NETWORK LAYER INTERNET TOPOLOGY CONSTRUCTION

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AGENDA

- Internet Topology and its Representation
- Existing Topology Representations
- Subnet Level Topologies
- Subnet Inference with XNET
- Current Research

Internet Topology

- Internet Topology Maps
  - Represented as a graph G(V,E) such that V is the set of objects and E is the set of links between objects in V.
  - Vertices:
    - Autonomous Systems (ASes)
    - Routers
    - Router Triangles
    - Interfaces
    - Subnetworks (Subnets)

Internet Topology

- Inter-Connections
  - Policy-based connections
  - Subnets
  - Routers
- Do we really have a distinction between components in the Internet and their inter-connections?
- Or is it a matter of representation and interest?

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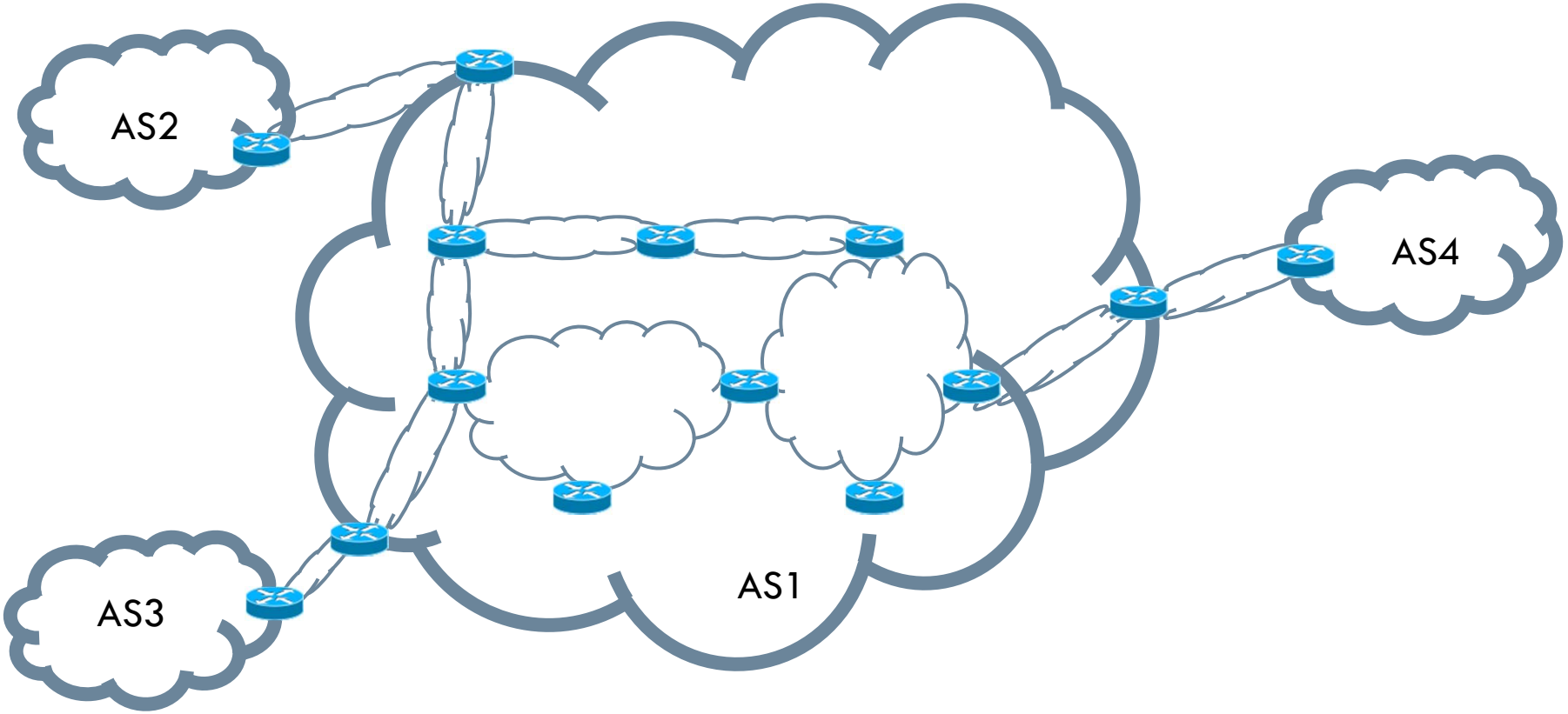
Existing Internet Topologies

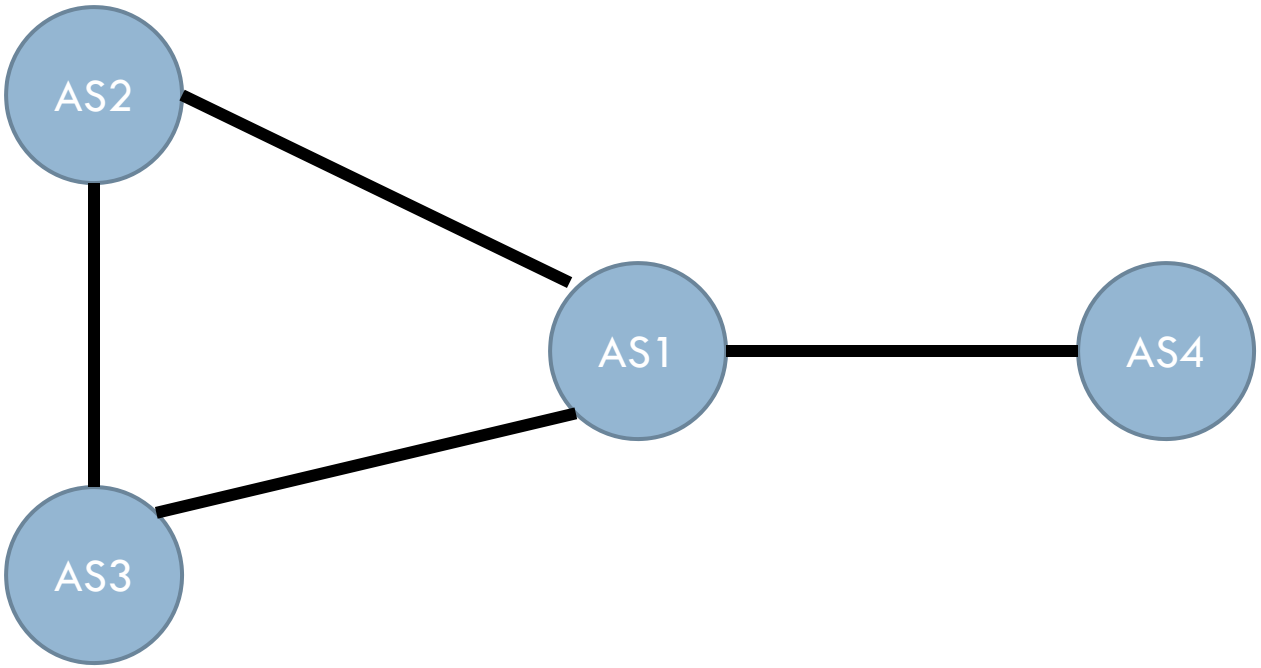
- AS Level
- Interface Level
- Router Level

Existing Internet Topologies
AS Level



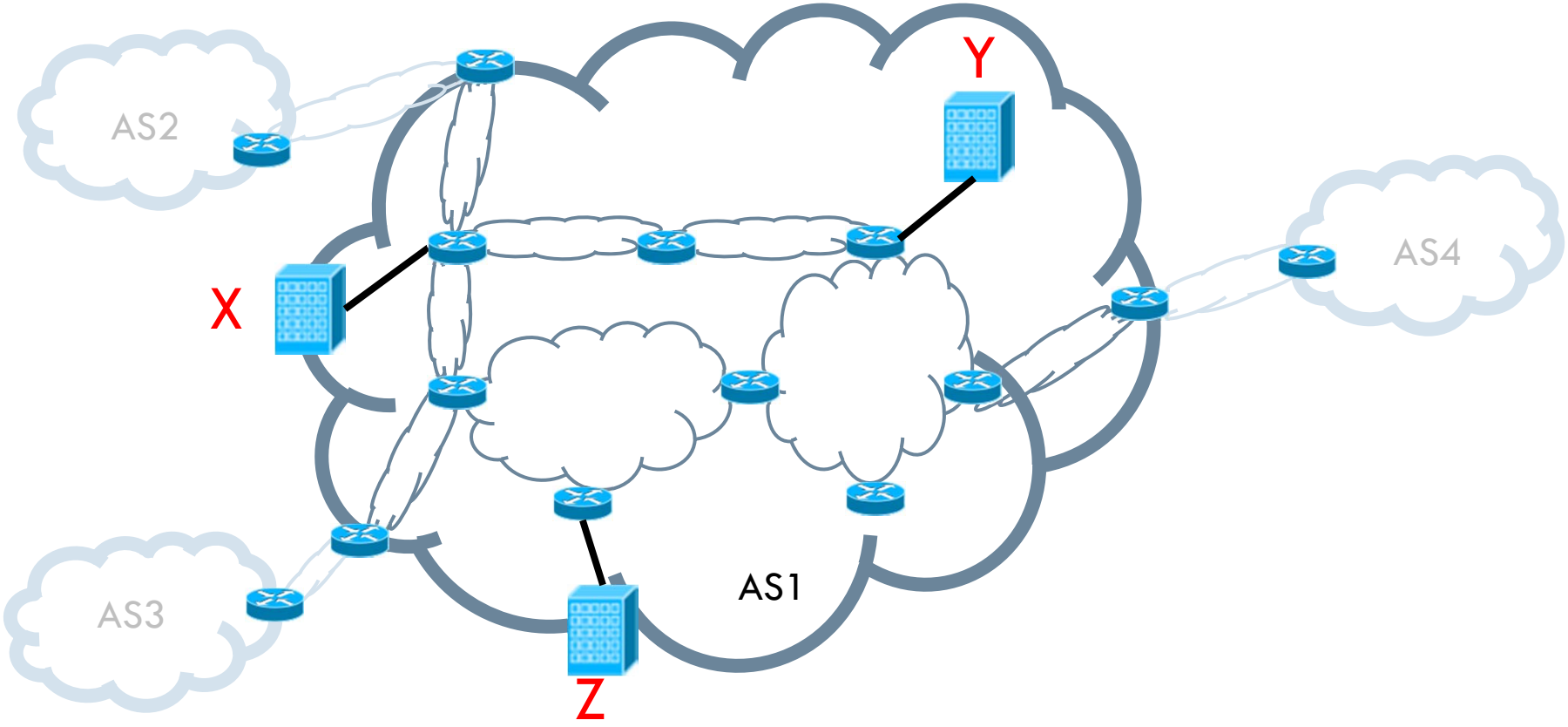
A Sample Section of the Internet Topology at the Network Layer

Existing Internet Topologies
AS Level



AS Level Representation

Existing Internet Topologies Interface Level



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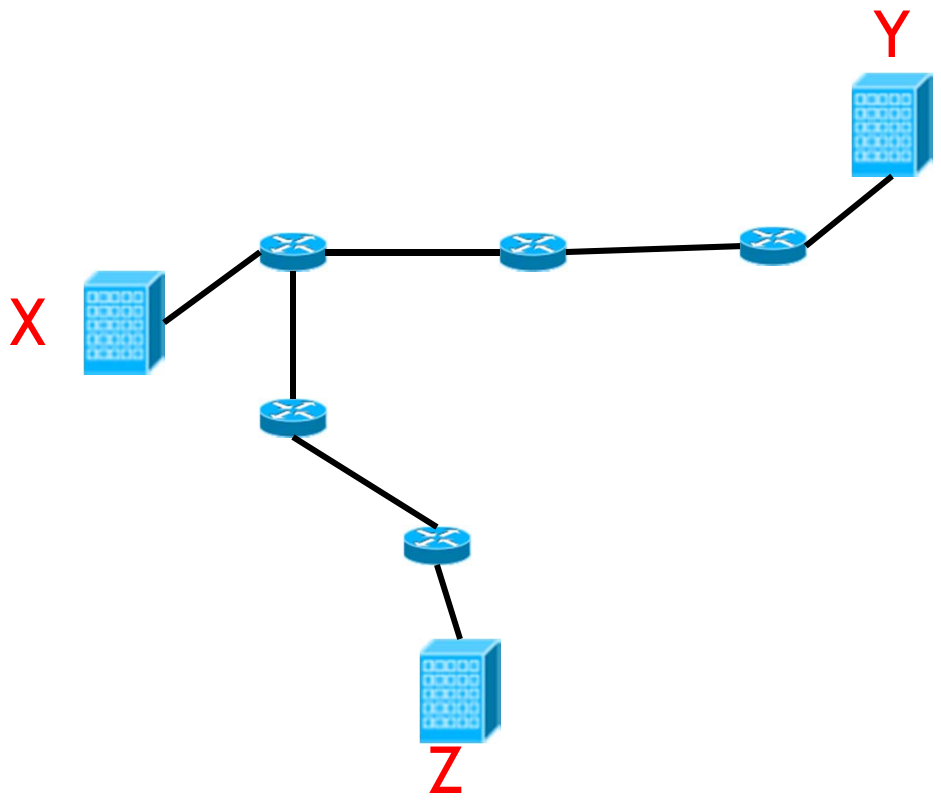
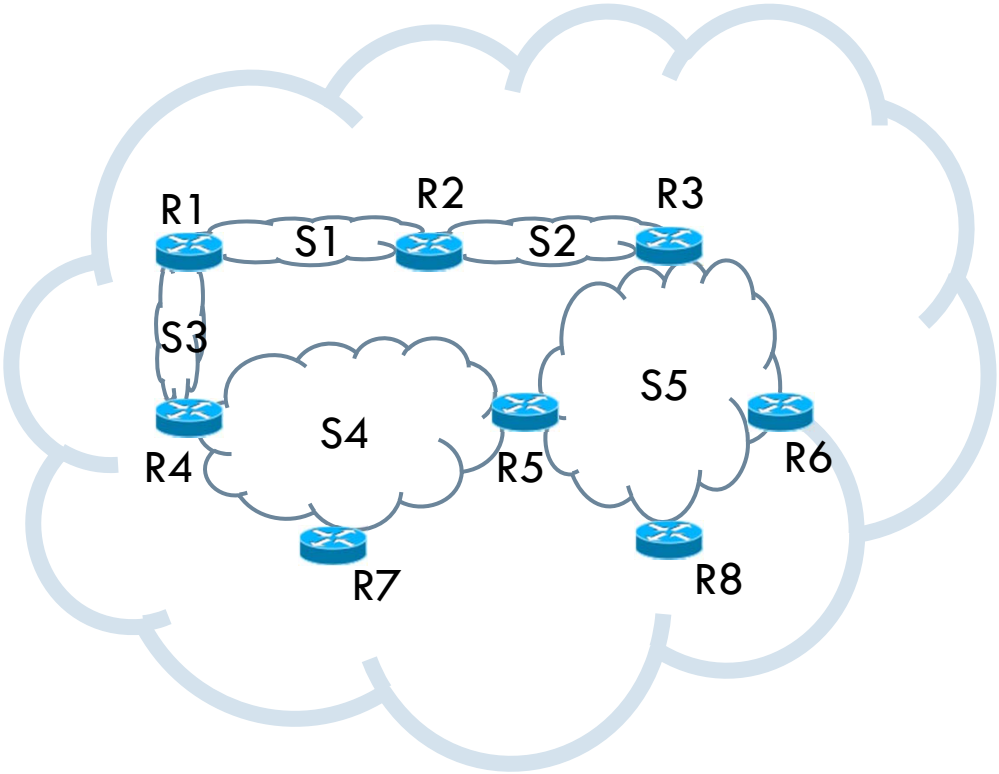
Existing Internet Topologies Interface Level



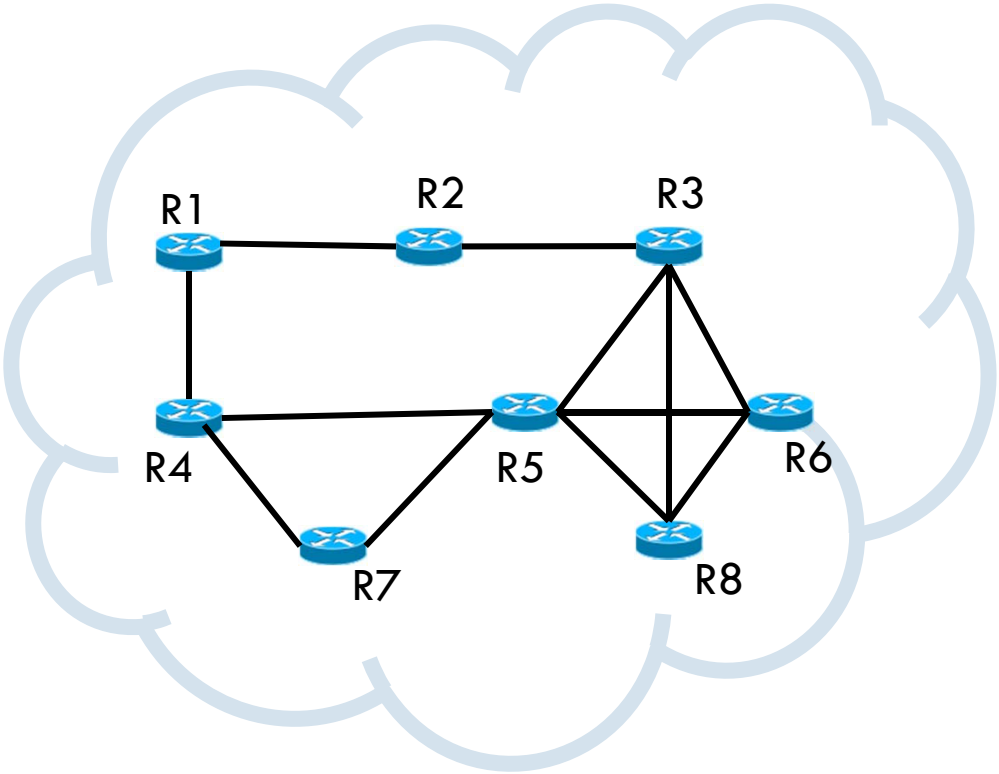
Interface Level Representation

Existing Internet Topologies
Router Level



A Sample Section of the Internet Topology at the Network Layer

Existing Internet Topologies
Router Level



Router Level Representation

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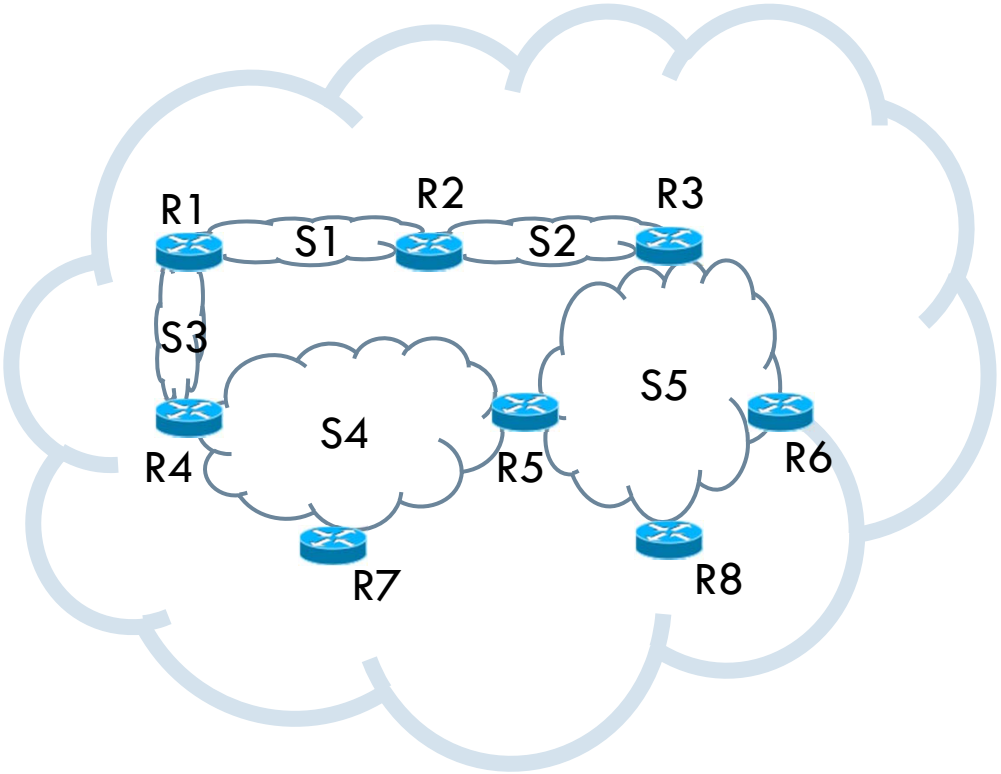
Subnet Level Topologies



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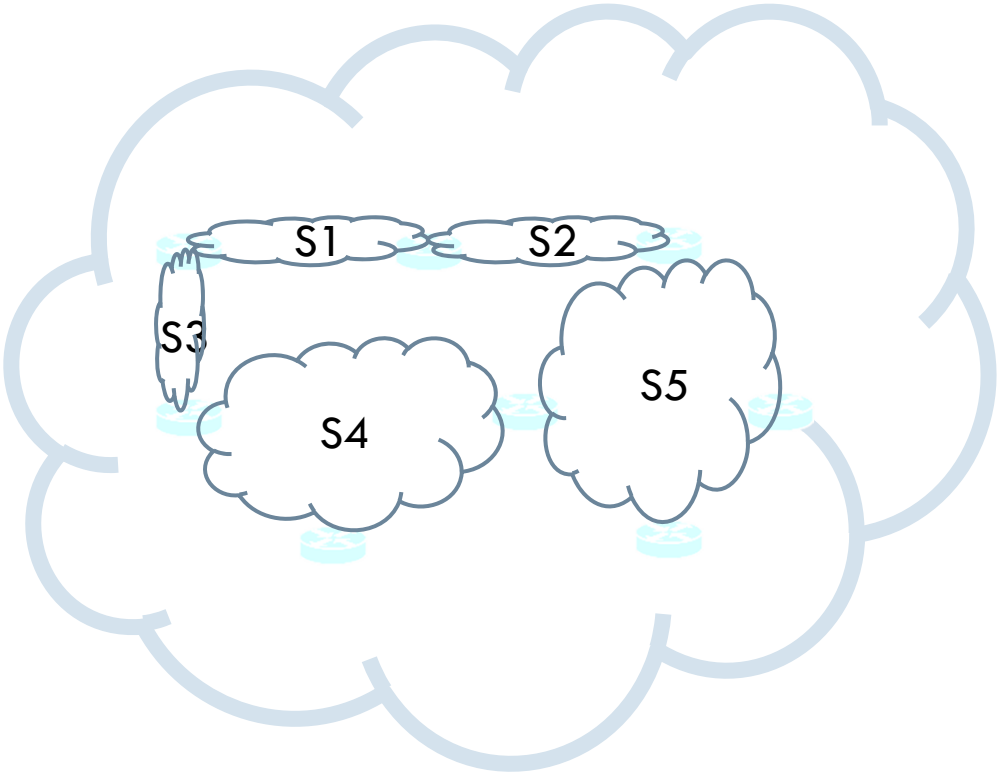
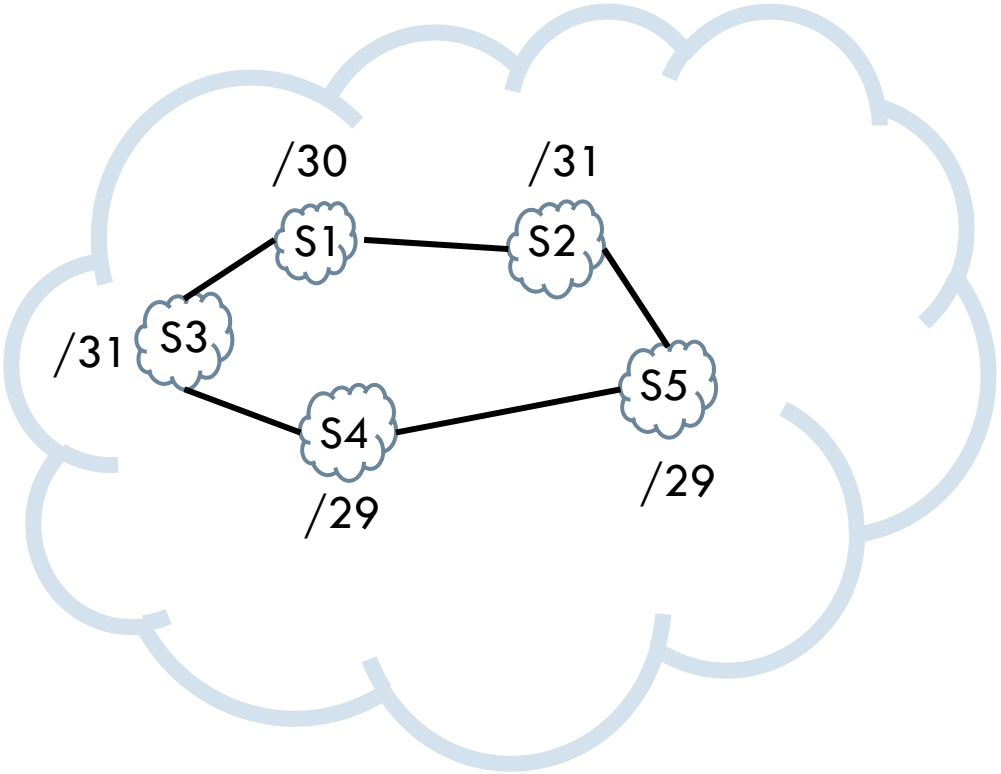
Subnet Level Topologies



Subnet Level Topologies



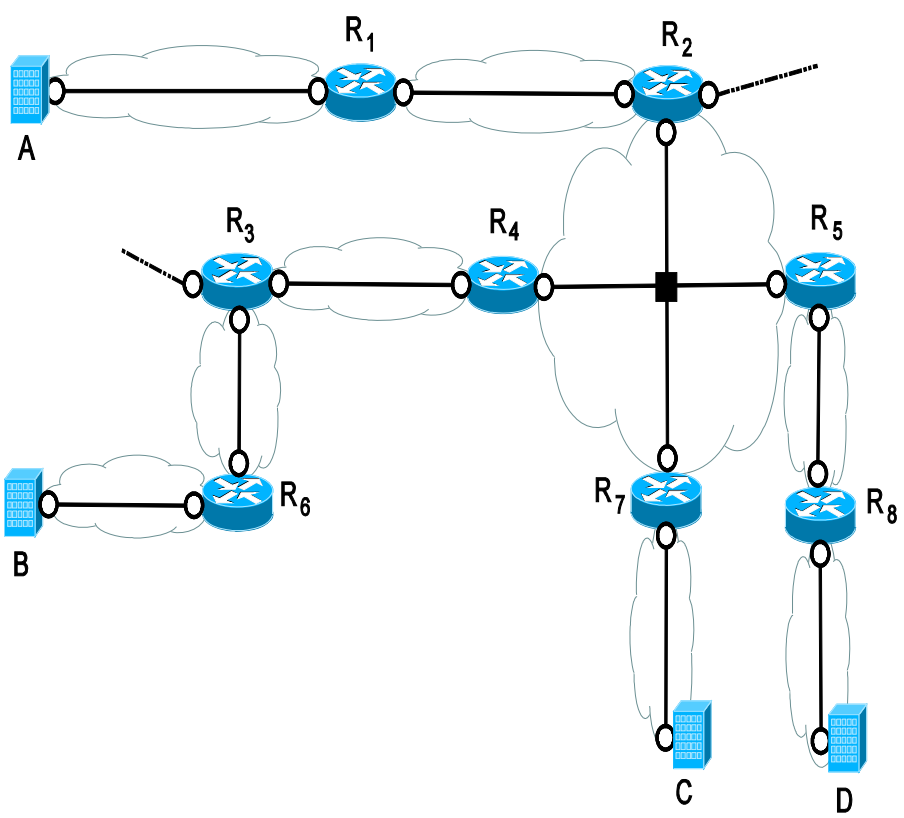
Subnet Level Representation

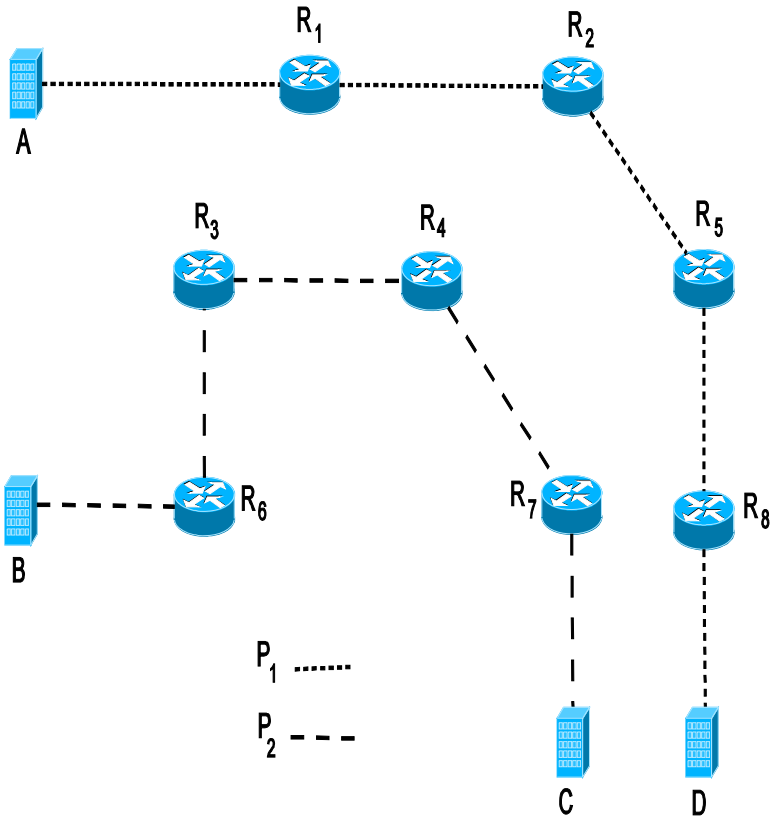
Subnet Level Topologies

- Subnet Level Internet Topologies
  - A subnet S is defined by the set of interfaces that it accommodates
  - A vertex in the graph is a subnet
  - A link between two subnets represents the router that directly connects two subnets to each other
  - TraceNET is a tool for building subnet level Internet topologies
  - XNET is another tool for inferring individual subnets

Utility of Subnet Level Topologies

- Building node-and-link disjoint end-to-end paths for overlay network design





Utility of Subnet Level Topologies

- Studying Subnet Level Topology Characteristics
  - Degree Distribution
  - IP address space Utilization
  - Betweenness
  - Assortativity
  - Clustering Coefficient
  - and so on…

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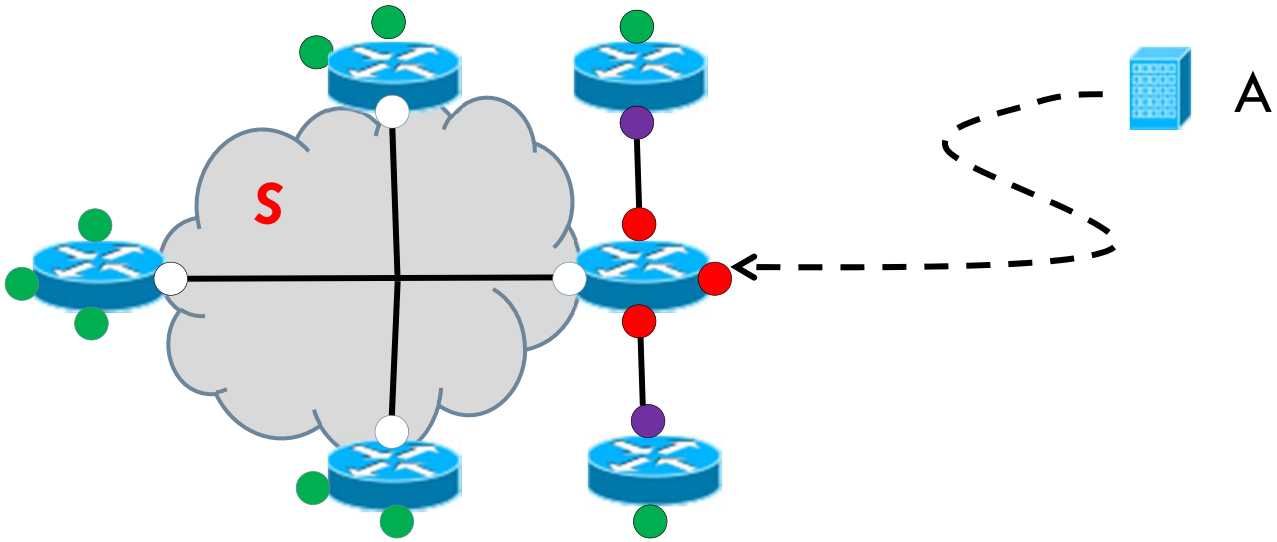
Subnet Inference with XNET

- ExploreNET (XNET)
  - Given an IP address *t*, XNET builds the subnet *S* hosting *t*
    - Collects all alive IP addresses accommodated by *S*
    - Labels *S* by its observed subnet mask
- TraceNET
  - Given a destination address *d*
    - Returns a list of subnets appearing between the source and the destination address *d*

Subnet Inference with XNET

- XNET vs TraceNET
  - Both are based on the same principles
  - TraceNET has more data to draw inference (subnets and IP addresses appearing in previous hops)
  - XNET can be utilized in uniform random subnet sampling
  - TraceNET sampling possesses source dependency bias

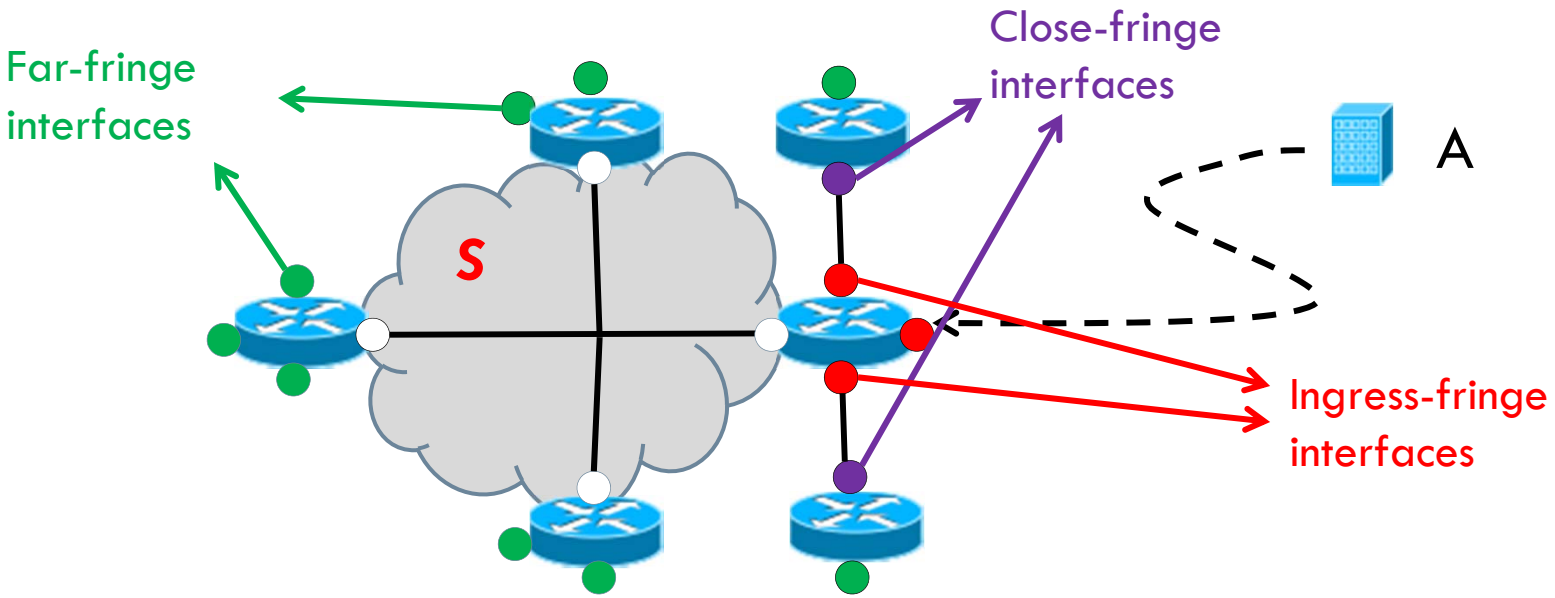
Subnet Inference with XNET



Subnet Inference with XNET

- Scope Delimitation Test
- Far Fringe Interface Detection Test
- Ingress Fringe Interface Detection Test
- Close Fringe Interface Detection Test

Subnet Inference with XNET



Fringe Interface Detection

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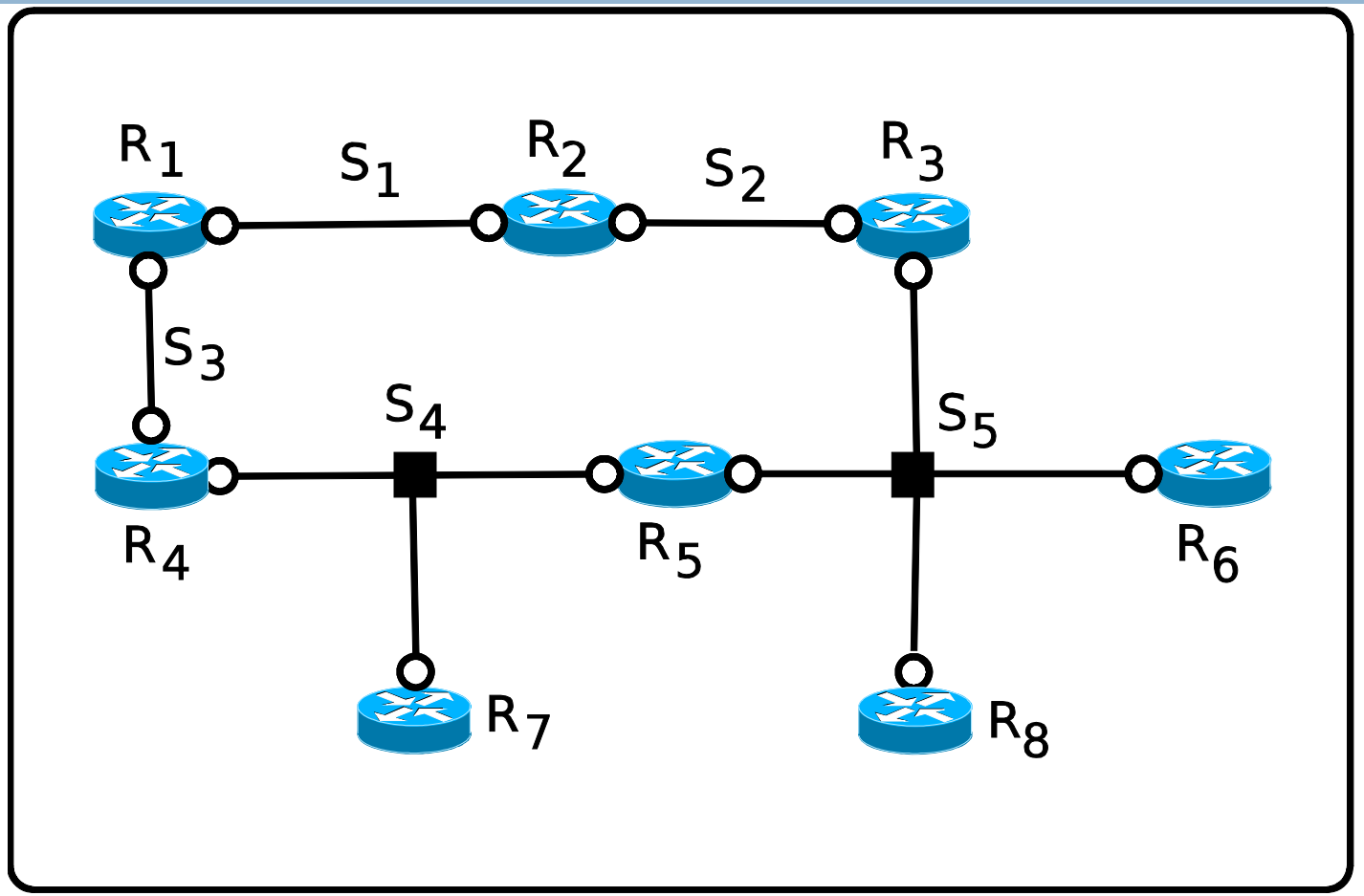
Current Research

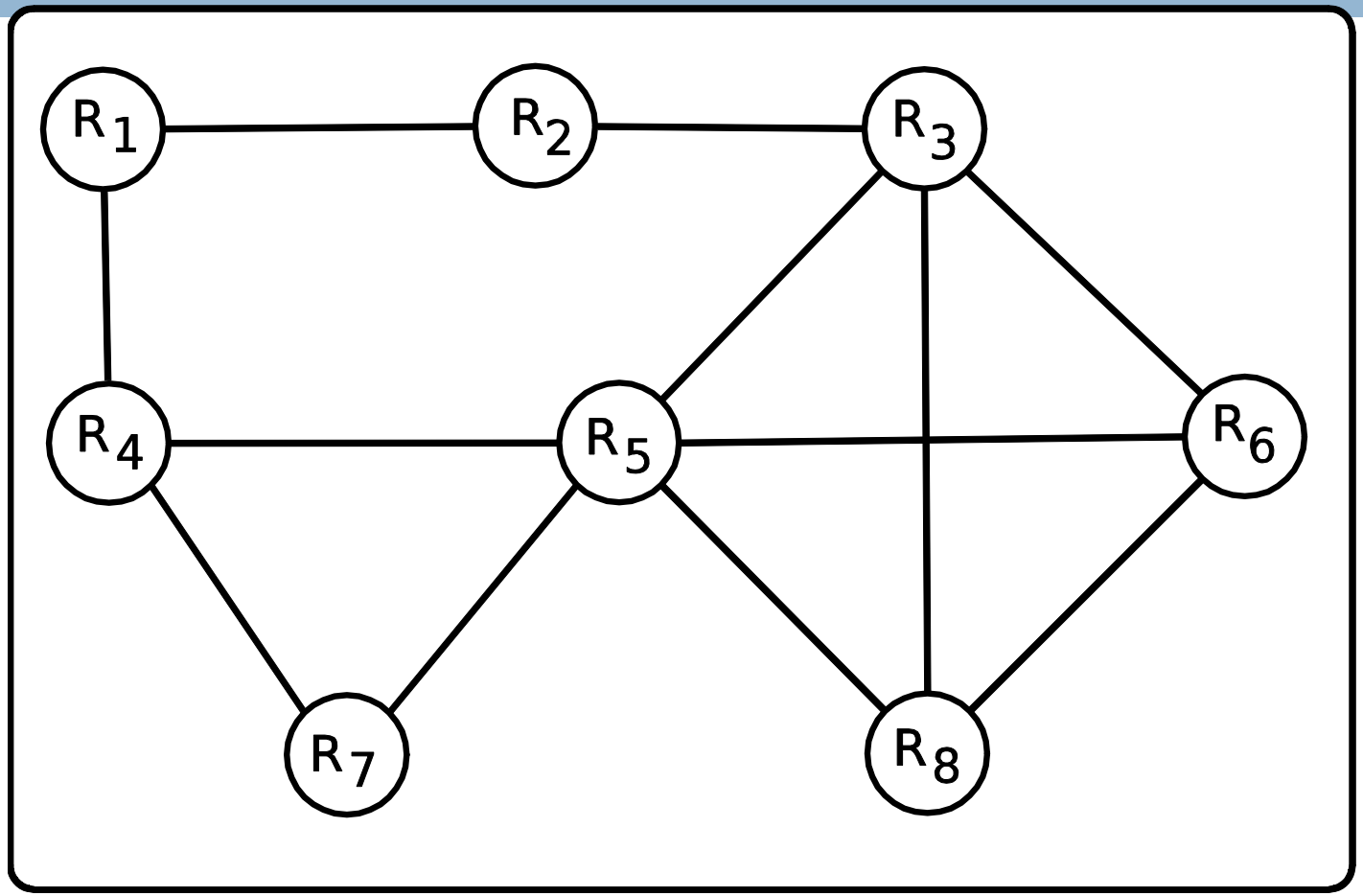
- Network Level Internet Topology Maps
- A mathematical framework for sampling subnets using XNET
- Developing a network generation model based on subnets

Internet Topology Representations



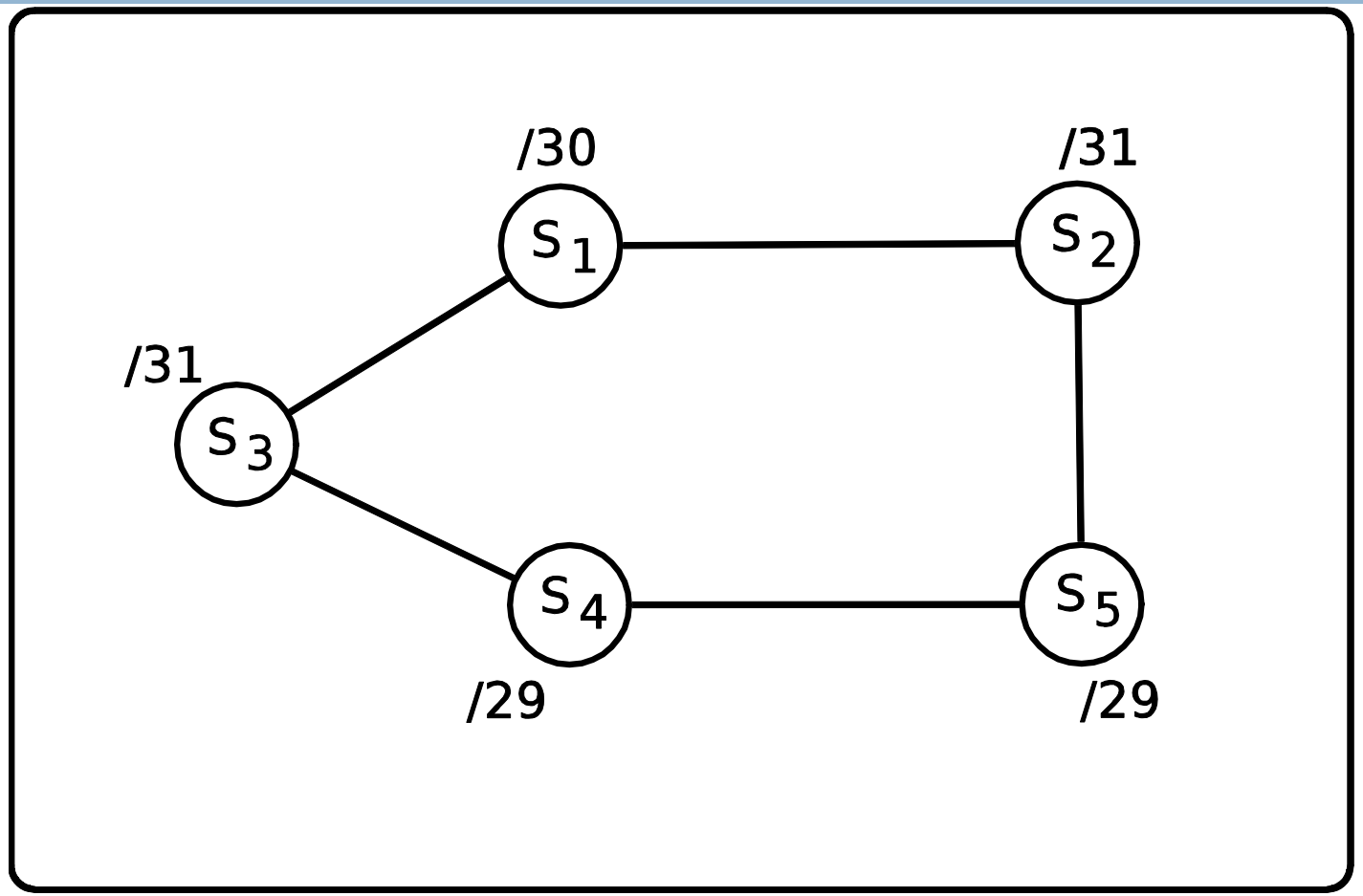
Example Internet Topology

Internet Topology Representations



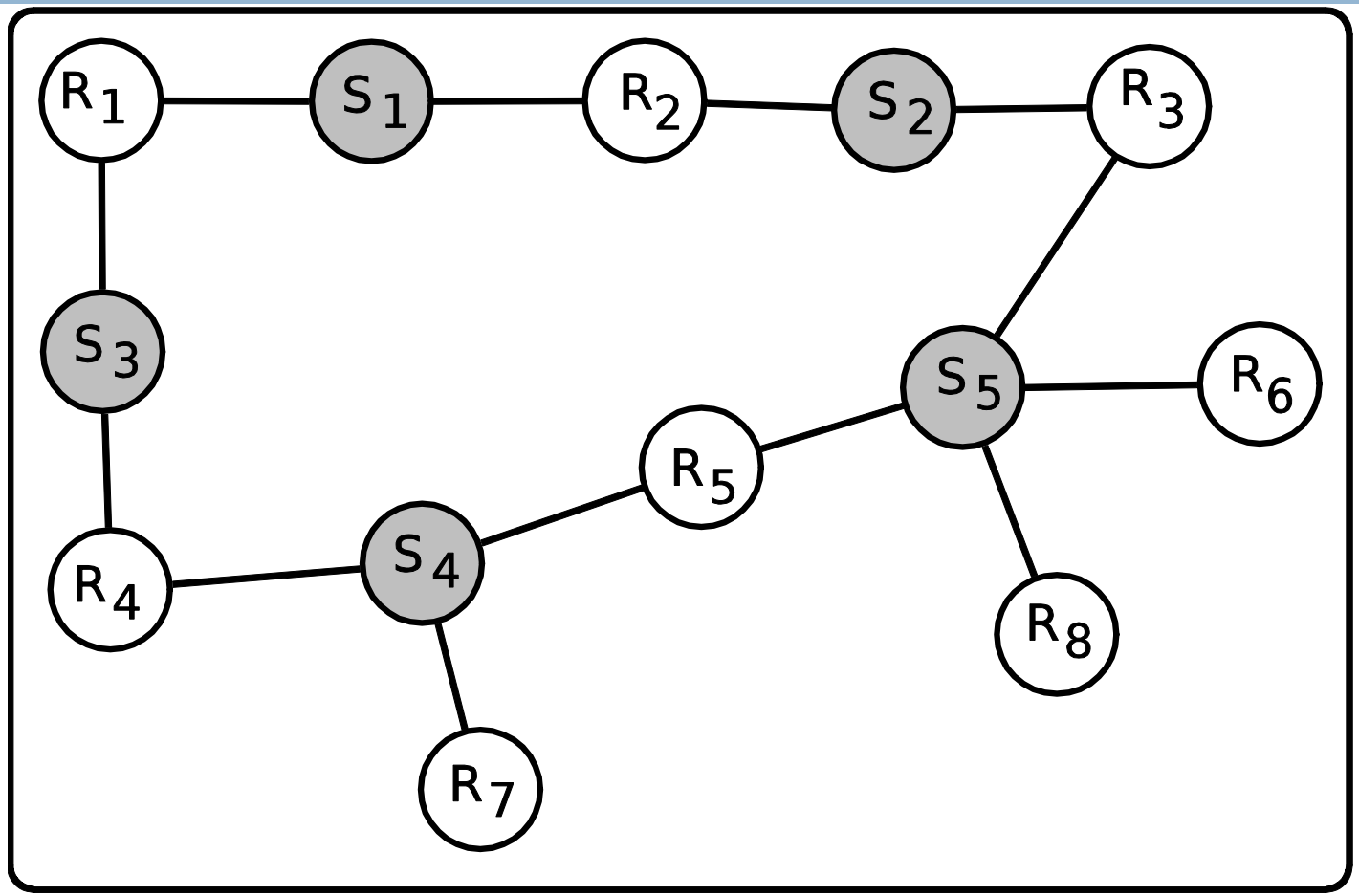
Router Level Representation

Internet Topology Representations



Subnet Level Representation

Internet Topology Representations



Network Level Representation

Discussion

- Questions & Comments

Evaluations

- Characteristics of subnets in six geographically disperse Tier-2 ISP networks
  - PCCW Global (ISP-1)
  - nLayer (ISP-2)
  - France Telecom (ISP-3)
  - Telecom Italia Sparkle (ISP-4)
  - Interroute (ISP-5)
  - MZIMA (ISP-6)

Table 1: Alive IP address distribution for target ISPs

ISP-1	ISP-2	ISP-3	ISP-4	ISP-5	ISP-6	Total
45,018	54,636	17,170	8,380	21,209	16,453	162,866

Evaluations

Table 1: Subnet prefix length distributions for ISPs

	ISP-1	ISP-2	ISP-3	ISP-4	ISP-5	ISP-6	Σ
/20	3	4	0	0	0	0	**7**
/21	3	0	0	0	0	0	**3**
/22	7	7	0	0	0	0	**14**
/23	3	2	0	1	6	0	**12**
/24	24	110	1	2	14	36	**187**
/25	25	8	0	7	6	7	**53**
/26	123	14	0	11	28	10	**186**
/27	152	17	7	28	78	34	**316**
/28	262	26	29	82	215	70	**684**
/29	440	48	115	131	419	136	**1289**
/30	899	418	316	177	2179	535	**4524**
/31	429	552	7394	2378	1567	1494	**13814**
Σ	**2370**	**1206**	**7862**	**2817**	**4512**	**2322**	**21089**

Table 2: Mean and standard deviation of prefix lengths for ISPs

	ISP-1	ISP-2	ISP-3	ISP-4	ISP-5	ISP-6	Σ
Mean	29.20	29.61	30.91	30.67	30.04	30.35	30.36
Std	1.64	2.23	0.38	0.89	1.04	1.23	1.21

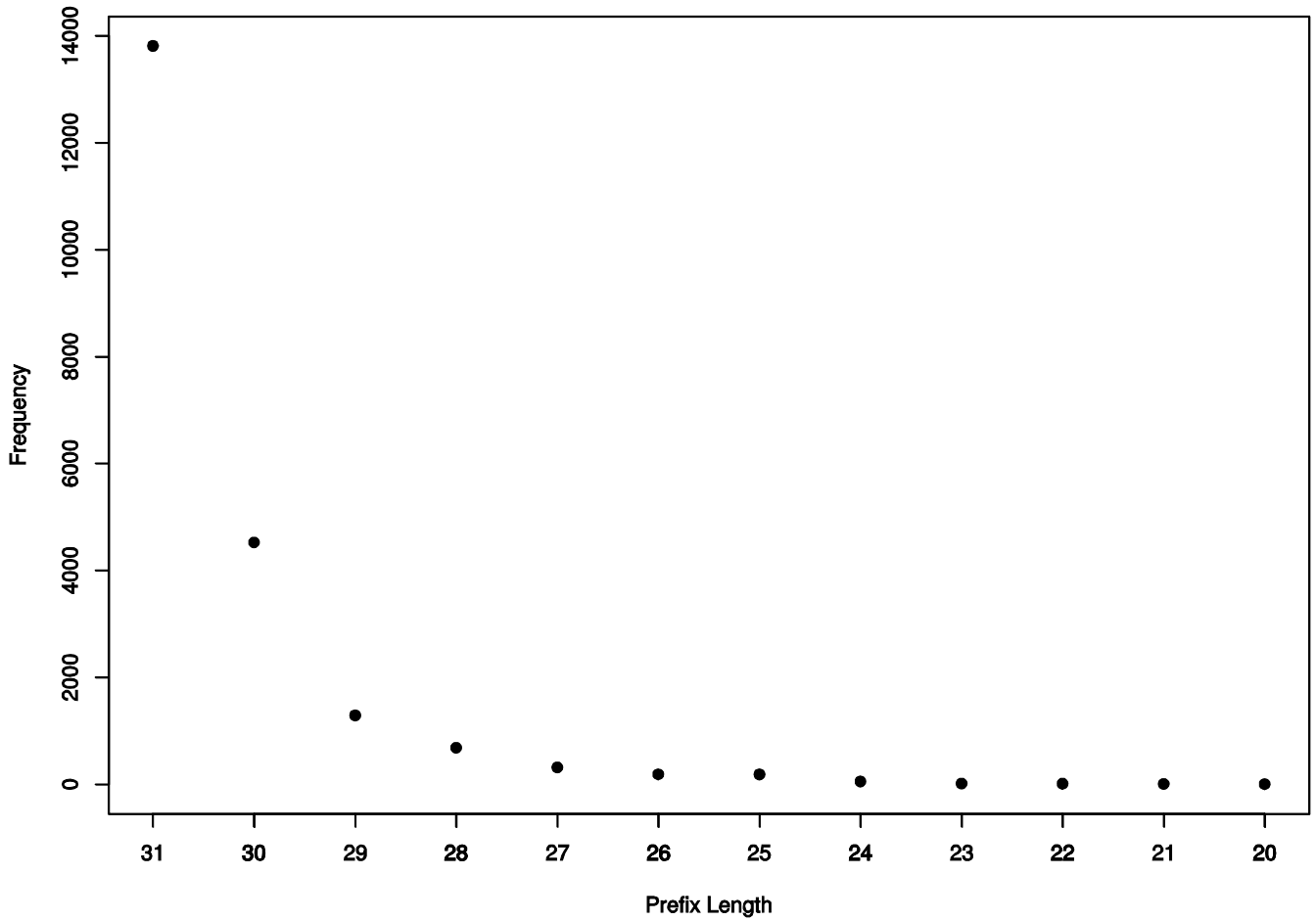
Evaluations

Table 1: IP address space utilization of ISPs

	ISP-1	**ISP-2**	**ISP-3**	**ISP-4**	**ISP-5**	**ISP-6**	$\mathcal{U}$
/20	11790	15728	0	0	0	0	**96%**
/21	5939	0	0	0	0	0	**97%**
/22	6946	6969	0	0	0	0	**97%**
/23	923	785	0	197	2040	0	**64%**
/24	3803	26855	109	398	2547	8818	**90%**
/25	1610	632	0	503	397	564	**56%**
/26	3338	590	0	308	1144	426	**50%**
/27	2595	330	112	421	1351	641	**57%**
/28	1896	193	192	529	1661	596	**53%**
/29	1721	132	390	559	1402	553	**62%**
/30	1798	836	632	354	4358	1070	**50%**
/31	858	1104	14788	4756	3134	2988	**100%**
$\mathcal{U}$	**73%**	**93%**	**92%**	**74%**	**63%**	**84%**	**80%**

Evaluations

- Power Law in Prefix Length Distribution



Evaluations

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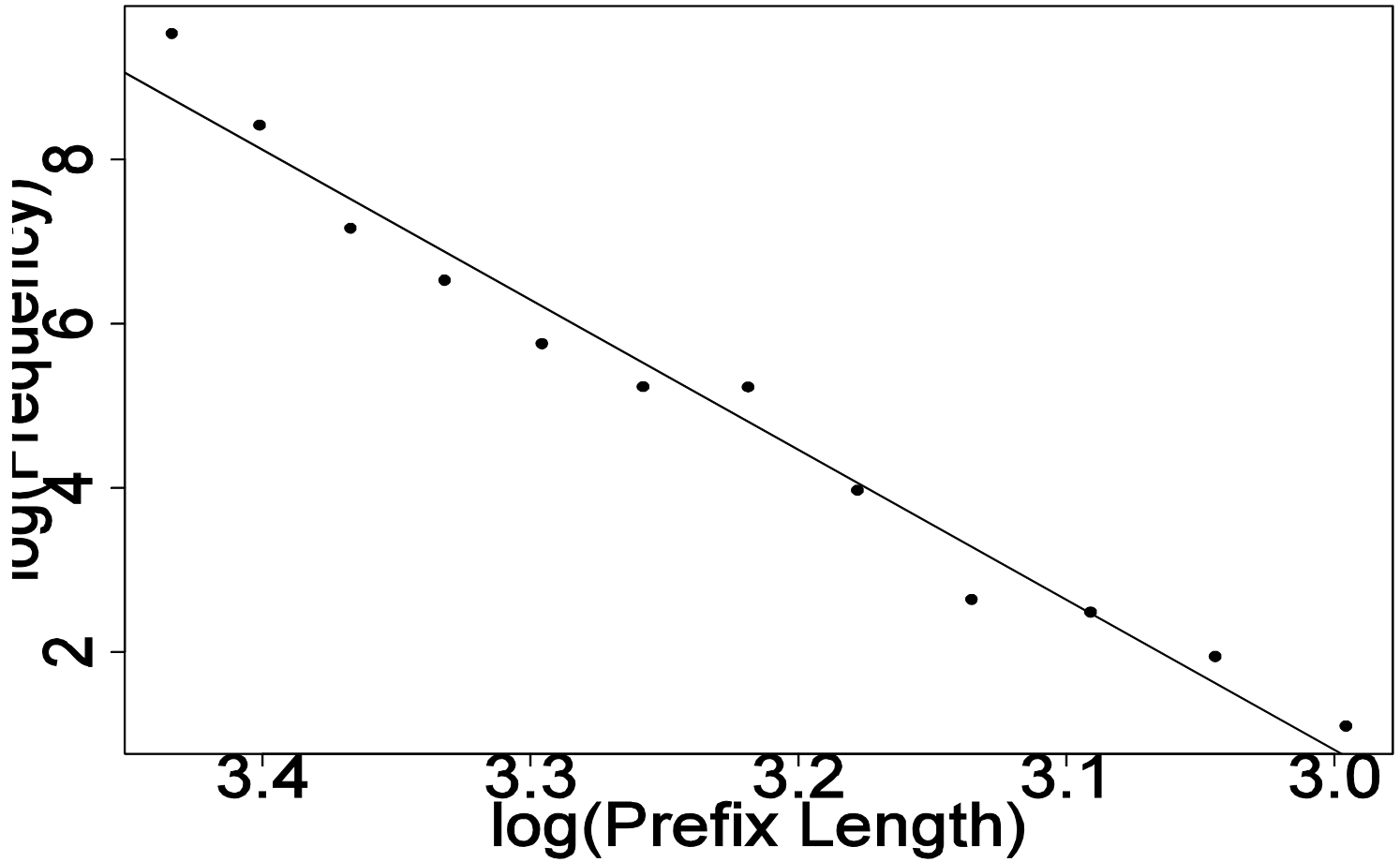

Subnet Inference with XNET

Algorithm 1 EXPLORENET

Require: t /*A target IP address*/
Ensure: S /*Subnet S along with all alive IP addresses and its observed subnet prefix*/

```
1: t^h ← find hop distance to t
2: l ← designate a pivot interface
3: for p ← 31 to 0 do
4:     S̄ ← form temporary subnet containing l with prefix p
5:     for all i^ip ∈ S̄ do
6:         if i^ip is not tested before then
7:             if i^ip passes Scope Delimitation Test then
8:                 if i^ip fails Non Far-Fringe Interface Detection Test OR
                   i^ip fails Non Ingress-Fringe Interface Detection Test OR
                   i^ip fails Non Close-Fringe Interface Detection Test
                   then
9:                     Shrink S̄ by one level and return S ← S̄ with its alive IP addresses
10:                end if
11:            else
12:                Shrink S̄ by one level and return S ← S̄ with its alive IP addresses
13:            end if
14:        end if
15:    end for
16: end for
```