Interconnection economics: issues and models

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Goal

• Show that economics (game theory) are key to understand current interconnection trends

• Discuss interesting economic issues in interconnection but accept that current state-of-the-art research = many disparate, fragmented models

• In many cases models make wrong assumption!

• Can we provide a generic data set which can be used to test the validity of assumptions (Nikos Laoutaris)?

• But be humble enough... simple models should be enough to understand key trends and strategies
Topics

• New business model trends in the internet
  – CPs, CDNs, ISPs, T1s,…

• New interconnection pricing paradigms and issues
  – Paid peering, net neutrality

• Economic models
  – Non-cooperative, cooperative

• Research directions
  – Data-driven economic analysis
  – Evolution of market structure and competition
The Internet traffic

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

• 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
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 strategies

• **T1 transit market**: global connectivity
  - low margins, very competitive and efficient, relatively low barriers of entry (no need to build an access network), leverage on **content aggregation** and on **existing** transit agreements with T2 customers

• **L3**: become a content distributor, raise its revenue by increasing the transit traffic into eyeball access networks
  - to get content from multiple CPs, an ISP needs to have a single contract with L3 (**content aggregation**)  
  - exploits **content externalities** of the **2-sided market** (CPs – T2 ISPs)

• **Cogent**: low-cost transit provider
  - price war on transit prices to attract CPs and other customers
  - threatens to make transit market unstable

• **Market threat**: no clear need for T1 services since T2 can substitute T1 services by peering (see next comments), need T1 only for the “tail” of the connectivity & content
Internet strategies (cont.)

• T2 market (ISPs): **few** large players, almost global coverage (DT, BT, Telefonica, AT&T,...), **leverage on eyeball aggregation**, but **high access network cost**, 2-sided market

• Can bypass T1 global connectivity services by peering at NAPs where they are already present
  - Only leverage of T1s: they are content aggregators
  - **but** possible bypass by T2s connecting directly to the **few large** CPs
  - connect to T1s for the **rest** of the CPs (aggregation of the heavy tail)

• Need to use their monopoly power on eyeballs to bargain for paid peering with T1s and large CPs
  - is fair because of larger cost for providing access aggregation than to provide content aggregation
  - **but** issues with regulation, potential conflict with net neutrality
  - **who has the biggest bargaining power?** (2-sided market externalities)
Internet strategies (cont.)

• Content providers (CPs): care for content to be available with good QoE to eyeballs, natural monopolies for their own content

• Large CPs (Google, etc) have their own “T1” network, interconnect at many points to T1 and directly to T2 networks to save on transit cost and control better QoE
  – by doing strategic load balancing of their traffic into a T2 network they can force lower prices and increase their bargaining power
  – similarly they can use “single hop access” strategy to avoid paid peering or demand lower transit prices (chicken game)

• Small CPs pay to benefit from content aggregation services offered by a T1 (transit) or by a CDN
Internet strategies (cont.)

• **CDNs**: content aggregators, *bypass* T1, pay for injecting content traffic into T2 networks (“sender” pays model, consistent with also choosing QoS by CP)

• Natural part of the content distribution value chain (content providers -> CDN -> eyeball ISP), get a share of the content provider profit

• Pay eyeball ISPs for terminating content to eyeballs
  – leverage low prices since the alternative is for ISPs paying more for transit and having worse customer QoE
  – leverage on content aggregation
  – ISPs leverage higher prices by offering better services (deep caching,...)
Internet strategies (cont.)

• Users: demand flat rate access
  – hard to change, needs collective agreement by ISPs
  – competition of ISPs only on QoE

• Regulators: ensure the market is efficient
  – ex-ante and ex-post regulation
  – hard to predict the evolution of the market
  – hard to assess efficiency
  – is there enough competition?
Conclusions (so far)

• Very complex ecosystem
• Many important questions
  – do ISPs have real monopoly power over eyeballs?
  – churn of customers (of ISPs, CPs)
• Market dynamics and risk
  – who invests first
  – who profits from other’s investments
Internet business relations

• ISPs have business relationships to generate revenue
  – **Peering**: exchange traffic on an equal basis
  – **Transit**: global connectivity service, customer-provider relation

• New trends: paid peering, partial transit,…
  – Are these economically justified?
  – Can we explicitly compute the appropriate prices based on actual network market data?
Content peering: Prisoner’s dilemma?

- 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 (negative externality)
A simple Internet income model (B. Krogfoss)

Internet income view

Internet Profit (P) = Content Revenue (∑k) + Subscriber Revenue (∑s) = 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

Internet profit with increasing content peering

ISP profit, increasing bandwidth per content provider

ISP 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:

\[ \max(x - V_1)(y - V_2) \quad \text{subject to} \quad x + y = U \]

Fall-back position if negotiations break

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

\[ p_{21} = \frac{1}{2} [n_1 \log(n_1 + \theta n_2) - n_2 \log(n_2 + \theta n_1) + (n_2 - n_1) \log(n_1 + n_2)] \]
Content provider – eyeball network

Transit provider

Content provider

t / user

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

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

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

(which he can cash)

\( c \) = cost of upgrade/user

Fall-back position if negotiations break

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

\[ p = \frac{1}{2} n(c + (v - u)(1 - \theta)) \]
Strategy to reduce $ in paid peering

• “Single hop access”: obtain cheap transit and send content traffic through a peer
• Paid peering $ < “cheap” transit

“Why should I pay you 10$/Mbps if I have to pay only 1$/Mbps through TP?”
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
Paid peering improves competition in CP

- 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!
Strategic degradation of peering

• B can buy 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?
Charging CPs and net neutrality

- Interesting model by J. Musacchio and J. Walrand

\[ B = c^u t^w e^{-p/\theta}, \quad 0 < u, w \quad u + w < 1 \]
\[ R_C = (a - q)B - \alpha c \]
\[ R_T = (q + p)B - \beta t \]

Assume T chooses \((t, p, q)\). Then C chooses \(c\) to max

\[ R_C = (a - q)c^u t^w e^{-p/\theta} - \alpha c \]

Given this \(c(t, p, q)\), T chooses \(t, p, q\) to max

\[ R_T = (p + q)c^u t^w e^{-p/\theta} - \beta t \]

When is Social Welfare maximized? q=0 or q\(\neq\)0?

\[ q < 0 \quad q = 0 \quad q > 0 \quad \frac{a}{\theta} \]
Remarks

- In practice $p$ is fixed? $a$ is variable?
- Need to understand the asymmetry of C and T
- Is the 2-sided market platform = C+T?
- How different are the cooperative model solutions?
- Can we stick real numbers?
Conclusions

• Need to agree on **few** economic models for interconnection

• Simple but address the specific issue
  – exploit synergies in the value chain

• Define an experimental procedure for validation
  – derive key industry economic parameters (costs, elasticities, …)
  – compare the results of more than a single model
  – choose a place to start
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.
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”