ITER:
A Computational Model to Evaluate Provider and Peer Selection in the Internet Ecosystem

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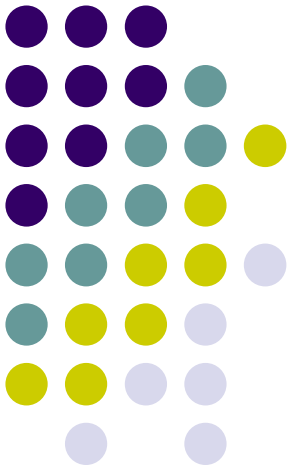
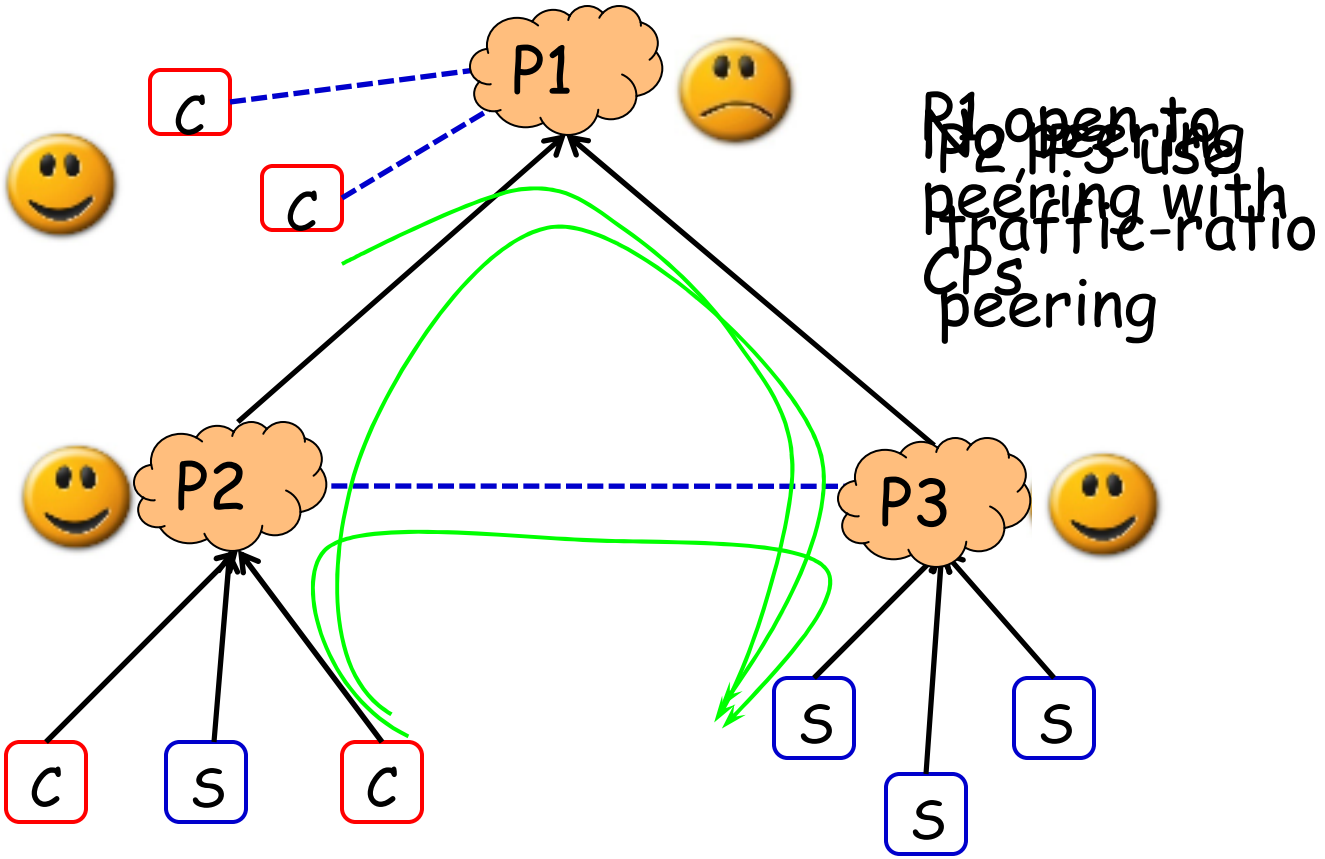
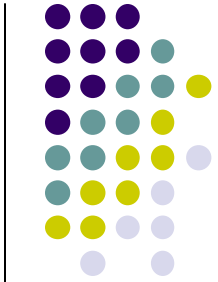


Provider/peer selection strategies

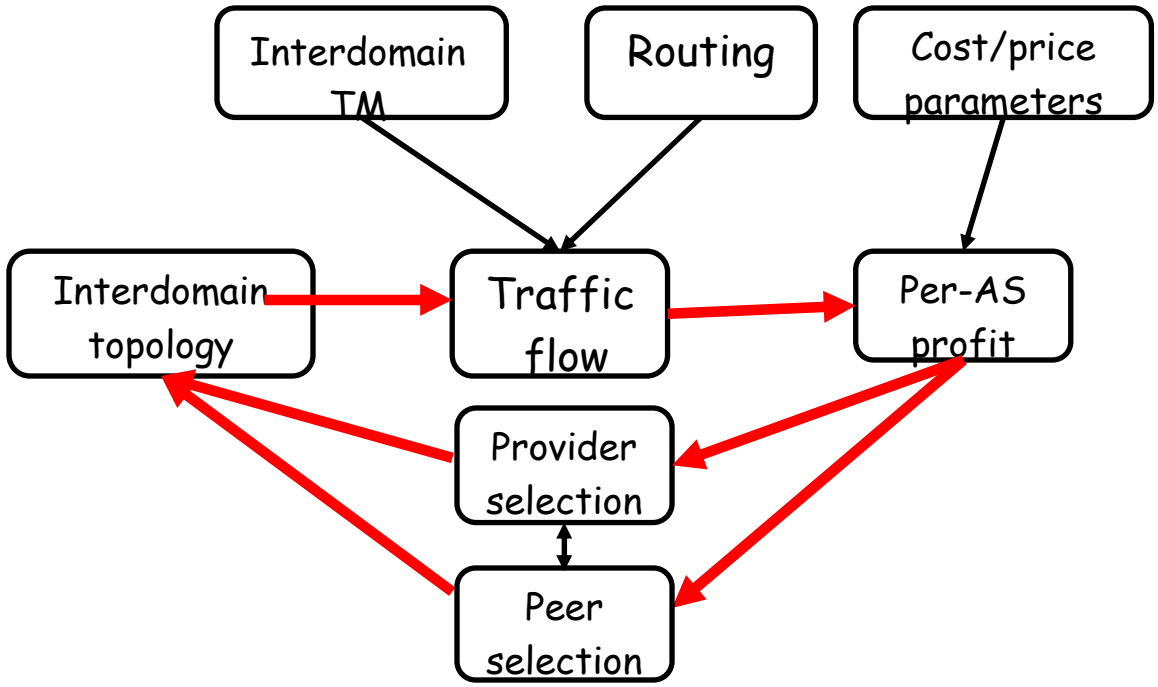


High-level questions in this research



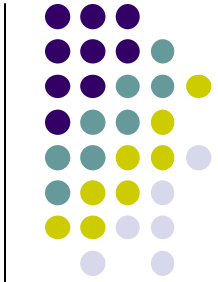
- Networks rewire their connectivity (select providers and peers) to optimize an objective function (typically profit)
  - Distributed
  - Localized spatially and temporally
- What are the local implications of provider and peer selection strategies for the involved ASes?
- What are the global, long-term effects of these distributed optimizations for the whole Internet?
  - Topology and traffic flow
  - Economics
  - Performance (path lengths)

Our model of interdomain network formation (ITER)



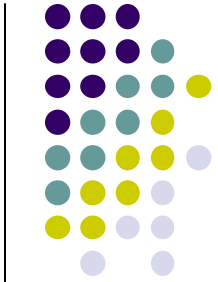
- Compute the "attractors" of this dynamical system
  - Point attractor: When no network has the incentive to change its connectivity
  - Limit cycles: an oscillation between a number of network topologies

Approach



- What is the outcome when networks use certain provider and peer selection strategies?
- Model the Internet ecosystem as a dynamic system
  - Real-world economics of transit, peering, operational costs
  - Realistic routing policies
  - Geographical constraints
  - Provider and peer selection strategies
- Compute attractors
  - Point attractors or limit cycles
- Measure properties of the steady-state
  - Topology, traffic flow, economics

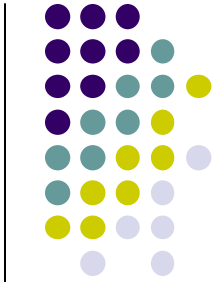
Network Types



- Enterprise Customers (EC)
  - Stub networks at the edge (e.g. Georgia Tech)
  - Either sources or sinks
- Small Transit Providers (STP)
  - Provide Internet transit
  - Mostly regional in presence (e.g. France Telecom)
- Large Transit Providers (LTP)
  - Transit providers with global presence (e.g. AT&T)
- Content Providers (CP)
  - Major sources of content (e.g. Google)

Provider and peer selection for STPs and LTPs

What would happen if..?

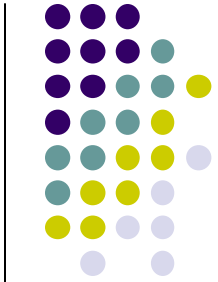


- The traffic matrix consists of mostly P2P traffic?
- P2P traffic benefits STPs, can make LTPs unprofitable

- LTPs peer with content providers?
- LTPs could harm STP profitability, at the expense of longer end-to-end paths

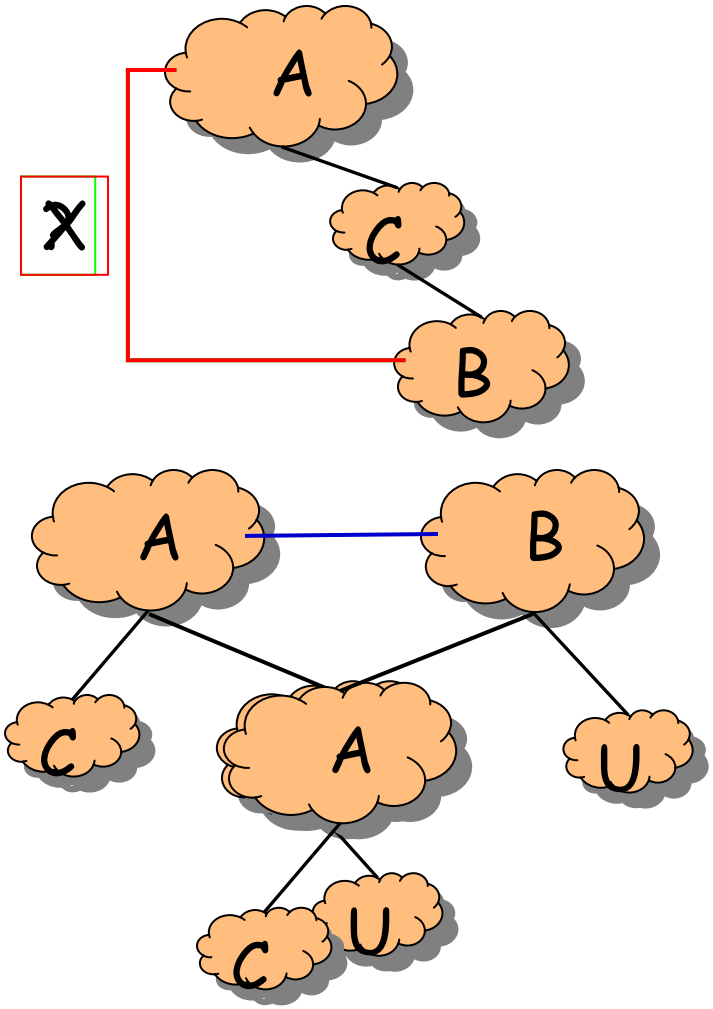
- Edge networks choose providers using path lengths?
- LTPs would be profitable and end-to-end paths shorter

Provider and Peer Selection



- Provider selection strategies
  - Minimize monetary cost (PR)
  - Minimize AS path lengths weighted by traffic (PF)
  - Avoid selecting competitors as providers (SEL)
- Peer selection strategies
  - Peer only if necessary to maintain reachability (NC)
  - Peer if traffic ratios are balanced (TR)
  - Peer by cost-benefit analysis (CB)
- Peer and provider selection are related

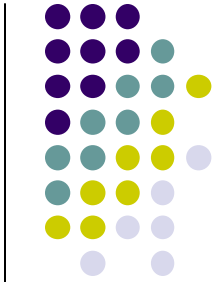
Provider and Peer Selection are Related



- Restrictive peering

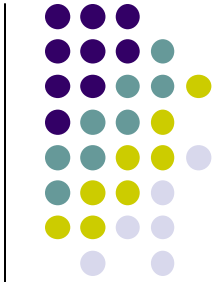
- Peering by necessity
- Level3-Cogent peering dispute

Economics, Routing and Traffic Matrix



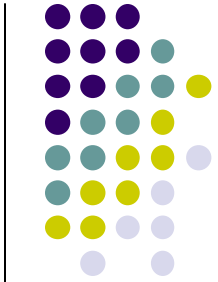
- Realistic transit, peering and operational costs
  - Transit prices based on data from Norton
  - Economies of scale
- BGP-like routing policies
  - No-valley, prefer customer, prefer peer routing policy
- Traffic matrix
  - Heavy-tailed content popularity and consumption by sinks
  - Predominantly client-server: Traffic from CPs to ECs
  - Predominantly peer-to-peer: Traffic between ECs

Algorithm for network actions



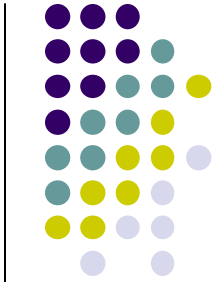
- Networks perform their actions sequentially
- Can observe the actions of previous networks
  - And the effects of those actions
- Network actions in each move
  - Pick set of preferred providers
  - Attempt to convert provider links to peering links "due to necessity"
  - Evaluate each existing peering link
  - Evaluate new peering links
- Networks make at most one change to their set of peers in a single move

Solving the Model



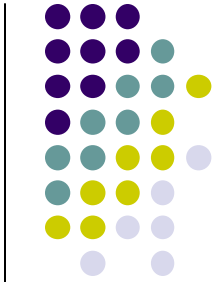
- Determine the outcome as each network selects providers and peers according to its strategy
- Too complex to solve analytically: Solve computationally
- Typical computation
  - Proceeds iteratively, networks act in a predefined sequence
  - Pick next node n to "play" its possible moves
  - Compute routing, traffic flow, AS fitness
  - Repeat until no player has incentive to move (point attractor)
    - Or until we have detected a limit cycle

Properties of the steady-state



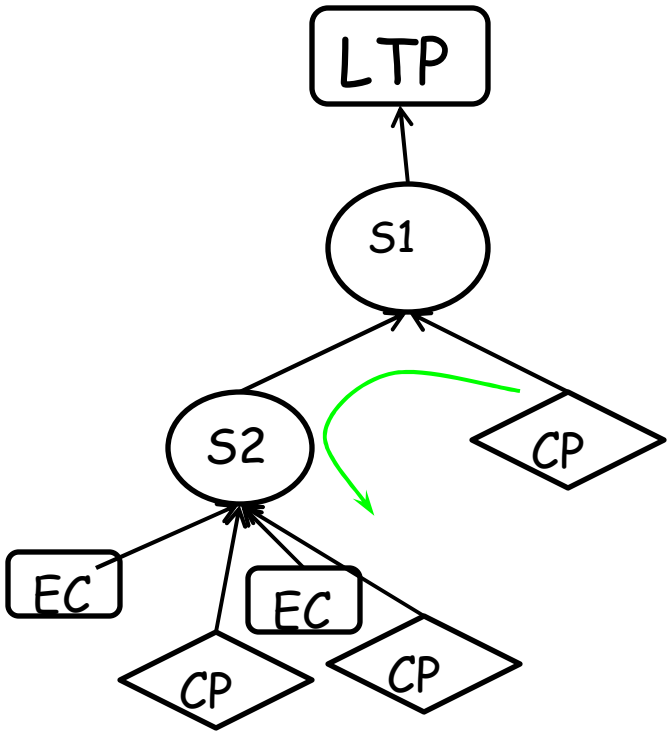
- Do we always reach a point attractor?
  - Yes, in most cases (but see paper for some cases of limit cycles)
- Is point attractor unique?
  - No, it can depend on playing sequence and initial conditions
  - But, different attractors have statistically similar properties
- Multiple runs with different playing sequences
  - Average over different runs
  - Confidence intervals are narrow

Canonical Model



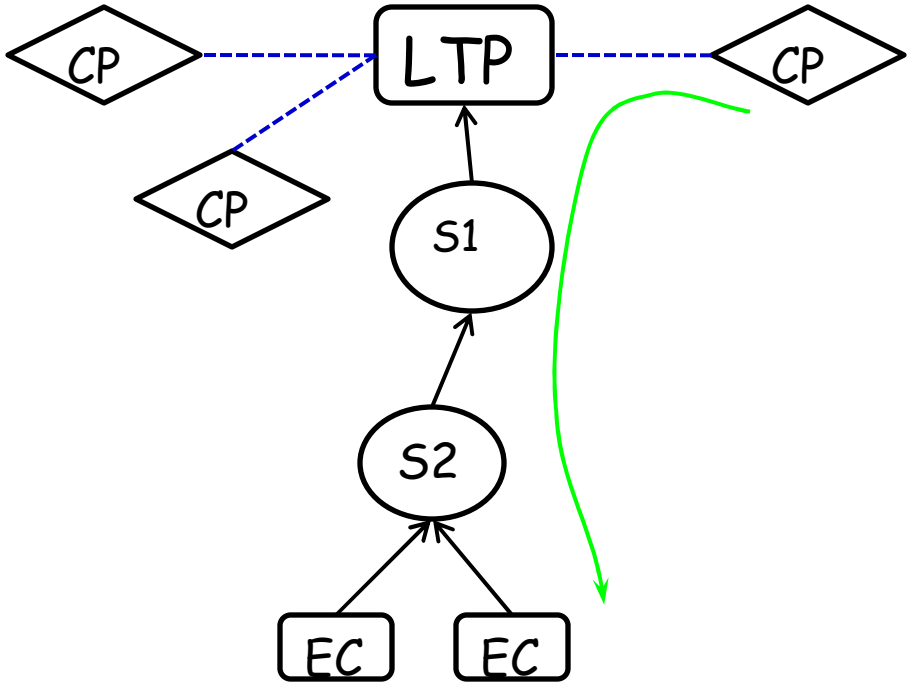
- Parameterization of the model that resembles real world
- Traffic matrix is predominantly client-server (80%)
  - Impact of streaming video, centralized file sharing services
- 20% of ECs are content sources, 80% sinks
- Heavy tailed popularity of traffic sources
- Edge networks choose providers based on price
- 5 geographical regions
- STPs cheaper than LTPs

Results – Canonical Model



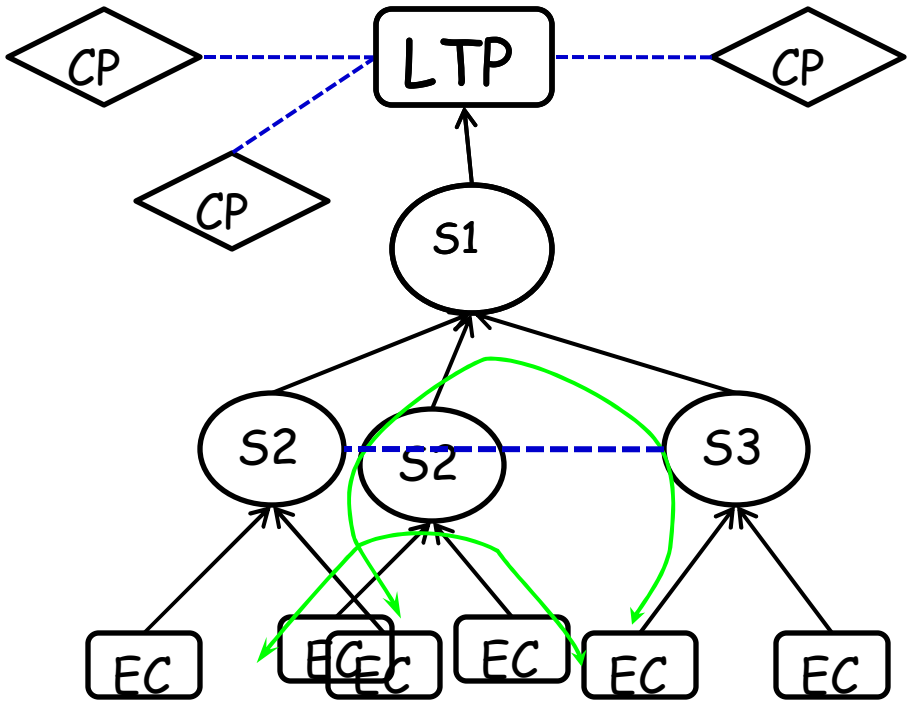
- Hierarchy of STPs
- Traffic can bypass LTPs – LTPs unprofitable
- STPs should not peer with CPs
  - CPs choose STPs as providers

Results – Canonical Model



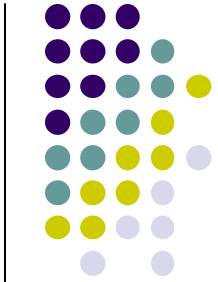
- What-if: LTPs peer with CPs
- Generate revenue from downstream traffic
- Can harm STP fitness
- Long paths

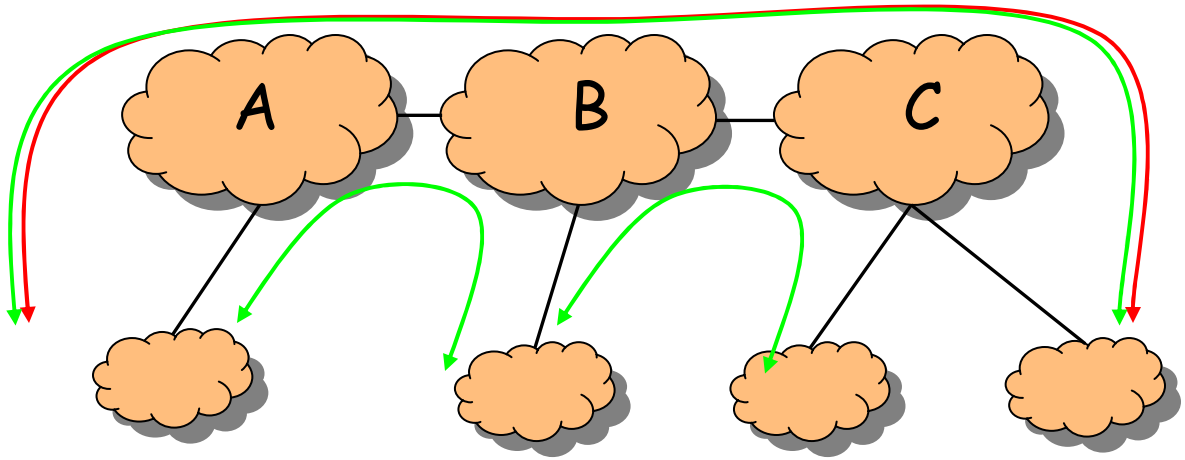
Deviation 1: P2P Traffic matrix



- P2P traffic helps STPs
- Smaller traffic volume from CPs to Ecs
- More EC-EC traffic => balanced traffic ratios
- More opportunities for STPs to peer

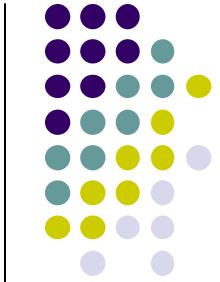
Peering Federation





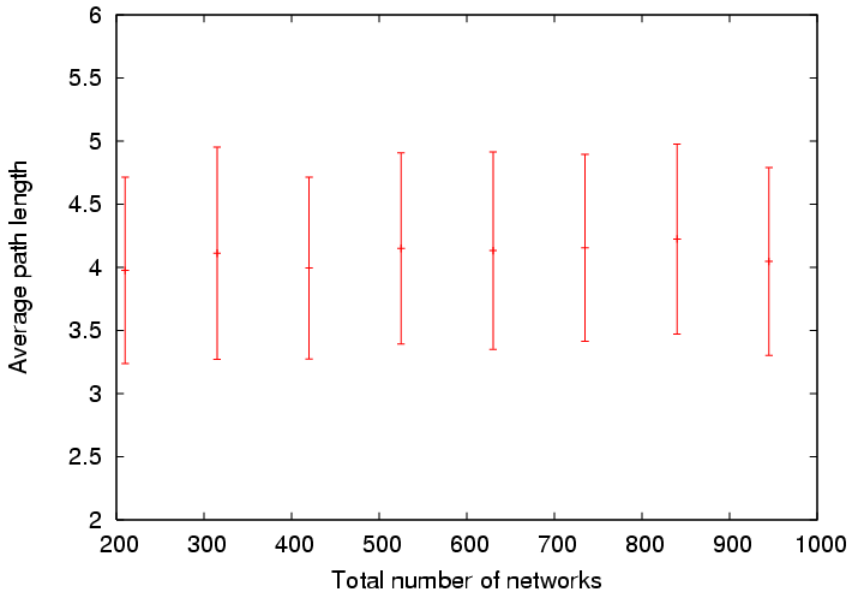
- Traditional peering links: Not transitive
- Peering federation of A, B, C: Allows mutual transit
  - Longer chain of "free" traffic
- Incentives to join peering federation?
- What happens to tier-1 providers if smaller providers form federations?

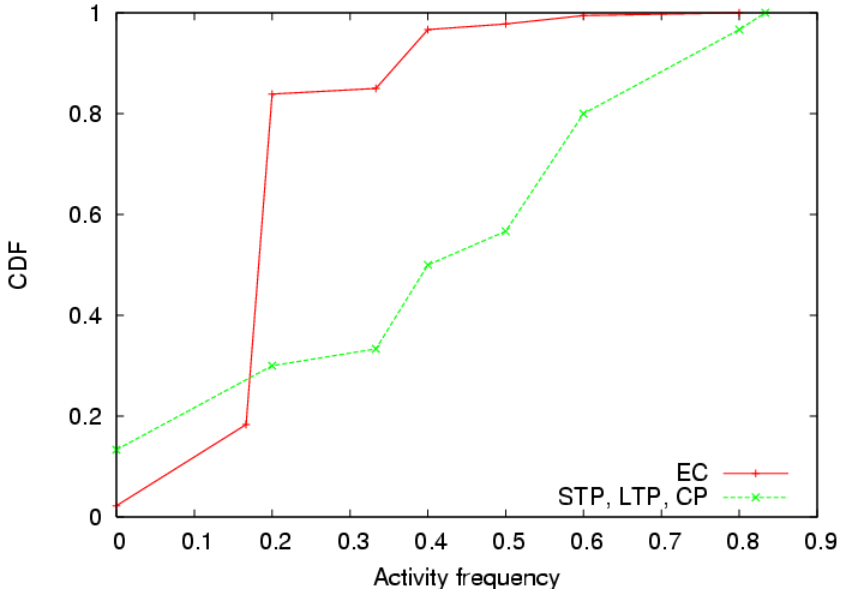
Conclusions



- A model that captures the feedback loop between topology, traffic and fitness in the Internet
- Considers effects of
  - Economics
  - Geography
  - Heterogeneity in network types
- Predict the effects of provider and peer selection strategies
  - Topology, traffic flow, economics, and performance

Model Validation





- Reproduces almost constant average path length
- Activity frequency: How often do networks change their connectivity?
  - ECs less active than providers – Qualitatively similar to measurement results

Previous Work

- Static graph properties
  - No focus on how the graph evolves
- "Descriptive" modeling
  - Match graph properties e.g. degree distribution
- Homogeneity
  - Nodes and links all the same
- Game theoretic, computational
  - Restrictive assumptions

- Dynamics of the evolving graph
  - Birth/death
  - Rewiring
- "Bottom-up"
  - Model the actions of individual networks
- Heterogeneity
  - Networks with different incentives
  - Semantics of interdomain links