A Cost Model for Network Traffic
(with an application to paid-peering)

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with
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[Paid-peering]
Outline

• These are really two talks
• But they are related
• Part 1: Formalizing a cost model for network traffic
  [CCR’12]
• Part 2: A value-based framework for peering agreements
  [ITC’10, NANOG 49]
• The cost model can be useful for measuring peering “value”
Part 1: Formalizing a Cost Model for Network Traffic
Optimizing Network Costs

- Traffic-related costs contribute to the total cost of running a network
- Routing in recession: configuring routing in a network to minimize traffic-related costs
- Relatively easy: How do Individual elements contribute to costs? Harder: How much do individual ingress-egress flows cost?
- Need a holistic traffic cost model that can attribute costs to individual flows
Need for a Traffic Cost Model
Need for a Traffic Cost Model

Cost-based paths selector
Need for a Traffic Cost Model

network topology, routing information

Cost-based paths selector
Need for a Traffic Cost Model

Traffic Matrix

Cost-based paths selector

network topology, routing information
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Output

low cost paths for each destination

network topology, routing information
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network topology, routing information

Traffic Cost Model (?)

Output

low cost paths for each destination
Need for a Traffic Cost Model

A holistic traffic cost model

Traffic Matrix

network

Traffic Cost Model (?)

low cost paths
Costs for operating a network

- **Traffic costs**
  - Paying for transit, port costs, cost for laying fiber
- **Operational costs**
  - Paying salaries to employees
- **Equipment and maintenance costs**
  - Buying networking gear, service fees to vendors
- **Miscellaneous costs**
  - IT related, real-estate, etc
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**Goal: A simple but still useful cost model**

- Buying networking gear, service fees to vendors

- **Miscellaneous costs**
  - IT related, real-estate, etc
Applications

• **Min-cost routing**: Optimal routing of ingress-egress flows to minimize cost
• **Peering Location selection**: Which location to establish peering with a neighbor?
• **Peering evaluation**: What is the “value” of a peering link?
A Traffic Cost Model
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backhaul cost
A Traffic Cost Model

backhaul cost

interconnect cost
A Traffic Cost Model
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\[ C_N = C_F + C_U \]

Total Cost = Fixed Cost + Usage-based Cost
A Traffic Cost Model

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Total Cost = Fixed Cost + Usage-based Cost

\[ C_F = \sum c_b(p_1,p_2) + \]

Fixed Backhaul cost for all (PoP, PoP) pairs
A Traffic Cost Model

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\[ C_F = \sum_{p1,p2} c_b(p1,p2) + \sum_{a,p} c_i(a,p) \]

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Fixed Backhaul cost for all (PoP, PoP) pairs

Fixed Interconnect cost for all (AS, PoP) pairs

\[ C_U = \sum (c_i(f) + f) \]

Ingress Interconnect Cost
A Traffic Cost Model

\[ C_N = C_F + C_U \]

Total Cost = Fixed Cost + Usage-based Cost

\[ C_F = \sum c_b(p1,p2) + \sum c_i(a,p) \]

\( C_F \) = Fixed Backhaul cost for all (PoP, PoP) pairs

\( C_U \) = Ingress Interconnect Cost

\( C_U \) = Fixed Interconnect cost for all (AS, PoP) pairs

\[ C_U = \sum_i (c_i(f) + c_b(f)) \]

\[ \sum_i (c_i(f) + c_b(f)) \]

\( C_U \) = Backhaul Cost

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\[ C_N = C_F + C_U \]

**Total Cost = Fixed Cost + Usage-based Cost**

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**Fixed Backhaul cost for all (PoP, PoP) pairs**

**Fixed Interconnect cost for all (AS, PoP) pairs**

\[ C_U = \sum (c_i(f) + c_b(f) + c_e(f)) \]

**Ingress Interconnect Cost**

**Backhaul Cost**

**Egress Interconnect Cost**
A Traffic Cost Model

\[ C_N = C_F + C_U \]

Total Cost = Fixed Cost + Usage-based Cost

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Fixed Backhaul cost for all (PoP, PoP) pairs

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Ingress-egress flows

Ingress Interconnect Cost

Backhaul Cost

Egress Interconnect Cost
Cost Optimization

- We focus on optimizing traffic-dependent costs
- Requires an operator to determine the cost associated with each ingress-egress flow
- Interconnect costs based on 95th percentile of total volume at that interconnect: \( \text{cost} = \text{per\_bit\_price} \times V_{95} \)
- Approach 1: Assume \( V_{95} \) is linear function of average rate
  - Flow’s contribution = \( \text{per\_bit\_price} \times \text{constant} \times \text{flow\_rate} \)
- Approach 2: Use Shapley Value
  - Flow’s contribution = Shapley value across all flows at that interconnect
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Approximation!

Computationally expensive!
Application 1: Minimize Cost of Routing Traffic

- Objective: Minimize total cost of all ingress-egress flows
- Constraints: Backhaul, interconnect link capacities
- Knobs: egress (pop, AS) for each flow

- NP-hard to determine optimal routing! Use a greedy algorithm to approximate the optimal solution

- Iteratively, for each flow f in descending order of flow costs
  - For each PoP p, find the cheapest AS at p which has a route to f’s destination
  - Assign f to the cheapest egress (PoP, AS) pair
Cost Optimization

Cumulative Fraction of Savings vs. Fraction of Flows

- Backhaul $>>$ Interconnect
- Backhaul $\approx$ Interconnect
- Backhaul $<<$ Interconnect
Cost Optimization

- Moving 10% flows gives 65% of the total cost savings.

- Backhaul >> Interconnect
- Backhaul ≈ Interconnect
- Backhaul << Interconnect
Part 2: A Value-based Framework for Peering Decisions
Evaluating Potential Peers

- To peer or not to peer...

A  B
Evaluating Potential Peers

• To peer or not to peer...

Should I peer with B?

A

B
Evaluating Potential Peers

• To peer or not to peer...

Should I peer with B?

Settlement-free or paid-peering?
Evaluating Potential Peers

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- What price would B accept (or offer)?
- Settlement-free or paid-peering?
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Settlement-free or paid-peering?

A

???

B
Value Based Peering

• Price based on the “value” of the link

• For a network, define the notion of economic “fitness”
  • fitness = revenue – interconnect costs – backhaul cost

• Value of a peering link is the difference in fitness with and without the link
  • Value = f_{with} - f_{without}

• Revenue and costs could change on peering/depeering
What Affects Peering Value?
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A $$$$ B

T

$$$$ $$$$
What Affects Peering Value?
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- Interconnect cost changes:
  Avoid a transit provider
What Affects Peering Value?

- Interconnect cost changes: Avoid a transit provider
- Backhaul cost changes: Peering link changes how traffic is routed in a network
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What Affects Peering Value?

- Interconnect cost changes: Avoid a transit provider
- Backhaul cost changes: Peering link changes how traffic is routed in a network
- Revenue changes: Attract/lose traffic due to new peering link
The Fair Peering Price
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- A and B see values $V_A$ and $V_B$
The Fair Peering Price

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- What should be the paid-peering price?
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- Fair price is $(V_A - V_B)/2$
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The fair price equalizes the benefit that A and B see from the link
Why Peer at the Fair Price?

- Peering with the fair price is optimal
  - Both networks see better fitness by peering at the fair price
  - As compared to the case where peering link does not exist
- Peering with the fair price is stable
  - No network has the incentive to unilaterally de-peer the other
  - Unique Nash Equilibrium
- Optimal and stable as long as $V_A + V_B > 0$
  - Either $V_A$ or $V_B$ can be negative, as long as total is positive
  - For cost-benefit peering, both $V_A$ and $V_B$ must be positive
Some Hard Questions..

• Value-based peering is fair, optimal and stable.
  • But what (if any) is the right notion of fairness?
  • Equal value? Equal cost?

• How can networks estimate peering value?
  • Peering trials..
  • A cost model to estimate peering value

• What if networks lie about peering value?

• What happens if everyone uses value-based peering?
  • Density of peering links, end-to-end path lengths..
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The ITER Model

• **ITER:** Agent-based computational model to answer “what-if” questions about Internet evolution

• **Inputs:**
  • Network types: transit provider, content provider, stub
  • Peer selection methods, provider selection methods
  • Geographical constraints
  • Pricing/cost parameters
  • Interdomain traffic matrix

• **Output:** Equilibrium internetwork topology, traffic flow, per-network fitness
The ITER Approach

- Compute equilibrium: no network has the incentive to change its providers/peers
Using ITER to simulate value-based peering

- Small but realistic internetwork topology: transit providers, content providers, and stubs

- Interdomain traffic matrix: most traffic flows from content providers to stubs

- Provider selection: price-based

- Peer selection: value-based, cost-benefit and traffic-ratio peering
ITER Results: Value-based Peering

• Higher density of peering links with value-based peering as compared to peering by traffic ratios or peering by cost-benefit analysis

  • Peering links that cannot be formed with cost-benefit analysis are feasible with value-based peering

  • Shorter end-to-end paths

• Payment direction: The same network can end up on either side of a paid-peering relationship

  • What happens in practice?
Thanks!
The papers are online at www.caida.org/~amogh
Feedback, comments, criticism: amogh@caida.org
Evaluation

• Access to routing and traffic data from an access ISP in UK
• No access to backhaul and interconnect cost data
• Considered three cost scenarios:
  – Backhaul >> Interconnect (large ISP or cheap transit scenario)
  – Backhaul ≈ Interconnect
  – Backhaul << Interconnect (content provider or expensive transit scenario)
• Evaluated cost optimization using the greedy approach
• What-if scenarios:
  – Where to peer?
  – Which new peer to establish peering with?
  – How useful is an existing peering relation?
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Evaluating Current Peers
Evaluating Current Peers

Why is B still a settlement-free peer?
Evaluating Current Peers

Why is B still a settlement-free peer?

Does B benefit more than me?
Evaluating Current Peers

Why is B still a settlement-free peer?

Should I demand payment? Should I delve deeper?

Does B benefit more than me?
Negative Peering Value

\[ f_A: \$50k \quad \text{and} \quad f_B: \$100k \]
Negative Peering Value

\[ f_A: \$50k \quad f_B: \$100k \]
Negative Peering Value

\[ f_A: \$50k \rightarrow \$60k \quad f_B: \$100k \rightarrow \$95k \]
Negative Peering Value

\[ V_A = $10k \quad V_B = -$5k \]

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$52.5k \smile$

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Negative Peering Value

$V_A = $10k$

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$f_A: $50k \rightarrow $60k$

$f_B: $100k \rightarrow $95k$

$52.5k \smile$

$102.5k \smile$
Hiding peering value

- Assume true $V_A + V_B > 0$ and $V_B > V_A$
  - A should get paid $(V_B - V_A)/2$

- If A estimates $V_B$ correctly, and claims its peering value is $V_L$, where $V_L << V_A$
  - B is willing to pay more: $(V_B - V_L)/2 :)$

- If A doesn’t estimate $V_B$ correctly, and $V_L + V_B < 0$, the peering link is not feasible!
  - A loses out on any payment :(

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