1 Motivation: Inter-Domain Service Guarantees

- Modern applications demand end-to-end (QoS) guarantees:
  - High availability
  - Low latency
  - High bandwidth
  - Low jitter, etc.

- Intra-domain QoS:
  - Leased circuits
  - VPN tunnels

- Inter-domain QoS: Very limited

One proposed solution: path mediation:
- Logically centralized path brokers (using PCEs, SDN, etc.) [1]
- ISPs provide QoS-enabled pathlets [2]
- Brokers stitch them end-to-end → bandwidth markets, etc. [3]

2 Observation: The Internet Gets Flatter over Time

- Richer interconnectivity at IXP [4]
- Paradigm shift towards network virtualization and SDN [5]
- IXPs adopt new technologies for their members
- Public IXPs are flourishing:
  - Up to 100s of members each
  - TBps of traffic
  - 100s of locations worldwide
  - Concurrent peering of ISPs at multiple IXPs
  - Constantly expanding peering ecosystem

3 Proposal: Control eXchange Points (CXPs) as Path Brokers over IXPs

- Key idea: Use IXPs as switching elements of CXPs:
  - Good path diversity
  - Maximal coverage of potential users
  - Well-connected deployments
  - High bandwidth and availability
  - Provider neutrality

- Result: rich inter-IXP overlay fabric (aka the IXP multigraph):
  - Open new TE possibilities across domains
  - Deploy incrementally for maximum impact
  - Use for inter-domain e2e QoS

- Nodes = IXPs (CXP switches)
- Edges = inter-IXP pathlets:
  - Over shared ISP members
  - [Edges] >> [Nodes]

4 Potential of CXPs on IXP Multigraphs

- ~5 IXPs cover:
  - >40% of IPv4 space (directly)
  - >91% of IPv4 space (1-hop customer cone)

- Effective incremental adoption of guaranteed e2e services

- Mapped multigraph (based on EuroX dataset):
  - 229 IXPs, 49k overlay (IXPs, ISPs, IXP) edges → high density
  - Up to 100s of distinct ASes (ISPs) between IXPs
  - Path diversity >> direct connectivity (edge multiplicity)

- Generalized inter-domain routing policies:
  - Incentive anyone can provide a path
  - Up to 29 times increase in path diversity over valley-free routing
  - Examples of policy generalization:
    - 1) Valley-free with multiple IXPs links
    - 2) Extension of (1) with IXPs links anywhere on the path

6 Path Stitching Algorithms over CXPs

- Path stitching embedding problem:
  - Embed e2e paths on inter-IXP multigraphs
  - Subject to latency and bandwidth constraints

- Our proposal [6]:
  - Sample-select approach as heuristic online algorithm
  - Use deterministic or randomized heuristics (dijkstra, random walks)
  - Hybrid online-offline algorithms

- Insights (full results at [6]):
  - Algorithms scale to the sizes of the multigraph
  - Diverse request mixes can be served
  - Performance comparison framework
  - Evaluation code: https://bitbucket.org/vkotronis/cxp_experimentation

7 References

2. GODFREY, P. B., GANICHEV, I., SHENKER, S., AND STOICA, I. “Pathlet Routing”. In ACM SIGCOMM (2009).
4. DREANHERE, A. AND DOVROLIS, C. “The Internet is Flat: Modeling the Transition from a Transit Hierarchy to a Peering Mesh”. In ACM CONEXT (2010).