European Internet Traffic:

Problems and Prospects of Growth and Competition

A LSE-Tech White Paper

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Executive summary

The current structure and use of the internet is significantly different from its form as recently as ten years ago and this holds major implications for all of its stakeholders. The relationships among those who own the telecommunications networks, those who offer digital goods and services and those who look after the public interest are necessarily altered. Since its inception, the internet has experienced numerous major changes in structure and usage and we can expect that this current transformation will itself lead to further reconfiguring of technologies and uses in only a few years. In the meantime, it is necessary to understand what those changes are and how they affect growth and competition.

Here we set out to describe the new industry context of telecommunication network operators that holds implications for pricing bargaining power and control over some key elements of network management. As the European internet exchanges (IXs) carry around one third of European digital traffic and increasingly constitute nodal institutions of the internet, we focus on the traffic they carry, what they reveal about the dynamics of the internet, and how they structure relations among the three major categories of traffic overall: traffic that passes through exchanges, managed IP (private traffic and transit) and intra-network traffic. Each of these is governed by different institutions and economic principles. In this way we can show prevailing trends and the impacts of changes in traffic that explain some critical aspects of change in network management.

Of total estimated internet traffic in Europe, about 30% is routed through the internet exchanges while much of the rest of it remains obscure and incommensurate, with diversified data sources presenting an asymmetric relationship between data and analytical approaches. Given the high proportion of internet traffic that passes through European internet exchanges, it is not surprising that public interests would be expressed in the form of interventions to resolve disputes when market mechanisms cannot. Central to the smooth operation of this, as with other markets, is the availability of reliable information.

A new trend is arising: increasingly internet services providers [ISPs] connect to an internet exchange rather than buying transit from tier 1 providers. In Europe three exchanges dominate: DE-CIX, AMS-IX, and LINX. Tier 1 providers (often former incumbents) could be drawn into a race to the bottom for transit as the price they offer ISPs will depend on the sum of remote transit prices offered by competing backbone providers and the decreasing cost of remote peering in large European internet exchanges. In the short to medium term the strategic options for network operators appear limited. We describe four potential directions of movement: "status-quo plus", lateral transformation, accentuated move to services, and integration.

We also shed light on the relationship between traffic on the internet and the business activities that are related to it. This is one way of addressing a familiar set of issues about pricing, access, "freedoms", subsidies and policies. However, we approach this from a perspective that most participants find uncomfortable because it exposes various forms of economic exploitation, free-riding, and cross-subsidizing that may be disturbing, but would be more damaging to ignore.

At industry level, including among regulators, incumbents, and other stakeholders, there is an incomplete understanding of strategic options and this, along with inadequate analysis, carries the risk of policy making that cannot be sufficiently evidence-based. Furthermore, the resulting information asymmetry provides too many arbitrage opportunities and too much secretive activity to allow us to regard the network economy as a semi-transparent marketplace.

Finally, we show how the governance of the European internet, especially that of the internet exchanges, affects its structure and use. The scale, level of competition, and revenue-generating powers differ greatly and this report shows how alternative strategies could strike a balance among stakeholders. Therefore, the value of our analysis is to clarify what is obscure in the current debate on pricing and internet structure within the European context.

Our key findings are[1]:

1. Internet traffic: We estimate that 30% of Europe's internet traffic is routed through not-for-profit internet exchanges [IX], with the remaining traffic mainly routed through transit and/or private internet exchange points. Since telecom operators use internet exchanges to transport a significant amount of the overall

[1] This analysis differs from neo-classical macro-economic studies in that we have analyzed the structure, architectures, mechanisms, and traffic in internet exchanges and their implications for pricing, business

traffic in the IX, their influence on pricing could be greater than it currently appears. This finding suggests the value of further analysis of both the economics and the business relations among network operators, the exchanges themselves, and the stakeholders within exchanges.

2. Peering and transit prices: Although there are strong indications of a correlation between internet peering prices in the large exchanges and European transit pricesthe lack of data visibility raises questions about how business models affect how internet traffic is charged for.
3. Regulation: There is a functioning self-regulated market for peering agreements. However, if disagreements on pricing results in users were being disconnected, we could expect to find more pressure on regulatory authorities to intervene[2]. It is our view that all stakeholders should engage in negotiation based on greater information transparency to avoid such interventions if the consensus is for a functioning regime of self-regulation.
4. Information: The whole community needs accessible data on internet traffic to enable evidence-based policy. While we can measure a great deal about traffic on the internet, there remains a great deal that is obscure, incommensurate or inaccessible[3]. The first implication is that firms' strategic decisions are often based on scanty information, and the second is that policy-making is suffering from a lack of evidence to support effective interventions. This is an area where further scholarly work could lead to strengthening existing self-regulatory regimes.

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[2] See Appendix 1 for the case of Cogent vs. France Telecom

[3] See Appendix 2 of this document for a discussion of information asymmetry problems.

1. Introduction

This report provides insight into the challenges for measuring internet traffic and linking it to strategic options for telecom operators. Overall, internet traffic is comprised of many components. This paper deals with how the internet changes in structure and usage and how we can expect that this current transformation will itself lead to further reconfiguring of technologies and uses. As an indicator of these changes, we focus on the role of internet exchanges as indicators of and catalysts for the changing internet economy in Europe. We also consider their particular operational characteristics and how they are used by domineering internet companies such as Google and Amazon.

Since the mid-2000s the structure of the communications network has been altered to accommodate rising traffic demand, new uses of the internet, and especially new business models. For companies such as Akamai, Amazon, Google, Netflix, Spotify, and Facebook, and others operating as content delivery networks (CDN), cloud services, video/audio providers and social networks, these new business models constitute their purpose[4]. They help to define the very character of the internet as we currently know it. Their ability to carve out new operating realms has altered their relationships with network owners. Internet exchanges are market places where massive data traffic is exchanged and have become important elements not only for internet businesses, but also for the economy as a whole.

Over the past year, debates leading up to the 2012 ITU World Conference on International Telecommunications[5] have cast new light on the interrelated interests of national governments, telecommunications companies and all those who do business on or simply use communication networks. While much of the discussion has centred on the idiosyncratically interpreted term “net neutrality”, beyond this is a dispute about who pays for what on the infrastructure, and how different types of traffic can be charged for.[6] Underlying these debates are suspicions that those who control infrastructure might be setting too high prices, that those using the infrastructure are

[4] Some of these companies are called in the literature “over the tops” (OTT); we have chosen to call them simply internet companies.
[5] http://www.itu.int/en/wcit-12/Pages/default.aspx (ETNO, 2012a)
[6] See also: http://news.cnet.com/8301-13578_3-57557347-38/u.n-summit-votes-to-support-internet-eavesdropping/

failing to pay their way and free-riding, that those who create disproportionately high demand are paying the same as those whose demands are modest.

Most key participants in these debates, however, have too little access to information about the structure, functions and dynamic characteristics of the communications networks to assess competing claims. Two features are particularly poorly understood: the effect of changing business practices in the internet and the characteristics of traffic on the networks. We addressed the first of these in our LSE-ETNO Research White Paper of 2011 (Liebenau, Elaluf-Calderwood & Karrberg 2011). We focus on the second here. The products of our research are analyses, interpretations and new data that can provide the foundation for better, evidence-based policy-making both within firms and within the public realm.

The general picture of architectures underpinning how data are routed among users and service providers is relatively well understood. In addition to internally sourced activities, network operators carry traffic by peering and transit through a variety of transactions that are roughly measured by their own metering, or that of vendors (e.g. Cisco and Sandvine) and consultants (e.g. Informa, Netindex, etc.). For the most part, however, this monitoring does not take into account the value of different kinds of traffic and so we cannot know, for example, what proportion consists of low value, "always-on" monitoring as opposed to high value commercially sensitive data. Only those who are engaged directly in those business practices know these features.

We estimate that 30% of Europe's internet traffic is routed through not-for-profit internet exchanges [IX], with remaining traffic mainly routed through transit and/or in private internet exchange points. It is also apparent that transit prices are decreasing in most markets in Europe (Norton 2012b; Weller & Woodcock 2012; Capacity Magazine 2012).

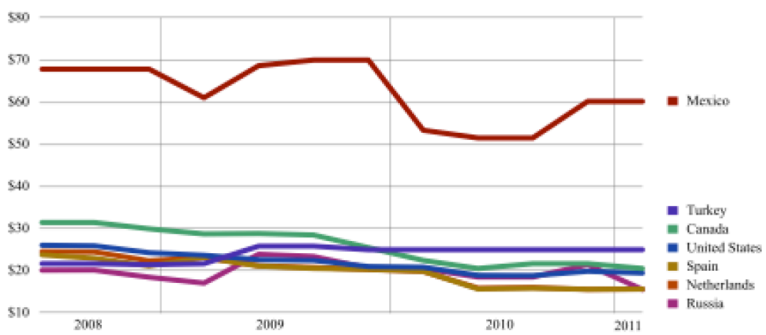

Figure 1: Transit prices trends (Source: Telegeography; cited in OECD, 2012)

In the rest of this report we explore the significance of this apparent correlation between decreasing internet peering prices in the large European internet exchanges and the overall decreasing European transit prices. We also consider what this implies about bargaining power for internet traffic prices and the extent to which it is increasingly dependent on internet exchanges.

2. Research on changes to internet traffic demand

The internet as a network of networks has been measured in terms of cables laid (Blum 2012), data transferred (Cisco 2011) and other relevant variables as defined by the Internet Engineering Task Force [IETF], the Cooperative Association for Internet Data Analysis [CAIDA] and other specialist groups[7]. This emergent internet is driven by the requirements for high quality of service and rising demands for bandwidth in addition to periods of business speculation and shifting national goals. The way this appears, however, varies greatly, depending on how data are collected.

Most of the methods used to understand the growth and direction of the internet focus on compiling data that measure autonomous system numbers (ASNs), traffic, transit and peering agreements (Claffy 2011a & b), or connection speeds (Clark et al. 2011). However, each of these counts is only partially accurate and none are complete with regard to the totality of digital traffic, with much of it focusing on the US market. Much traffic is carried over private networks and is very hard to investigate and measure (Claffy 2009). The traffic data sources used for our analysis are ASNs, peering traffic, classified traffic by type (as with the Cisco VNI data, 2012), reports on traffic volume by Renesys (2012), Akamai (Belson et al. 2011 & 2012) and Sandvine (2011 & 2012) and data compiled by the International Telecommunications Union (ITU 2011). We have also used other reports, such as the description of ASNs consolidation by Telenor (Hallingby and Erdal 2011), and industry reports on pricing and related topics (e.g. Howard et al. 2011).

Internet exchanges (IX) in Europe, where public peering arrangements and sometimes traffic volumes are well documented, provide ample opportunity to perform necessary

[7] See Appendix 1 for more on issues related to metrics and data sharing measurements of the internet. They relate also to current developments from the Federal Communications Commission that might be mirrored in Europe in due course.

analyses[8]. The same cannot be said of transit[9] where we are limited to a range of consultancy data and telecommunication firm internal reports linking data from disparate sources to pricing and quantity of traffic (Valancius 2011). To understand the forces driving the internet, and crucially the innovation processes that take place within it, we need a much more detailed and coherent view of the scale and character of traffic. We also need new kinds of qualitative evidence relating to the role of regulators and of interactions among developers, network managers, telecommunication systems operators, fixed and mobile platform owners and other stakeholders such as big users and consumers groups.

For business models analysis, we turned to consultancy reports such as those by the Boston Consulting Group (BGC 2011), Analysis Mason (Kende 2012), Plum (2011), and AT Kearney (2010a & b), company annual reports, specialised reports on particular technologies, industry intelligence bulletins and published materials of all kinds from organisations representing the industry. There are similarities and differences in the regulatory approaches from both sides of the Atlantic. We consider declarations by regulators about their own initiatives based on government or international policy guidelines, reports commissioned by industry players such as the Cullen Reports (2012), those released by the Body of European Regulators for Electronic Communications [BEREC] and consumer group reports. Furthermore, the debate on regulation is often presented as a binary choice between self-regulatory regimes versus stringent and structured frameworks, when in reality the picture is more multidimensional than that and varies among geographic regions (BEREC 2012).

3. Estimating internet traffic: components and trends

Previous approaches to understanding internet traffic have commonly focused on national contexts or macro aggregation of transit data. Otherwise, they have focused on the issues raised from interconnection. However, not only is it clear that traffic passing through the large exchanges is almost oblivious to national borders, it is also clear from detailed studies of traffic within Norway (Hallingby and Erdal 2011 & 2012), the first such comprehensive national study, that much traffic is increasingly, and very

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[8]AMS-IX for example provides a comprehensive data set, with historical data at https://www.ams-ix.net/statistics. Another source is EURO-IX with publishes reports from several of the IX in Europe at https://www.euro-ix.net/europe,.

[9] See: http://www.telecompaper.com/news/france-telecom-commits-to-more-transparency-in-peering--865732

significantly, invisible to normal monitoring. International traffic crossing national borders is growing, while prices for transit seem to decrease, as seen in figure 1. Although some of this drop is associated with technical changes (e.g. cheaper ports technology), in any case it marks a business-changing trend. Decreasing prices, taken along with increases in bandwidth usage (see figure 2), is to be expected as unit costs drop, but there is no direct correlation between growth rates and transit charges.

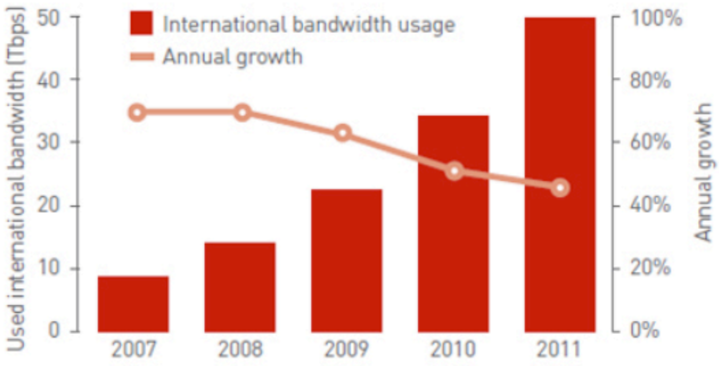


Figure 2: European capacity trends (Source: Capacity Magazine, October 2012)

A generic socio-economic equation for internet traffic is as follows[10]:

"Total internet traffic = Internal traffic (private) +interconnection traffic (private) + internet exchange traffic (public) + internet exchange traffic (private) "

By focusing our analysis in one component of internet traffic – internet exchanges - we address trends out of the scope of reports and research provide by consultants on the telecom sector. In the following section we describe how internet traffic is exchanged, the role of IX, differences between European and US internet exchanges, and we outline IX traffic trends in Europe.

Internet exchanges: a starting point for analysis

We start with aggregate estimates of national traffic for Europe generally and then for Europe's three dominant internet exchanges, those in London, Frankfurt, and Amsterdam. We can then analyse these aggregates in conjunction with our own

[10] We divide traffic in four groups as this is how we can measure it: internal traffic is provided by network owners who deliver content directly to users (e.g. TV services by incumbents and cable operators); interconnection traffic is exchanged outside internet exchanges; and remaining traffic is peered in internet exchanges either through public ports (openly accessible for our estimations) or private ones.

qualitative assessment of the categories provided by Cisco or those used by specialist industry analysts (such as Quantum-Web, 2012)[11].

This sheds light on the extent that competition, control and convergence are at the core of the changes for the emerging internet. Just as there is not one internet, there is not one single measure that captures the key features, even for as straightforward a question as, "*how much internet traffic is there*?" One internet is the direct successor of the ARPANET, an internet of commons where largely undifferentiated net neutrality principles and universal access principles apply. Most of the current debate on net neutrality focuses on this internet. However, a second internet has emerged, and it can be portrayed as driven by commercial interests and is composed of multiple networks providing specialised content with varying quality and services requirements.

Private and public peering: relevance and change

European internet traffic has traditionally been routed through transit contracts where smaller ISPs buy access to the whole internet through a layered model of access by using tier-1 providers that might be telecommunication network operators or global ISPs. The ISP often physically connects in a facility operated by the tier-1 provider. Increasingly this is changing whereby multiple ISPs connect instead in about 250 internet exchanges around the world, more than half of them located in Europe[12].

While public peering allows many networks to interconnect via a more cost-effective shared connection, private peering is the direct interconnection between only two networks, across a tier-1 or tier-2 physical medium (e.g. direct cable or fiber connection) that offers exclusive, dedicated capacity. Early in the history of the internet, many private peering arrangements occurred across circuits provisioned by telecommunications operators at individual carrier-owned facilities. Today, most private interconnections are made at exchanges or telco-neutral co-location facilities, where a direct cross-connect can be provisioned between participants within the same building. IP transit is a simpler form of interconnection. Most tier-1 and some large tier-

[11] We have chosen to use either one or the other according to careful definitions of categories, and in some cases we have felt it necessary to devise our own categories based on relevance or on what we believe European IX are able to provide, and to account for likely multiple counting. Additionally we have compared whether the ASNs can be categorized as is done by Hurricane Electrics, ALEXA or similar categorization techniques (Alexa, 2012)[11]. We have reflected these data back to Euro-IX data to minimise multiple counting.

[12] Euro-IX has 139 members, https://www.euro-ix.net

2 ISPs are willing to sell dedicated access to their networks via private leased-line circuits. However, because of the resources required to provision each private peer, many networks are unwilling to provide private peering to small networks, or to new networks that have not yet proven that they can provide mutual benefit. Some companies, such as Facebook, actively engage in searching for many peering partners to increase the perceived quality of access to their pages[13].

Very large content providers are also contracting with content delivery networks, or building their own private networks - as Google does - where they use private peering. Very large backbone providers (such as Level 3 or Cogent) engage in private peering arrangements as they challenge even large incumbents in Europe with global ASN accessibility. There have been several published cases of disagreement (such as between the French regulator ARCEP and France Telecom vs. Cogent) leading to temporary service interruptions for users in Europe[14]. See Appendix 1 for the full case description.

New roles of internet exchanges

An internet exchange can in some ways be compared to a switching station, where different internet service providers or system stakeholders connect to each other. Smaller ISPs who serve a region or parts of a country will be able to exchange traffic with each other rather than buying transit from a large backbone/core/global ISP/upstream provider. A large internet exchange point, such as AMS-IX in Amsterdam, may bring together hundreds of tier-1, tier-2, and tier-3 ISPs, CDNs, hosting service providers, mobile companies and others. In the case of AMS-IX this amounts to more than 500 ASNs.

In contrast to those in the US, European internet exchanges are mainly operated by academic or non-profit membership organisations. In the US, data centre providers such as Equinix and Telehouse typically offer internet exchange as a commercial service. Most countries in Europe have at least one exchange that keeps domestic traffic within the country. In this sense, IX are contrived monopolies and due to risk of traffic capture, conflicts of interest, and mistrust among competitors, an independent company is most

[13] https://www.facebook.com/peering/
[14] See for example Cogent vs. France Telecom, Cogent vs. Telia Sonera: http://gigaom.com/2008/03/14/the-telia-cogent-spat-could-ruin-web-for-many/ http://www.fiercetelecom.com/story/cogent-and-orange-france-fight-over-interconnection-issues/2011-08-31 and case been followed by the French regulator, ARCEP.

often in charge of the premises. This does not mean, however, that exchanges do not differentiate among customers (BEREC 2012).

Public peering points could become overloaded and create sources of packet loss, which results in the current standard of "best-effort" level of service. However, IX in both Europe and the US strive to equal the performance of private peering connectivity and most European exchanges move large traffic volumes without significant packet loss. Unlike the bidirectional private arrangements, public peering enables multiple streams of traffic. The business arrangements for the cost of traffic are estimated using economic assumptions based on balanced and best effort levels of service (Clark et al. 2011)

Some industry observers estimate that the vast majority of internet exchanges worldwide consist of not-for-profit associations of participating internet service providers (Mitchel 2011). Much of the data on public peering traffic is available through the IX, but very little detail is openly available on private peering arrangements. They themselves in many cases do not monitor this traffic. By bringing together enough peering partners, running costs and new equipment are paid for.

European exchanges offer different business models from US counterparts

Let us consider the core commercial characteristics of internet exchanges. Business models for peering affect how internet traffic is routed and look different in Europe from the US. The US internet exchanges are mostly large-scale commercial operations that combine co-location services with public peering, while European IX separate out co-location services from the operation of the switch fabric. The operation of the internet exchange fabric is generally offered by a not-for-profit association of the peering participants.

These associations have a budget and staff to operate the infrastructure on behalf of the associated members and seek to provide the best service possible for the lowest possible price. While they need to maintain enough cash for working capital and anticipated upgrades they are also required not to make a profit from their activities. This is why European IX tends to lead worldwide in dropping prices. An overview of the differences between European and US IXPs is provided in Table 1.

	Legal neutrality modes of operation	Governance mode	Type of peering agreements available	Pricing goals	Pricing flexibility
European IX model	Carrier-neutral ISP-neutral co-location-neutral	Not-for-profit formal member association	In any co-location company that has the peering fabric installed	Recover costs	Fixed – every member pays the same
US IX model	Carrier neutral ISP-neutral	For-profit corporation	Only within the co-location operator's space using only the co-location operator's peering fabric	What the market will bear	Negotiable – important players may be lured in with preferential terms and pricing

	Contracts	Peering fabric distribution	Peering is predominantly	Information shared	Cross connects
European IX model	Co-location contract and IX member contract are required	Spread across potentially many competing co-location operators	Public	Openly	Run your own, inexpensive one-time fee, or low recurring fee to co-lo operators
US IX model	One contract for all co-lo locations and peering services	Spread only across the co-lo provider's data centers	Private	Selectively	Only co-lo operators can run core connects priced around $300/month

Table 1: Comparison of internet exchanges in the US and Europe (based on Norton 2012a)

The difference between the structure and governance of European and US IX is further evidence that we can no longer describe a singular, worldwide model of the internet. Rather, we need to regard the internet as a patchwork of interconnected networks that differ significantly between regions. Business models for connecting networks through public and private peering consequently differ in Europe and the US.

European IXs are spread across multiple co-location providers whereas US-based IX are generally contained within the same co-location provider building or specially designed locations. One implication of this is that an ISP can choose a co-location provider with a different mix of price/product/service and there is an open market for co-location space. There is comparably little negotiation room with the co-location provider if one needs to be at a particular internet exchange in the US.

The aggregate volume of traffic over the public peering fabrics tends to be historically larger in Europe than in the U.S. The technical experiences of large European IX in public peering could in the future benefit US IX because of their experience in handling large-scale traffic (Mitchel 2011). As the US based IX are often for-profit operations it is part of their business model to provide commercial value such that the more interlinked the customer base, the more difficult it is for customers to leave; IX have the ability to lock-in their customers[15].

Quantifying internet traffic in European internet exchanges

European IX created an umbrella organization, Euro-IX, to gather traffic data, benchmark, and provide other services to the community of exchanges. They also gather information on regulatory issues within the region and from other jurisdictions that could have an impact on their membership[16]. As of the end of 2012, Euro-IX had 139 members including the top three who carry about 63% of total traffic: DE-CIX in Frankfurt, AMS-IX in Amsterdam, and LINX in London. These are large exchanges with peak traffic well above 1Tbps. These giant exchanges are followed by a few with close to or above 500Gbps (CERN, Moscow, Stockholm, Paris). The majority of exchanges handle much smaller traffic volumes.

Figure 3: Approximate share of traffic through European IX (Source: Euro-IX; Own analysis)

In figure 3 we show an approximate share of traffic through European IX. International traffic plays a large role in European exchanges and AMS-IX claims that over 70% of its peering partners are networks from outside the Netherlands, making it the most

[15] http://seekingalpha.com/article/248263-this-week-s-interxion-ipo-colocation-the-european-way?source=hp_latest_articles
[16] https://www.euro-ix.net/

international IX in the world[17]. Traffic seems to have doubled every 4-6 months in the internet exchanges for the past decade but due to an increase in private interconnects in Europe, this growth rate is slowing with regard to public peering (Mitchel 2011).

Figure 4 below shows how real-time entertainment is the largest traffic type in Europe (video and audio), followed by web browsing, file sharing, social networking, and communications (mainly VoIP).

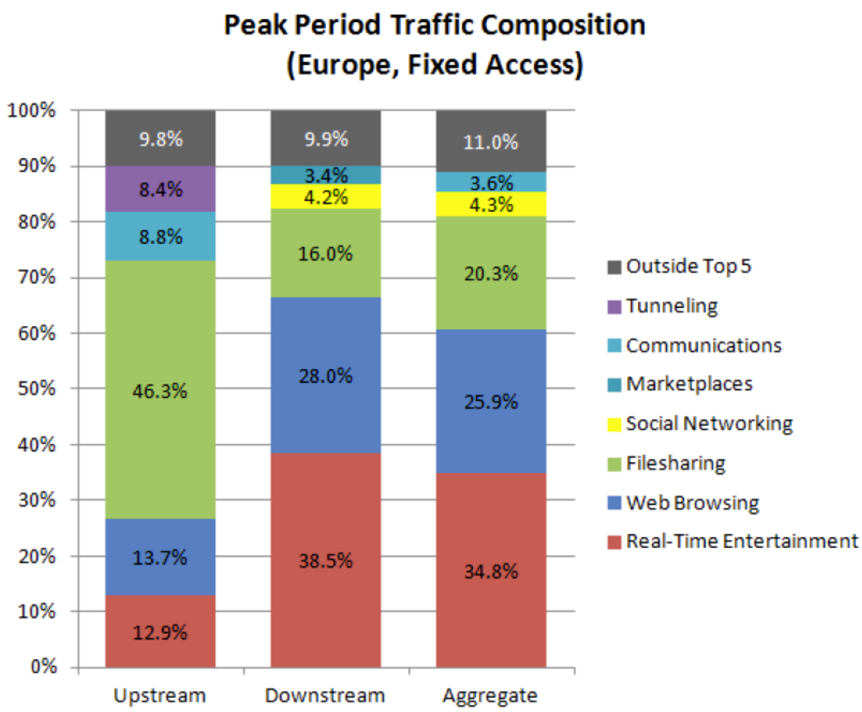


Figure 4: Aggregate traffic composition in Europe (Sandvine 2012b)

In the UK the major generators of content online are all video providers: BBC iPlayer (5.1%), Netflix (2.51%), Lovefilm (1.46%), and 4oD (1.1%), but due to their regional character and restrictions, they fail to be among Europe's top ten services overall. According to Sandvine (2012), the top ten applications in Europe make up 80% of peak traffic, as seen in table 4. In the US, Netflix is the main traffic driver with 29% of composite traffic and it alone accounts for one-third of capacity infrastructure costs in the US (Sandvine 1H report 2012).

[17] https://www.ams-ix.net/connect-to-ams-ix/benefits-of-connecting

Aggregate European Traffic	
Application	Share
HTTP	24.14%
YouTube	20.10%
BitTorrent	14.94%
eDonkey	3.98%
Facebook	3.76%
Flash Video	3.54%
RTMP	2.63%
MPEG	2.26%
Skype	2.13%
iTunes	2.04%
Top 10	79.52%

Table 2: Main types of European internet traffic (Sandvine 2012b)

Publicly available data provide only a partial picture of digital traffic. For example, LINX in London seems to be the largest private interconnects exchange in the world, servicing dedicated connections for financial institutions and many other sensitive services[18]. Its proportion of private traffic, however, is unclear since only a very few IX in Europe, such as M-IX in Milan, report openly on how much private traffic is exchanged (some 15-20% of peak traffic in the case of M-IX)[19]. Arbor Networks estimated in February 2010 that 60% of Google's traffic was being channeled through direct interconnects that link its data centres to one another[20]. Assuming this share has not decreased, and combined with table 2 above, this would indicate that at least some 12% of peak time traffic in Europe consists of Google's privately routed YouTube traffic[21].

Similar indications of incomplete information can be found in most of the 139 exchanges in Europe and it appears the move of a significant proportion of traffic from public to private peering arrangements is rising. Although the pricing structure is not visible in detail, trends indicate increasing reductions of the actual prices paid for ports in exchanges, regardless of the type of traffic transported. Next, we have observed traffic volumes through all European internet exchanges and estimate average total exchange

18 https://www.linx.net/pubtools/trafficstats.html?stats=decade
19 http://www.mix-it.net/
20 http://www.pcworld.com/article/191993/google_traffic_dominates_the_internet.html
21 In interviews we have further confirmed our belief that privately peered traffic makes up at least 20% of total traffic volume in Europe.

speeds for public peering to be approximately 8.7Gbps in October 2012[22]. If we take the conservative estimate that privately peered data volumes correspond to 20% of total peered traffic,[23] this yields total peered internet traffic of 10.9Gbps and a total volume of some 3600 PB (petabytes) per month. When comparing our own estimates to those of Cisco's Visual Networking Index[24], we note that traffic through the internet exchanges make up about 30% of Cisco's estimated total traffic on the internet. This is explained by the fact that Cisco includes managed IP traffic and other traffic observed at the end-points of the network that do not necessarily pass through the internet exchanges.

European internet traffic estimates 2012 (PB / month)	Total internet traffic in Europe	Of which real-time entertainment [25]
Traffic in European IX (LSE estimates 2012)	3,594 (30% of Cisco total estimates)	1,258 (29% of Cisco total estimates)
Cisco VNI total traffic estimates (2012)	11,930	4,358

Table 3: Internet traffic as observed in internet exchanges versus Cisco's total estimates

Company participation in IX - The example of AMS-IX

AMS-IX in the Netherlands is a leading internet exchange with an estimated 22% of total internet traffic among European exchanges. AMS-IX provides detailed information on its peering partners, and their acquired switching capacity. The top 40 (of just over 500) peering partners make up 71% of the total AMS-IX switching capacity and we assume that this corresponds roughly to actual peak traffic being exchanged. The largest peering partners in terms of volume are broadband operators, hosting firms, CDNs and media firms, with incumbent telecommunications companies constituting almost 25% of these peering partners. It can also be assumed that switching capacity is directly correlated to peak capacity, which varies with the types of applications carried over respective networks.

[22] From data from individual exchanges and Euro-IX for October 2012
[23] An estimate confirmed in interviews
[24] www.cisco.com/en/US/netsol/ns827/networking_solutions_sub_solution.html
[25] Source Cisco VNI 2012: real time entertainment defined as consumer internet video

Switching capacity is an estimate rather than a precise measurement of average capacity or total traffic. Nevertheless, we see that the national broadband champion of the Netherlands, KPN, tops the list, followed by a mix of broadband and cable operators, backbone providers, media companies, and hosting and cloud providers. Out of the 40 top providers in terms of switching capacity, more than one third of them are telecommunications operators (9 of them incumbents and 5 mobile/broadband operators), controlling about 30% of switching capacity among the top 40 significant players. In this sense telecommunications operators occupy central positions for public peering in the internet exchanges. How they are faring in the private peering market is obscured by lack of available open data but anecdotal evidence of the shift from transit to private peering might indicate a reduction in their overall revenue-generating opportunities.

Organisation	Type of firm	Total switching capacity (GE)
KPN	Incumbent	367
Ziggo	ISP	320
Akamai International BV.	CDN	240
Leaseweb	Managed & Cloud hosting	240
UPC Broadband Operations B.V.	Cable operator	220
Vodafone D2 Gmbh	Mobile operator	200
Highwinds Network Group, Inc.	Game CDN	160
OVH	Managed & Cloud hosting	160
Atrato IP Networks	IP transit and carrier solutions	100
RTL Nederland Interactief B.V.	Media	100
Giganews, Inc.	Media	80
Google Ireland Limited	CDN, content provider	80
Microsoft	Managed & cloud services	80
NPO	Media	80
Virgin Media Limited	Media	80
Telenor Global Services AS	Incumbent	64
EdgeCast Networks, Inc	CDN	60
IP Transit, Inc.	Backbone provider	60
Limelight Networks	CDN	60
Tele2 Nederland B.V.	Mobile operator	60
Telefónica o2 Germany	Incumbent	60
Easynet Limited	Managed & cloud services	50
OJSC "MegaFon"	Mobile operator	50
AT&T Global Network Services	Incumbent	40
Cambrium BV	Managed & cloud services	40
Facebook, Inc	Social networking	40
Init Seven	Colocation, FTTH	40
Interoute Managed Services	Managed & cloud hosting	40
Online Breedband BV	Broadband operator	40
Softlayer	Managed & cloud hosting	40
Turk Telekom A.S.	Incumbent	40
Belgacom International Carrier	Incumbent	32
TDC A/S	Incumbent	32
Base IP B.V.	Mobile operator	30
Portugal Telecom	Incumbent	22
ROMTELECOM S.A.	Incumbent	20
AOL, Inc.	ISP, service provider	11
Vodafone	Mobile operator	4
Netnod	Internet exchange	2

Table 4: Top 40 AMS-IX members and their estimated traffic volume (AMS-IX; LSE analysis)

4. Analysis

At least two trends can be seen from our analysis of internet exchanges: the first is a shift to private from public peering in the internet exchanges. More content delivery networks and other internet businesses are choosing to have part of their traffic distributed by private peering and increasingly content providers are deploying CDNs at tier-3 to be closer to customers.

The second trend is a product of the dominance of real-time entertainment among content provision leading to increasing challenges to provide quality of service to customers. This generates incentives for internet businesses and non-telecoms stakeholders to seek to gain access to customers not only at tier-1 and tier-2, but also tier-3 to deploy CDN servers. It is in this way that CDNs have become important players in internet exchanges.

Internet modularity, new topologies and business model impact

Internet exchanges are key components to understand how business models are shaped by changes in the structure of the internet towards a modular architecture. Focusing only on other forms of interconnection does not give full explanations of the current evolving internet dynamics. The growth of IP traffic volumes fuels cost increases both with regard to capital expenditures and operating expenditures but the average revenue per end user for internet access is flat or decreasing in Europe (ITU 2012; ATKearney 2011)[26]. Increasingly, traditional telecommunication services are provided by IP networks and the prospect is that legacy networks will be fully substituted for by IP networks.

New services such as video streaming require high quality of service [QoS] standards for delivery over domestic networks. This need gives an opportunity to network operators to provide QoS delivery for certain services in order to get incremental revenues able to finance network upgrades and the introduction of new technologies such as fiber to the home. Moreover, it could allow other internet companies to increase their customer base and extend the services they can provide.

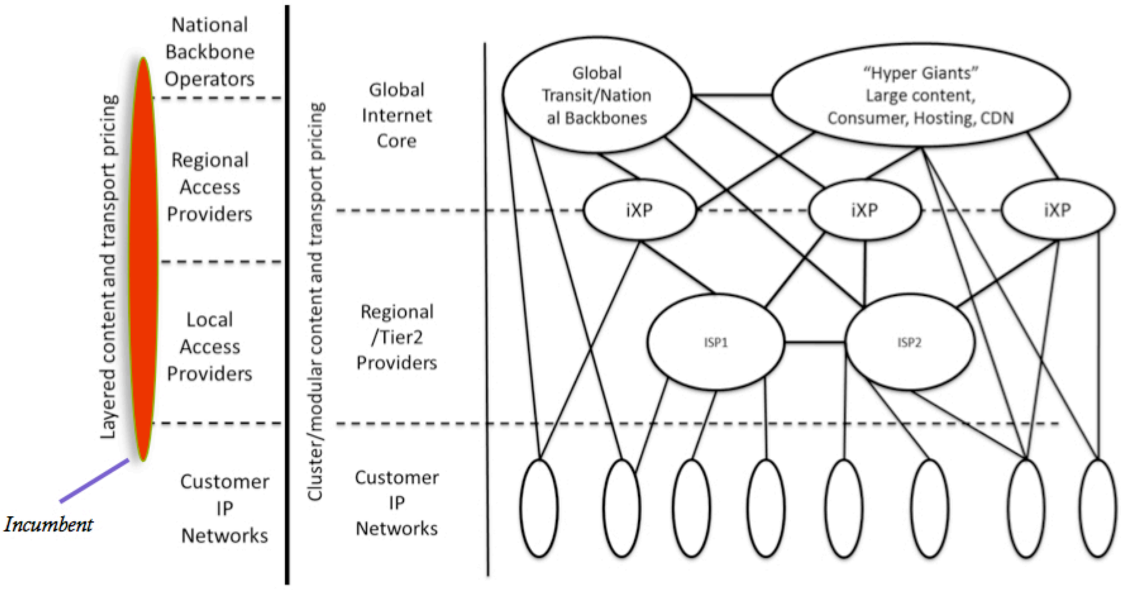
[26] ITU now claims that world fixed broadband prices fell 75% between 2008 and 2011 (ITU 2012)

However the use of QoS as the only economic and traffic measure has drawbacks. Many of the efforts to understand the measurement of the internet focus on a misguided emphasis on quality of experience/service [QoE/S]. Whilst the end user experience and the quality of the service delivery have an impact on the perceptions of the ability of telecom operators to satisfy customers, current metrics are inadequate to assess such experience entirely or to describe how it can be enhanced. To continue the focus of the discussion on quality based on current metrics such as latency, jitter, outages, etc. does not lead to better understanding of what is happening to the emergent properties of the internet. There is a clear need to do so at least for the sake of addressing legal and regulatory perspectives.

A major reason for this change stems from infrastructure innovation fuelled by users accessing more dynamic content on more devices. As the importance of online channels for the distribution of content grows, firms assume growing importance also of dynamically constructed and targeted content. Mobile and connected internet devices further affect new user behaviour.

In figure 5 below we show how the standard internet model of four tiers has been replaced by a modular model[27] of three levels, the worldwide internet core, regional providers, and customer IP networks. Assessing traffic at internet exchanges reveals how traffic is exchanged among these three levels, who the players are, and which practices are efficient for different types of traffic, either public or private.

[27] See also Liebenau et al. 2011.



Source: Labovitz (2010) and Liebenau et al (2012)

Figure 5: The change from a four-tiered vertical model to a modular internet model

Changing architectures changing transit and peering business

Transit arrangements, as seen in figure 1, along with peering prices have declined despite increasing traffic and this has occurred most significantly for those who have a strong bargaining position such as large media and entertainment firms. Anecdotal evidence indicates that prices for CDN services have declined with growing traffic for the last four years, and generally ranges between 1 and 12 cents per GB in the US. Very large media and entertainment firms (those distributing more than 3PB per month such as Netflix) only pay between 1 and 3 cents per GB delivered[28]. The underlying reasons for lower transit prices might include decreasing peering costs in internet exchanges, and this practice is fuelled by European exchanges continuously lowering their prices to protect their not-for-profit status. It is also the case that backbone costs fall as new multiplexing technologies allow ISPs to deliver traffic more efficiently (Norton 2012a). While total peering costs for ISPs consist of IX peering cost and the international transit price to connect, transit costs[29] include the circuit required for the ISP and the variable cost associated with the traffic carried upstream to the internet and depend upon co-location costs.

[28]http://blog.streamingmedia.com/the_business_of_online_vi/2012/09/cdn-pricing-stable-survey-data-shows-pricing-down-15-this-year.html

[29] Transit costs are sometimes called wavelength or capacity, and it is defined as transit cost equal to co-location cost + backbone cost + upstream port cost. In this case we refer only specifically to IP traffic or data traffic.

This form of interconnection is attractive for smaller tier-2 and tier-3 ISPs that may not be located near a public internet exchange point or other internet exchange. It can be inferred, based on current business models, that many lower-tier ISPs have neither the technical resources nor the traffic volume to justify a private peering relationship with a higher-tier ISP. In a competitive market for international transit, large internet exchanges enjoy economies of scale and offer lower prices for ISPs than in markets where peering prices are higher, as with regional internet exchange points, where costs are affected by the number of members connecting to the exchange.

Incumbents could therefore be drawn into a race to the bottom for transit as the price they offer ISPs will depend on the sum of the remote transit price offered by competing backbone providers and the cost of remote peering in large European internet exchange points. In this way the large IX in Frankfurt, Amsterdam, and London will drive down transit prices offered by incumbents in markets as far away as Eastern and Southern Europe.

Norton (2012b) believes that transit prices decrease on average by 30% per year in the US, but such claims are contested. For maintained profitability, sufficient economies of scale are needed in order to keep networks cost-effective while expanding capacity[30].

Strategy implications for telecom operators

Our analysis allows us to provide some insight into the strategic implications for telecom operators regarding the increasing role of internet exchanges in setting prices for transit, and how a modular provision of internet services has changed their role. The strategies that we suggest below address the means by which more stakeholders, including telcos, can monetize the changes in the newly modularized internet. The trend seems to be to open up peering as an alternative to interconnectivity, along with changes in traffic patterns that pose major challenges to telcos. We set out four strategic approaches that telco operators can consider. We believe that these can help to address problems of perceived business value and the lack of confidence of stock markets as well

[30] In response to this, Deutsche Telekom for example, prefers to be discriminatory in their choice of peering partners and to keep a policy of engaging in transit deals where they have tighter control over pricing. Another example is apparent from the conflicts between Cogent and France Telecom. See also Appendix 1. As telecommunications companies are squeezed between increasing customer demand and content provider push, distorted market pricing is aggravating a misunderstanding of quasi-markets for traffic provision. Some telecommunications operators are actively accusing content providers and other internet businesses of being "free riders" on their networks.

as the perceived lack of innovation by these firms when compared to new internet companies:

- **"Status-quo plus":** Network operators endeavor to provide quality services over well-maintained infrastructure and they have the option to focus on these activities and continue to work towards ever greater efficiency and higher quality of service. This is seen by many telecom operators as their most desirable value proposition. The state of competition in Europe, however, is such that the basic provision of infrastructure requires some economies of scale, which implies companies similar to Level 3 that can compete to provide low cost services. Current market rules can be regarded as militating against mergers or any perceived reduction in competition, even where, as in Austria, four operators compete for shares in a small market. So, for "status-quo plus" to be feasible, policies towards competition and scale economies will need to be altered.
- **Lateral transformation:** Network operators could reconsider their core business and shift, not necessarily dramatically, towards becoming content delivery networks. If we take voice telephony and providing connectivity to be included in this new form of CDN, we could see the trend towards providing such services increasing, as begun by Telefonica. To give access at tier-3 to other internet businesses seems a strategy that could reduce network operators' bargaining powers.
- **Move to services:** The Comcast model of diversified services provision, including especially plentiful content, is another space for strategic movement. That model does not exist in Europe, except perhaps to a limited degree within the BT Group (e.g. through their alliance with the BBC and new sports coverage), so we cannot imagine exactly what the market response to that might be or the reaction of regulators. Nevertheless, a move to content provision would change the relationships among participants in the market and is likely to stimulate new forms of competition and perhaps investment.
- **Integration:** All of the options above describe some form of reconfiguring of the basic business models of network operators and those who have the greatest stake in their operations of the ICT infrastructure. The most successful businesses operating on the internet are typically structured not as simple vertically integrated firms, but rather as "modular" businesses that take advantage of the modular architecture and the behaviour of customers that encourages modularity. While other players have begun integrating backbone and ISP offerings, media and CDN

services, the network operators could strive for their own engagement in the discreet modular ways of doing business that has proved to be effective, especially for the large American internet companies. Similarly, BT and Telecom Italia have invested heavily in cloud computing, a trend that could grow if nurtured.

While these implications for strategy follow from our evidence, we regard them primarily as a means of framing the relationship between the evidence we have about institutions and trends, and the changes that key stakeholders may envisage.

5. Conclusions

It remains difficult to claim that any researcher has a clear, full view of what the dynamics and structure of the internet has become. What is apparent from many indicators is that demand is shifting (Liebenau et al. 2012), the means by which traffic is been transported is changing and the business models associated with such shifts are responding (Weller & Woodcock 2012). Through our approach we have been able to show how the analysis of traffic gives us an understanding of the distinctive characteristics of the European networks, how they are used and what kinds of business models are challenged under the current conditions. We can also have a better view of the trends the players are caught up in, such as a shift to private from public peering and how internet businesses and non-telecoms stakeholders seek to gain access to customers not only at tier-1 and tier-2, but also at tier-3.

These trends and our analysis lead us to five observations that shed light on the problems and prospects of growth and competition faced by European network operators and users. They address the situations of information, regulation, structure, pricing, and strategic options.

a) ***Information***

While we can measure a great deal about traffic on the internet, there remains much that is obscure, incommensurate or inaccessible. This has two kinds of consequences. The first is that incomplete understanding means that strategic decision-making could be ill-informed and policy-making cannot be sufficiently evidence-based. This seems to indicate that although traffic on internet exchanges is measurable, it is unclear how all of the remainder of the traffic is transported. Therefore, strategies are devised without a thorough analysis of the state of traffic and with insufficient data. Secondly, much information is asymmetrical, allowing for considerable arbitrage on the part of those generating large amounts of traffic. This results in a semi-transparent marketplace.

The consequences of this state of affairs are that the actions of major stakeholders, including large ICT corporations, regulators and the businesses that are built upon the internet become increasingly unpredictable. To make things worse, national forecasts of traffic do not sufficiently account for or explain new emergent traffic patterns. This aggravates the problems of regulatory uncertainty and investor confidence. Finally, information asymmetry problems hamper the studies of academics and other analysts, whose work is intended to provide explanations for and insights into traffic patterns, pricing structures and commercial behaviours.

b) ***Regulation***

We have described how the current multi-stakeholder approach to pricing and business models – with norms of membership and handshake practices - especially with regard to public peering through internet exchanges, is challenged by both a shift from contracted transit to peering agreements and also from public to private peering arrangements. Furthermore, anomalies in peering such as the conflicts between Cogent and France Telecom invite just the sort of regulatory intervention that the peering community had sought to avoid at the outset (ARCEP 2011d). Given the extremely high proportion of internet traffic that passes through European IX, it is not surprising that public interest would be expressed in the form of interventions to resolve disputes. Beyond dispute resolution, however, if systemic problems emerge with the structure of the IX then we can expect further, perhaps unwelcome, extensions of regulatory powers[31].

c) ***Structure***

Our analysis demonstrates that approximately one third of European internet traffic passes through internet exchanges in the EU. Another large share is identified by Cisco as "managed traffic"[32] and does not pass through internet exchanges, and the rest is perhaps a mix of intra-network and other types of traffic. It is not clear how stable this tripartite structure of the internet is or even how they interact, but it is clear that the three categories are governed by conflicting economic principles. One reason for that is that each operates as a different kind of exchange regime, with internet exchanges mixing non-monetized membership agreements with commercial services (e.g. private peering), managed traffic operating as an open competitive marketplace, and intra-carrier traffic operating within a regulated sector.

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[31] The case of Cogent and its conflict with France Telecom, in which ARCEP, the French regulator, intervened, is an example of the current dilemmas confronted by European regulators as well as telecommunications operators. http://www.telecompaper.com/news/competition-authority-rules-on-cogent-ft-peering-case--897464. In Appendix 1 of this document a full explanation on the implications of this case is summarised.

[32] 20-25% by Cisco VNI estimations

d) ***Pricing***

We have seen that internet exchange costs have been dropping, including for private peering[33]. The increased efficiency of European internet exchanges along with their not-for-profit status behaves according to the overall trend for a decrease in transport prices for IP transit. We see the effect of changes in traffic characteristics shaping the structure of the industry. Given that incumbent network operators are dominant players providing transit services in Europe, the prospect of decreasing prices and the shift to peering challenges their current business model and their bargaining power to new players.

e) ***Strategic options***

In the short-to-medium term the strategic options for network operators appear very limited indeed. We describe four potential directions of movement in our analysis: "status-quo plus", lateral transformation, accentuated move to services, and integration. It should be no surprise that different pictures are used to describe the internet economy and that the strategic implications and public policy responses diverge. Some of these differences can be explained by differing conceptualizations of what the industry consists of and how those components interact. Some of them can be ascribed to outmoded, layered models of the technology and the roles of businesses within those layers. Much of it, however, can be regarded as a consequence of the extreme information asymmetries that analysts encounter whenever they attempt to understand the interrelationships that dynamically emerge and disappear. This analytical problem is a serious inhibitor of better relations with investors; and it is certainly a barrier to independent research. While many incumbents are fully engaged in providing "status-quo plus" solutions as their primary business focus, the current internet trends weaken the European telecom industry's bargaining power, revenue sources, investment credibility and present and future competitive edge on innovation (ETNO 2012b). Given the combined pressures on network operators from customers and public policy initiatives to upgrade the infrastructure and their declining share values, the situation we describe demands reconsideration of how pricing, revenues, and the sources of funding for public initiatives are derived.

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[33] Our interviews among incumbents support the view that a main reason for the fall in transit prices relates to falling peering prices in the internet exchanges. However, there is no simple correlation between advances in technology, increasing carrying capacity, and cost. It is widely accepted that technology providing 4-10 times more capacity is only about twice as expensive. It is also the case that with the invention of peering, transit providers have made changes in their business models. The best example of this is the entrance of the likes of Level3 and Telefonica into the CDN market.

6. Acknowledgements

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7. Appendices

Appendix 1: Cogent Communications vs. France Telecom: Internet traffic and peering agreements under French competition law

This case illustrates what can happen when internet traffic and peering agreements meet French competition law (David 2012). The core issue was the refusal by the incumbent to let the low cost ethernet service provider connect to its network in France[34], with arguments that it constituted an attack on net neutrality principles (ARCEP 2012a).

In 2005, Cogent, a US internet services and data transport company, signed a data transit agreement with France Telecom through Orange's transit operator business, Open Transit. According to this "peering agreement", the exchange of data between networks, usually free, was subject to "peering fees" when traffic between transit operators becomes asymmetric. The contract stated that France Telecom would charge a fee to open new capacity if the incoming traffic on its network was 2.5 times higher than its outgoing traffic. The purpose of such a policy was to protect France Telecom's domestic network, Orange, from congestion. At this time, Mega Upload – which has since been shut down by U.S. authorities – was a customer of Cogent. The amount of video uploaded by subscribers of Orange caused a strong asymmetry in the traffic (up to 13 times greater in one direction than in the other). France Telecom asked Cogent to pay for the opening of additional capacity of interconnection. Cogent challenged this demand, claiming that it was a violation of the antitrust laws and, among other things, that France Telecom was compromising the peering system.

The Competition Authority held that France Telecom's demand was not anti-competitive (ARCEP 2012c). France Telecom did not refuse to give Cogent access to its network. Between 2005 and 2011 France Telecom opened several times, for free, new capacity to meet Cogent's demands. However, it asked Cogent to pay for the opening of new capacity in accordance to its contract regarding peering, without challenging the

[34] http://www.fiercetelecom.com/story/cogent-and-orange-france-fight-over-interconnection-issues/2011-08-31

capacities already provided. The court explained that such a demand was not unusual in the internet industry in case of traffic asymmetry. In this case, the demand was held to be legitimate because the traffic was highly asymmetric and Cogent was aware of its contractor's peering pricing policy.

Even though France Telecom's request was held to be legal, the Competition Authority pointed out the lack of transparency and formalized relationship between the domestic network of France Telecom Orange and its transit operator business Open Transit. It held that this situation made it difficult to control potential margin squeeze and discriminatory practices, which therefore eased the implementation of such illegal practices.

The consequences of the discrepancies on how to address the issues of internet neutrality have been for ARCEP to raise a First Commitment Decision in September 2012 (ARCEP 2012b) (David 2012):

> "Three types of stakeholders operate in the internet connectivity market: a) internet service providers (ISPs) such as Orange (part of France Telecom), which provide internet access services to end-users; b) content providers; and c) transit operators, such as Cogent or France Telecom.
>
> The internet connectivity market comprises exchanges of internet traffic between ISPs (including France Telecom/Orange) and among ISPs and content providers and transit operators (such as Cogent). In general, ISPs and content providers purchase transit services from one or more transit operators in order to connect to the internet and deliver traffic to the internet users. However, ISPs are also able to connect with each other directly, without a transit operator, via "peering" agreements that consist in traffic exchanges without payments. These peering agreements are commonly free of charge, but some peering agreements may involve remuneration if the traffic exchanged between the operators is not balanced.
>
> In the case at stake, Cogent claimed, inter alia, that France Telecom compromised the sustainability of the peering system by requesting payment for opening up additional technical capacity for access to the subscribers of its ISP subsidiary, Orange.

> Pursuant to France Telecom's peering policy, which is also adopted by most other transit operators in France, and was specified in its contract with Cogent, a fee may be charged where the requested traffic capacity exceeds a determined traffic ratio. In consideration of the high asymmetry of traffic exchanges between France Telecom and Cogent, the Autorite, in its decision, did not express concerns on the payment required by France Telecom, based on the elements known in the case at hand. However, the Autorite was concerned by the lack of transparency in the relationship between Orange as an ISP and France Telecom ("Open Transit") as a transit operator, due to the absence of formalization of their internal exchanges. More transparency in their business relations could help to detect possible abusive margin squeeze or anticompetitive discriminatory practices in the future.
>
> In view of the mentioned concern the Autorite obtained from France Telecom the following commitments, to:
>
> > i) Define a formal internal protocol between Orange and its transit division Open Transit specifying the conditions for the provision of internet connectivity services France, and
> >
> > ii) To implement a monitoring system of the internal protocol.
>
> Following the market test, which proved positive, these commitments were made binding by the Autorite for a period of two years. The Autorite will remain vigilant during this period."

France Telecom proposed to formalize and monitor the application of an internal protocol between Orange and Open Transit describing the technical, operational and financial rules applicable to the supply of interconnection services. Following some consultations and adjustments, the Antitrust Authority decided that these commitments were relevant, credible, and verifiable and made them mandatory. In the event of future litigation, they should enable the Authority to verify that France Telecom has not implemented discriminatory or margin squeeze practices against competitors.

Appendix 2: Transparency of data and information asymmetry

Data access problems and information asymmetry have long prevailed in the internet economy. Numerous non-for-profit and educational organizations monitoring the internet, such as CAIDA (Claffy, 2008c; CAIDA "WIE 2012") have worked to overcome this handicap. Contrary to a widespread commercial belief that reports from Cisco, Google, Akamai, Netindex, Sandvine and others present an adequate commercial view of the internet, the sheer volume of assumptions and different metrics used to provide the analysis and forecasts of such industry reports makes it difficult to get a comprehensive view of multiple areas of the internet.

Although the Internet Engineering Task Force paper on terminology for describing interconnection [RFC 4084] (Klensi 2005) is very clear on the definition of internet connectivity, current and evolving business models, particularly those used by Google, Akamai, Facebook and others go beyond the five categories used to describe interconnectivity: web connectivity, client connectivity only-without a public address, client only-public address, firewalled internet connectivity, and full internet connectivity. These companies and others are able to provide business solutions that mix some of these categories not only at the service layer but also at the network and transport layers.

It is also clear that the data dearth is not a new problem in the field; many public and private sector organizations have tried and failed to solve it. In 2001 CAIDA, with the support of the US National Science Foundation, tried to create an internet measurement data catalogue to support sharing of internet measurements, but the presumption of data sharing among multiple stakeholders was necessarily limited because the real obstacles for data sharing are economic (time and money), ownership (legal) and trust (privacy) constraints.

Thus the research community continues to be handicapped by inadequate data for network research. The traditional model of getting data from public infrastructures to inform policy making has led to mixed results. Regulators have tended to be reluctant to force disclosures of how the internet is structured, used and financed (Houle et al., 2007). However, the opaqueness of the infrastructure to empirical analysis has generated many problematic responses.

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