The Evolution and Economics of Internet Interconnections

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**About the Author**

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Dr. Dovrolis has been an editor for the *IEEE/ACM Transactions on Networking* and the ACM Communications Review (CCR). He served as the Program co-Chair for the PAM'05, IMC’07, CoNEXT’11, and as the General Chair for HotNets’07. He received the National Science Foundation CAREER Award in 2003.

His most relevant prior work to this report includes publications in:

a) The evolution of the Internet at the Autonomous System level from 1998 to 2010 [1], exploring the transformation of the latter from a hierarchical to a horizontally-dense (“flat”) structure [2];

b) The economics of Internet interconnections, and of peering in particular [3, 4, 5]; and

c) The development of network measurement tools to evaluate network performance and to detect traffic discrimination in the Internet [6, 7, 8].

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Dr. Dovrolis is a Steering Committee member of the Measurement Lab (M-Lab), a consortium of research, industry, and public interest partners dedicated to providing an ecosystem for the open, verifiable measurement of global network performance.
About this Report

The author was asked by counsel for Comcast Corporation, based on his expertise in the evolution and economics of Internet interconnection, to offer an objective and neutral overview of the techno-economic structure of Internet interconnections and their evolution during the last 20 years.

The author was also asked to offer his assessment of whether certain claims by Cogent (see Declaration of Mr. H. Kilmer) and Netflix (see Declaration of Mr. K. Florance) submitted on the record in this proceeding are accurate, whether these claims justify regulatory intervention in Internet interconnection arrangements, and whether such intervention would benefit the Internet ecosystem as a whole. These three points are discussed in the last three sections of the report.

The opinions expressed in this report are solely of the author and do not necessarily reflect the opinions of Comcast (or any other Internet firm), Georgia Tech, M-Lab, or any sponsors of the author’s research.
Executive Summary

I have examined the declarations submitted in this proceeding, in the Matter of Applications of Comcast Corporation, Time Warner Cable Inc., Charter Communications, Inc., and SpinCo for Consent To Transfer Control of Licenses and Authorizations, MB Docket No. 14-57, by Mr. Ken Florance on behalf of Netflix, Inc. and Mr. Henry Kilmer on behalf of Cogent Communications Group. In my opinion, they misrepresent many aspects of the Internet ecosystem – its history, its recent evolution, its direction – and the technical and economic factors that characterize it today. In particular, the mechanisms of traffic routing and capacity provisioning, what options are available, and which parties are most able to influence the quality of routed traffic, are not reported accurately or clearly. I provide this report to correct the misconceptions or misstatements that I have observed. Although I begin with a background on the Internet backbone’s structure and evolution, I then comment in particular on the following key points:

- The traditional lines between various Internet firms – enterprise networks, content providers, transit providers, content delivery networks, and access networks – have blurred and many of today’s networks have multiple roles and provide multiple services. The arrangements under which these networks have interconnected have evolved as well. Today, it makes no sense to decide who should pay whom, or who should peer with whom, based on a historical classification of each firm’s Internet role. Instead, each interconnection should be evaluated independently based on the costs and benefits it introduces to each party.

- Over the past decade, the backbone has become very competitive, there is abundant connectivity at all layers and among all types of providers, and access providers have many interconnection relationships in which they do not pay for transit. Where providers like Cogent used to dominate the transit market and charge providers such as Comcast for transit, today Comcast and Cogent are more or less in the same business – both serve end-users of various sizes, both provide transit, and if the two peer for free, it is because doing so helps both their businesses. Thus, Cogent’s focus on the “Tier-1 vs. Tier-2” classification is an anachronism with no particular relevance to the current environment or ongoing policy debates.

- Settlement-free peering is reasonable when the arrangement is of roughly equal benefit to both parties, taking into account both value and costs. The “traffic-ratio” metric is a commonly used proxy to evaluate if a peering link is of roughly the same value for both parties, but it is not the only one and more sophisticated cost-benefit analyses can be used that consider the costs on the receiving network as well as the economic benefits that the transferred flows will generate for each party. If one of the parties benefits much more from the interconnection than the other, or imposes far more cost on the other, it is reasonable to consider a paid-peering relationship.
• Direct interconnection arrangements between content providers and access providers are beneficial to the content provider because the latter ensures capacity and may even reduce the transport costs for the traffic flow (by removing a middleman transit provider). At the same time, the direct arrangement will impose costs on the access network. **These costs include not only the costs of the dedicated interconnection arrangement, but also the costs of accommodating the incremental traffic flow all the way from the interconnection point to the end-user** – costs that may increase over time if the sending content provider takes advantage of the direct interconnection to send traffic with less compression or higher resolution, for example.

• **Paid-peering payments are very different from “termination access fees,” although that is the talismanic terminology that Netflix and Cogent have used.** Access providers cannot demand direct interconnection arrangements (or payments) from the various content providers, CDNs, and other networks that send them traffic. Those providers always have the option of sending their traffic to an access provider by using the various indirect transit providers that provide the core interconnectivity of the Internet; no access provider can fulfill its role reliably and efficiently without being densely interconnected with several transit providers. Access providers simply offer the option of direct interconnection (through paid-peering) as an alternative to the sender’s purchase of transit services. Paid-peering may also be offered as a way for a settlement-free peer to send traffic that exceeds the limitations of the parties’ settlement-free peering arrangement in terms of traffic exchange constraints.

• Although Netflix and Cogent suggest that Comcast forced Netflix into direct interconnection by causing congestion on its routes with Cogent, it is important to remember that it is the networks that send traffic over the Internet (including content providers) that control how to route that traffic. Thus, a content provider can choose which routes to use, whether to split its traffic over several different routes, and whether to send it directly to another network (via a direct interconnection arrangement if it has one) or over the many indirect routes available into access providers’ networks. These routing decisions can be made in real-time and they can be adjusted on a minute-by-minute basis depending on the measured performance of each interconnection, cost considerations, and the usage constraints of each interconnection. **In contrast, the receiving network cannot control the routing of the traffic it receives. It cannot stop a content provider from pushing all its traffic over one interconnection link rather than spreading it among several, or from using up all available capacity on a particular link the moment it becomes available, creating serious congestion issues.**

In addition, I conclude that if content providers, or transit providers carrying content providers’ traffic, could demand free direct interconnection with access networks, as Netflix and Cogent seek through regulation, there would be several negative impacts on consumers and the Internet in general.
• **First, forcing networks to provide free direct interconnection to any requesting provider would place significant and unfair financial burdens on consumers.**

  ➢ End-users (i.e., access providers’ customers) would have to pay the dedicated transport costs of a particular content provider’s traffic, whether or not they even subscribe to that content provider, which may be significant when larger providers, like Netflix, are at issue. Meanwhile, the content provider (i.e., Netflix) would not only get subsidized transport to an access network, but also subscription or advertising revenues that it earns because it has access to that network.

  ➢ Eliminating all paid-peering would place all financial burden for the growth of the Internet exclusively on end-users – a situation that has never before prevailed in the Internet ecosystem. End-users would have to pay not only for Internet access but also for investments in the network core, something that has traditionally been defrayed by contributions from content providers, CDNs, and other “large” Internet players.

• **Second, there is no way or reason to differentiate between content providers (and their partners) and other network providers in setting such a rule; and in any event content providers can simultaneously be transit providers and CDNs themselves.** There is no basis to differentiate among so-called “terminating access networks” (i.e., all access providers) and transit providers like Cogent, because those categories are equally fluid – transit providers like Cogent provide access to the Internet for their customers. And why would it be deemed acceptable for a transit provider to collect compensation from small access networks and content providers, and send traffic between the two, but wrong for those same small access providers and content providers to pay for direct paid-peering interconnection, eliminating the “middle man” (i.e., the transit provider) from the path? If all networks have the right to seek direct interconnection to every other network, and all can do so for free, this essentially would eliminate the transit market, among other collateral effects, and further exacerbate the problems just described about supporting the Internet’s backbone going forward.

• **Third, paid-peering (and transit) arrangements create incentives for efficiency – these arrangements provide senders of Internet traffic reasons to invest in compression technologies and other ways to reduce their traffic loads.** When everything is “free” to the sender, those incentives disappear, so bandwidth demands will increase rapidly – with the access networks presumably tasked with the endless job of maintaining sufficient bandwidth for all possible needs. This will simply increase the strain on the Internet and on the consumers who use it.
In short, regulatory intervention to prohibit access providers from collecting payments for direct interconnection arrangements with content providers or their intermediaries is not only unnecessary, but would also be unfair to end-users and harmful to the evolution of the Internet ecosystem.

Finally, with respect to certain claims made by Mr. Florance and Mr. Kilmer, I explain why their premise that access providers’ paid-peering arrangements are the same as “terminating access fees” is false. I demonstrate that the purported benefits to access providers of participating in “Open Connect” may not be a benefit at all to certain providers; that the proposition that Comcast should not be charging for interconnection is anachronistic and unjustified; that the claim that Comcast caused congestion on the interconnection links between it and Cogent is implausible and ignores the reality that Netflix controls how its traffic is routed and that Cogent continued to route Netflix’s traffic over congested links; and that the assertion that whether a network paid for or was paid for interconnection has always been based on whether the network was a member of the historic “Tier-1 club,” rather than whether the network provided a mutual exchange of value, is fiction.
1 The Internet Ecosystem

We usually think of the Internet as a communication network. It is much more than that, however. The Internet is a dynamic and self-organized “network of networks”. The networks that participate and form the Internet can belong to an individual or family, a small business, a global enterprise, an ISP, a content provider, etc. Each of these networks operates independently, has its own objectives, and operates under its own constraints. Their common goal, however, is that they want to form a connected inter-network in which every individual network can reach every other network. From this point of view, we can also think of the Internet as a techno-economic ecosystem in which various “species” interact through different types of relations (antagonistic or symbiotic) to meet their diverse objectives.

The larger individual networks often follow an administrative process in which they are registered as “Autonomous Systems” or ASes, so that they can have their own provider-independent addresses, and to have more than one direct interconnection with other ASes. Individual users or smaller businesses, on the other hand, are typically connected to the Internet through another AS (e.g., their residential ISP or the AS they work for). Today, the Internet consists of about 50,000 ASes [9].

The set of these ASes is constantly changing as new firms and organizations connect to the Internet, while others merge or shut down. The interconnections between these ASes are also highly dynamic because they are determined by economic, performance or strategic objectives, while the “ecosystem’s landscape” is constantly in a state of flux. It should be emphasized that these interconnections are not just some cables that connect the networking gear of different companies; an interconnection between two ASes represents a business agreement, and as such it is formed only when it is beneficial for both parties. It is amazing (but certainly not a coincidence) that, despite this distributed and heterogeneous decision-making process that is executed in parallel by about 50,000 players, the Internet has always remained connected (with only few disruptions that are discussed later in this report).

1.1 The “Species” of the Internet Ecosystem

Autonomous Systems are often classified based on their main functional role or business objective. I summarize this classification next (emphasizing, at the outset, that many ASes which at one time fit neatly into a single one of the categories below today play multiple roles in the ecosystem).

1.1.1 Traditional AS Classification

- **Enterprise Networks:**
  Most registered ASes fall in this category. They are typically corporations or organizations that want to connect to the Internet with their own, provider-independent addresses. For instance, a major university, a federal
organization, or a manufacturing company with multiple sites would be classified as an enterprise network.

• **Access Providers:**
  These are firms that sell *Internet access* to residential and business customers (mostly through broadband technologies such as DSL or DOCSIS, but possibly also through fiber optics or wireless connections). Historically, firms such as Comcast and Verizon would be classified as access providers.

• **Content Providers:**
  These are firms that generate Internet content, such as online video, news, e-commerce, online social networking, or Web search results. The revenues of these firms are generated mostly through user subscriptions, advertisements, and online sales. For example, Netflix, Google, Facebook, and Amazon would be classified as content providers.

• **Transit Providers:**
  These are firms that operate geographically large and high-capacity backbone networks. Historically, transit providers were paid by all other types of ASes to transfer data over large distances. Firms such as Cogent, NTT, and Level3 would be classified as transit providers. From the start, many transit providers also were access providers at least to business networks.

• **Content Distribution Networks (CDNs):**
  These are firms that replicate Internet content in their distributed storage infrastructure ("caches"), serving download requests from locations (typically third party IXPs, explained below, where they have deployed caches) that are close to end-users. The customers of CDNs are typically content providers. For instance, firms such as Akamai and Limelight are CDNs.

• **Internet Exchange Points (IXPs):**
  These companies operate well-connected facilities ("Internet hotels"), mostly at major urban centers, in which different ASes can be present and interconnect with each other (if they choose to do so). They are paid by the ASes that use these facilities [10]. For instance, Equinix and NetIX are IXP providers.

1.1.2 **Versatile, Multi-Role ASes**
This traditional classification system can be misleading today. As discussed more in Section 2, the Internet ecosystem has gone through a major transformation during the last ten years. The largest ASes (at least in terms of generated or transferred traffic) try to be more independent and versatile, playing multiple roles at the same time. For instance, the major content providers (e.g., Netflix, Amazon) have
developed their own CDNs and some have even begun supporting third-party services on those “private” CDNs; in some cases (e.g., Google), content providers operate their own international backbone networks. Some transit providers (e.g., Level3) have also diversified their role by offering CDN services to content providers and others. Certain access providers (e.g., Comcast) also have deployed large, high-capacity backbone networks so that they now provide transit service to other networks, CDNs, etc.; additionally, they do not need to rely on the services of other transit providers as much or at all. And of course, content is not only generated by content providers, but also from all Internet users, and consequently, from all ASes.

This diversification of the business roles and functions of ASes has major implications, as will be discussed later, for the economics of Internet interconnections. We can no longer determine who should pay whom based on the single business function that has been historically associated with each AS. By the same token, old classifications no longer have much relevance, including for example the “Tier-1” classification discussed below. *Today, every interconnection must be evaluated independently by the interconnecting parties to determine what its terms should be, examining the costs and benefits that that interconnection brings to each party* [11,12].

**A point about terminology:** in the rest of this report, when I refer to an AS based on the traditional classification (e.g., “a transit provider”), I mean that it acts in this role at that specific instance, not that this is the only role of that AS.

### 1.2 Interconnections Between Autonomous Systems

An interconnection between two ASes can be of different types. These types control both the traffic that can be exchanged and the economics of the interconnection (who pays whom and for what purpose) [13]. In the following, I review the major types of AS interconnections:

- **(Global) Transit:**
  This is an asymmetric relation in which one AS is the “customer” and the other is the “provider.” The provider offers the customer routes that can reach any network in the Internet, and it “advertises” the addresses of the customer to the rest of the Internet. The customer pays the provider for the traffic it sends to and receives from the Internet.¹

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¹ Typically, the customer pays based on usage, billed at the 95th percentile of the five minute average traffic load. Also, the customer typically pays only for the most heavily used direction of the transit link. This means that a customer may pay based on the traffic into its network from third party senders.
• **Settlement-Free Peering (SF-peering):**
  This is a symmetric relation (“peer to peer”). The two peering ASes agree to exchange traffic that is destined to them or their customers\(^2\) for “free”, based on the mutual exchange of transport value each AS obtains from the other. Thus, SF-peering interconnections are established when there are roughly equal costs and benefits for both parties. For instance, two ASes may want to establish a SF-peering interconnection to reduce the fees they would otherwise pay to their transit providers. ASes typically establish criteria specifying the conditions under which they will establish SF-peering links with other ASes; these are often publicly posted. Traditionally, a rough balance of traffic has been deemed a necessary element for many SF-peering relationships, as well as roughly equivalent network facilities and sufficient traffic to merit dedication of one or more 10Gbps links [13]. In some instances, where one network provides unique network routing value (e.g., transport to another country), that can provide value that would make up for a less balanced traffic flow and thus justify an SF-peering arrangement.

• **Paid Peering (Paid-peering):**
  This type of interconnection (sometimes also referred to as “on-net transit”) can be thought of as an intermediate solution between the previous two types (namely, transit and SF-peering relations). Similar to transit links, a paid-peering interconnection is asymmetric: one party is the customer and the other is the provider; typically, the former sends far more traffic than the provider sends back (if any) and/or has much less to offer in terms of mutual “transport” or “network” value. Similar to SF-peering relations, the only traffic that can be exchanged is traffic flowing between the two ASes or their customers. A paid-peering interconnection may be chosen to provide a redundant route alternative to an indirect transit route into the network – something large CDNs may do to ensure that they have several options for quality routing. A paid-peering arrangement may also make sense when a party has a large amount of traffic destined for the receiving network, and direct interconnection would be less expensive and/or more predictable and reliable than relying on an indirect transit provider to reach that network. Paid-peering arrangements are commercially negotiated and may be very simple contracts or agreements that are reached as part of larger, multifaceted arrangements.

• **Other kinds of interconnections:**
  As the Internet has evolved, the level of sophistication in the available interconnection types has been increasing to meet more specialized needs and cost structures. For instance, a Partial-Transit relation provides transit

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\(^2\) For this purpose, “customers” include not just retail customers but transit/paid-peering customers; traffic can be sent to any of these entities, but *not* to the provider’s other SF peers.
service but for only a subset of the global routes or ASes. A *Backup*
interconnection is used only when a primary interconnection has failed or is
congested. ISPs also are experimenting with interconnections beyond the
regional IXPs described above; they are testing models that would provide
interconnection deeper into their networks, which might make sense and
save money for content providers or CDNs with enough traffic to make this
worthwhile. I believe that in the future we will see more advanced
interconnection types in which different routes may cost more or less
depending on their distance, capacity, or number of intermediate ASes. Such
innovations can improve Internet performance because they create economic
incentives to offer better routing and more well managed networks with
more available capacity.

2 The Evolution of the Internet Ecosystem
Since the commercialization of the Internet core in the mid-90s, the Internet has
gone through a gradual but major transformation during the last 20 years.
Specifically, it has evolved from a highly hierarchical structure to a more "flat",
horizontally-dense structure [2,14]. Roughly speaking, we can separate this 20-year
period in two phases: the hierarchical era (mid-90s to mid-00s) and the "flat" era
(mid-00s to present).

2.1 The Hierarchical Internet (Mid-90s to Mid-00s)
Originally, there were only a few transit providers that had the resources and
"know-how" to operate geographically large IP-based backbone networks. At the
top of the hierarchy, there was a set of ten to fifteen *Tier-1* providers. These were
large, national (U.S.) and global ASes that would establish peering links with all
other Tier-1 ASes and, therefore, they did not need to have a transit provider
because they could reach every network in the Internet through their customers or
through other Tier-1 providers. This fully interconnected mesh of Tier-1 providers
is referred to as the "*Tier-1 club*" or the "*Tier-1 clique*.”

Lower in the hierarchy, there were many *Tier-2* transit providers, which were
customers of one or more Tier-1 providers. Tier-2 providers often had a regional
footprint. Access and content providers would often be customers of both Tier-1
and Tier-2 providers, placing them at Tier-3. At the Tier 3 level of the hierarchy, we
would find most enterprise networks.

Because of the previous hierarchy, most Internet traffic would need to go through
three to six ASes before it could reach its destination. Those long inter-ASes paths
often caused delays and congestion. Additionally, it was quite hard to identify the
ASes, or the ASes' interconnection, that were responsible for any observed
performance problems.
Most traffic would ultimately need to flow through one or two Tier-1 providers, generating large revenues for them. When a Tier-1 provider routed traffic directly from one customer to another customer, it would often be paid twice for the same traffic (i.e., on both ends of the transmission).

Tier-1 providers have often been involved in bilateral disputes (the so-called “Tier-1 peering disputes”). A common reason behind these disputes is that one or more of their SF-peering interconnections were very imbalanced in terms of traffic. Most of these disputes were resolved, but only after causing significant pain to the customers of the involved Tier-1 providers. It is worth noting that at least some of those disputes were eventually resolved through the establishment of paid-peering links, even though the details of those agreements were never publicly disclosed.

2.2 The Flat Internet (Mid-00s to Present)
In the last decade or so, the structure of the Internet has changed. The establishment of many peering links across ASes of the same or different role has transformed the Internet from a hierarchical to a “flat,” horizontally-dense structure. Today, most traffic can be routed from its source to its destination through only a couple of ASes, because many more ASes are directly connected, regardless of their supposed “Tier,” using any and all of the interconnection types described above. [14]

This transformation has been caused by mostly the following developments:

a) Many networks, including large access and content providers, invested in the development of their own backbone networks, reducing the volume of traffic they have to route through transit providers, and bringing their networks directly into contact with the interconnection points of other networks.

b) The establishment of IXPs at major urban centers made it much easier and cheaper to interconnect directly with many other ASes. After the initial cost of setting up a connection at the premises of an IXP, an AS can connect directly (through “public” or “private” interconnections) with many other ASes that are also present at that IXP. Again, this reduces the volume of traffic that needs to be routed through transit providers, and helps increase interconnectivity.

c) The penetration of CDNs around the Internet, closer to the end-users in the relevant region of the country, reduced significantly the amount of traffic that needs long-distance transit. It is common today, at least in the United States,
that an Internet user will download most traffic from servers that are located at the nearest IXP (the major U.S. IXPs are located in New York City, the Washington, DC area, Atlanta, Miami, Chicago, Dallas, the Bay area, and Seattle), although at times CDNs make real-time routing decisions based more on load-balancing or economic calculations than distance to a requesting user.

A small number of content providers (Netflix, Google, Facebook, Amazon, etc.) generate a large (and increasing) percentage of the total amount of Internet traffic. These content providers have started using CDNs (sometimes their own CDNs) and/or their own backbone networks to bring traffic closer to end-users and interconnect directly with at least larger ISPs: generally to avoid or reduce their transit fees.

In this new, flat Internet, the terms “Tier-1/2/3 provider” are often misleading. For instance, a historically Tier-2 provider may engage in SF-peering with a historically Tier-1 provider, and may sell transit service competing with Tier-1 providers.

The transformational developments described above also had a major effect on the price of Internet transit. As noted, more providers invested in their own fiber backbones, so they no longer bought as much transit service, which forced transit prices down. The development of CDNs – first conceived of as a way of reducing transit fees, further drove down demand for transit. And, access providers with new large backbone facilities also began offering their own competitive transit services to third parties, thus producing even more downward pressure on transit pricing. To stay competitive in the flat Internet, transit providers had to drop their monthly transit prices, over time, from over $1000 per Mbps in 1998 to less than $1 per Mbps today, and pricing continues to drop [13]. It is worth noting that streaming a high-definition movie through a transit provider today costs less than a penny; indeed, the over-the-top streaming video business came about largely because network investment and commercial forces made the transport of content so inexpensive.

3 Good (and Bad) Network Interconnections

Whether an interconnection arrangement will provide high quality and efficient transport depends primarily on two factors: routing and available capacity. The routing component determines the sequence of links, and thus the sequence of ASes, that a traffic flow will go through. The capacity component determines whether the corresponding links are heavily loaded, and thus whether they can transfer the traffic with negligible queuing delay and/or packet loss.

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4 In 2009, 30% of the total Internet traffic was generated by 30 ASes [14]; today, just a single content provider, Netflix, generates more than 30% of the peak traffic in the United States.


3.1 The Routing Component

The flow of traffic in the Internet does not follow simple optimization objectives, such as “choose the route with the minimum number of hops.” At the inter-domain level (i.e., between different ASes), routing decisions are based on local policies set by each AS.

In the outgoing direction (the “egress paths”), an AS can control how to route its traffic. Specifically, it can choose which neighboring ASes it will route the traffic through and at which locations it will pass the traffic to that (or those) ASes. For example, if Netflix is a transit customer of Cogent and a paid-peering customer of Comcast, Netflix may choose to route its traffic to Comcast through the paid-peering interconnection or through Cogent, or it may even split its traffic between these two interconnections. These routing decisions can be made in real-time and they can be adjusted on a minute-by-minute basis depending on the measured performance of each interconnection, cost considerations, as well as the usage constraints of each interconnection.

In the opposite direction however (the “ingress paths”), it is not possible for an AS to control the routing of the traffic it receives. For example, a receiving AS cannot dictate (other than by contract) where it receives traffic from a sending party: this is the so-called “hot potato routing” practice, in which a sending AS will drop off traffic as close to its source as possible, leaving the receiving network with the cost of transporting it all the way across the backbone – notwithstanding that the parties have a second interconnection point far closer to the destination of the traffic. Similarly, a receiving AS cannot stop the sending AS from pushing all its traffic over one interconnection link rather than spreading it among several, from using up all available capacity on a particular link the moment it becomes available, or from sending too much traffic over an interconnection link, potentially creating serious congestion episodes in which traffic is delayed or even dropped.

3.2 The Capacity Component

Together with routing policies, the performance of an interconnection also depends on the capacity of the corresponding links. Typically, if the utilization of a link during peak-usage time periods is more than 70%, the link can experience congestion episodes in which traffic is delayed or even dropped.

In a transit or paid-peering interconnection, the customer generally dictates the number of peering links, their location, and the required capacity of each link. In SF-
peering interconnections, on the other hand, the two parties decide all these aspects of the agreement together. They typically also agree on how they will deal with long-term growth and sudden spikes. For instance, they may decide that they will review the utilization level at each peering link every three months, that the sending AS will not be using “hot potato routing”, and/or that the receiving AS will be informed well in advance about any major changes in expected traffic volumes. SF-peering interconnections can be terminated when the sending AS violates this “peering etiquette,” though issues generally are worked out cooperatively given the parties’ joint interest in resolution.

A naïve way to think about the cost of a bilateral AS interconnection is that it is only the cost of the corresponding router ports that need to be directly connected. Depending on the capacity of these ports and the number of physical locations at which the interconnection is taking place, this cost may be from two to three hundred dollars to a few tens of thousands of dollars, which seems like a relatively low cost given the size of major providers.

The reality, however, is that the real costs of an interconnection are much higher. Suppose that X and Y are two ASes that interconnect at ten locations with 40Gbps SF-peering links. But say that X starts flooding these links to the point that the links are running at 100% utilization, potentially also dropping some traffic. To handle the incoming traffic flow, Y may need to upgrade its capacity not only at the corresponding routers, but also throughout all network paths through which it exchanges traffic with X – all the way through the last mile, where capacity is most expensive. And if X directs this traffic to many different paths of Y at different times, the latter will need to upgrade its interconnection and transport capacity at multiple locations throughout its network. Such an upgrade may require Y to purchase more and/or faster routers, increase the capacity or density of its links, to modify its internal traffic engineering and network management provisions – and more. In other words, capacity upgrades are not simply the acquisition of an additional port, nor are they a purely local operation; they cause cascade effects that require network-wide planning and optimization.

In summary, the interconnection between two ASes is not simply the agreement to share a link and two router ports. Instead, it is an agreement to share the entire infrastructure of each AS. This is an important point that should be considered when we estimate the cost of a substantial capacity upgrade in a peering interconnection – particularly when it is being driven primarily by one party’s needs.

### 3.3 Who is Blamed When an Interconnection Performs Poorly?

It is quite hard for Internet users (and sometimes even for network operators) to identify the exact location of congestion that may be affecting their quality of experience, especially when the end-to-end path traverses more than one or two ASes. For example, a Comcast customer that experiences many “re-buffering events” while watching a Netflix movie would not know whether the problem is at her home
network, within Comcast’s network, at the Netflix origin servers, at the CDNs that Netflix uses, at an intermediate transit provider, or at an interconnection between any of these ASes. This creates the potential for “finger-pointing” between the involved ASes, and can make it harder and slower to address the root cause of congestion. For example, there may be congestion within both the receiving network (Comcast in this hypothetical) and the transit network or the CDN, but Comcast would have no way of knowing reliably that other segments of the end-to-end network path are also congested. Thus, the receiving network could undertake substantial investment to upgrade its network and/or its interconnection with the transit provider, only to find out eventually that the end-to-end performance problems experienced by its subscribers persist.

Additionally, based on my observations in the marketplace, Internet users typically complain to their access provider (Comcast in my example) when they experience the effects of poor interconnection, probably because that is the only network provider they directly interact with (and pay). As a result, the risk of poor network performance is mostly borne by access providers like Comcast. For instance, it is my understanding that congestion episodes have caused a flood of calls to the technical support centers of access providers. Additionally, frustrated customers may switch to another access provider when they experience congestion, independent of the actual location of the congested links. Under this pressure, the access provider may be compelled to make upgrades to its interconnections even when the congestion is caused by other ASes’ conduct and even when these upgrades do not make economic sense.

4 The Economics of Internet Interconnections

4.1 Who Should Pay Whom?
In traditional telephony, it was typically the caller that was charged for a call, not the called party. In most telephone markets, this rigid pattern was enforced by a regulatory authority. In the case of Internet traffic, if AS X sends traffic to AS Y over an interconnection arrangement, who should pay for the costs of the traversed network infrastructure? In contrast to telephony, in the case of the Internet this question has been answered by the participants themselves, through voluntary commercial agreements.

This debate usually does not focus on global transit interconnections/services, presumably because in that case it is clear that the customer needs the provider’s infrastructure to transfer the traffic to another party’s network. This has not provoked the same policy considerations to date.⁷

⁷ Of course, as noted above, some transit providers are also access providers, and thus some of the traffic they carry remains “on-net” (i.e., it does not leave the transit provider’s AS) even when they sell global transit. This raises the question, why is
But there has been much debate in the past few years about who should pay (or whether there should be payment) in the case of peering interconnections, i.e., whether such arrangements should be settlement-free or paid-peering. There is a fallacy in this dichotomy, however, because SF-peering is not truly “free.” If a peering interconnection is somewhat equally beneficial for X and Y, and if the two ASes can split the costs, one reasonable approach is that neither party pays the other. This is exactly the rationale behind SF-peering links; the two ASes agree that a direct interconnection would be (almost) equally beneficial for both of them and so they do not pay each other. On the other hand, if one of the two ASes benefits much more from the interconnection than the other, or imposes far more cost on the other, it is reasonable (and has traditionally been the case) to consider a paid-peering relationship. Thus, in determining what is equitable for various peering arrangements, we need to consider the relative value of the interconnection for each of the two involved parties and the cost each would bear absent the agreement. But how can we estimate the relative value of an interconnection between two ASes?

4.2 The Economic Value of a Traffic Flow
For most Internet applications today, the economic value of a particular traffic flow is paid to the source of the traffic, not the destination. For instance, in the case of video, which constitutes more than 60% of the Internet traffic today, Internet users pay an online video provider to watch movies, or they watch them for free but the video provider generates revenue from advertisements those users see. Or, in the case of e-commerce sites, users pay those sites (the source of the traffic) through their purchases and, typically, viewing advertisements. Or, when users use a search engine or an online social network, they also look at advertisements that create revenue for the sources of that traffic. There are certainly exceptions (e.g., some peer-to-peer applications), but for the majority of Internet traffic today, it is a fact that the economic value of a traffic flow is exploited significantly by the sender. Additionally, establishing a direct interconnection arrangement to support that traffic flow is beneficial to the sender, since it ensures capacity and may even reduce the transport costs for the traffic flow (by removing a middleman transit provider), thus increasing the value of the traffic flow for the sender. At the same time, the direct arrangement will impose costs on the receiving AS including the costs of accommodating the incremental traffic flow over its network, and, over time, it may generate more costs – for example, if the sending AS takes advantage of the direct interconnection to send traffic with less compression.

Consequently, if a peering arrangement is mostly used to transfer traffic from AS X to AS Y, X surely receives a meaningful economic utility from this arrangement. Note that X may receive another utility from this arrangement – it may obtain a lower cost than it would have to pay to send the same traffic to Y through transit provider

paid-peering viewed as controversial while transit service is considered "business as usual"?
interconnection arrangement. Beyond what is needed the interconnection arrangement.

4.3 Traffic Ratios and Cost-Benefit Analysis

The “traffic-ratio” metric is a commonly used proxy to evaluate if a peering link is of roughly the same value for both parties. For a link between X and Y, the “traffic-ratio < q” constraint states that the average traffic load in either direction should be less than q times the average traffic load in the opposite direction. Typical values of the parameter q are between 2 to 5. If this constraint is violated, and especially when that happens often and/or by a large extent, one of the two parties is likely to perceive that the economic value of this direct interconnection is (very) unequally distributed between the two parties and to insist either that the traffic balance is restored or that the nature of the relationship is revised.

It is often claimed, especially by content providers and CDNs, that the traffic-ratio constraint does not apply in the case of modern Internet traffic because the latter is highly asymmetric (the traffic flows mostly from content providers and CDNs towards access providers and enterprise networks). As a preliminary matter, I note that there are many stable SF-peering agreements among large transit/access networks today, which implies that the traffic-ratio constraint is not violated at those interconnections. While this is not the case for the interconnections of content providers or CDNs, such ASes were historically viewed as customers of network services, and thus they have always been expected to pay a transit or access provider for transferring their traffic.

In any event, the traffic-ratio metric is certainly only one, admittedly simplistic, mechanism to evaluate the mutual value of an SF-peering interconnection between two ASes. More sophisticated cost-benefit analysis can be used by each party, considering the actual costs of delivering the traffic not only through the corresponding peering ports but on an end-to-end basis, as well as the economic benefits that the transferred flows will generate for each party. If AS X would benefit much more from a direct interconnection with AS Y, while at the same time imposing additional costs on AS Y, it is reasonable to expect that Y will request a paid-peering relation with X in which the payment from the latter will amortize the costs associated with the arrangement and the corresponding economic value between the two parties. Importantly, if their respective valuations differ widely,

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8 A heavily unbalanced traffic flow may impose costs on the receiving network far beyond what it had to expend to support the outgoing traffic for which it needed the interconnection arrangement.
and as a result they are not able to agree, then each AS has alternative ways to obtain the connectivity it needs.

### 4.4 The Role of Paid-Peering Agreements in the Evolution of the Internet

Such negotiations can lead to the establishment of stable and fair paid-peering direct interconnections that would not be possible under the parameters of SF-peering. These arrangements thus increase the interconnectedness of the Internet. Additionally, paid-peering interconnections typically result in lower costs and shorter network paths compared to transit interconnections.

Economists often think about the Internet as a two-sided market: one side of the market has end-users (or “customers”), the other side has content providers, and in between there is an Internet “platform” that allows the two sides to communicate [19,20,21,22]. A key question in the economic theory of two-sided markets is how to allocate the price that each side of the market should pay to the platform. Even though that research does not provide a clear-cut answer (the optimal price allocation depends on the specific setup of each model and on its parameters), it approaches the problem from the right perspective: if there is a cost associated with transferring content to end-users, and if content providers generate substantial value from these transfers, then some fraction of the platform’s costs should be paid by the content providers or by their transport agents. This is another way to understand the rationale behind paid-peering interconnections.

As the Internet evolves, I expect to increasingly see sophisticated interconnection agreements that provide more flexibility, better economics, and more stable network performance to the involved parties. For instance, AS X may want to pay AS Y only for selected routes and to condition pay depending on the performance level of those routes. Or, two ASes may agree to be SF-peers for some types of traffic but paid-peers for all other traffic. The network locations for peering interconnection may move closer to the network edge, at least for larger senders of traffic. At the same time, Internet firms are using more advanced tools for traffic measurement and performance monitoring, allowing them to examine in a real-time manner whether the performance conditions of an interconnection agreement are violated. These are indications of a healthy competitive marketplace, and we can expect that they will increase the overall efficiency, robustness and performance of the Internet ecosystem.

### 5 Paid-Peering and Network Neutrality

The debate about Internet peering (namely whether access providers should be permitted to establish paid-peering interconnections with other ASes) has recently been presented to the public as a debate about the “neutrality” of the Internet. This has created confusion and several misunderstandings. The public is led to believe that peering disputes mean that they will not be able to access certain sites or services unless the content provider pays their ISP some “terminating access fees.”
Another hyperbolic concern is that certain types of traffic, say Netflix or Skype, will be subject to deliberate degradation of service and congestion by ISPs that offer similar services.

5.1 What Does Network Neutrality Mean?

The FCC has focused its net neutrality rules on the last mile, where a receiving network may be in the position to undertake the types of improper conduct that have been the focus of the net neutrality rules – blocking or degrading an individual edge provider’s traffic. No provider should engage in such conduct, nor should any provider demand compensation for not engaging in this conduct.

Even beyond the strict confines of the net neutrality legal regime, I take the view that providers should not be discriminating against individual content provider’s traffic at any point in the network. With the exception of malicious/unlawful traffic, every intermediate provider at any point along the route should do its best to deliver all traffic at its highest possible performance, subject to the constraints imposed by the available routes and network capacity, and subject to the interconnection terms that the intermediate ASes have agreed on. In so stating, I am not proposing an expansion of regulation – just describing a behavioral norm that I believe is widely respected throughout the ecosystem.

Consistent with my views, I and several other Internet researchers, have designed measurement tools that can detect such traffic discrimination in the Internet [6,7,8,16,17,18]. These tools are publicly available at M-Lab and they are used by thousands of Internet users every day. It should be noted that such traffic discrimination events occur very rarely, especially in the United States, and when they do occur, they result in major negative publicity for the corresponding ISP.

My understanding is that many major providers today have provisions in their SF-peering agreements that specifically prohibit the receiving network from even inspecting traffic across the parties’ interconnections for reasons unrelated to operational or legal reasons.

5.2 Are Peering Disputes Related to Net Neutrality-Type Concerns?

Traffic discrimination practices are clearly not relevant to the recent paid-peering disputes. The former involve the intentional service degradation of a selected portion of Internet traffic. Peering disputes, on the other hand, represent market-based, content-agnostic disagreements about the price of providing dedicated capacity from one network to another. It is not ultimately about access to the receiving network, since the sender retains other access options (i.e., through transit providers). It is also not about performance, since those other routing options can also provide high quality access. It is simply about the price of dedicated direct interconnections versus interconnections that traverse shared, indirect paths. Such disagreements are common in any market and they are resolved through economic analysis, bargaining, and compromise.
6 The Risk of Regulatory Intervention

Cogent and Netflix request regulatory intervention to prohibit Comcast (and, in other proceedings, other ASes that traditionally have been labeled as “access providers”) from collecting payment for direct peering with content providers or their intermediary ASes. I believe that such regulatory interventions would not only be unnecessary but will harm the evolution of the Internet ecosystem. I explain my position next.

First, paid-peering payments are very different from “termination access fees,” although that is the “talismanic” terminology that these parties tend to use. Notably, Comcast does not demand the payment of such fees from the various ASes that send it traffic. It simply offers the option of direct interconnection (through paid-peering) as an alternative to the sender’s purchase of transit services. Paid-peering may also be offered as a way for a SF-peer to send traffic that exceeds the limitations of the parties’ SF-peering arrangement in terms of traffic constraints.

A second issue is the economic incentives that will result from such regulation. If a content provider or CDN could demand SF-peering with any access provider (and practically all ASes can be viewed as access providers, as discussed in Section 2), content providers and CDNs would not have the incentive to optimize their traffic operations (e.g., compressing traffic prior to delivery, or storing many profiles of each DASH video stream). Rather, they could simply shift their costs to network operators and expect that the next-hop AS (the access provider) would bear the burden of figuring out some way to keep increasing its capacity to accommodate all received traffic and avoid congestion.

Similarly, nothing would preclude the content provider or CDN from making erratic routing decisions, moving traffic from point to point (or, if the rule applied to transit providers like Cogent as well, from transit route to transit route), forcing the access provider to repeatedly build capacity at various points, or maintain huge amounts of spare capacity across the Internet with all its partners, bearing the cost of repeatedly stranded facilities or idle equipment and capacity.

A third issue is the implementation of such regulation. Paid-peering interconnections are not used only by content providers or CDNs (or their transit providers), but by other networks, such as smaller access providers that may arrange direct access to a particular network. Why would a regulator control the interconnections between some ASes but not between others? Would CDNs get free access while smaller ASes had to pay? Why would it be deemed acceptable for a transit provider to collect compensation from small access networks and content providers, and send traffic between the two, but wrong for that same content provider to pay for a direct paid-peering interconnection, eliminating the “middle man” (i.e., transit provider) from the path? Again, there is no clear and major difference today between large access and transit providers. They are not fundamentally different in terms of their network infrastructure and function.

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A fourth issue relates to the viability and evolution of the Internet ecosystem and the network core. If content providers can demand SF-peering interconnections with access providers, then any AS should also be allowed to demand SF-peering with any other AS. The reason is that any AS can claim to be a content provider (they all generate some traffic) and any AS can be described as an “access provider” (they all consume some traffic). There are many potential, and unforeseen consequences of this type of rule. The first victim of such regulation might well be the traditional transit providers, because their customers (or potential customers) could demand SF-peering interconnections with access providers instead of purchasing transit; their business models would dissolve if all direct interconnection were cost-free. Further, and critically, as I explain below, interfering with the efficient operation of the Internet interconnection marketplace and shifting the bulk of the costs to end-users is likely to disrupt the massive flow of new investment necessary to ensure a robust backbone and ever-expanding Internet facilities. This raises serious concerns about the Internet’s evolution.

A final remark about the necessity of regulation: Internet peering disputes are not new. As mentioned in Section 2 (see also Footnote 3), peering disputes between Tier-1 providers have occurred from time to time. Those disputes were always quickly resolved by network operators, often through negotiation and mutual compromises, without ever requiring regulatory intervention. The current disputes are not fundamentally different so as to warrant dramatically different action by regulatory bodies. Plus, the price of transit has dropped by 99%, which strongly suggests that there is no market failure here.

7 Looking Forward: Who Will Pay for the Continuing Growth of the Internet?

Even though the Internet has always been full of surprises, there are two observations that we can reliably expect to remain true in the future. First, the Internet will continue to grow in terms of number of users, new applications, and volume of traffic exchanged. In the last few years, the annual traffic growth rate is about 35%-55%, depending on when, where, and how it is measured [23]. This means that, in the absence of any capacity upgrades, networks today will need to be able to carry twice the amount of traffic currently carried in about 18-28 months from now. Clearly, if major capital expenditures in networking capacity cannot be sustained, it will only take a few months for the existing infrastructure to get severely congested.

The second observation is that whenever there is an increase in the access capacity of Internet users, a new wave of applications is quickly invented that manages to use that capacity. For instance, soon after DSL and cable broadband access became widely available, the first peer-to-peer file sharing applications were developed, and
it did not take much time to saturate those early broadband links. When the access capacities increased to more than 2-4 Mbps – and when CDNs exploded and providers’ investments in backbone facilities shrunk the cost of transit – online video began to flourish, now encompassing high-definition video streaming products such as Netflix. I expect that as the broadband access capacities begin to increase to about 100Mbps (downstream), we will see in the next few years a new wave of applications that will quickly utilize that capacity.

This relentless traffic growth and the associated evolution of Internet applications will require a persistent and substantial capital investment in Internet infrastructure. In particular, it is the last mile of the network, i.e., the access links that connect millions of households to the Internet, that will require the largest capital expenditures in the next decade or so. The obvious question is: who is going to pay for this major overhaul of the Internet access infrastructure?

If we eliminate the option of paid-peering interconnections through regulatory intervention, we are effectively placing all financial burden for the growth of the Internet exclusively on end-users (access providers’ customers) – a situation that has never before prevailed in the Internet ecosystem. End-users will have to pay not only for Internet access but also for investments in the network core, something that has been traditionally been defrayed by contributions from edge providers, CDNs, and other “large” Internet players. Additionally, end-users will have to pay the dedicated transport costs of a particular content provider’s traffic, whether or not they even subscribe to that content provider – which may be significant when larger providers, like Netflix, are at issue. Meanwhile, the content provider (i.e., Netflix) would not only get subsidized transport, but subscription or advertising revenues that it earns because it has access to that access network. Not only is this inconsistent with how the Internet has evolved and grown, it may also be insufficient for the continuing growth of the Internet. Given that edge providers benefit from this communication platform, as do their transport agents, and some of them are among the most profitable companies today, shouldn’t they also financially contribute to the Internet’s growth and evolution?

8 Comments on Certain Claims by Netflix and Cogent

8.1 Comments on the Declaration of Mr. K. Florance (Netflix)
- In §2 of Mr. Florance’s declaration, he claims that Comcast uses its market power to “impose a terminating access fee on Netflix and others.”
  • As I discuss above, this misrepresents how Internet interconnectivity works. A terminating access fee is a mandatory fee that must be paid to the access provider so that the corresponding traffic can reach its destination. But there are other routes content providers like Netflix could use to reach Comcast (and since this dispute is fairly recent, apparently did use for many years) without paying Comcast any fee.
Moreover, if Mr. Florance were correct that this was a terminating access fee, you would expect every terminating access provider to try to extract such a fee from Netflix. Yet, as he notes in his declaration, Netflix has reached hundreds of agreements with terminating access networks for settlement-free transfer of traffic. The likely reason for this disparity between business arrangements with Netflix is that these (typically smaller) networks saw value in exchanging traffic directly with Netflix on a settlement-free basis rather than pay the transit costs of receiving Netflix’s traffic from a third-party transit provider. But other, larger networks that have built their own backbones, like Comcast, and that do not incur the transit costs to send and receive Netflix traffic, likely do not realize the same benefits of settlement-free direct connections with Netflix, so Netflix’s tactics to impose transit costs on them are less susceptible to success.

- In §18, Mr. Florance asserts that Netflix can install the Open Connect appliances as deep into Comcast’s network as the latter would like, and that this would provide several benefits to Comcast and its customers, which Comcast should have accepted. 
  - Deeper network connections may in fact benefit access providers by reducing the load on their backbones (or, for access providers without their own backbone facilities, this could reduce their transit costs). But that does not mean that the relationship inherently qualifies for SF peering. As discussed in Section 3 of this report, the relative value and costs of a peering interconnection should be evaluated based on the costs and benefits it provides to each party. Notably, Comcast would continue to bear the cost of dedicated space and power, and would continue to bear the cost of building capacity as Netflix’s traffic expands. While the price in this arrangement might be lower than the price for interconnection at an IXP, there is no reason to assume it would be zero.

- In §26, Mr. Florance claims that “Comcast succeeded in departing from the previous business norm under which the terminating access network paid for the delivery of traffic to its network, or received such traffic without payment.” 
  - This view of the “business norm” is outdated. As discussed in Section 2 of this report, large access networks today often have their own nation-wide backbone, and so they may need the services of a transit provider for only a small fraction of their traffic. For this reason, as noted above, smaller access providers have a much greater incentive than larger ones to establish SF-peering links with content providers and CDNs (so that they decrease their transit costs).

- In §29, Mr. Florance alleges that “Comcast began a practice in 2009 to 2010 in which it allowed its ports with certain settlement-free transit networks and CDNs to congest”. 
  - This is at best misleading. As discussed in Section 3 of this report, based on my observations of this market, the cost of bad performance is paid mostly by access providers. It would be unwise for Comcast to deliberately cause
congestion to its own customers. At the same time, capacity upgrades or new links cannot be set up overnight and they are costly. If the traffic ratio constraints of Comcast’s SF-peering interconnections were persistently violated, it would have been reasonable for Comcast to seek to restore its peer’s compliance with the terms of those agreements. This is common practice. Why should we think about this as “normal business practice” only when transit providers do it?

- In §41, Mr. Florance claims that “Comcast began to allow Cogent’s routes into Comcast to congest.”
  - As discussed in Section 3, an AS cannot control the ingress path of the traffic it receives. If there was congestion at the links between Cogent and Comcast, it was not necessarily Comcast’s fault. While I know only the details the involved parties have revealed, in my view, responsible network providers work hard to avoid congesting their links not only by building capacity but through regular capacity planning meetings with their peers and through traffic grooming (i.e., rerouting or encouraging a customer to reroute) traffic off congested links. It seems to me that Cogent could have addressed this situation far more cooperatively than it reportedly did, and with less harm to the Quality of Experience of its own and of Comcast’s customers. Similarly, Netflix has not satisfactorily explained why it did not route the traffic to Comcast through other, non-congested routes, especially when its decision not to use other, non-congested routes reportedly hurt its paying customers and was simply poor Internet “hygiene” that is not expected of such large players in this ecosystem.

- In §46, Mr. Florance claims that “adding port capacity costs less than $10,000 -- a cost which is typically amortized over three to five years by the access network.”
  - This figure is accurate if we only consider the cost of peering to be equivalent to buying a few ports. As discussed in Section 3 of this report, however, capacity upgrades are not a localized operation. A significant increase in the capacity of an interconnection may require simultaneous capacity upgrades in several other links and routers. Otherwise, the bottleneck is just moved from the interconnection links elsewhere in the same network.

8.2 Comments on the Declaration of Mr. H. Kilmer (Cogent)
- In §26, Mr. Kilmer contends that “Comcast and TWC, although not Tier-1 networks, have been able to obtain settlement-free peering from certain Tier-1 providers, including Cogent, because of their market power arising from their control of access to the consumers who use them for broadband Internet service.”
  - It is hard for me to see how any network could be forced into a SF-peering interconnection (without government intervention). Another way to interpret the relation between Cogent and Comcast is that – assuming Comcast was not interested in purchasing transit from Cogent once it had its own backbone capabilities – Cogent actually preferred SF-peering
interconnection with Comcast, compared to having no direct connection with Comcast at all. This allows Cogent to then attract transit customers who want short paths to Comcast’s subscribers.

- In §43, Mr. Kilmer claims that Comcast and TWC “are not Tier-1 ISPs. They do not provide the infrastructure and support for the Internet that Tier-1 providers do”.
  - As discussed in Section 2 of this report, the historical distinction between Tier-1 and Tier-2 (or access providers) is of little practical consequence today. Should we evaluate the value an AS brings to a relationship based on whether it happened to be a member of a particular “club” established more than a decade ago? Or does it make more sense to evaluate a provider based on its investment in its transmission links, the total traffic it carries, the number of people that it serves directly, and similar factors? The marketplace has been gravitating toward the latter approach, and interconnection arrangements today turn on these types of factors, not outdated Tier rules.
  - It is certainly hard to quantify the “support for the Internet” that any Internet firm offers, though it seems to me unfair and unjustified to allege that Comcast has not provided “support for the Internet”. We should not ignore that most peering disputes during the last 15 years, sometimes causing reachability disruptions to millions of users, involved Cogent (see Footnote 3).

- In §55-§60, Mr. Kilmer argues that “Comcast’s Balanced Traffic Ratio Requirement Makes No Sense.”
  - First, it is important to note that a “traffic ratio constraint” is used by many ASes, not just Comcast. In fact, the existence of a traffic ratio clause is the norm in SF-peering policies, as Cogent is well aware given its past peering disputes over the same issue.
  - Second, Mr. Kilmer criticizes the use of traffic ratio constraints, but without offering an answer to the obvious question: how will two ASes determine if an SF-peering interconnection is (roughly) equally valuable for both parties such that they should share the costs? To be clear, traffic ratio considerations are not an end of themselves, but rather a proxy that has been used by many networks for several years to determine mutual value.

- In §68, Mr. Kilmer claims that “the cost of upgrading all of the connections between Comcast and Cogent (...) would have been approximately $120,000.” And it is further stated that “in March 2014 Cogent offered to pay for Comcast’s expenses in upgrading the connections with Cogent. Comcast refused.”
  - As was also discussed in my response to Mr. Florance’s declaration, these cost estimates refer only to the cost of the ports between Cogent and Comcast – they do not capture the other required interconnection costs or the capacity upgrades that will certainly be required more deeply into
Comcast’s network. *An interconnection is not just a “shared link”; it is a “shared network.”*

• Further, what would happen if Cogent kept increasing the volume of traffic it sends to Comcast? Cogent’s revenues would increase the more (Netflix or other) traffic it sends to Comcast, while Comcast’s costs would increase as it carries these larger and larger traffic loads. And since Comcast would presumably be required to maintain whatever amount of capacity Cogent required to keep the direct interconnection between the two providers uncongested, neither Cogent nor Cogent’s customers would have any reason to send traffic in an efficient manner, meaning Comcast’s costs would increase all across its network on an ongoing basis. In a marketplace where direct connections have always been formed and maintained only when they were deemed to be mutually beneficial, why should Cogent enjoy growing benefits while Comcast is saddled with growing costs?
References


