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 $d$:

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

$s \rightarrow d \in R: \text{cost } \leq r$

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:

$$\text{Cost of total flow on } A\text{'s link: } C_A(f_A)$$

$$+$$

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

$$-$$

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

Subject to:

$$A \text{ sends } x_A \text{ from } s \text{ to } d$$
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