content to be delivered in real-time and in high quality to the end-users. This peering or hosting service provides additional monetisation opportunities for the ISP [13, 14], but raises the issue of whether it violates the principle of net neutrality by giving an unfair advantage to some CPs [15]. Opponents of net neutrality believe that CDNs do not degrade or interfere with other traffic, and only benefits end-users, while proponents argue that by engaging CPs in this manner, ISPs are implicitly favouring content from those CPs who can afford to pay them, leaving the smaller cash-strapped ones behind.

2.2.2 Economic Aspects

ISPs have strong economic incentives to reject network neutrality—they have seen their traditional revenues being eroded by Over the Top (OTT) services, such as voice-telephony by Skype, messaging by Whatsapp, and video conferencing by Facetime. Further, peer-to-peer applications such as BitTorrent have dramatically increased traffic loads in their network, putting upward pressure on their capital and operational expenditure. These have prompted several ISPs at various times to block or throttle OTT services [16], leading to outcry from the public. ISPs however are demanding more flexibility to manage traffic in their network, such as by throttling downloads by aggressive peer-to-peer applications, and by creating paid fast-lanes for content from specific CPs, thereby opening the doors to a new revenue stream for investing into network infrastructure [17].

Consumers are generally led to believe that net neutrality is economically beneficial to them, predominantly by keeping Internet connectivity uniform across providers, and forcing them to compete on price. Other argue that this benefit is illusory, since the shrinking margins for ISPs will eventually lead to degraded service. Robert Kahn, the co-inventor of Internet Protocol, warns against net neutrality by noting that it could substantially reduce investment, distort innovation, and harm consumers [18]. Not investing in network infrastructure can have a significant impact on the economy over time, and has been estimated by some analysts as a tax on the Internet, amounting to $55 per month on top of an average fee of $30 per month [19]. Lastly, there is also the possibility that allowing fast-lanes can allow the ISP to gain revenue from CPs, which can subsidise Internet connectivity costs for consumers [20].

CPs have economic reasons to support net neutrality so they do not have to pay ISPs for quality enhancement. That being said, quality is of paramount importance to CPs—this is evidenced by Netflix's payment to Comcast to prevent throttling for their subscribers, and by large CPs such as Google routinely entering into (unpaid) peering arrangements with ISPs to position their caches close to their users. Net neutrality has the potential to protect smaller CPs, who may not have the deep pockets to pay ISPs for prioritization of their content.

Differentiation or discrimination? Opponents of net neutrality, who are in favour of a tiered Internet, are of the view that charging a higher price for a better-quality product is "product differentiation", not "price discrimination". A few examples put forth in this context are passengers buying premium airline tickets for the privilege of priority boarding and seating, and users paying toll for travelling on a highway. People do not consider these services discriminatory, but merely as getting the quality of service commensurate with what one is willing (and able) to pay [21]. Thus, forcing net neutrality would lead the market to offer a standardized (same-quality) product at the same low price, and this would eliminate the incentive for ISPs to develop high-end innovative services and technologies [18]. However, critics argue against these analogies by noting that consumers have little or no control of such behind the scenes “paid prioritisation” deals between ISPs and CPs [22].

2.2.3 Societal Aspects

As present societal perception seems to be overwhelmingly in favor of net neutrality, with advocacy groups and the popular press equating it to a “free” Internet. The legitimate concern seems to that ISPs may become the “gatekeepers” of the Internet if net neutrality regulations are not put in place. We believe that the argument is a bit more nuanced than this. While blocking of (legal) content is of course inexcusable, traffic prioritization (paid for by the CP) need not necessarily be against societal interest (indeed zero-rating of content and the use of CDNs already constitutes some form of prioritization). The fundamental issue seems to be that paid prioritization has to-date been a back-room deal between a CP and an ISP, with the consumer having no voice; it is therefore no surprise that consumers seek to prevent such deals via regulatory means. This however risks creating a “tragedy of the commons” whereby an under-investment in broadband infrastructure keeps service quality poor for everyone. We wonder if the nature of the argument might change if the consumer could have a say in traffic prioritization for their specific household, and indeed propose such an approach in Sect. 2.4.

2.3 A Worldwide Perspective

In this section, we give a perspective of net neutrality discussions taking place in several nations around the world.

2.3.1 United States

The net neutrality debate reinvigorated in the US in 2005 following revelations that the Federal Communications Commission (FCC) fined Madison River Communications, an ISP in North Carolina, for preventing customers from using a VoIP service that was directly competing with their own VoIP service [23, 24]. In late 2005, AT&T was reported as saying that OTT providers (for services such as voice, video, etc.)

such as Google, Yahoo! or Vonage should pay them a fee for the privilege of using their infrastructure, and for AT&T to have a return on investment on the capital spent for laying the infrastructure [25, 26]. In 2007, there was a huge backlash when it became known that Comcast was starting to ‘downgrade’ peer-to-peer BitTorrent traffic [27]. This action by Comcast was widely viewed as a mechanism to prevent peer-to-peer traffic from using a large amount of bandwidth. Complaints were filed with the FCC following this observation, and in late 2008 the FCC ordered Comcast to stop discriminating against BitTorrent traffic [28]. This order was later reversed by the D.C. Circuit court in early 2010 after it questioned the FCC’s authority to issue net neutrality rules. In December of that year, the FCC issued the *Open Internet Order*, which is essentially three rules aimed at (i) preserving transparency in network operations, (ii) preventing blocking of legal content, and (iii) prohibiting unreasonable discrimination of lawful network traffic [29]. The order was subsequently challenged by Verizon in September 2011 on the grounds that the FCC does not have the authority to issue these rules [30], and in January 2014 the D.C. Circuit courts overturned the rules (ii) and (iii) while retaining rule (i) [31].

Maintaining its stance on net neutrality, the FCC in May 2014 proposed new rules that prohibited ISPs from blocking/discriminating against lawful web-sites, but allowed them to create fast-lanes [32, 33]. Essentially, fast-lanes allow ISPs to charge CPs such as Netflix, YouTube and Hulu to prioritise (i.e. preferentially treat) their traffic. Although such an approach could open doors for improved quality-of-experience (QoE) for end-users while giving ISPs a new degree of freedom (i.e. service quality) to exploit for increasing their revenue, these rules were met with a huge backlash from the public, activists, and content providers such as Amazon and Netflix because fast-lanes were perceived to give license to ISPs to violate net neutrality by throttling or blocking arbitrary traffic streams of their choice without regard to consumer interest [34–36]. In one manifestation of this fast-lanes model, the CP pays the ISP a lump-sum (or annual) amount for creation and maintenance of long-term fast-lanes. Netflix’s peering payment to Comcast in early 2014, believed to be in the order of $15–20 million a year [13], is as an example of this model.

To counter the consumer backlash, AT&T in October 2014 proposed an alternative whereby the fast-lanes are driven by end-users rather than by ISPs [37–39]. In other words, this proposal empowers the FCC to prohibit the creation of fast-lanes by ISPs, but instead puts the onus on the end-users to decide which sites and services (video, VoIP, gaming, and others) should receive priority treatment. While the proposal has received measured support from a few quarters—academics, Free Press, Center for Democracy and Technology [40, 41]—who have in the past unequivocally opposed ISP-driven fast-lanes, others remain largely sceptical.

Finally, after more than a decade of deliberations and backflips, in February 2015, the FCC reclassified broadband as a utility, and passed rules that banned fast-lanes, i.e. preferential treatment of traffic via payments from CPs, also known as paid-prioritization, and blocking or throttling legal content from lawful web-sites [42]. In addition, the rules apply equally to wireless broadband, not just fixed broadband. These open Internet rules went into effect in June 2015 [43]. We can expect that these rules will be challenged by ISPs in the coming years.

One of the reasons that net neutrality remains such a contentious issue in the US is that the competition in the US retail fixed-line broadband market is limited; it is often only between the local cable network and the local telecom network [44]. According to the Center for Public Integrity [45], US operators have the tendency to expand and capture more territory in a bid to avoid competition from more than one provider. The resulting lack of competition has made net neutrality advocates particularly nervous about the various discriminatory practices used by ISPs. Competition in the mobile broadband sector however is more robust, which explains why the FCC has until recently (Feb 2015) applied lighter net neutrality rules to mobile operators [46]. There are myriad of technology choices such as 3G, 4G and WiMAX offered by four top carriers: Verizon Wireless, AT&T, Sprint and T-Mobile [47, 48].

2.3.2 United Kingdom

In the UK, there is healthy competition for broadband Internet [44, 49] after "local loop unbundling" was mandated by the regulator Ofcom. It was estimated that 70% of households in the UK were served by at least four broadband providers in 2010. This competition puts onus on the ISPs to ensure good service and reduce churn. That being the case, a majority of large ISPs in the UK have attempted to rate limit peer-to-peer traffic during peak times using deep packet inspection (DPI) platforms [44]. Nevertheless, competition between ISPs ensures adequate quality and performance of popular applications, and thus net neutrality has hitherto not become a serious issue in the UK.

2.3.3 European Union

Europe's approach to net neutrality has emphasized transparency and competition [46]. Like the UK, many European households have a choice of using one from among three or more fixed-line broadband providers [46]. In April 2014, the European Parliament voted to implement net neutrality rules that would prevent ISPs from charging data-intensive CPs such as Netflix for fast-lanes [50]. Under the ruling, ISPs can only slow down Internet traffic to ease congestion, and cannot penalize specific services for heavy data use. However, on 2 March 2015, the EU member nations reached an agreement that would allow prioritisation of some "specialised" services (i.e. creation of paid fast-lanes), and authorised blocking of lawful content [51]. The European Council of Ministers specified that if ISPs did prioritise services, then they would have to ensure a good standard of basic web access for consumers [52].

In contrast to the above ruling, two countries in Europe—The Netherlands and Slovenia—have enacted tougher net neutrality rules, similar to the rules adopted by the US [53]. The issue in the Netherlands was that operators warned of end-user monthly bills increasing if they do not charge CPs offering popular content. As a result of the net neutrality laws, telecom operators raised the charges paid by consumers, but this did not affect Internet usage [54]. Moreover, as zero-rating deals are not permitted, Vodafone was fined EUR 200,000 for unmetering the pay-tv channel HBO [55].

2.3.4 Canada

Canada's net neutrality rules were established in 2011 [56]. ISPs are required to disclose their network management and traffic treatment policies to Canadian Radio-television and Telecommunications Commission (CRTC) [57, 58]. CRTC releases quarterly reports of the number of throttling complaints it receives and whether any have been escalated to warrant action. Surprisingly, there are no penalties for ISPs that fail to abide by the rules and no limits on throttling seem to be in place that is common knowledge [57, 58].

2.3.5 Chile and Brazil

Chile was the first country to pass net neutrality legislation back in 2010 [56]. The legislation mandates no blocking and no content discrimination. Even so, mobile operators were offering zero-rating services for selected content such as Facebook and Twitter. In June 2014, such offerings were stopped by the Chilean telecommunications regulator [59].

In Brazil, a legislation called "Internet Bill of Rights" was passed on 22 April 2014. The bill prohibits telecom companies to change prices based on the amount of content accessed by users [60]. It also states that ISPs cannot interfere with how consumers use the internet.

2.3.6 India

In 2014, telecom operators in India expressed concerns that popular OTTs such as Viber, Skype and Whatsapp were undermining their revenue stream incurred from voice calls and SMSes. The net neutrality debate in India was triggered when Airtel announced new data plans to surcharge users for using third-party VoIP services, but hastily retracted the plans after public outrage [46]. In April 2015, Airtel launched "zero platform" [11] similar to "http://www.internet.org" offered by its rival Reliance [61], that allows subscribers to access select content at zero cost, with the data not counting towards their usage quota. The charges are borne by CPs. The Telecom Regulatory Authority of India (TRAI) has released a consultation paper regarding regulation of OTT services. The outcome is awaited [62].

2.3.7 East Asia

Net neutrality has been studied by the governments of Japan, Hong Kong, Singapore and South Korea, and other countries in this region. In Singapore, carriers can sell fast lanes to content providers [63]. The Infocomm Development Authority (IDA) of Singapore requires ISPs to ensure that user access to legitimate websites is not slowed down to the point where online services become "unusable". However, it does not ban throttling, which means ISPs have the option of slowing down access to certain web sites, without rendering them unusable. Issues about throttling in South Korea were raised in 2012 [64] due to the heavy load imposed by the use of the Samsung Smart TV. High density living and effective retail competition differentiate these advanced Asian economies from the scenario in the US [46].

2.3.8 Australia

Today, net neutrality is not a major issue in Australia [65] owing to the significant retail competition, akin to Europe [66]. According to a communications report of the Australian Communications and Media Authority (ACMA), there were 419 ISPs operating in Australia in June 2013, 9 of which had more than 100,000 subscribers [66, 67]. The recent launch of video streaming services (such as Presto, Stan, and Netflix) has led to a significant increase in broadband network traffic [68], sparking public discussions on net neutrality. For example, only within a week of Netflix launching, iiNet accused Telstra for poor Netflix performance [69]. The Australian market has its own version of net neutrality in the form of "unmetered" content. For example, two ISPs in Australia—iiNet and Optus, have rolled out "Quota-Free" services for Netflix [10].

Governments particularly in the Asia-Pacific region such as Singapore, Malaysia and Australia are recognizing the importance of residential broadband in fostering economic and social growth. Unlike privately owned networks, public funded networks will provide a wholesale platform on which retail service providers (RSPs) can compete to offer their services to consumers. The National Broadband Network (NBN) in Australia is a prime example as it aims to provide 100 Mbps to over 93% of households in the country at an overall estimated cost of around $40 billion [70].

2.4 A Three-Party Approach to Fast-Lanes

We would like to propose a new approach to fast-lanes that overcomes the two major shortcomings of fast-lanes as they are currently perceived. The first concern is from consumers, who feel left out from the back-room negotiations between ISPs and CPs regarding creation of fast-lanes. The second concern is from CPs, who are irate at the bulk payments that ISPs expect in return for creation of long-term fast-lanes that may in fact be necessary only for a fraction of the traffic streams. We describe below how our approach addresses these two issues.

The first tenet of our approach is that we give consumers a voice in the fast-lane negotiations, by giving them a single knob to control the fraction of their broadband link that they allow the ISP to create fast-lanes from. This parameter, termed α, is in the range [0, 1]; if set to 0, the consumer essentially disables fast-lanes on their broadband link, while if set to 1 the ISP has access to the entire link bandwidth from which they can carve fast-lanes. An intermediate setting, say 0.8, instructs the ISP to leave at least 20% of the broadband link capacity at all time for best-effort traffic. At the moment we limit the fast-lane creation to the consumer's dedicated broadband access link, so the α-knob setting for one consumer does not affect other consumers. We believe this is a good starting point, since there is evidence that the access link is most often the bottleneck, especially as the number of household devices and concurrent users grows. Our approach of having a per-household knob allows subscribers to independently choose the level of net neutrality for their household, possibly based on their preference or traffic-mix, as explored in Chap. 3. Needless to say the ISP has an interest in getting users to set their α-knob as close to 1 as possible, for which they may offer financial incentives, explored in Chap. 4. For more sophisticated customers, we have also developed a richer user-facing interface that allows them to configure bandwidth on a per-device basis in their household, explored in Chap. 5.

The second tenet of our approach is that we replace the the bulk payments between CPs and ISPs with micro-payments in the following way: fast-lanes are no longer static arrangements negotiated in the back-room, they are dynamically invoked via open APIs available for any CP to invoke for a specific traffic stream. This allows a CP to choose if and when to invoke it, such as only for high-value customers or upon onset of congestion. This pay-as-you-go elastic payment model (much like pricing models for cloud compute) allows CPs to better match their fast-lane costs with their revenues, which is of particular value for smaller CPs. Figure 2.1 shows our architecture in which fast-lanes are dynamically managed via CP-facing APIs on the peering link, while providing user control (either a simple α-knob or a more sophisticated interface for per-device bandwidth control) via user-facing APIs; a specification and implementation of these APIs using software defined networking (SDN) technology will be presented in Chap. 3, while an analysis of the economic benefits is undertaken in Chap. 4.

Summary: Our proposal paves the way for all three entities, ISPs, end-users and CPs, to jointly exercise control over fast-lanes. End-users can set their individual

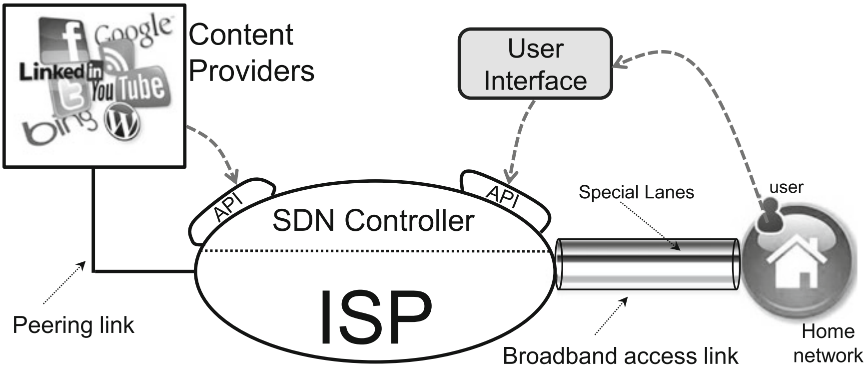

Fig. 2.1 Sytem architecture

α-knob to correspond to the degree to which they embrace fast-lanes for their household, CPs can choose if and when to invoke the fast-lane API in return for a micro-payment to the ISP, and ISPs can experiment with fast-lane pricing models that could be based on time-of-day or demand profile. We believe our proposal addresses the shortcomings of today's approach to fast-lanes, and has a good chance of overcoming the stalemate in which net neutrality discussions are currently locked.

2.5 Existing Solutions

2.5.1 Quality Control Techniques

The body of literature on QoS/QoE is vast, and *bandwidth-on-demand* capabilities have been envisaged since the days of ATM, IntServ and RSVP. These mechanisms equip the ISP with tools to manage quality in their own network, but little has been done by way of exposing controls to end-users and content providers.

2.5.1.1 Bandwidth Management

Early attempts at exposing QoS to external entities include the concept of bandwidth broker for ATM networks [71], and protocols for QoS negotiation (e.g. XNRP [72]). Tools for exposing network bandwidth availability are starting to emerge, though predominantly for data center users, such as Juniper's Bandwidth Calendaring Application [73] implemented over an OpenFlow-based network. Bandwidth-on-demand for bulk data transfers between data centers has also been explored in the Globally

Reconfigurable Intelligent Photonic Network [74] and NetStitcher [75], with the latter exploiting the elasticity in bulk data transfer to schedule it during diurnal lulls in network demand. Elasticity has also been leveraged by [76] to improve ISP access network performance.

Several broader frameworks developed for enterprise, WAN and data-center networks to control service quality: [77] proposes models and metrics towards enhanced user experience; [78] allows QoS control in the enterprise; PANE [79] inspires some of our APIs for application-network interaction which allows multiple applications to automatically interact with the network and to set the low-level quality related configurations using a set of programmable interfaces; Procera [80] develops a framework for network service creation and coordination; Jingling [81] out-sources enterprise network features to external providers; while our own framework in Chap. 3 develops APIs for content provider negotiation with an ISP [82]. Note that none of these APIs specifically target home networks or deal with consumer interfaces.

2.5.1.2 Access Virtualization

The works closest to ours are those that virtualize the access [83] and home [84, 85] networks. Separation of network infrastructure providers from network service providers has been deployed by the concept of "Open Access Networks" [86, 87]. However, this model does not envisage allowing a residential user to have multiple network service providers. Access networks have been virtualized in NANDO [83] which allows multiple service providers to share infrastructure and consumers to choose which network operator to use for each service, e.g. video, voice, or data. While it addresses consumer and network concerns, it does not consider the role of content providers. This model is very attractive for public access infrastructure (e.g. in Australia or Singapore), but it remains to be seen if private ISPs will be willing to share infrastructure with each other.

Several papers have used SDN technology to virtualize network infrastructure, and some [84, 85] have virtualized home networks, though not ISP access networks. In [84], the home network is sliced by the ISP amongst multiple providers of services, such as smart grid metering, network management and even video content providers. SDN is used to virtualize the network and so isolate the slices. With this approach the ISP cedes long-term control of the slice to the CP (it is, however, unclear what policies dictate the bandwidth sharing amongst the slices), which is different from our architecture in which the ISP only "leases" well-specified resources to the CP on a short-term per-flow basis. Both models have merits and are worth exploring, though we believe our approach is likely to be more palatable to ISPs as they can retain more control over their network. Another work [85] also considers slicing access to home networks, but emphasises giving the home user control of how their network is sliced, though at a lower session-parameter level than our single α virtualization control.

2.5.1.3 User Control

HCI research has captured the growing complexity of managing home networks [88], and surveys of existing router/OS-based tools have revealed usability problems as a major impediment [89]. We are by no means the first to propose new tools and architectures for the home network—Kermit [90] gives visibility into network speeds and usage for household devices; [91, 92] propose out-sourcing residential network security and troubleshooting to an off-site third-party; [84] proposes slicing the home network into independent entities for sharing by multiple content providers such as video services and smart grid utilities; HomeVisor [93] offers a home network management tool enabling remote administration and troubleshooting via high-level network policies; Improving home user experience using dynamic traffic prioritization is studied in [94], which actively identifies traffic flows of interest (by monitoring the application window) and signals the home router to serve the flows with a higher priority; [85] presents interfaces and apps similar to ours (presented in Chaps. 5 and 6) for the user to interact with the underlying network to control quality for different applications.

Tools similar to the ones we propose in Chap. 6 are also starting to emerge in the market: HP offers SDN apps for improving performance or security in enterprise networks [95], VeloCloud [96] offers cloud-based WAN management for branch offices, and LinkSys has recently introduced a cloud-managed smart WiFi router [97]. These parallel efforts corroborate that SDN and cloud-based tools are likely to gain traction in years to come, and our work facilitates adoption of enterprise/WAN models to the home environment.

While all the above works are relevant, we distinguish our work in Chap. 5 by considering two-sided control in which both the end-user and the CP simultaneously exert influence over traffic prioritization, and develop an economic model to support it.

2.5.2 Differentiated Pricing Models

We now briefly review the different smart data pricing (SDP) models and the economics around fast-lanes (touching upon aspects including net-neutrality and sponsored content).

2.5.2.1 Pricing Models for End-Users

Pricing of broadband Internet, i.e. what an ISP charges the end-user, has been extensively investigated. Broadly, these pricing schemes can be classified as being static or dynamic. Static pricing includes flat-rate pricing, where a user only pays a fixed charge in a billing period regardless of the volume of data used in that period. To bridge the growing gap between ISP costs and revenue, several ISPs around the world are offering newer pricing schemes such as usage-based pricing (fee paid is proportional to the volume of data used), tiered pricing (a fixed quota charge and any overage charges for exceeding the quota), and time-of-day pricing (higher charges during peak-hour usage compared to off-peak hours).

Dynamic pricing includes schemes such as day-ahead-pricing (charges for the next day are guaranteed the previous day), and congestion-based pricing (charges depend on the congestion in the network [98]; users pay higher prices during higher congestion levels). An excellent survey of the different pricing models aimed at end-users is given in [99, 100].

Our work in Chap. 4 is orthogonal to the above studies on user-pricing, since we do not aim to affect user-prices or user-behavior, and indeed want to keep fast-lane economics largely transparent to users [101]. Consequently, our scheme is oblivious to the data plans that the end-users have contracted with their ISPs, and we do not make any attempt to affect user behavior by time-shifting their traffic demands.

2.5.2.2 Two-Sided Pricing Models

Several recent works have considered two-sided pricing models, wherein the ISP charges both end-users and CPs. In [25], it is shown that under certain circumstances, net-neutrality regulations can have a positive effect in terms of total surplus under monopoly/duopoly ISP regimes. The work in [102] also studies a two-sided non-net-neutral market, but additionally takes into account QoS provided by the ISP to the end-user. By defining a model for total end-user demand, and using the mean delay of an M/M/1 queue as the QoS metric, the authors theoretically evaluate the conditions under which a charge made by the ISP to the CP would be beneficial (to either of them).

The work in [103] considers a model comprising a monopoly ISP, a set of CPs, and end-users. Focusing on the utility of the ISP/CPs and the resulting social welfare, the authors argue in favour of establishing priority-based pricing and service differentiation rather than on effecting net-neutrality regulations. Using game-theoretic analysis and incorporating models for congestion control algorithms such as TCP, [104] arrives at a number of interesting conclusions: most notably, when regulations are beneficial and when they are not. The authors also introduce the notion of Public Option ISPs, which could be an alternative to enforcing tight regulations.

These works largely consider (semi-)static payment arrangements and evaluate the resulting utility gains using game-theory; by contrast, our model differs by considering dynamic fast-lanes that are created and destroyed on-the-fly, wherein CPs make per-session decisions based on run-time factors such as network load [105].

2.5.2.3 Economics of Sponsored Content

The concept of “sponsored content” has been studied before [106, 107]—in this model, the end-user pays a lower fee to the ISP due to CP induced subsidies (Facebook traffic being considered "in-network" and not counting towards the user's quota is an example of this). The CP can benefit by attracting more traffic from the end-user, while the ISPs can reduce churn and retain customers. Although our work is loosely linked to this concept, it differs in not ascribing any subsidies to the end-users; moreover, unlike sponsorship models that are long-term contracts between CPs and ISPs, we study the efficacy of a model that permits paid-prioritisation at much smaller time-scales (i.e. at per-session granularity).

2.6 Conclusions

In this chapter, we have provided a comprehensive perspective of net neutrality and fast-lanes, an important problem that has been widely debated over the past several years. We have provided perspectives covering the techology aspects (such as zero-rating and CDNs), economic aspects (pros/cons for ISP, CPs, and consumers), and societal views. We have summarized the deliberations in the US, UK, continental Europe, Canada, South America, Asia, and Australia, showing how perceptions (and consequent regulation) vary significantly around the world. Lastly, we have presented a radical solution that addresses the fundamental shortcomings of current fast-lane approaches, and provides a potential win-win-win solution for ISPs, CPs, and consumers alike. We hope that this chapter highlights the nuanced nature of the debate around net netutrality and fast-lanes, and presents a viable path forward to overcome the current stymie in this debate.

We believe there are several research directions in this topic that can have a significant impact on the Internet ecosystem, and lead to the evolution of novel network architectures. We investigate some of these important research problems in the rest of this thesis, beginning with the SDN-inspired creation of dynamic fast-lanes and slow-lanes over the residential access link requested by content providers.

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