The Internet is Flat: Modeling the Transition from a Transit Hierarchy to a Peering Mesh

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## Changes in the Internet

- Goal to produce model to reflect observed changes in three Internet factors:
  - An increasing fraction of traffic originates from a few providers
  - Major content providers have expanded geographically
  - More Internet Exchange Points (IXPs) means it is cheaper and easier for ASes to establish peering links

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# Model Description

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## ASes Have Interconnection Agreements

- Two types:
  - Transit agreements (provider/customer)
  - Peering agreements (bilateral exchange)
- ASes dynamically change agreements to:
  - Minimize operating expenses
  - Maximize revenue, performance, reliability
- Leads to a co-evolutionary feedback loop
  - Changes in topology, routing, and economics lead to ASes changing strategies, which further change topology, routing, and economics

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## ITER Game Simulation

- Each AS “plays” on each turn
  - Play order in a chosen sequence
    - Randomly chosen starting node
  - Adjusts connectivity subject to constraints
- Game stops at an equilibrium if one exists
  - Authors say equilibrium reflects the best the Internet could do under the given conditions

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## Acknowledged Limitations with ITER Simulation Approach

- Simulation depends on a large number of parameters
  - Produces widely different results depending on exact parameterization
    - Authors justify their choices
- Simulation is computationally expensive
  - Limits the size
- Very hard to validate results
  - Many data needed are secret

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## Simulate Both Flat Model (New) and Hierarchical (Traditional)

- Fraction of total traffic sourced by content providers
  - Higher for flat, lower for hierarchical
- Number of regions in which content providers are present
  - Higher for flat, lower for hierarchical
- Peering threshold for transit providers
  - Lower for flat, higher for hierarchical

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## AS Network Types Modeled

- Enterprise Customers (ECs)
  - Do not peer and do not have customers
- Content Providers (CPs)
  - Have no customers but do peer and are major sources of traffic
- Transit Providers (TPs)
  - Large (LTPs) and small (STPs)
  - Main business is to provide Internet connectivity to their customers

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## Traffic Model

- Content provider traffic
  - Flows from CPs to enterprise customers and transit providers
- Non-content provider traffic
  - Flows among enterprise customers and transit providers

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## Economic Model Makes Significant Assumptions

- Reasons given: lack of publicly available information and need to simplify model
  - For example:
    - Assumes a commoditzed market for transit providers
    - Assumes cost of transit service is primary factor in transit provider fitness
- Unclear if these assumptions are realistic

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## Peer Selection Policies

- Threshold-based peering
  - Peer if approximately the same amount of total traffic
- Peering by necessity
  - Peer if needed to maintain global reachability
- In flat model, peering guidelines looser
  - Leads to more peering

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## Model Initialization

- Tries to use known properties of Internet topology
- Large transit providers start fully connected with peering links
  - No other peering links at initialization
- Preferential attachment model for remaining initial connections
- Initial properties strongly influence results
  - Is preferential attachment realistic enough?

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## AS Actions in Each Move

1) Provider selection
2) Try to peer with providers
3) Check for potential peering candidates

- Assumes it is feasible to make frequent changes
  - May not take into account business realities

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## Results of Simulations: Hierarchical vs. Flat Internet

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## Results of Simulations

- Results depend heavily on initial topology and playing sequence
  - Use of assumptions in initial topology may lead to skewed results
- Authors decide significant factors in results are those that do not vary across simulator runs
  - Within each category of simulation (flat vs. hierarchical), some "Macroscopic Metrics" remained consistent
    - Examples follow

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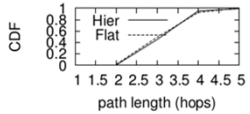
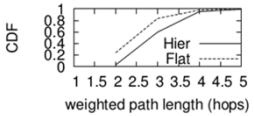
## Path Length (Hops)

- Unweighted length similar for flat and hierarchical
- Weighted length:
  - Fraction of traffic over paths with at most that length
  - Peering links between content providers and transit providers reduce weighted length in flat

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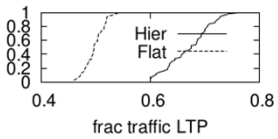
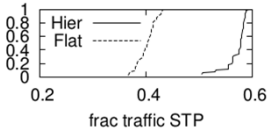
## Fraction of Traffic Transiting Large and Small Transit Providers

- For both, flat reduces percent of traffic that transits at least one of that type of provider
- In flat, more peering leads to avoiding providers
- Reduces revenue and fitness of providers

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## Fraction of Traffic through Unprofitable Providers

- Greater in flat than hierarchical
- Authors speculate this might lead to mergers, bankruptcies, and eventual consolidation of transit provider market
- Is authors' view realistic? Will providers change strategies (in ways not reflected by the model) if heading towards unprofitability?
  - Unclear how such changes would affect the validity of the rest of the model

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## Conclusions

- Changes in the three factors studied can change the Internet from tiered hierarchy to mesh of horizontal interconnections
  - Fraction of total traffic sourced by content providers
  - Number of regions in which content providers are present
  - Peering threshold for transit providers

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