Routing and Peering in a Competitive Internet

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Peering

- Multiple network providers: AT&T, Sprint, etc.
- *Peering points*: connection points between network providers
- Key issue: What is the value of interdomain routing?

Outline

- Provider objectives
- Routing in a competitive internet
- Future directions

Provider objectives

Assume we are given two providers with following goals:

- The sending network S: Outgoing traffic should exit as cheaply as possible

- The receiving network R: Incoming traffic should be sent to destination at minimum cost

Sender's strategy: *nearest exit* or "hot potato" routing.

Routing in a competitive Internet

Henceforth: Assume peering point locations are fixed.

- Optimal routing and nearest exit routing

- Game theoretic models

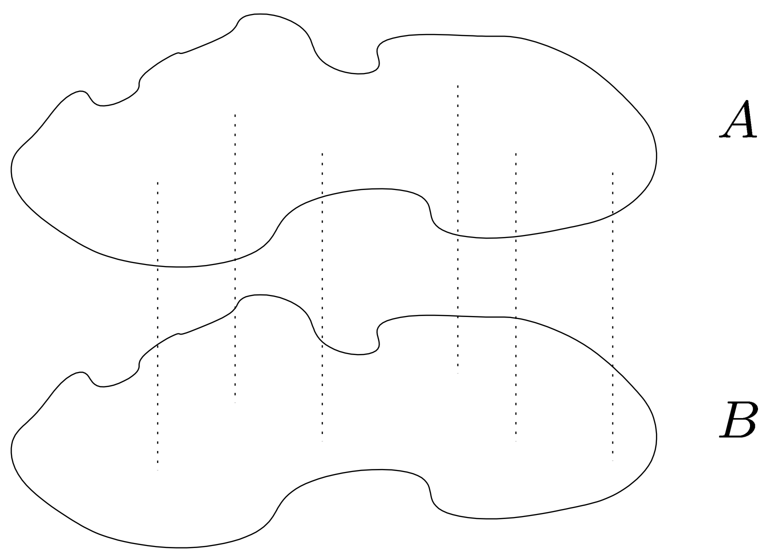
Optimal routing: the traditional framework

- Flow on link (i, j): f_{ij}
- Cost incurred on link (i, j): $C_{ij}(f_{ij})$
- Minimize $\sum_{(i,j)} C_{ij}(f_{ij})$
  subject to source-destination flow constraints

Note: *As if* only one network provider exists.

“Nearest exit” routing: the competitive Internet

- Two network providers connected by peering points



- Each minimizes cost only within their own network

Optimal vs. nearest exit routing

- All costs linear: $C_{ij}(f_{ij}) = d_{ij}f_{ij}$

- Peering points: $p_1, \ldots, p_n \in N$ (zero cost)

Optimal routing:
Shortest path between s and d.

Nearest exit routing:
Provider 1 sends from s to nearest peering point p_i.
Provider 2 uses shortest path from p_i to d.

Comparison

How much worse than optimal routing is nearest exit routing?

Theorem:

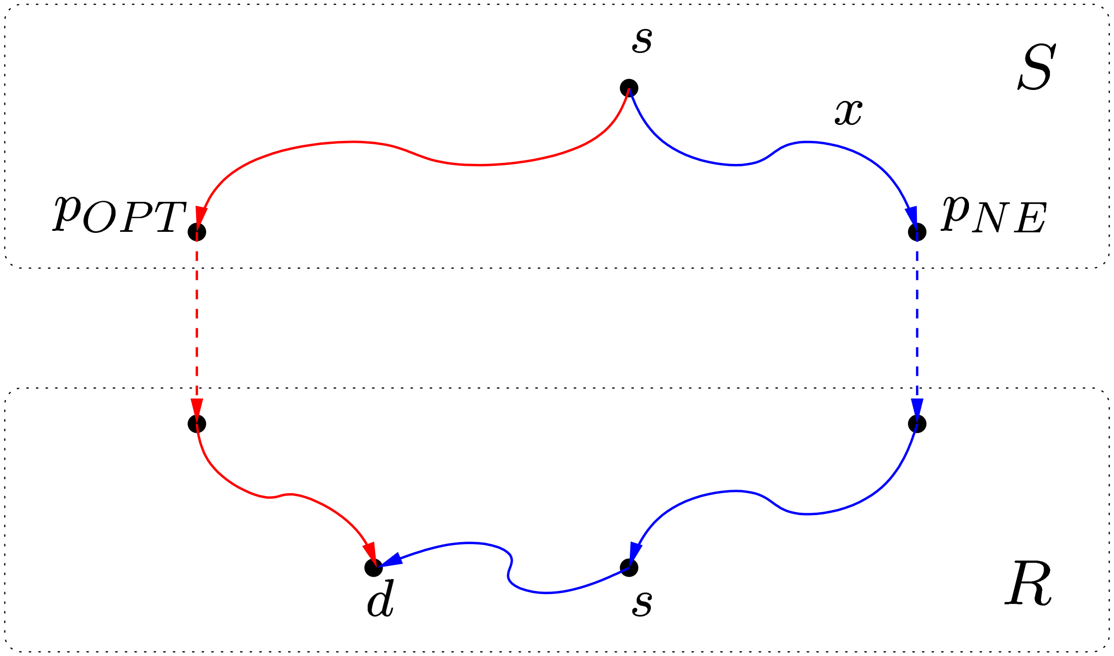
If:

- All costs are linear, and
- $S = R$

Then:

Nearest exit routing cost $\leq 3\times$ optimal routing cost

Proof of bound



Blue: Nearest exit routing

Red: Shortest path routing (cost = r)

Proof of bound

Note: $x \leq r$ by definition of nearest exit routing.

One possible receiver route from p_{NE} to d:

$p_{NE} \rightarrow s \in R$: cost $x \leq r$
$s \rightarrow d \in R$: cost $\leq r$

So total nearest exit cost is $\leq 3r$.

In general?

In general, nearest exit cost is arbitrarily worse than optimal.

Competitive routing as a two-stage game:

1. Providers choose prices for use of their links

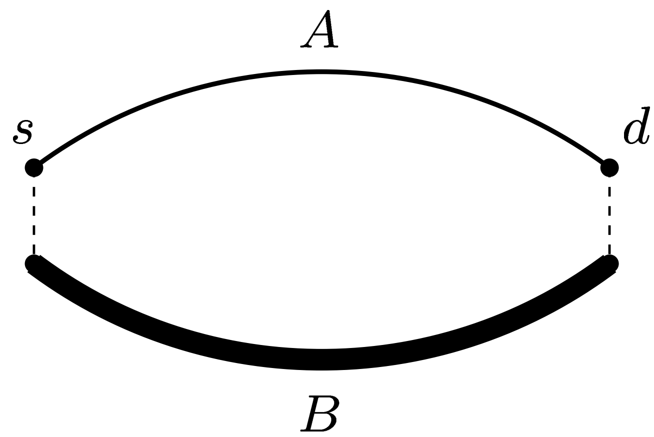
2. *Given prices*, providers determine how best to route flow

Is the optimal routing solution, with:

$$\text{price of link} = \text{marginal cost of link}$$

an equilibrium of this game?

Game theoretic models: example



Provider A: Wants to send x_A from s to d.
Provider B: Wants to send $x_B \ll x_A$ from s to d.

At optimal routing solution, marginal costs are low.

But at these prices, provider B has an incentive to raise his price.

Game theoretic models

Objective for provider A:

Minimize:

Cost of total flow on A*'s link*: $C_A(f_A)$

$$+$$

Payment to provider B: $p_B \times$ (A's flow sent on B's link)

$$-$$

Payment from provider B: $p_A \times$ (B's flow sent on A's link)

Subject to:

A sends x_A from s to d

Game theoretic models

We can analyze the optimal routing solution, which yields:

- flow f_i on link i
- price $p_i = C_i'(f_i)$ (marginal cost) on link i

Except in a completely symmetric situation,
the optimal routing solution is *never* an equilibrium of the two-stage game.

Future directions

Moral: We must not assume that the predictions of a global static optimization model will hold up in a competitive Internet.

Future research questions:

- Game theoretic analysis of routing for arbitrary networks
- Optimal strategies for individual providers

Future directions

- Pricing mechanisms to encourage optimal routing
- Protocol design to encourage optimal routing