Towards a Next-Generation Inter-domain Routing Protocol

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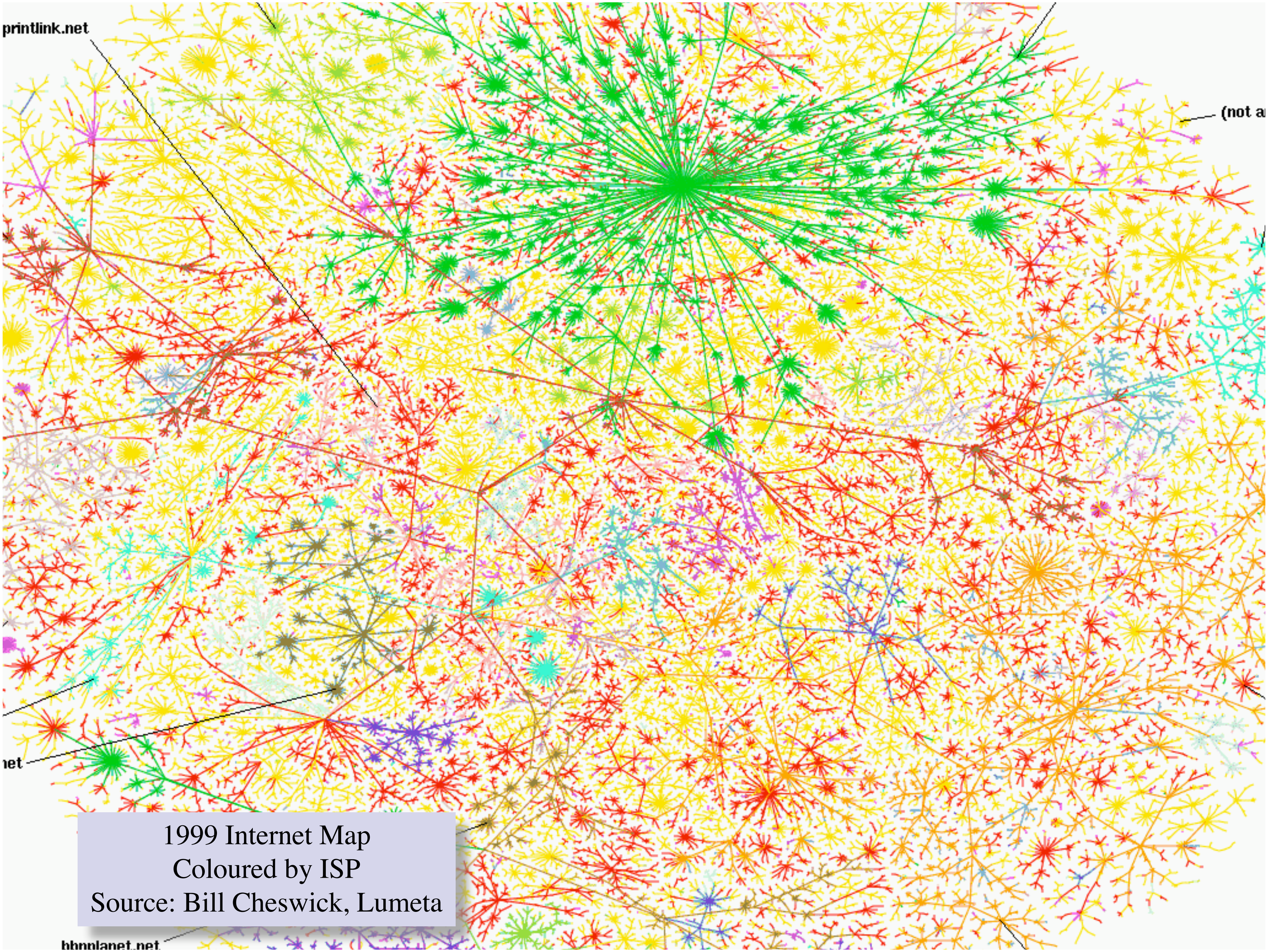
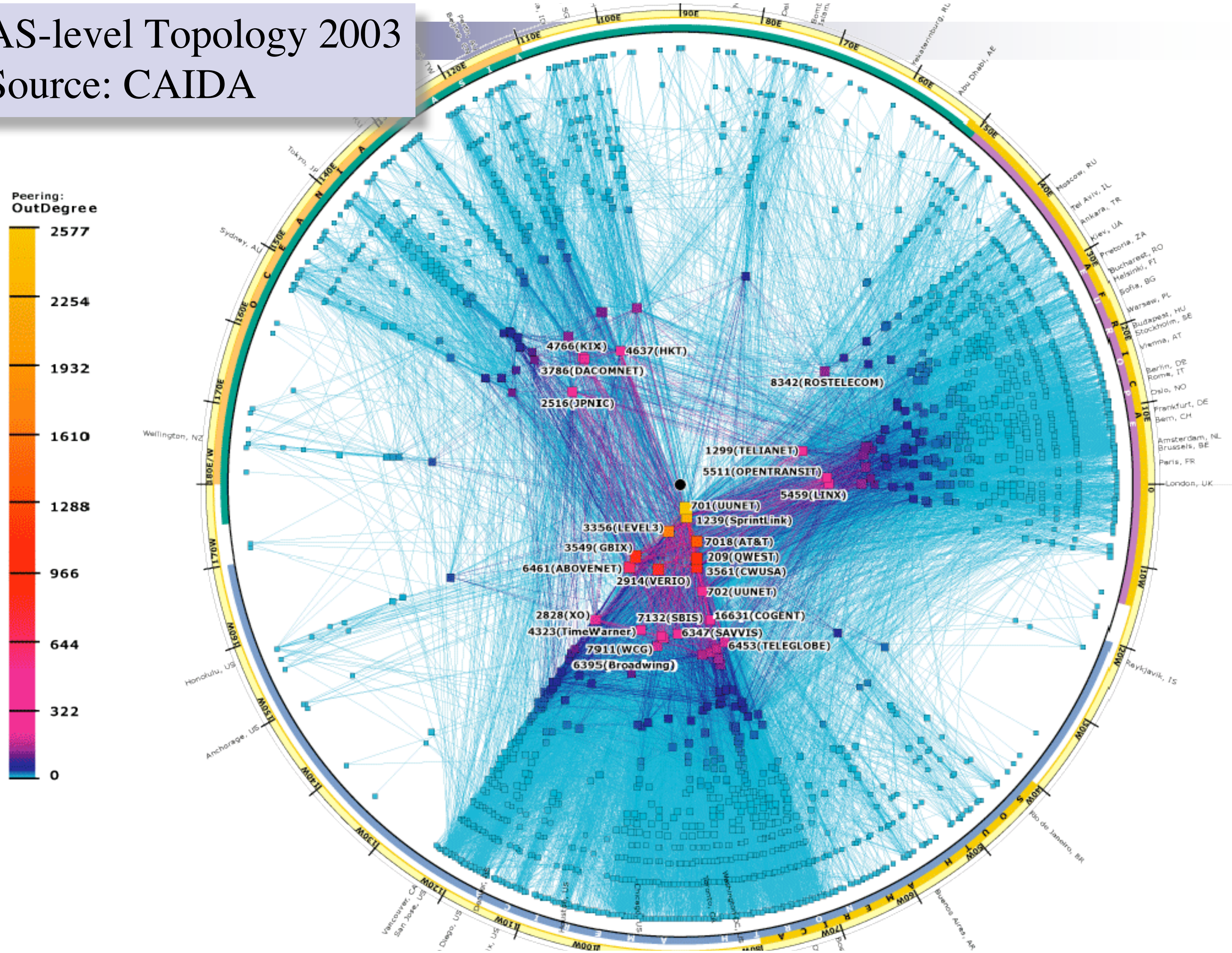
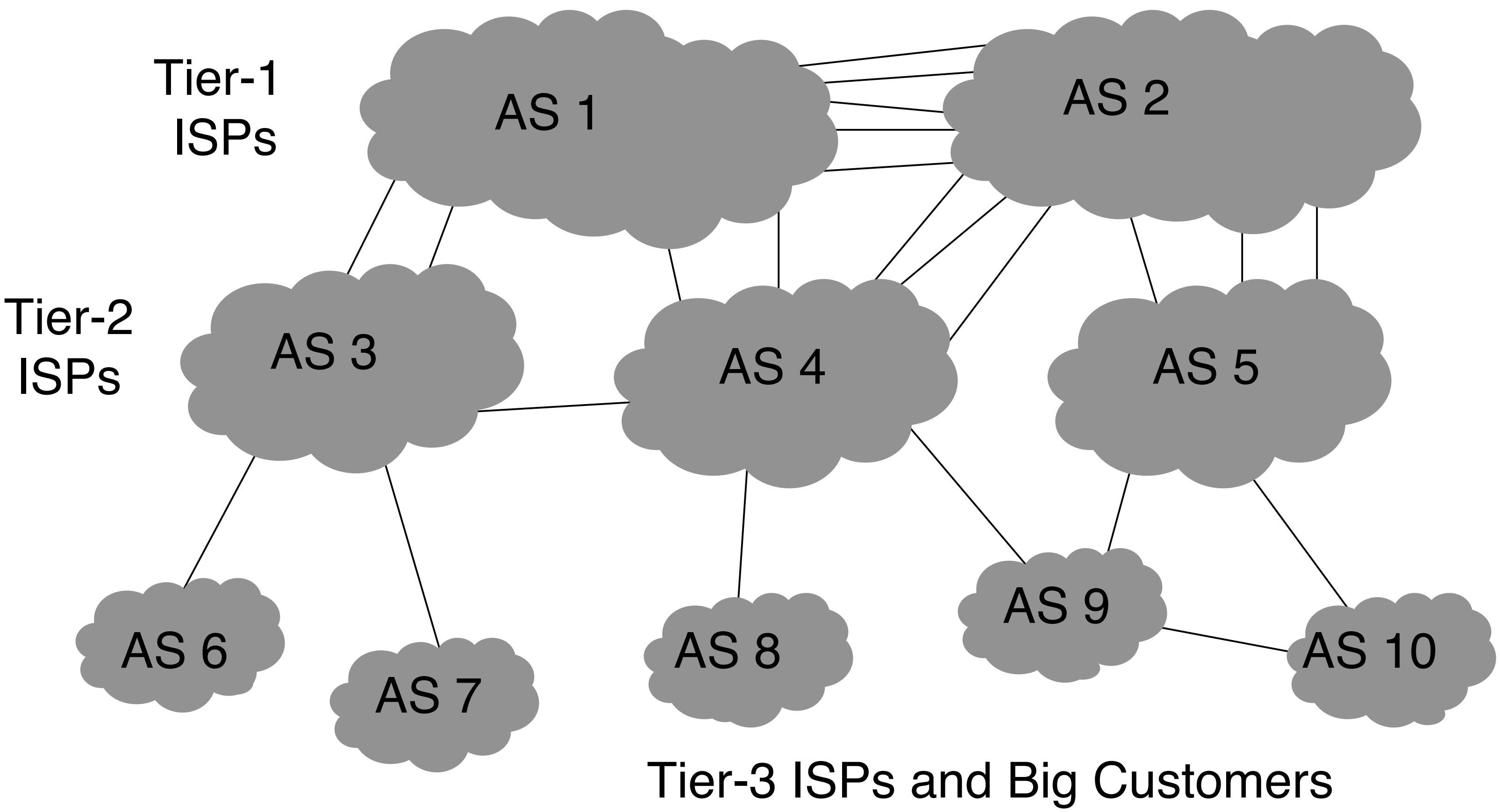


1999 Internet Map
Coloured by ISP
Source: Bill Cheswick, Lumeta

AS-level Topology 2003
Source: CAIDA



Inter-domain Routing



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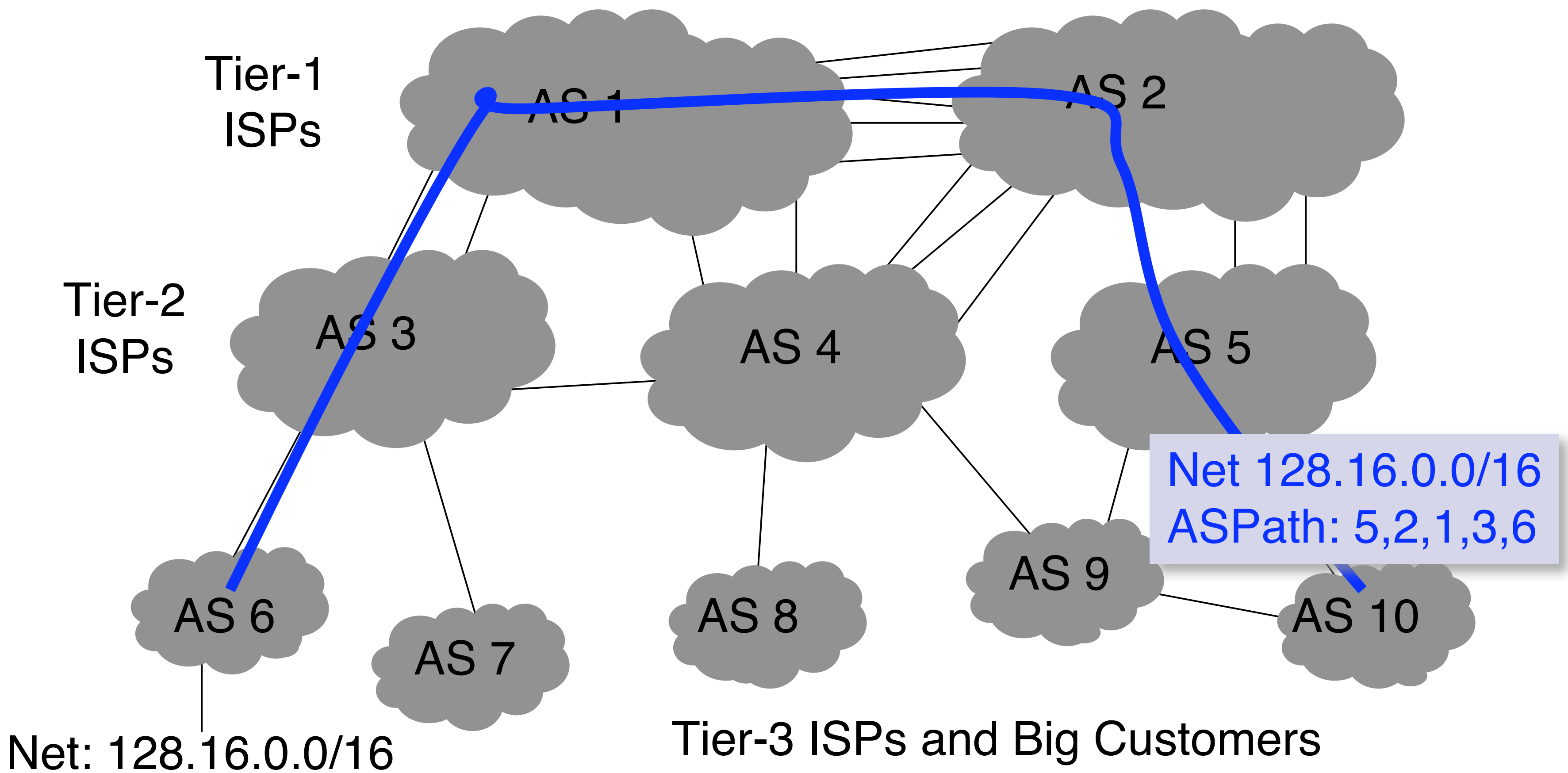

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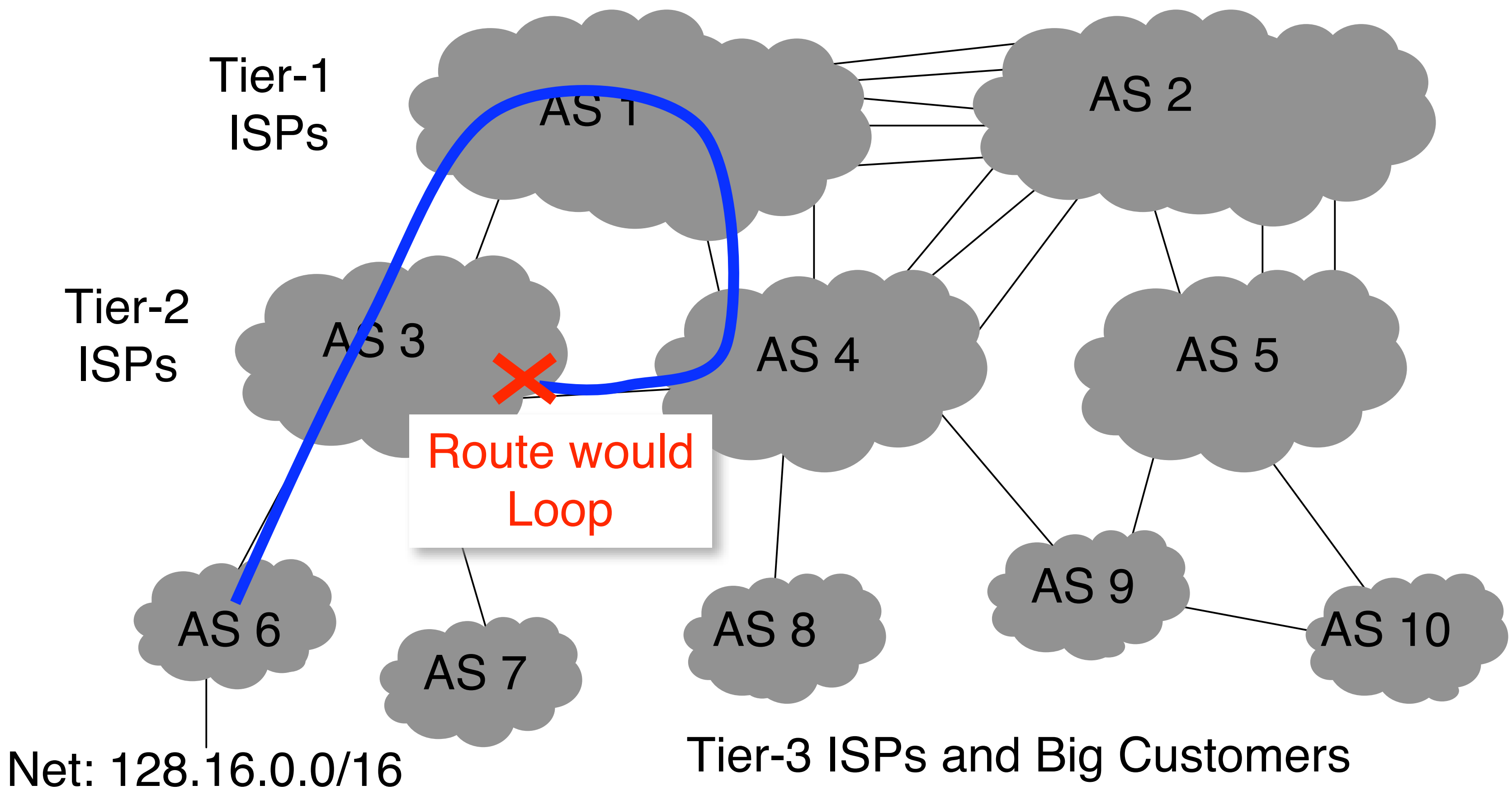

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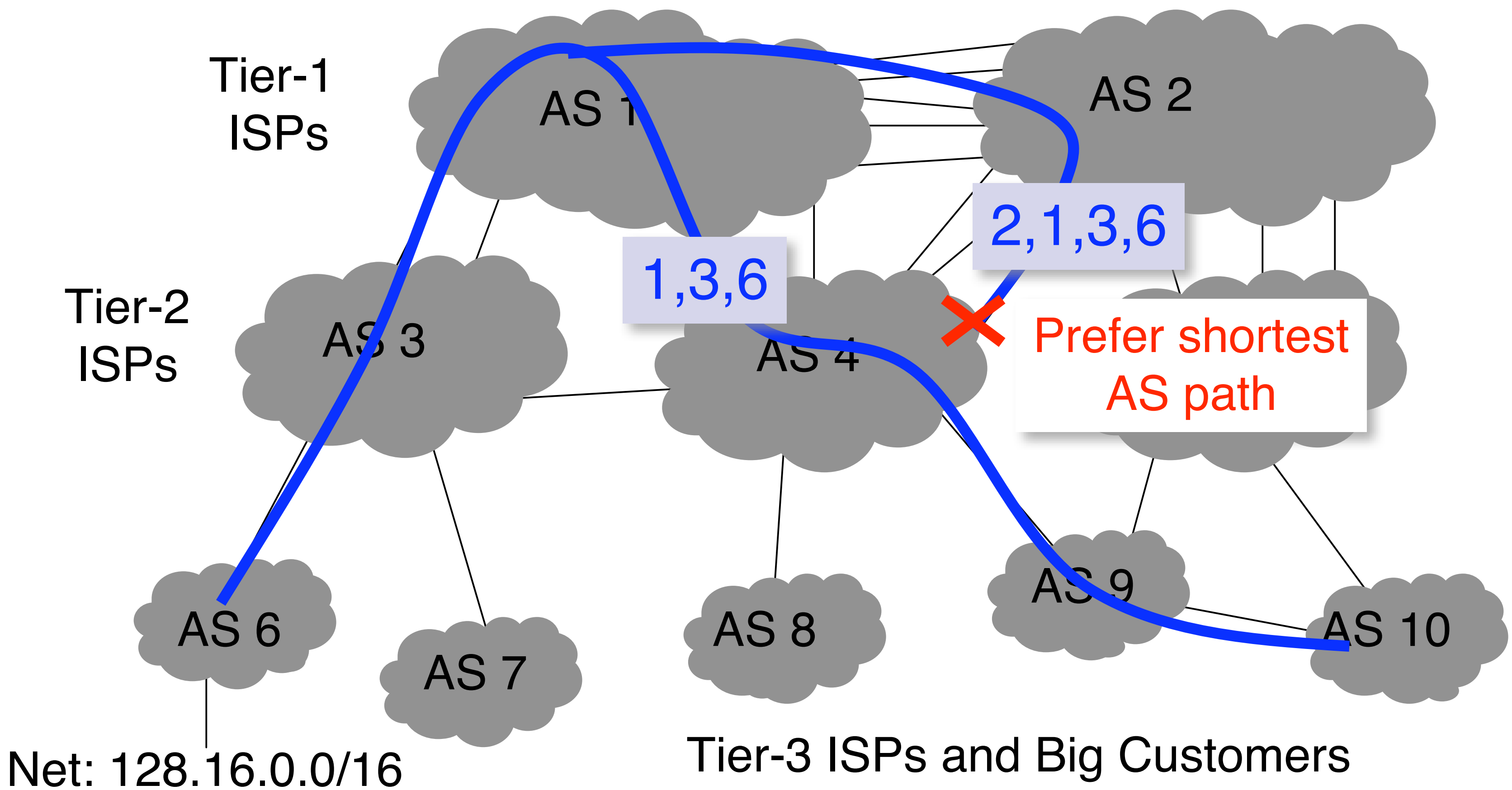
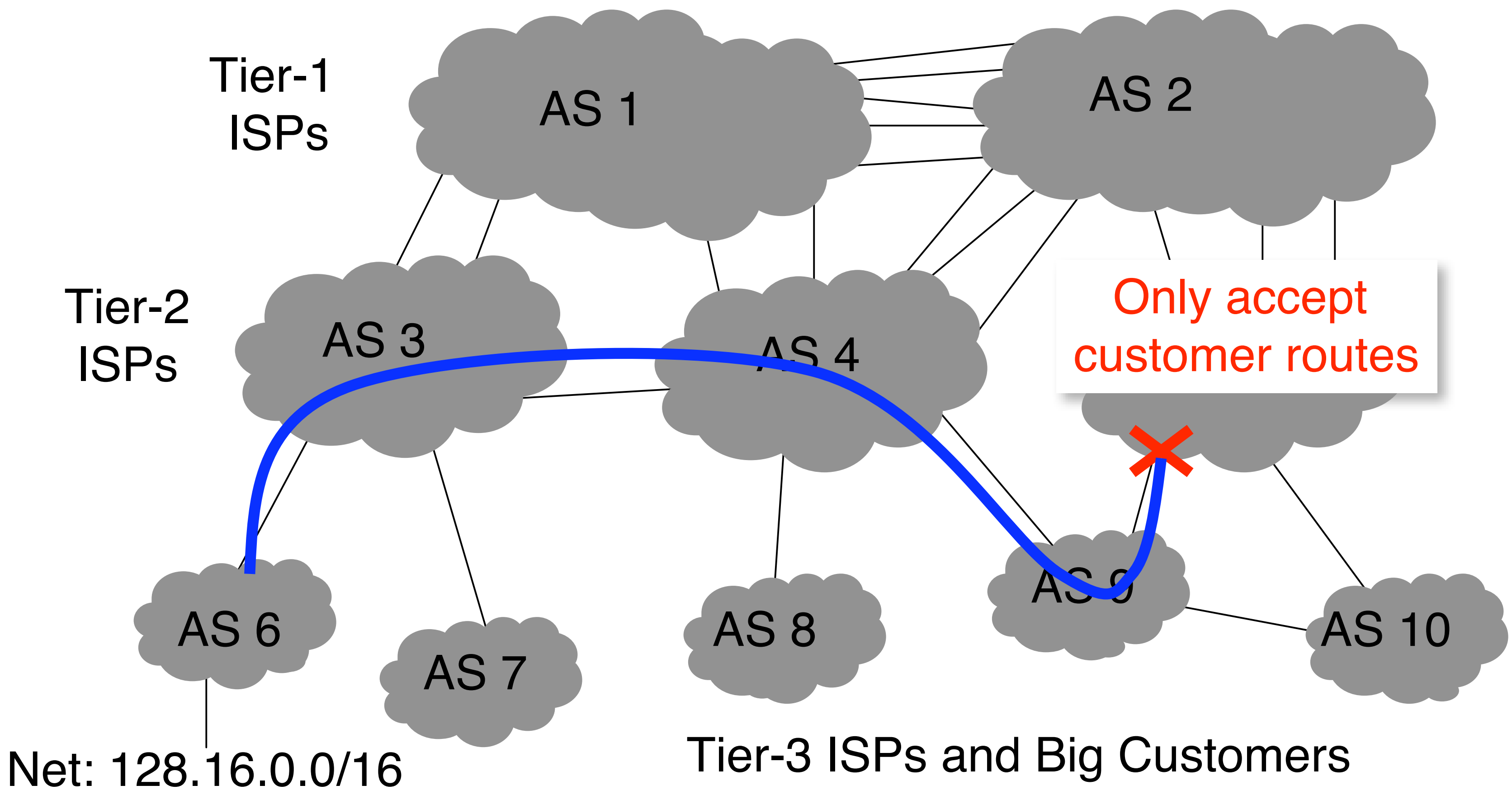


Inter-domain Routing Policy



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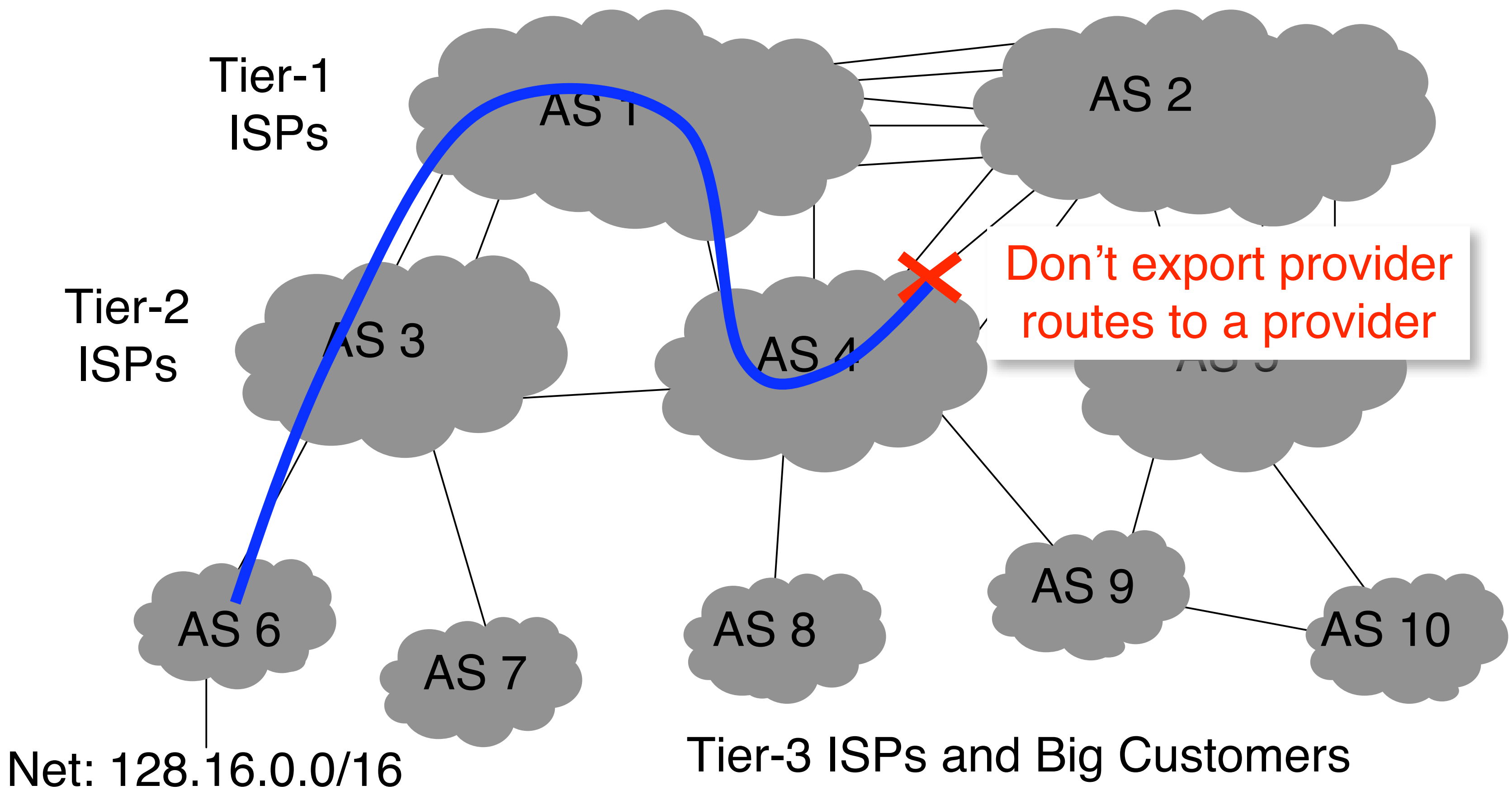

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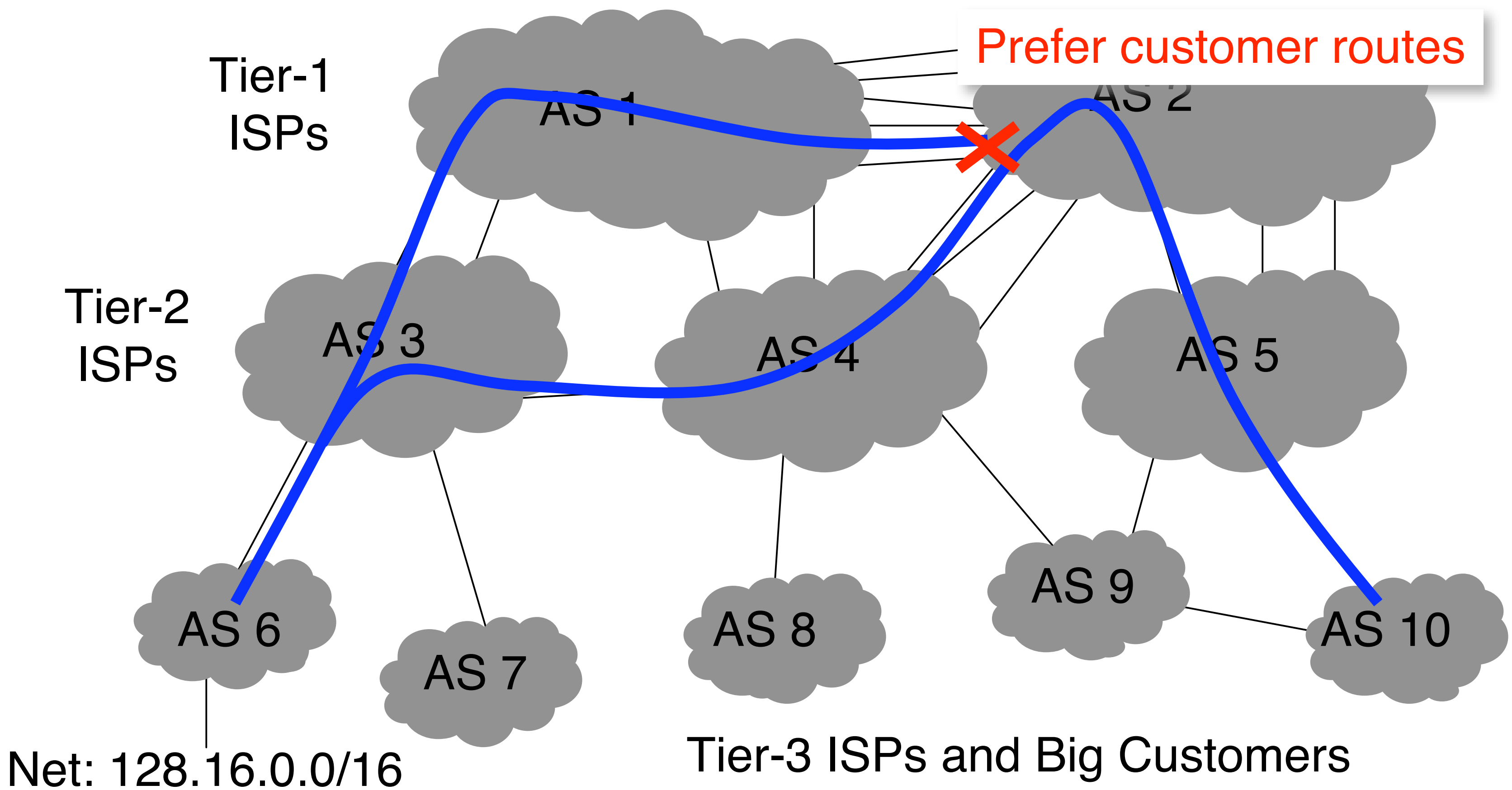


Inter-domain Routing

BGP4 is the only inter-domain routing protocol currently in use world-wide.

- Lack of security.
- Ease of misconfiguration.
- Policy through local filtering.
- Poorly understood interaction between local policies.
- Poor convergence.
- Lack of appropriate information hiding.
- Non-determinism.
- Poor overload behaviour.

What problem does BGP attempt to solve?

- *Global interconnectivity* between Internet providers.
- *Dynamic routing* in the presence of failure.
  - An approximation to *shortest-path* routing.
  - Subject to *local policy* constraints of each ISP.

Policy, policy, and policy

- An ISP’s routing policy is a commercial secret.
  - Don’t want to tell *anyone* else what the policy is.
  - BGP does policy entirely through local filtering of the set of possible alternative routes.

- Need path information to set a useful range of policies.
  - But path information inherently reveals information about routing adjacencies.
  - Can trivially infer many (most?) simple policies from looking at the routing tables.

Local Filtering

Doing policy entirely through local filtering is the root cause of many of BGP's problems.

- Low-level mechanism for configuring what not to accept is prone to misconfiguration.
- No semantics in the protocol as to why a route is used make it hard to discover errors or attacks.
- No information about alternative routes means BGP must to a lengthy path exploration to figure out which alternatives are feasible.
- No information about which alternatives will work for whom means BGP can't do effective information hiding.
  - Small changes in one part of the world are frequently globally visible.

Policy Hiding

- It’s not practical to hide most customer/provider routing relationships when using BGP.
  - Customer pays provider to advertise their route to the rest of the world.
- It is practical to hide many private peering relationships.

- Perhaps 95% of the “peerings” visible in route-views and RIPE appear to function as customer/provider links.
  - Note that the flow of money and whether a peering effectively functions as a customer/provider link are not necessarily correlated or revealed by the routing protocols.

Towards a Routing Framework

- Given that:
  - Most links function as customer/provider.
  - Customer/provider links are inherently visible to the world.
  - Additional semantics visible in the routing protocol would allow more informed route calculation, and permit better information hiding.
- Then it seems logical to design a routing protocol that uses this information explicitly.

IP Address Space

- The IP address space is a mess.
  - At best, a poor relationship between topology and address prefixes.
  - Many prefixes per AS.

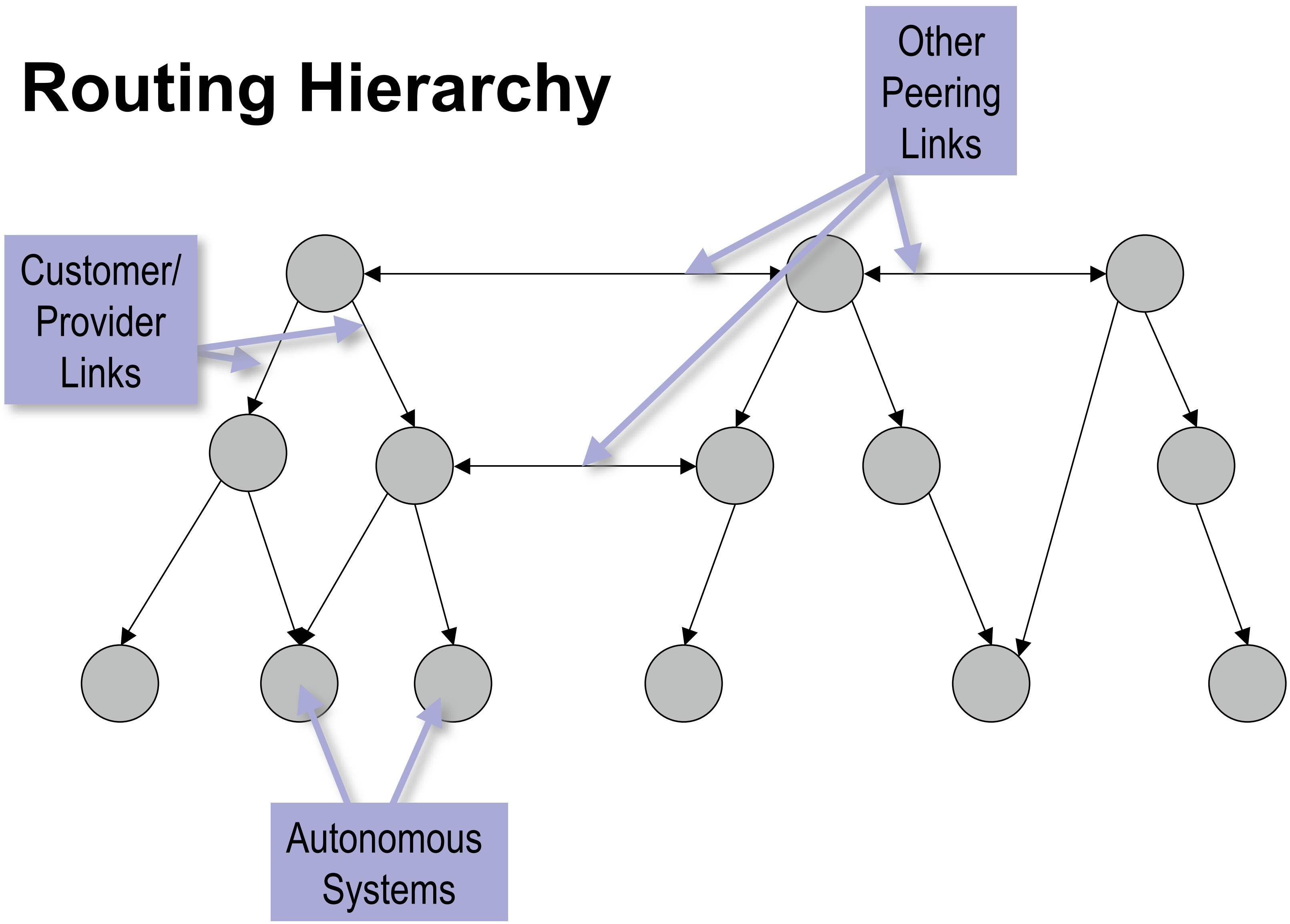
- Binding between address prefixes and organizations is pretty stable.
  - Routes to a prefix change much more rapidly though due to failure or reconfiguration upstream.

Towards a Routing Framework (2)

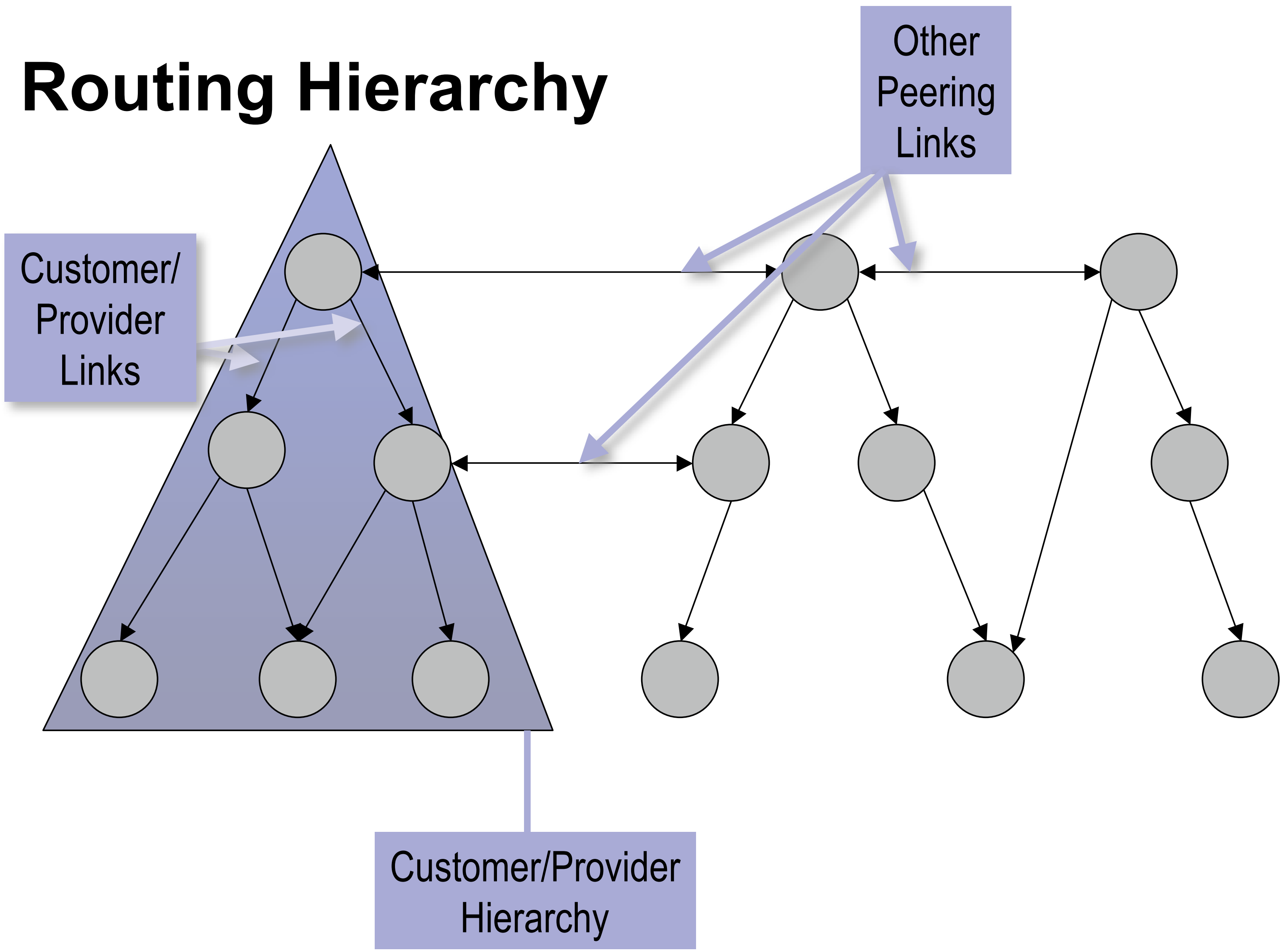
Separate dynamic routing from address prefix binding.

- Use one protocol to distribute bindings between an address prefix and an origin AS.
  - Relatively static binding.
  - Can use strong crypto and offline computation to secure this binding.
- Use another protocol to dynamically calculate paths to origin ASes.
  - Dynamic calculation, needs fast reconvergence.
  - Different security mechanisms are appropriate.

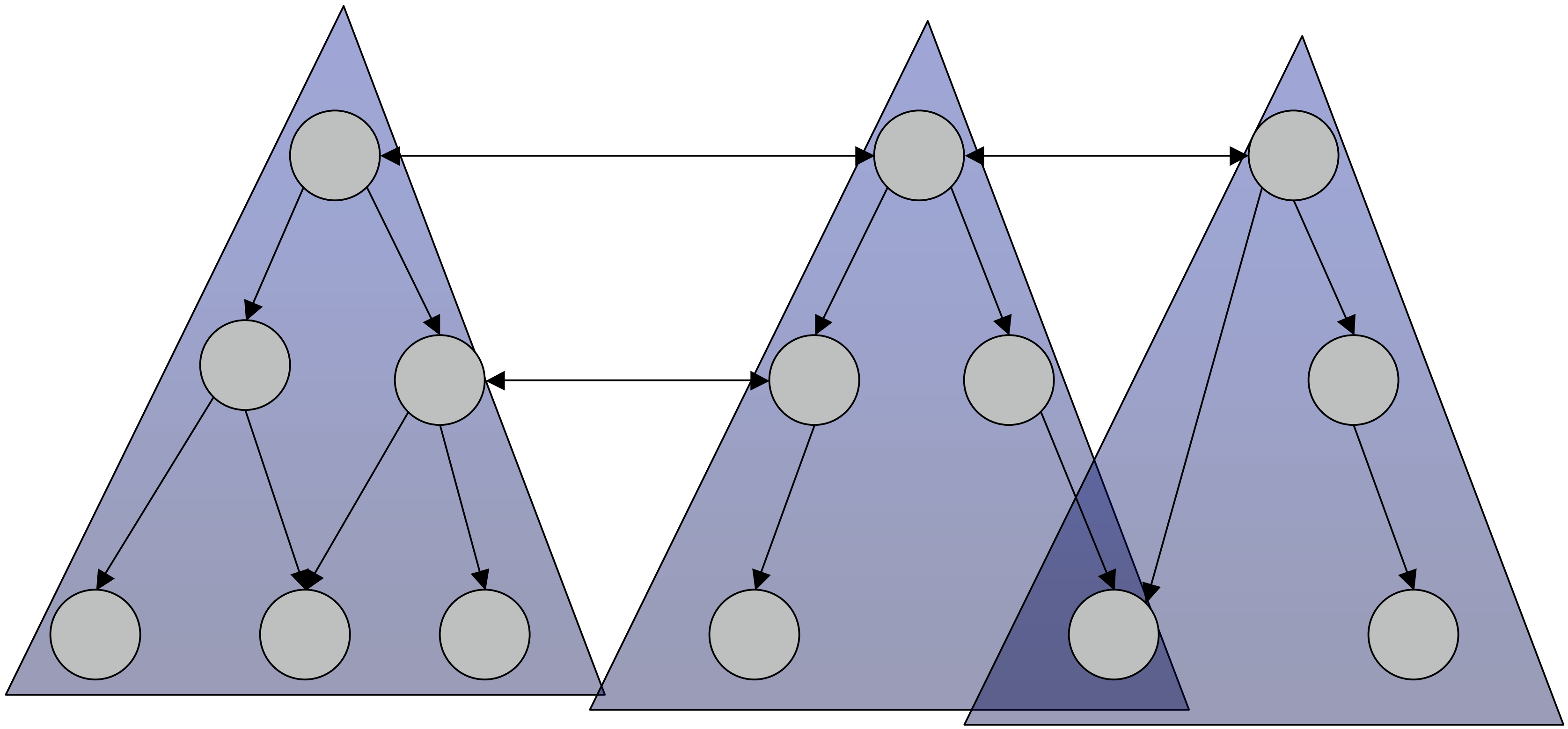
Routing Hierarchy



Routing Hierarchy



Multiple Routing Hierarchies

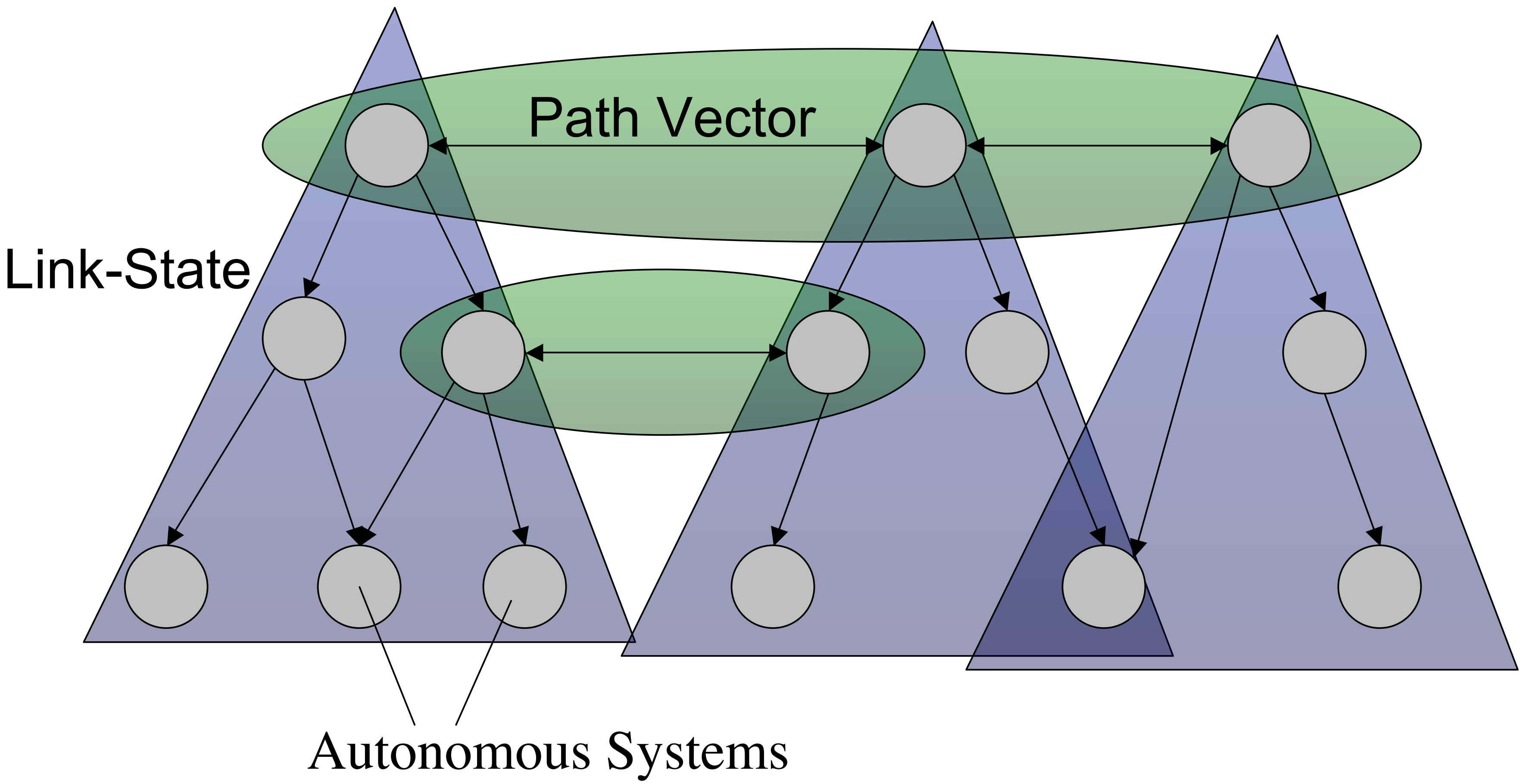


- There is more information available within a routing hierarchy than there is between them.
  - Different routing algorithms may be appropriate.

Routing Protocol Styles

- Link-state:
  - Great convergence properties.
  - Scales fairly well.
  - Can't easily hide policy information.
- Path-vector:
  - Poor convergence properties.
  - Scales well.
  - Can hide policy information and implement today's routing policies.

Hybrid Link-State/Path Vector (HLP)



Hybrid Link-State/Path Vector (HLP)

Within Customer-Provider link-state tree:

- Good convergence.
- More information.
  - Eg. alternative route pre-computation.
  - Explicit representation of backup link for multihoming.
- Default policy is simple (reduces misconfiguration errors) and robust.
- Improved default security.
  - Need to be a tier-1 to do much damage.

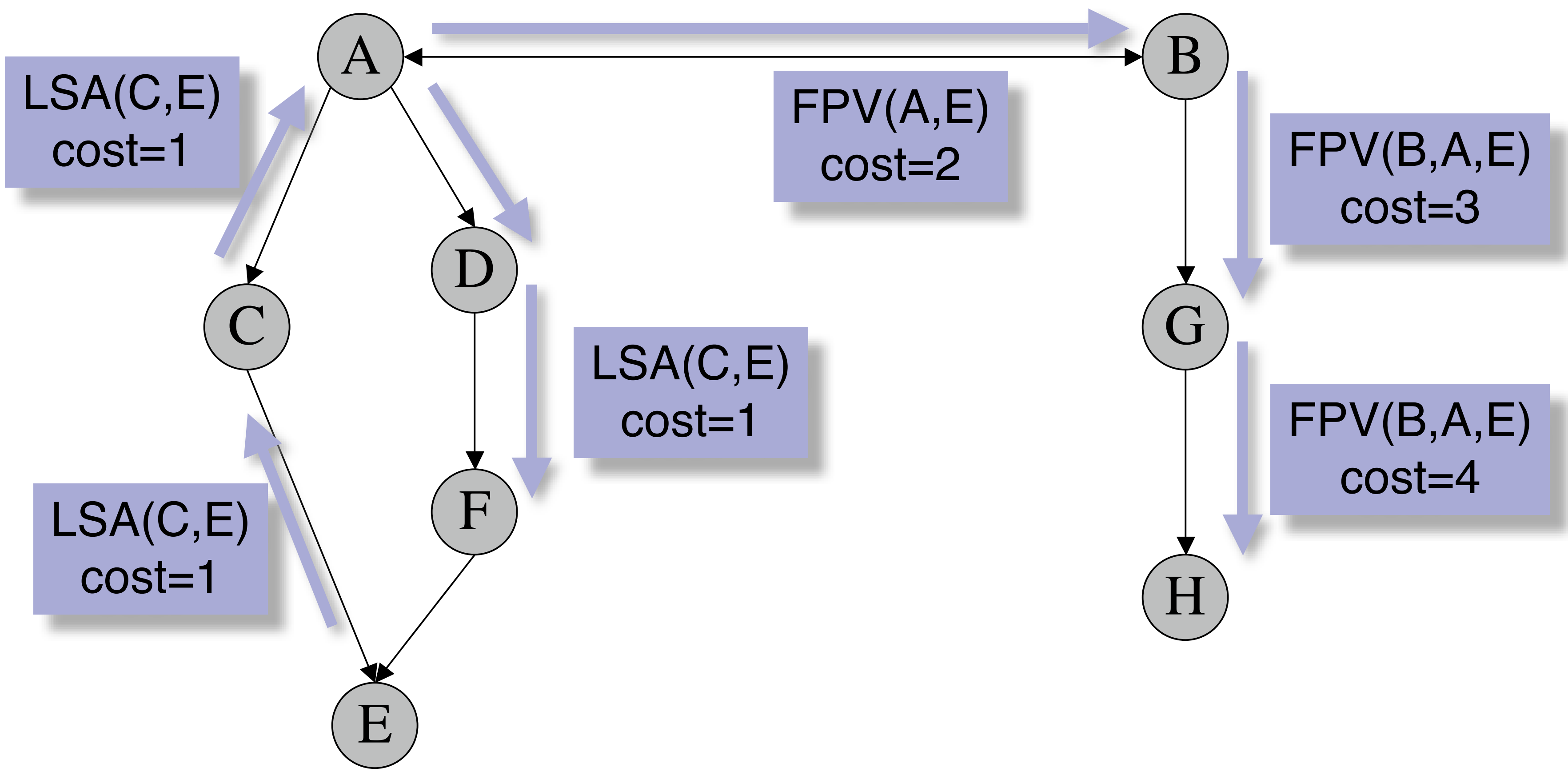
Hybrid Link-State/Path Vector (HLP)

Between Customer-Provider trees:

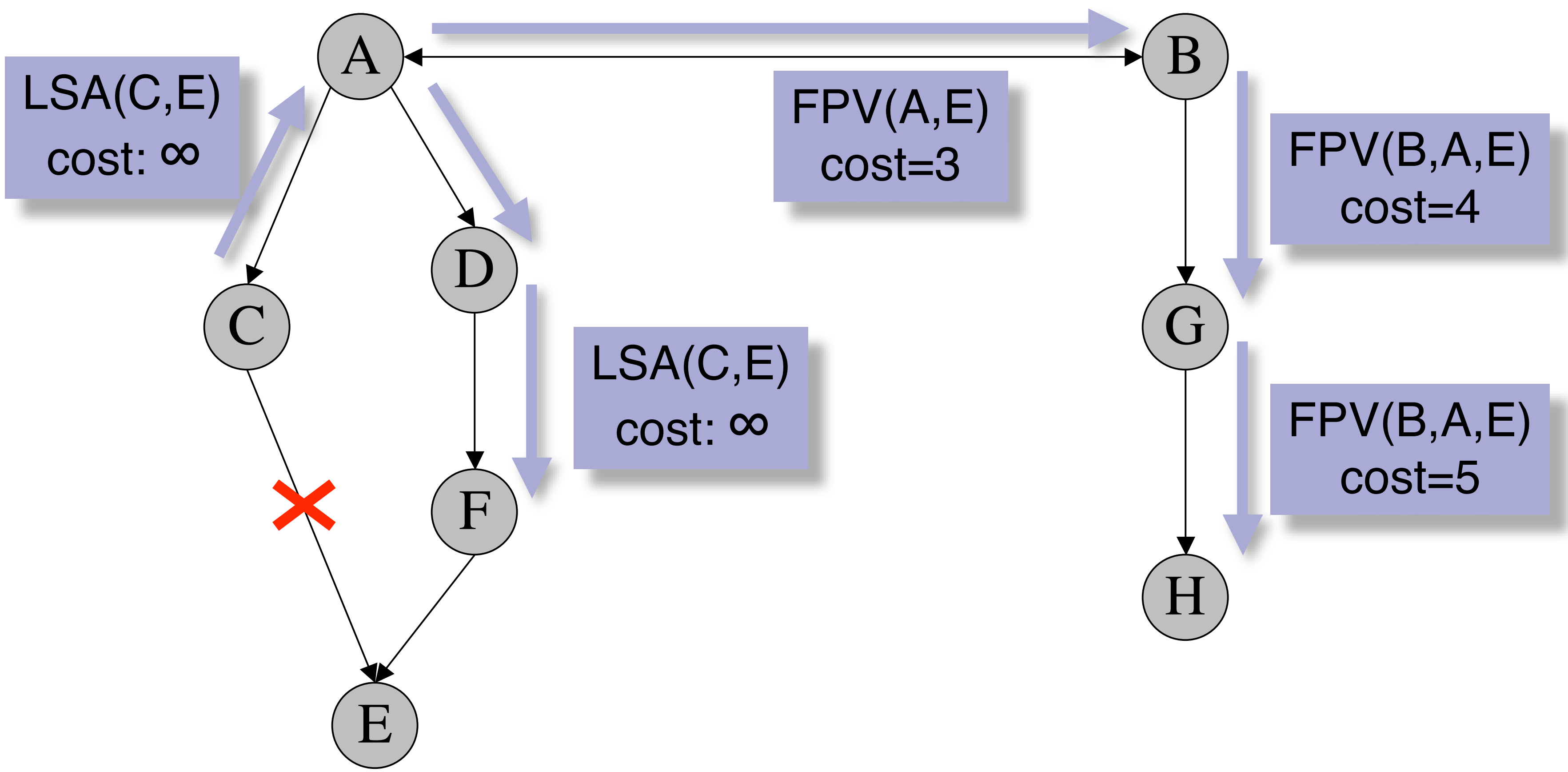
- Use fragmented path-vector (FPV), rather than full path-vector used by BGP.
  - Number of links routed using FPV decreased drastically.
  - Reduces path-exploration space.

- Degrade gracefully from link-state towards path-vector if ISPs need to use more non-default policies.
  - Worst case looks pretty much like BGP.

Routing Messages



Route Change



Hybrid Link-State/Path Vector (HLP)

Isolation and Information Hiding.

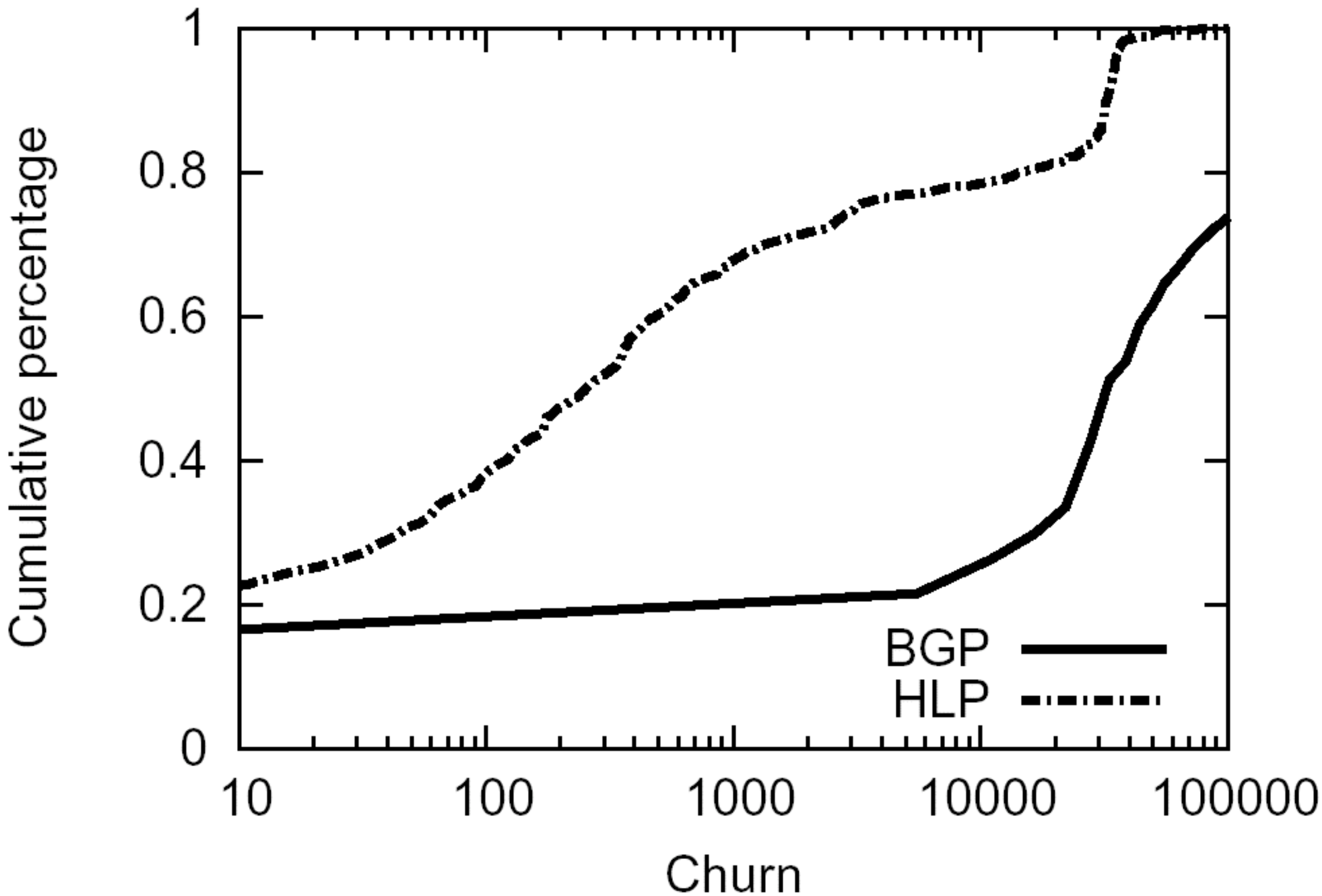
- Lots of information within a Customer-Provider tree.
- Don’t need to convey all changes into FPV.
  - Local changes that aren’t too critical can be hidden from the wider world because it’s easy to see that similar metric alternatives exist within the Customer-Provider tree.
  - Only large-scale changes need to be pushed via FPV.
- Significantly reduce global routing table churn.

Exceptions

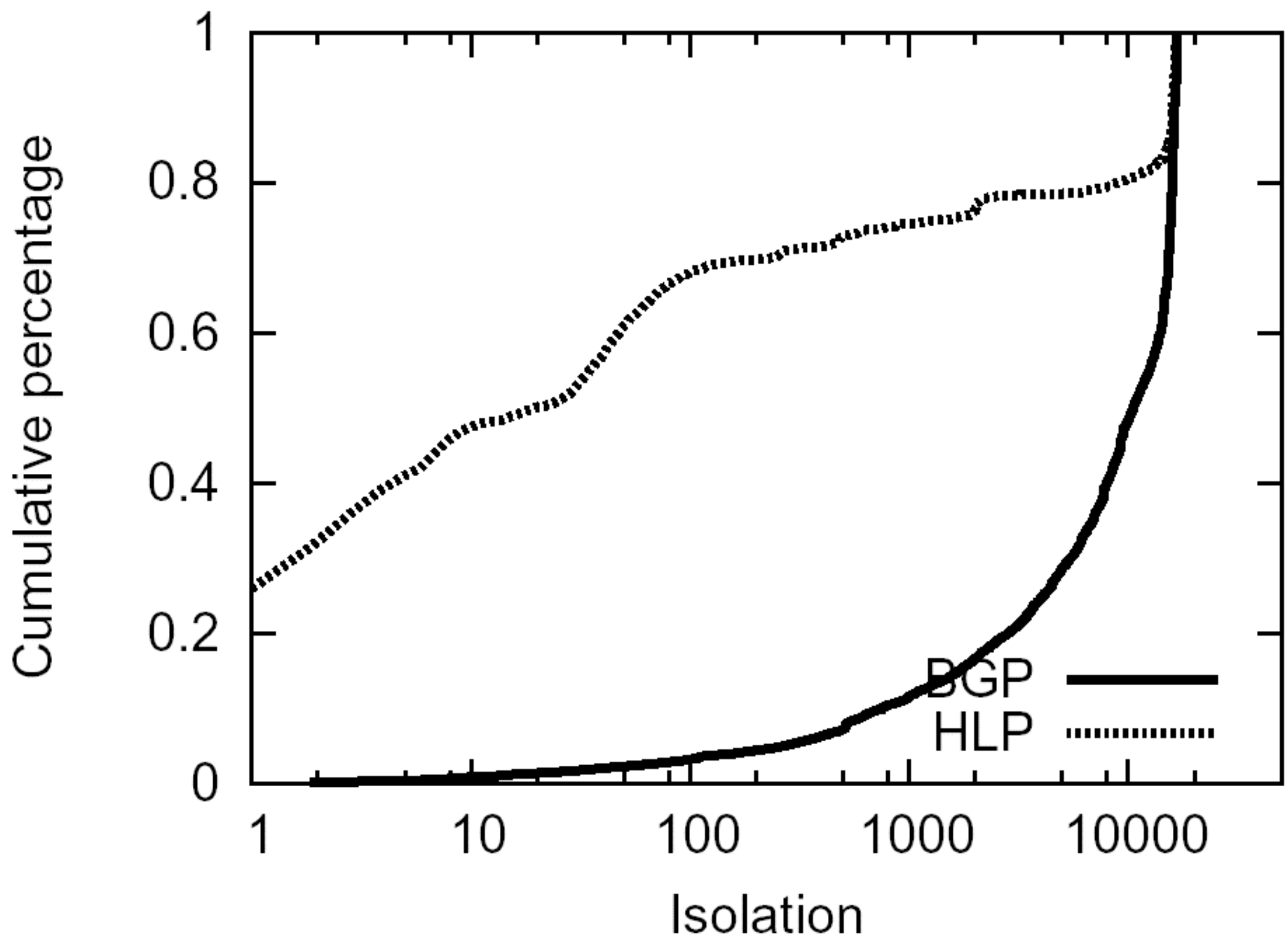
- Not all policies conform strictly to the hierarchy
  - Export-policy exception.
  - Prefer-customer exception.
- Dealt with in HLP by using FPV rather than Link-state.
- Fortunately this is rare. Frequency of export-policy exceptions:

Type	Oct '03	Jun '03	Jan '03
Prov-Prov	0.8%	0.1%	0.3%
Prov-Peer	0.5%	0.5%	0.4%
Peer-Prov	0.1%	0.1%	0.1%

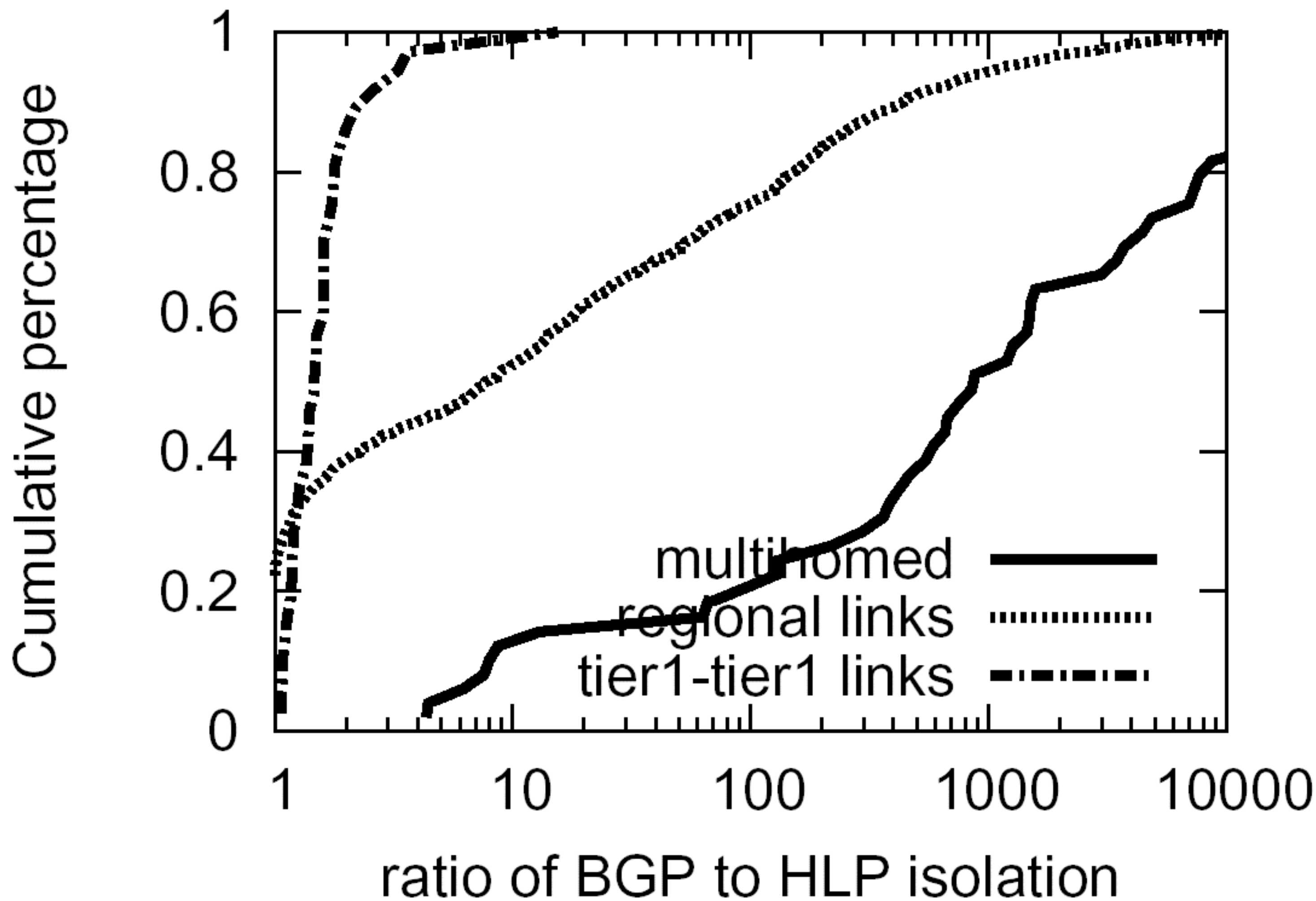
Performance: Routing Table Churn



Performance: Fault Isolation



Fault Isolation and Multihoming



Convergence

- BGP: Worst case is fully connected n-node graph:
  - Convergence time is $O((n\text{-}1)!)$

- HLP: In the absence of exceptions, worst case is:
  - Convergence time is $O(n^{k(D)})$
  - $k(D)$ is number of peering links on path to D

In the current Internet:

$k \leq 1$ for 90% of Internet routes

$k \leq 2$ for 99% of Internet routes

$k \leq 4$ for all Internet routes

HLP Advantages

- **Scalability**: route churn is the issue.
  - Information hiding.
  - Separation of prefix distribution from routing.
- **Convergence**:
  - Link-State converges fast.
  - FPV converges faster than Path-Vector because there are fewer infeasible alternates.
- **Security**:
  - Structure adds security.
  - Secure prefix distribution separately from dynamic routing.
- **Robustness**:
  - Harder to misconfigure, easier to figure out what the intent behind a route is.

HLP: Summary

- Understanding policy is critical to understanding how to change routing.
  - Need broad industry participation to get this right.
- Most policy is simple, some is very complex, some is inherently public, some must be kept private.
  - BGP doesn’t distinguish.
  - HLP tries to take advantage of the common case, and the inherent limitations on what can be kept private.
- Transitioning away from BGP will be really hard.
  - Can’t happen with strong incentive, and good consensus on where we want to get to.

Criteria for Successful BGP Replacement

- Interoperate with BGP without any serious degradation in capability during transition.
- Provide incremental improvement when customers and their providers both switch
  - outside-in deployment.
- Concepts must be familiar to ISPs.

Opportunity for Replacement?

- BGP must be seen to be failing.
  - Security problems being actively exploited?
  - Convergence problems too slow for high-value traffic (VoIP, IP-TV)?
  - Growth of multi-homing causes routing table growth/churn that is unsupportable?