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Survey of Characteristics of Internet Carrier Interconnection Agreements

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Introduction

The Internet, or network of networks, consists of 5,039 Internet Service Provider (ISP) or carrier networks, which are interconnected with one another in a sparse mesh.[2] Each of the interconnecting links takes one of two forms: transit or peering. Transit agreements are commercial contracts in which, typically, a customer pays a service provider for access to the Internet; these agreements are most common at the edges of the Internet. Transit agreements have been widely studied and are not the subject of this report. Peering agreements – the value-creation engine of the Internet – are the carrier interconnection agreements that allow carriers to exchange traffic bound for one another's customers; they are most common in the core of the Internet. This report examines and quantifies a few of the characteristics of Internet peering agreements.

The Survey

In preparing this report, we analyzed 142,210 Internet carrier interconnection agreements. We collected our data by voluntary survey, distributed globally through all of the regional Network Operators Groups between October 2010 and March 2011. The responses we received represented 4,331 different ISP networks, or approximately 86% of the world's Internet carriers, incorporated in 96 countries, including all 34 OECD member countries and seven of the 48 UN Least Developed Countries. For each agreement, in addition to the identities of the carriers party to the agreement, we asked the following three questions:

- Is the agreement formalized in a written document, or is it a "handshake" agreement?
- Does the agreement have symmetric terms, or do the parties exchange different things?
- What is the country of governing law of the agreement?

In addition, we made the following determination for each agreement:

- Is the agreement bilateral or multilateral?

In 1,032 cases, both parties to the same agreement responded to our survey, and in 99.52% of those cases, both parties' answers to each of the three questions were identical. We believe that, among other things, this indicates that respondents understood the questions clearly and were able to answer unambiguously and accurately.

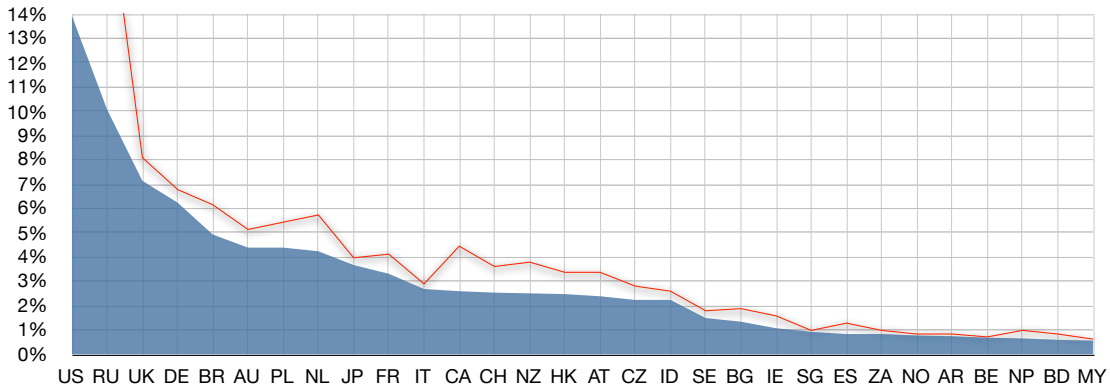

Figure 1: Top thirty countries of incorporation of the represented networks, as a percentage of those in the dataset.

The largest number of networks represented in the dataset were incorporated in the United States (466), followed by Russia (337), the United Kingdom (239), Germany (209), and Brazil (165). On the long tail of the curve, 45, or nearly half, of the countries were represented by three or fewer networks. The red line in Figure 1 indicates the total number of networks incorporated in each country; the blue area indicates those represented in the responses to our survey. In most countries, a significant and relatively uniform majority of the networks are represented in our data, but our coverage in the United States (30%) and Russia (52%) was disproportionately small relative to other countries, and this does slightly affect the results of some of our country-specific analyses of these two countries, as we discuss later.

Informal Agreements

Of the total analyzed agreements, 698 (0.49%) were formalized in written contracts. The remaining 141,512 (99.51%) were "handshake" agreements in which the parties agreed to informal or commonly understood terms without creating a written document. The common understanding is that only routes to customer networks are exchanged, that BGP version 4 is used to communicate those routes, and that each network will exercise a reasonable duty of care in cooperating to prevent abusive or criminal misuse of the network.[3] This huge number of informal agreements are arrived at by the "peering coordinators" or carrier-interconnection negotiation staff of the networks, often at self-organized regional or global "peering forums" that take place many times each year.[4]

Symmetric Terms

Of the agreements we analyzed, 141,836 (99.73%) had symmetric terms, in which each party gave and received the same conditions as the other; only 374 (0.27%) had asymmetric terms, in which the parties gave and received conditions with specifically defined differences. Typical examples of asymmetric agreements are ones in which one of the parties compensates the other for routes that it would not otherwise receive (known as "paid peering"), [5] or in which one party is required to meet terms or requirements imposed by the other ("minimum peering requirements"). [6] In the more common symmetric relationship, the parties to the agreement simply exchange customer routes with each other, without settlements or other requirements.[7]

Governing Law

No interconnection agreements were reported that utilized a country of governing law that was not also the country of incorporation as well as the location of primary operation of one of the two carriers party to the agreement. Stated another way, in no case did the parties choose a country of governing law that was not one of their own countries of incorporation and primary operation. This indicates that there is, as yet, no country that has such compelling rule of law in the field of

carrier interconnection as to incentivize this behavior. Contrast this with other areas of commerce in which countries tailor regulatory or legislative environments to attract business as, for example, the registration of much maritime shipping in Panama or banks in Switzerland.

Nonetheless, clear preferences were expressed in the data, with the distribution of countries of governing law being sparser than the distribution of countries of incorporation and operation. In other words, some countries' governing law was preferred to a greater degree than their frequency as a country of incorporation would suggest, whereas others were preferred for governing law less frequently than they appeared as a country of incorporation.

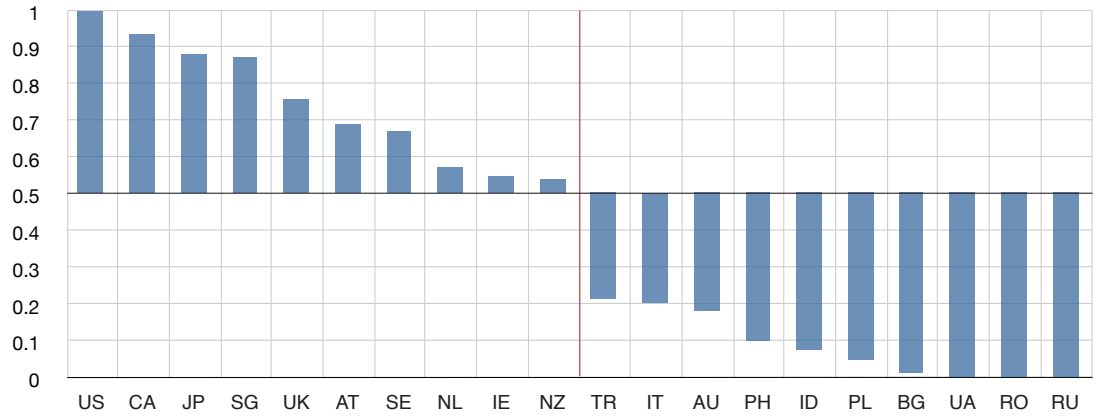

Figure 2: Probability of selection as a country of governing law, ten most-likely and ten least-likely countries

When we compare the frequency of appearance as a country of incorporation to the frequency of selection as a country of governing law (Figure 2), in nearly every interconnection agreement in which one of the two parties is incorporated in the United States or Canada that country is selected as the country of governing law in preference to the country of incorporation of the other party to the agreement. At the opposite end of the spectrum, there were no agreements in the dataset in which Russia, Romania, or the Ukraine was selected to supply governing law for an agreement with a country outside this group of three, even though 337 Russian, eighteen Ukrainian, and eight Romanian networks are represented in the dataset. Each time a Russian, Romanian, or Ukrainian network interconnected with a foreign network, the parties elected to use the other country's governing law.

National Interconnection Partners

Looking solely at the frequencies with which pairs of countries of incorporation appear within the dataset, it is possible to chart the relative number of connections between any country and all others. By way of example we chart the most frequent interconnection partners (those consisting of more than 1%) of each of the four countries that are most frequently represented in our dataset – the United States, Russia, the United Kingdom, and Germany (Figure 3).

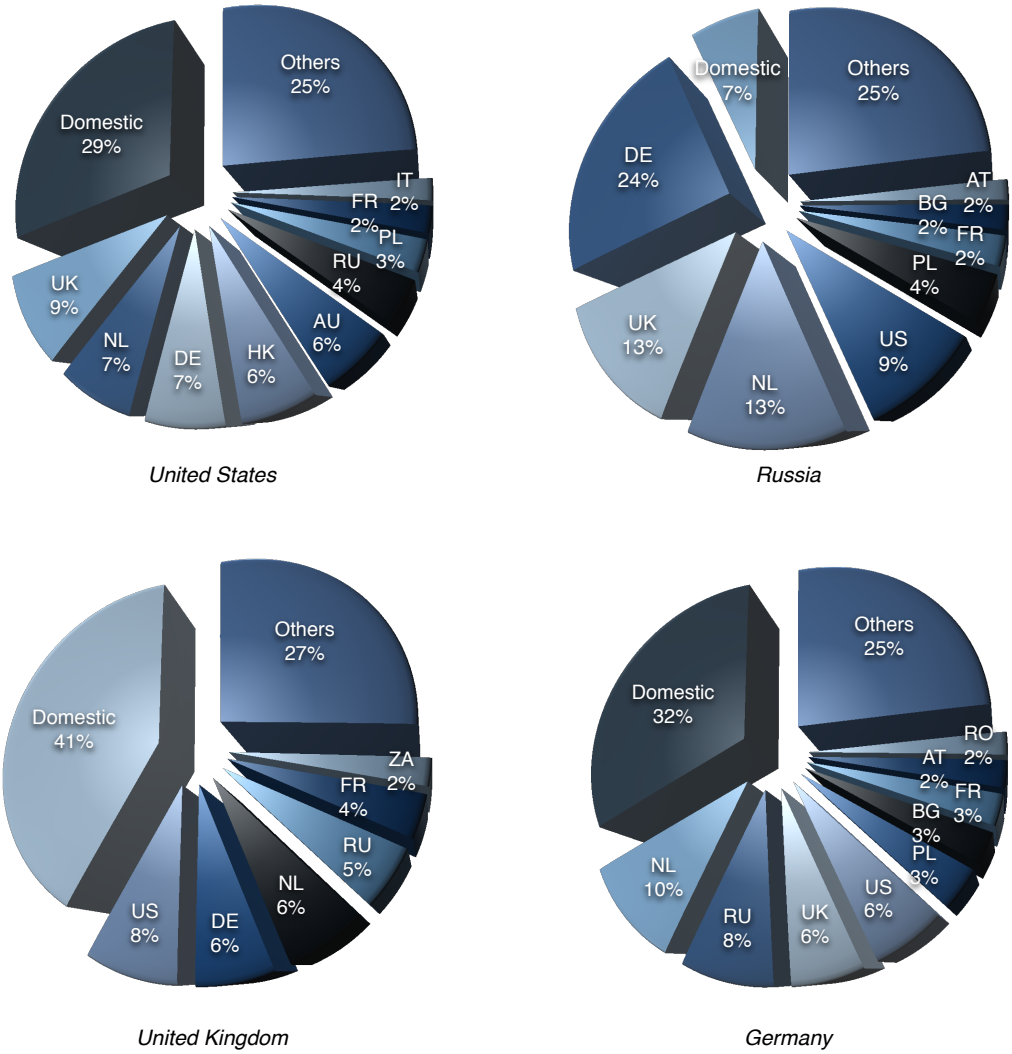

Figure 3: Trends in peering partners, selected countries

Among these partners, linguistic cohorts, geographically proximal neighbors, and frequent commercial trading partners are favored. The only real surprise is the relatively small share of domestic interconnection agreements observed within Russia, and we believe that this can be attributed to a selection bias in the dataset rather than to actual conditions on the ground; though we received many survey responses from networks that interconnect with U.S. and Russian networks, fewer were received from U.S. and Russian networks themselves, which would account for their relatively low shares of domestic interconnections.

Degree of Interconnection

Most of the networks represented have small numbers of interconnection partners. Of the 4,331 networks, 2,696 (62%) have ten or fewer interconnection agreements, and only twelve of the represented networks have more than 700 interconnection agreements.

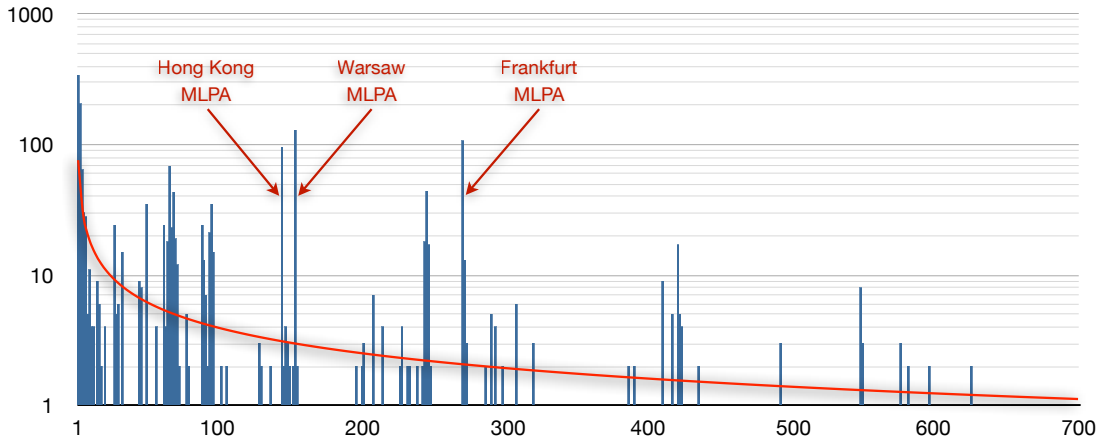

Figure 4: Distribution of number of networks (X axis) with each quantity of interconnection partners (Y axis)

A number of "spikes" are visible in the distribution graph (Figure 4), with major ones appearing clustered around the values 144, 154, and 271. These are the effect of large multilateral peering agreements (MLPAs), specifically the ones associated with the Hong Kong, Warsaw, and Frankfurt Internet exchange points.

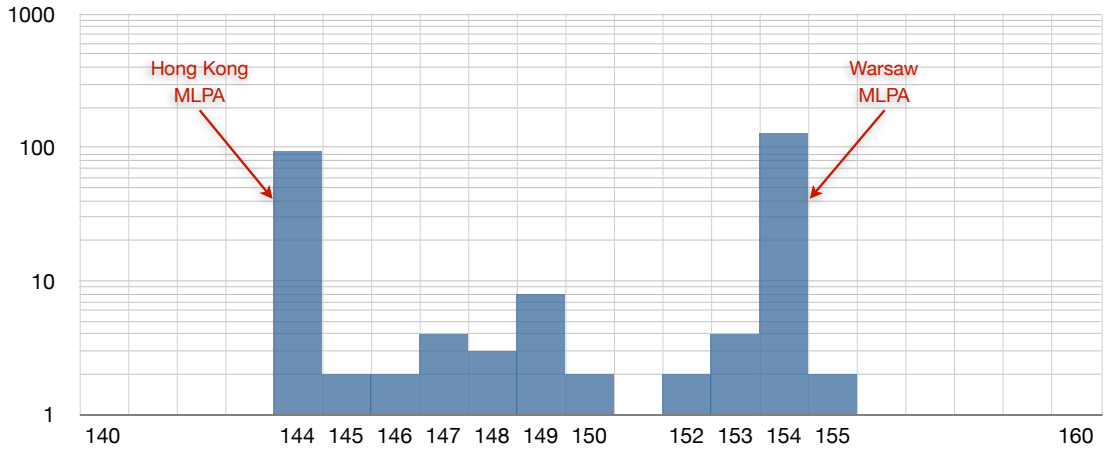

Figure 5: Expanded view of the Y axis range 140 - 160 from Figure 4, detailing the Hong Kong and Warsaw MLPAs

In each case, there exist a large number of networks that all peer with each other, creating a spike at that value, which trails off as a function of the portion of those networks that also have other interconnection agreements. To some degree, the volume of the tail to the right of the spike varies with the age of the MLPA, since MLPAs that have existed longer generally include members who have had more time to also form bilateral agreements outside the MLPA. Generally speaking, multilateral peering agreements are identifiable as spikes that have similar values in both X and Y axes in figures 4 and 5.

Unexpected Results

One unexpected result of this survey is a new understanding of the prevalence of multilateral peering. Multilateral peering, the exchange of customer routes within groups of more than two parties, has long been characterized as a practice principally engaged in by smaller networks. It has been commonly assumed that large networks decline to participate in multilateral peering agreements, and that multilateral agreements are therefore outside of the mainstream of peering practice. Although the method by which we collected our survey data does not allow us to compare absolute quantities of bilateral agreements to multilateral agreements, the majority of the Autonomous System pairs we observed were connected through multilateral agreements, and many of those agreements were very large, with dozens or hundreds of participants.[8] With the exception of the cluster circled in red (which consists of "tier-1" ISPs), each of the other vertical clusters in figures 6 and 7 represents a multilateral agreement, similar to the spikes in figures 4 and 5.

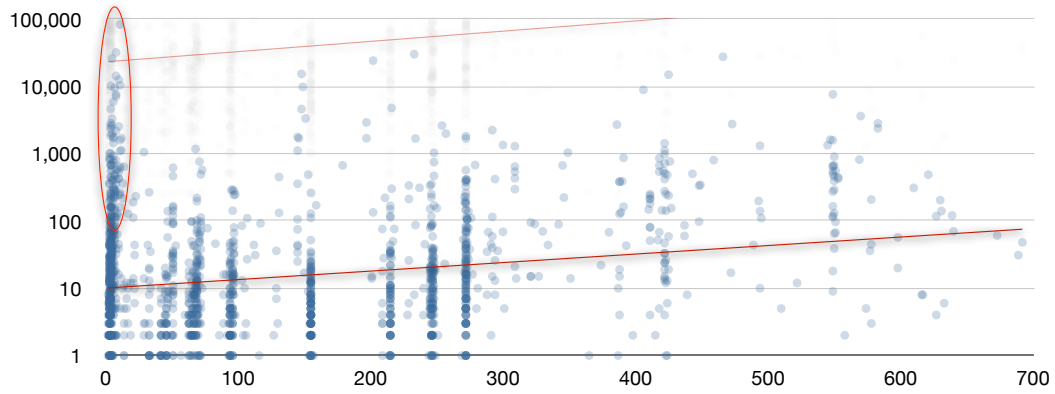

Figure 6: Number of advertised prefixes (Y axis) over number of interconnection partners (X axis) per carrier

It seems possible that, just as "donut peering" overtook "tier-1" peering in the late 1990s, multilateral peering may now be overtaking bilateral peering, at least in sheer numbers, if not necessarily in volume of traffic.[9] In both cases, market-dominant networks loudly derided as "peripheral" a practice that sought to render them irrelevant, but that practice slowly gained prevalence over time, becoming mainstream without ever receiving much notice. As an example, the 144 participants in the Hong Kong Internet Exchange multilateral peering agreement represent 10,296 AS-pair adjacencies, and *each one* of those participants individually exceeds the average "tier-1" carrier in degree of interconnection. When articulated in writing, multilateral peering agreements tend to follow the same general form and terms as other peering agreements, with the sole exception of having more than two parties.[10]

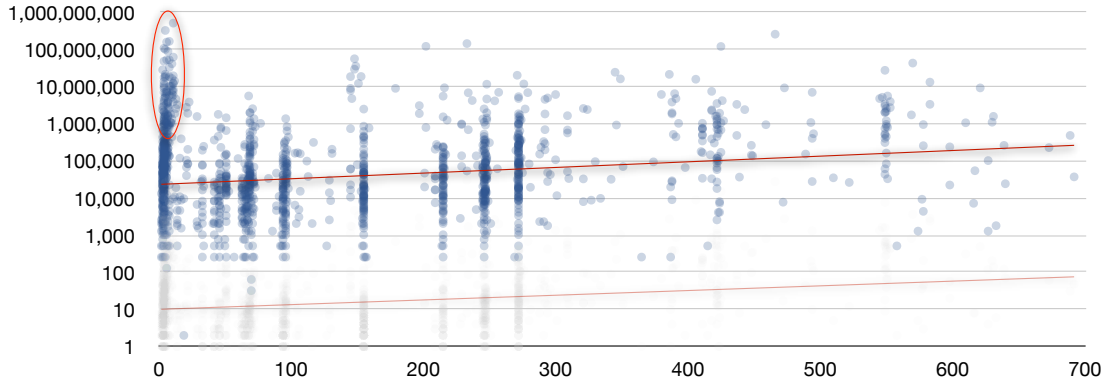

Figure 7: Number of advertised IPv4 addresses (Y axis) over number of interconnection partners (X axis) per carrier

Another finding of this survey, predictable on the face of it but to an unexpected degree, is how far the mainstream trend in number of interconnection agreements has left behind the legacy "tier-1" networks, which tend to rely upon very small numbers of interconnection agreements. The circled clusters in figures 6 and 7 represent the "tier-1" ISPs, each of which has a large number of advertised IPv4 prefixes, and consequently a larger number of actual IPv4 addresses, yet very few interconnection partners. Following the red line that indicates the average correspondence between size and number of interconnection partners to the right, most of the "tier-1" ISPs would have several thousand peers, if they were within mainstream ratios. By contrast, large content-distribution networks ("CDNs"), which have similar scale and degree of infrastructural investment tend to be exemplars of mainstream trends in our data, with very broad interconnection, both in absolute numbers and in geographic diversity. Although this may be self-evident, we expected to see a single order of magnitude difference between the number of agreements held by similarly sized networks in those two categories, whereas the actual difference was of two orders of magnitude.

Further Work Necessary

One weakness of this study, which provides reason for future work, is that we had relatively few mechanisms by which to compare the distribution of the responses we received to an objective "ground truth," or to preexisting datasets, in order to determine how statistically representative our survey respondents were to the Internet as a whole. Because previous studies of carrier interconnection agreements have been many orders of magnitude more narrowly focused than this one, they do not provide a statistically useful baseline against which we can characterize our dataset. A comparison against our own internal interconnection agreement data would have shed little light on how the survey dataset compares to the Internet as a whole and would have precluded including our own network's data in the survey. Furthermore, there is no mechanism for directly observing all of the peering agreements that exist in the Internet, and thus no ground truth to compare to. We hope that our foray into characterization of carrier interconnection agreements encourages researchers in the academic community to follow up with further work on the subject.

This paper and future versions may be found at http://pch.net/resources/papers/peering-survey

[1] Bill Woodcock, research director, woody@pch.net. Vijay Kumar Adhikari, on summer internship at PCH during his doctoral research at the University of Minnesota under professor Zhi-Li Zhang, vijay@pch.net.

[2] Smith, Philip, *Weekly Routing Table Report*, April 15, 2011, Transit ASes: http://thyme.apnic.net/rv3-data/2011/04/15/mail-global

[3] For a discussion of standard symmetric peering terms and conditions, read Chris Hall's http://www.highwayman.com/peering/peering_agreement.html. Although much more long-winded, the London Internet Exchange's model peering agreement also encapsulates the generally accepted terms of a symmetric peering agreement: https://www.linx.net/good/bcp/peeringagreement_draftv4.html.

[4] For a global schedule of Internet governance meetings, including many peering forums, see http://internetmeetings.org. For specific examples, see the Global Peering Forum website, http://peeringforum.net or the European Peering Forum website, http://www.peering-forum.edu.

[5] A discussion of MWEB, a South African ISP, transitioning from paid peering to normal peering can be read at http://mybroadband.co.za/news/broadband/16313-MWEB-peering-link-cuts-How-impacts-you.html. Specific solicitations of paid peering can be found on the websites of the AOL Transit Data Network, http://www.atdn.net/paid_peering.shtml; Cox Communications, http://www.cox.com/peering/paid-peering.asp; and Verizon Business, http://www22.verizon.com/wholesale/productguide/partnerportprogram.

[6] Bill Norton discusses the barriers to entry often contained in "minimum peering requirements" in his *Study of 28 Peering Policies*: http://drpeering.net/white-papers/Peering-Policies/A-Study-of-28-Peering-Policies.html. Original documents can be found on the websites of Comcast, http://www.comcast.com/peering; Tiscali, http://www.as3257.net/peering-policy; AT&T http://www.corp.att.com/peering; and Internet Solutions, ftp://ftp.is.co.za/tech/peering.pdf.

[7] Definitions and discussions of peering and its general terms can be found on the Packet Clearing House website https://www.pch.net/wiki/pch:public:glossary#p; Wikipedia, http://en.wikipedia.org/wiki/Peering; and Bill Norton's website, http://drpeering.net/white-papers/Ecosystems/Internet-Peering.html.

[8] An "Autonomous System" (AS) is a uniquely-identified Internet network. Autonomous System Numbers (ASNs) are the numeric identifiers assigned by the Regional Internet Registries (RIRs) and used within the Internet routing system to define a specific bounded network that has its own uniquely defined routing policies. An AS-pair is a pair of networks that interconnect with each other.

[9] "Donut peering" is the practice of small and medium-size networks peering with each other aggressively in order to reduce the detrimental impact of a larger network refusing to peer with them. This results in a "donut" of densely interconnected networks surrounding a self-proclaimed "tier-1" network – the "donut hole" that is poorly interconnected with the networks around it. For a further discussion of donut peering, see the Cook Report's November 2002 *Economics of IP Network Interconnection*, http://www.cookreport.com/backissues/nov-dec2002cookrep.pdf; or my own January 2003 lecture to the University of Minnesota Digital Technology Center, *Internet Topology and Economics: How Supply and Demand Influence the Changing Shape of the Global Network* http://www.pch.net/resources/papers/topology-and-economics. "Tier-1" is the moniker some carriers in the mid-1990s gave themselves as they attempted to form a cartel, peering with each other but nominally refusing to peer with any networks outside the cartel. Their misunderstanding of Internet growth rates led them to become irrelevant, as the portion of the market held outside the cartel grew exponentially while that inside the cartel grew in linear fashion.

[10] A range of typical multilateral peering agreements can be found on the websites of the Open Peering Initiative http://www.openpeering.nl/mlparegistry.shtml; the Kansas City Network Access Point http://www.kcnap.net/peering-policy.html; Red Bus Internet Exchange http://www.rbiex.net/assets/joining/mlpa.pdf; and the Indonesia Internet Exchange http://www.iix.net.id/library/iix-peering-agreement_ind.pdf. Note that their specific terms differ little if at all from those of the bilateral agreements discussed in note 2.