Interconnection in the Internet
References

Check out DrPeering.net

Internet traffic: Labovitz et al, “Internet Inter-Domain Traffic”

Analysis: content peering and the Internet economy, by B. Krogfoss

Material from Dr. Peering

http://drpeering.net/white-papers/A-Business-Case-For-Peering.php
http://drpeering.net/white-papers/Art-Of-Peering-The-Peering-Playbook.html

D. Clark, S. Bauer and W. Lehr: “Interconnections in the Internet: the policy challenge”
The Internet Traffic

• Hierarchy of providers
  – Global Tier-1, smaller Tier-2, regional Tier-3

• ... but today most Internet inter-domain traffic flows directly between large CDNs/content providers and consumer (eyeball) networks
  – Google increasingly pursuing edge peering strategies and represents an increasing share of the traffic

• Inter-domain traffic peaks (July 2009) exceed 39 Tbps and grew an annualized average of 44.5% between July 2007 and 2009

• P2P traffic is an increasingly less portion of the traffic
Traditional Internet Topology
US Tier-1 Peering
Emerging Internet Topology

- CDNs (Akamai, LineLight) and content providers (Google, MS, Facebook) are directly connected with consumer and Tier-1/Tier-2 networks
- Video (e.g. YouTube) “disguised” as Web traffic ~ 40% of all HTTP traffic
Internet business relations

- ISPs running ASs have business relationships to generate revenue
- Peering: exchange traffic on an equal basis
- Transit: customer-provider relation
- variations:
  - paid peering
  - partial transit
  - ....
**Transit**

**Definition:** *Internet Transit* is the business relationship whereby one ISP provides (usually sells) access to all destinations in its routing table.

Simple, Customer-Supplier, SLAs, Discounts, Metered service: the more you send/receive, the more you pay. Connectivity/Advertisement to the “Internet”
**Peering**

**Definition:** *Internet Peering* is the business relationship whereby companies reciprocally provide access to each others’ customers.

Peering is not a perfect substitute for transit, & is not transitive.
Content peering and the internet economy

- Content peering has helped ISPs reduce transit costs for video traffic
- ISPs may be compelled to accept content peering because of explosive video growth
- Widespread content peering decreases profits for all ISPs in the long term
A simple Internet income model

Internet income view

Internet Profit ($P$) = Content Revenue ($\sum k_i$) + Subscriber Revenue ($\sum s_i$) = $K + S$

Profit $T1$ ISP: $P_1 = 2 \eta t$
Profit $T2$ ISP: $P_2 = \eta (\beta + 0.75 \alpha - 1) + s$
Profit $T3$ ISP: $P_3 = \eta (\beta - 0.75 \alpha) + s$

Content peering view

Profit $T1$ ISP: $P_1 = \eta t$
Profit $T2$ ISP: $P_2 = \eta (\beta + 0.5 \alpha - 0.5) \cdot C_p (0.25) + s$
Profit $T3$ ISP: $P_3 = \eta (0.5 \beta - 0.5 \alpha) - C_p (0.25) + s$

ISP profit, increasing bandwidth per content provider

Internet profit with increasing content peering
Economics of paid peering

• Should a small network peering with a larger network pay?
• Should a content provider peering with a large eyeball network pay?
Networks of different sizes

\[
\theta = \text{effective \% of users}
\]

\[
V_i = n_i \log(n_i + \theta n_j) - c_T : \text{transit}
\]

\[
U_i = n_i \log(n_i + n_j) - c_P : \text{peering}
\]

Total benefit after peering:

\[
U = U_1 + U_2 = n_1 \log(n_1 + n_2) + n_2 \log(n_1 + n_2) - 2c_P
\]

Nash Bargaining solution:

\[
\max_{x+y=U} (x - V_1)(y - V_2)
\]

\[
p_{21} = -p_{12} = x^* - n_1 \log(n_1 + n_2) - c_P
\]

- Transit provider
- Total benefit of network 1
- Total benefit of network 2
- Bargaining set
- Fall-back position if negotiations break

\[
\begin{align*}
\frac{\text{Fall-back position if negotiations break}}{\text{Total benefit of network 1}} \\
\frac{\text{Total benefit of network 2}}{\text{Nash Bargaining solution:}}
\end{align*}
\]
Content provider – eyeball network

Transit provider

\[ V_1 = \theta n(v - t), \quad V_2 = \theta n(u - t) \]

\[ U_1 = nv - c_p, \quad U_2 = nu - c_p \quad \text{or} \quad n(u - c) - c_p \]

Total benefit after peering: \[ U = U_1 + U_2 \]

\( \theta = \% \) of users using content

\( v = \) value/user for CP,

\( u = \) increase of value/user for ISP

Nash Bargaining solution:

\[
\max_{x+y=U} (x - V_1)(y - V_2)
\]

\[ p = \frac{1}{2} n(1 - \theta)(v - u) \]

\[ p = \frac{1}{2} n(c + (v - u)(1 - \theta)) \]

Fall-back position if negotiations break
Strategy to avoid paid peering

- Single hop access: obtain cheap transit and send content traffic through a peer

Diagram:
- Content provider
- Transit provider
- Eyeball network
- Cheap transit because of single hop
- $1$ peering
- $10$?
- Charges $p$ the CP
Revenue free peering

- P=0, a typical revenue-free agreement
  - Approximately equal ISPs
  - Can not be determined if the balance of values favors one or the other ISP
  - The negotiation about relative value may be costly
  - Each ISP covers its internal costs from its own customers
Content ISP pays the access ISP

- CD pays A
  - The most common agreement in today’s CDN market
  - The carriage of high volume content generates costs for the access ISP (A)
  - ISP A may also take advantage of his market power by earning monopoly profits from overcharging the content provider (CD)
  - CD covers its costs from the content producers
Access ISP pays the content provider

• Payment from A to CD
  - Uncommon in today’s market
  - Suppose that ISP A is a small, rural ISP
  - If there is not a direct connection, flows from CD to A will come over an expensive transit link
  - A’s costs will be reduced by having a direct connection to CD
  - But if A is small, CD’s costs may be increased due to the direct connection
  - It makes sense that A pays CD
Transit prices as a limit

• Eyeballs must recover their incremental costs
• But do usage based costs scale linearly with usage?
• Transit as a limit, although...
  - In order CDNs to have better performance may be willing to pay a premium over transit price
  - On the other hand in order to obtain a better agreement CDNs may want to punish the eyeball unless they can get a discount off transit price
• But usage based costs are larger than transit prices which are declining over the years
Paid peering as a competitive threat

- Any company can buy Transit services for around $2-$9/Mbps, but...
- ...Google is paying about $0.50/Mbps for transit!
- To optimize performance and decrease costs, a company can buy Paid Peering from Comcast for around $1-$3/Mbps
- Paid Peering enables Google’s competitors to get access to Comcast eyeballs for around the same price as transit
- But Paid Peering provides better performance than Internet Transit
- Therefore, Paid Peering allows Google competitors to more easily compete with Google on performance and price without having to reach Google scale!
Illegal Paid Peering?

- Killing off paid peering
  - forces Google’s competitors to pay a higher cost to reach the eyeballs
  - leads to decreased performance especially for the small content providers as they no longer enjoy the performance benefits of Paid Peering
Economics of transit and CDNs

• Usage-based pricing for transit and CDN
• Market trends
• Conclusions
Internet Transit Billing Calculation (95th Percentile Measurement)

Metered Internet Transit Service

Upstream (Transit) Provider

5 minute samples

$t_0$

$t_1$

$t_n$

End Of Month Sort

highest

lowest

95th Percentile sample (Mbps)

* Internet Transit Price ($/Mbps)

= Monthly Cost of Internet Transit
### Internet Transit Prices (1998-2014) U.S. Internet Region

<table>
<thead>
<tr>
<th>Year</th>
<th>Internet Transit Prices (in Mbps, min commit)</th>
<th>% Decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>$1200 per Mbps</td>
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<td>1999</td>
<td>$800 per Mbps 50%</td>
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<td>2000</td>
<td>$675 per Mbps 19%</td>
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<td>2001</td>
<td>$400 per Mbps 69%</td>
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<td>2002</td>
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<td>2003</td>
<td>$120 per Mbps 67%</td>
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<td>2004</td>
<td>$90 per Mbps 33%</td>
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<td>2005</td>
<td>$75 per Mbps 20%</td>
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<td>2006</td>
<td>$50 per Mbps 50%</td>
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<td>2007</td>
<td>$25 per Mbps 100%</td>
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<td>2008</td>
<td>$12 per Mbps 100%</td>
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<td>2009</td>
<td>$9.00 per Mbps 33%</td>
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<td>2010</td>
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<td>2011</td>
<td>$3.25 per Mbps 54%</td>
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<td>2012</td>
<td>$2.34 per Mbps 39%</td>
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<td>2013</td>
<td>$1.57 per Mbps 49%</td>
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<td>2015</td>
<td>$0.63 per Mbps 49%</td>
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</tbody>
</table>

*Source: DrPeering.net*
Market Prices for Transit

Source: http://drpeering.net/white-papers/Internet-Transit-Pricing-Historical-And-Projected.php
PRICE OF TRANSIT

$2-3/Mbps

$1

$2

$400

$2-3/Mbps
Good news – Traffic always grows

YouTube @20% growth

Monthly Transit Fee

Jun-06 Jul-06 Aug-06 Sep-06 Oct-06 Nov-06 Dec-06 Jan-07 Feb-07 Mar-07 Apr-07 May-07 Jun-07 Jul-07

mbps

monthly fee
CDN Prices

Pricing: Current Costs and Market Trends

Video Delivery Pricing For Q1 2010

- 50TB: High $0.45 per GB, Low $0.40 per GB
- 100TB: High $0.25 per GB, Low $0.20 per GB
- 250TB: High $0.10 per GB, Low $0.06 per GB
- 500TB: High $0.06 per GB, Low $0.02 per GB

-This is per GB delivered pricing, not per MB sustained
-Pricing is for major CDNs who focus on global delivery
-Cheaper prices can be found by going to regional service providers
-Customers have different needs and requirements which determines the final price

-For quarterly pricing updates visit: www.cdnpricing.com

- No room for small CDNs
  - Price drop 40-45% in 2009 20-25% in 2010, Vol. Up 40-50%

12-month US-based
Main Findings

• The Transit and CDN Markets are doomed
  – The days of simple Internet Transit or vanilla CDN services are numbered
  – and any business model that is based on margins on something going to zero are doomed

• Will the Peering Sector survive?
  – "Does Peering Make Sense Anymore?"
Choosing peering vs transit

• Peering cost analysis
• The economic decision problem
• Conclusions
Analysis of Traffic Flow

Costs of Peering
1) Transport
2) Colocation
3) Equipment
4) Peering Fees

ISP A

Internet Transit Service

Global Internet

other destinations

Transit ISP

other destinations

ISP B

Internet Transit Service

Def.P
Analysis of Traffic Flow

Costs of Peering
1) Transport
2) Colocation
3) Equipment
4) Peering Fees
Peering Top 50

Top Internet Transit Traffic Destinations

<table>
<thead>
<tr>
<th>Policy (O=Open, S=Selective, R=Restrictive)</th>
<th>ASNum</th>
<th>Traffic Volume (in Mbps)</th>
<th>Company Name</th>
<th>Contact Name</th>
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% of Internet Transit Traffic

Histogram

http://drpeering.net/forms/peering-top-fifty-list.xlsx
Cost of Peering

Peering is NOT FREE
1) Transport Fees
2) Colocation Fees
3) Peering (Port, membership, etc) Fees
4) Routing equipment
Cost of Peering

Plug some #’s in
1) 10G Transport Fees: $6K/mo
2) Colocation Fees: $1K/mo
3) Peering (10GPort,membership,etc) Fees: $2K/mo
4) Routing equipment: $8K/mo
Total Cost of Peering: $17K/mo

Can peer ~ 7Gbps (for free) = $17K/7000=$2.43/Mbps best case scenario

Alternative to Peering: Transit at $5/Mbps
How do we compare peering and transit?

1M,2M,3M
Effective Peering Bandwidth / Minimum Cost of Traffic Exchange

Minimum Cost of Traffic Exchange = $2.34/Mbps

costOfPeering
minimumCostOfTrafficExchange = effectivePeeringBW

costOfPeering
minimumCostOfTrafficExchange = $17KperMonth
7000Mbp
= $2.34/Mbps
Peering Break Even Point

\[
peeringBreakEvenPoint = \frac{\text{costOfPeering}}{\text{priceOfTransit}}
\]

\[
peeringBreakEvenPoint = \frac{\$17,000 \text{ perMonth}}{\$5 \text{ perMbps}}
\]

\[
peeringBreakEvenPoint = 3400 \text{ Mbps}
\]
Effective Peering Range

$\text{effectivePeeringBandwidth} = \text{range}(\text{peeringBreakEvenPoint}, \text{effectivePeeringBandwidth})$

$\text{effectivePeeringBandwidth}_{S17K} = \text{range}(3.4\text{Gbps}, 7\text{Gbps})$
Peering Break Even Point

Peering vs Transit

With 2010 prices…

<table>
<thead>
<tr>
<th>Year</th>
<th>Transit Price (per Mbps)</th>
<th>Peering Cost (per month)</th>
<th>Peering Break Even Point</th>
<th>Effective Peering Bandwidth (w/10G port)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>$12.00</td>
<td>$10,000</td>
<td>833 Mbps</td>
<td>up to 7600Mbps</td>
</tr>
<tr>
<td>2009</td>
<td>$9.00</td>
<td>$10,000</td>
<td>1111 Mbps</td>
<td>up to 7600Mbps</td>
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<tr>
<td>2010</td>
<td>$5.00</td>
<td>$10,000</td>
<td>2000 Mbps</td>
<td>up to 7600Mbps</td>
</tr>
<tr>
<td>2011</td>
<td>$3.25</td>
<td>$10,000</td>
<td>3077 Mbps</td>
<td>up to 7600Mbps</td>
</tr>
<tr>
<td>2012</td>
<td>$2.34</td>
<td>$10,000</td>
<td>4274 Mbps</td>
<td>up to 7600Mbps</td>
</tr>
<tr>
<td>2013</td>
<td>$1.57</td>
<td>$10,000</td>
<td>6369 Mbps</td>
<td>up to 7600Mbps</td>
</tr>
<tr>
<td>2014</td>
<td>$0.94</td>
<td>$10,000</td>
<td>10638 Mbps</td>
<td>up to 7600Mbps</td>
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<tr>
<td>2015</td>
<td>$0.63</td>
<td>$10,000</td>
<td>15873 Mbps</td>
<td>up to 7600Mbps</td>
</tr>
</tbody>
</table>
Analysis of the industry

- Transit and vanilla CDN markets are based on margins -> doomed!
- Public peering goes away – private peering
  - Public peering ports will be very difficult to justify financially due to low cost of transit
- The peering industry sector will morph
  - 3 classes of customers: video distribution companies, high-performance network service companies, high-end customers
  - Access networks increase in power -> paid peering, competition for access to the last mile
  - Cooperative and enhanced inter-ISP services may bridge the gap:
    - The ETICS approach
    - Cross-AS cooperative CDN service
The CDN future challenge

• The value is not in the bits, but in the data surrounding the consumption
  – when, where, how frequent, other statistics

• The value is in the add-ons
  – reliability, quality, specialized to service needs

• Take a piece of the value
  – cooperative models: distribute content for $0/Mbit, get a share when purchases and clicks are made
ISP strategies towards peering/transit

• Peering vs transit is a strategic decision
• Reasons for peering / refusing peering
• “Peering games”: ISP strategic behavior in practical situations
  – strategies for obtaining peering agreements from networks which otherwise would charge for transit
Top 4 Motivations to Peer

① Lower Transit Costs
② Lower Latency [40-50 msec better]
  ③ Usage-based traffic billing [debated]
  ④ Marketing Benefits [good quality]

Also redundancy [multiple points of interconnection]
Top 10 Reasons NOT to Peer

① Traffic [and Investment] Asymmetry
② Transit Sales Preferred [“Once a customer, never a peer”]
③ Ports are for Revenue
④ Keep Transit Prices from sliding [less peers/competition]
⑤ Prefer SLAs [rapid repair]
⑥ Traffic Ratio denial [affect peering ratio with others]
⑦ Transit is Cheaper
⑧ Personality Conflicts
⑨ We aren’t true Peers
⑩ We don’t have the cycles
Changing Ratio

Before Peering: X:Y 1:1

After Peering: Y is lighter
Transit with Peering Migration

Transit Negotiations with Sales leads to Peering
(Should peering prerequisites be met)

- Explicit contractual migration
  - But Peering Prerequisites may have changed!
Paid Peering

- Paid peering as stepping stone
  - Cover transport costs for the interconnection
  - No additional overheads
  - Meet requirements for free peering
  - Good for early stage ISPs
• De-peer to change the “rules” (add peering points, paid peering)
  – Genuity vs Exodus, Cogent vs Level-3, Cogent vs Sprint
  – Demand for more interconnection points
  – Will not generate more revenue
Traffic Manipulation (I)

A forces traffic Over B’s transit
Traffic Manipulation (II)

- Good choice for content-heavy ISPs to force the path:
  - Stop announcing the route to the target’s peer
    - A is more or less indifferent on transit costs
    - But target pays transit now!
  - Mess with BGP
    - Prepend the AS for ISP B into its route announcements: BGP code at B will detect loop and invalidate A’s routes
- Web Spider deployment, replay traffic to meet peering ratios
Honey Approach

• Promote desirability of content (Yahoo)
• Huge portals with lots of heavy traffic, streaming events
• Potential peers can save transit money by peering and improve customers’ performance
• Can work for content heavy Tier-2 ISPs
Bait and Switch

- Large company appearing as the peer at negotiation phase
- Smaller prefixes at setup phase
- Peering relationship may not be torn down

New Startup Subsidiary
Strategic Degradation of Peering

- B buys transit from
  - A for $5
  - D for $10
- Peering link A-D
  - Congested, high latency
  - Not suitable for video
- B and C exchange heavy traffic, e.g. video flows
- Should D upgrade the peering link A-D or not?
  - Related to transit prices?
The Level 3 – Comcast dispute

- Akamai and LimeLight Networks have traditionally provided delivery of Netflix content to Comcast customers as CDNs, and paid Comcast for local interconnection and colocation.
- Level 3 has a longstanding transit agreement with Comcast in which Comcast pays Level 3 to provide its customers with access to the internet backbone.
- Level 3 signed a deal with Netflix to become the primary provider of their content instead of the existing CDNs. Rather than change its business relationship with Comcast to something more akin to a CDN, in which it pays to locally interconnect and colocate, Level 3 hoped to continue to be paid by Comcast for providing backbone connectivity for its customers. Evidently, it thought that the current terms of its transit agreement with Comcast provided sufficient speed and reliability to satisfy Netflix.
- Comcast realized that they would simultaneously be losing the revenue from the existing CDNs that paid them for local services, and it would have to pay Level 3 more for backbone connectivity because more traffic would be traversing those links. Comcast decided to try to instead charge Level 3, which didn’t sound like a good deal to Level 3.