NetQuery: A Knowledge Plane for Reasoning about Network Properties

Alan Shieh[†], Emin Gün Sirer, Fred B. Schneider

Department of Computer Science
Cornell University

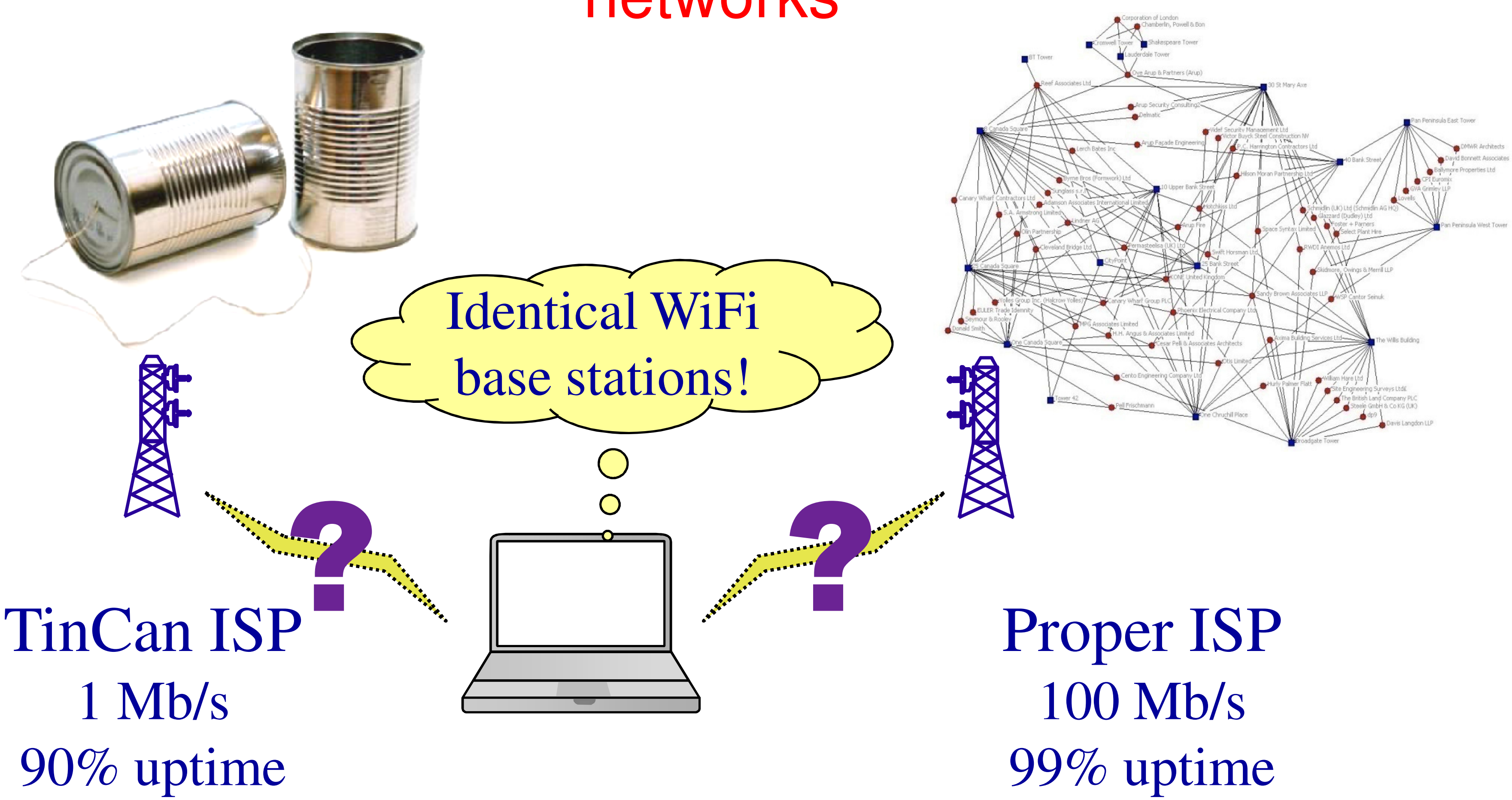
[†]Nicira Networks

Problem

- Existing networks do not provide mechanisms for querying the properties of network participants
  - All networks look the same
  - All clients look the same
  - No differentiation between network operators

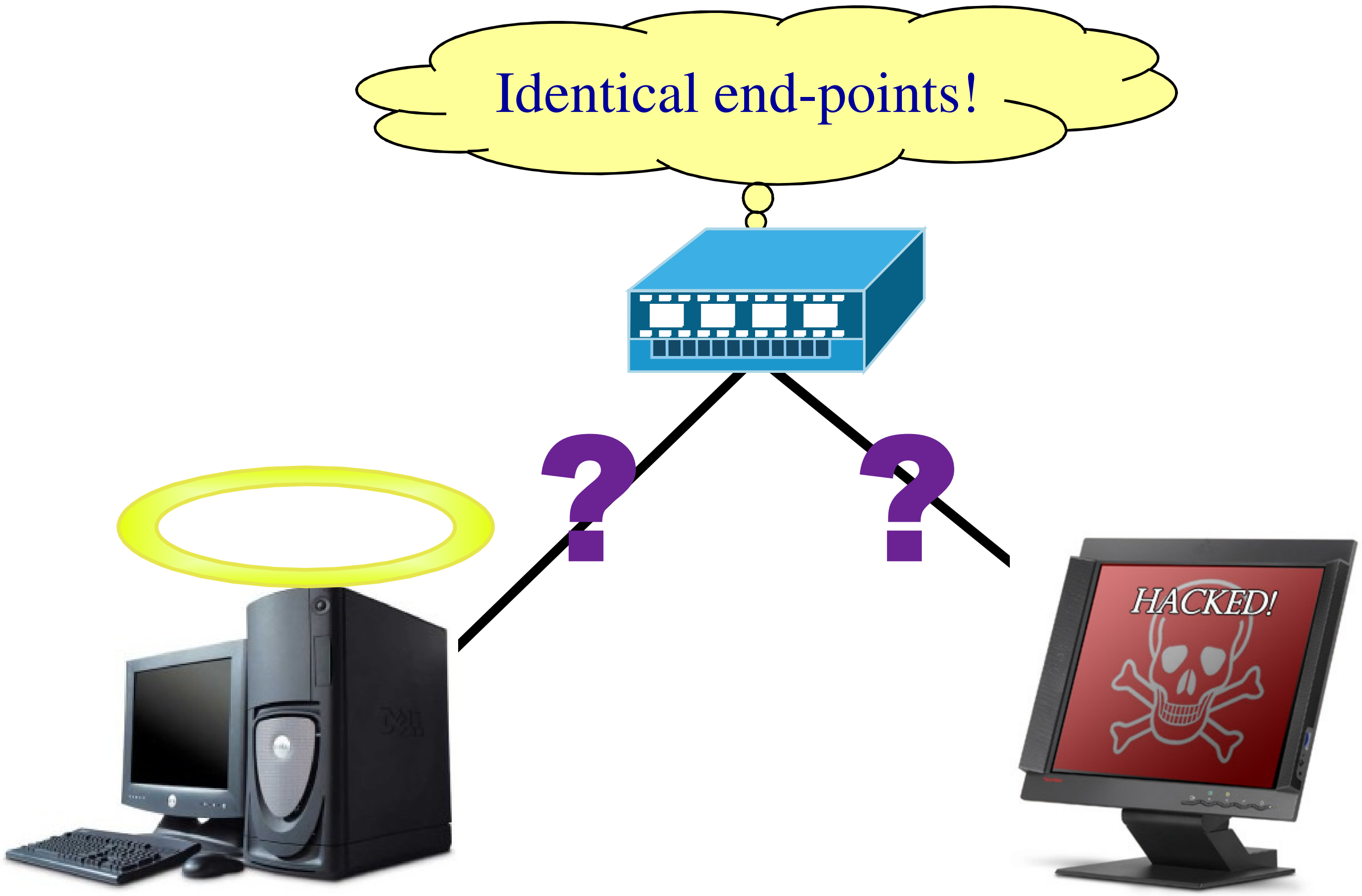
No mechanisms for querying network properties

Clients cannot differentiate between different networks



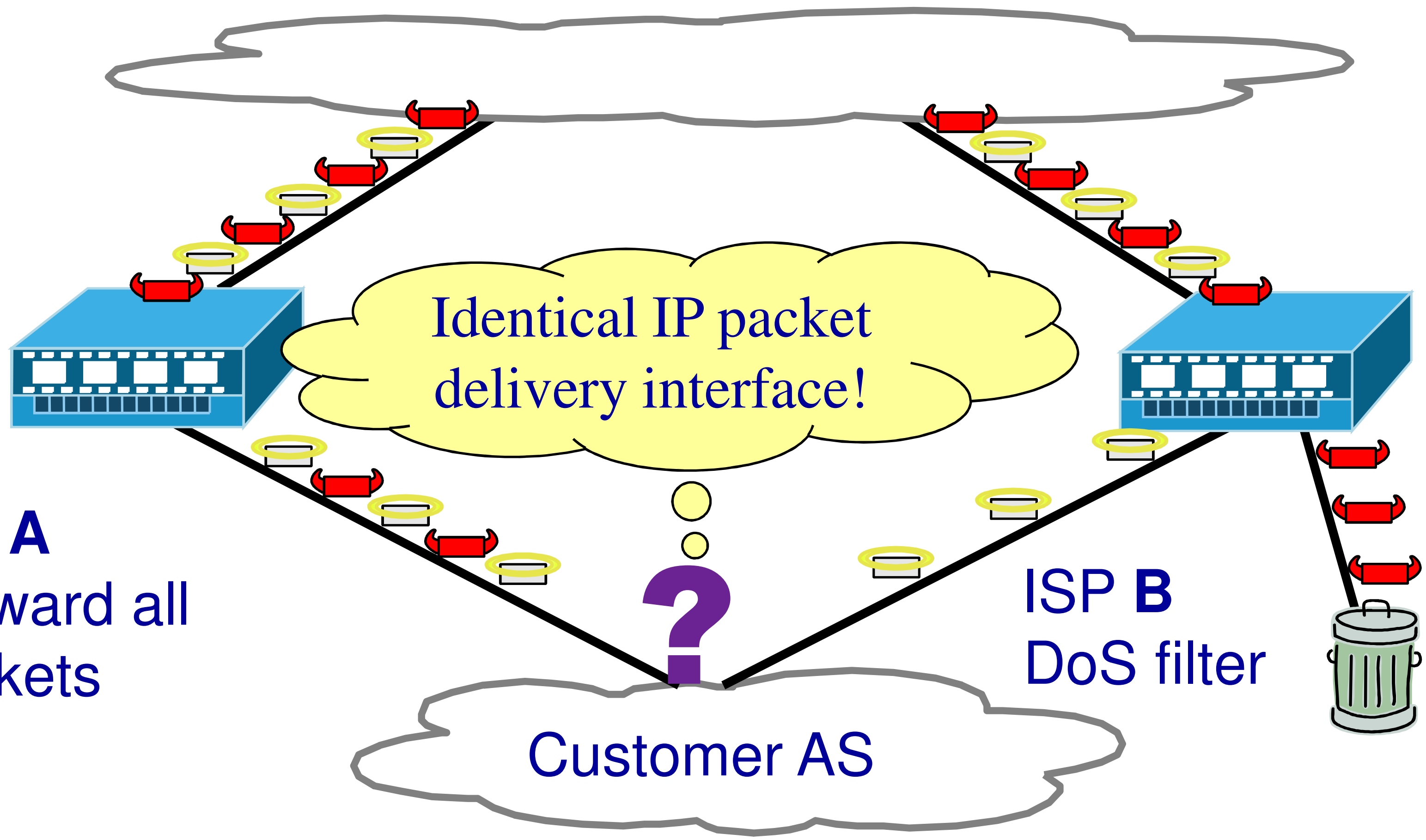
No mechanisms for querying network properties

Networks cannot differentiate between clients



No mechanisms for querying network properties

Networks cannot differentiate between other networks



Other examples

- What are the instantaneous performance properties of my ISP?
- Does my route from London to Langley go through China? (or, from Taiwan to Beijing through the US?)
- Do my ISPs failover paths provide sufficient capacity?
- Is my cloud provider's oversubscription within SLA limits?
- Are mutual backup links used only in response to failure?

Commoditization of Networks

- Networks have vastly different properties depending on their composition, configuration, management
  - Yet network operators cannot communicate these effectively

- Much past work aims to discover these properties from the data plane
  - Often requires smarts & hacks
  - Sometimes not possible

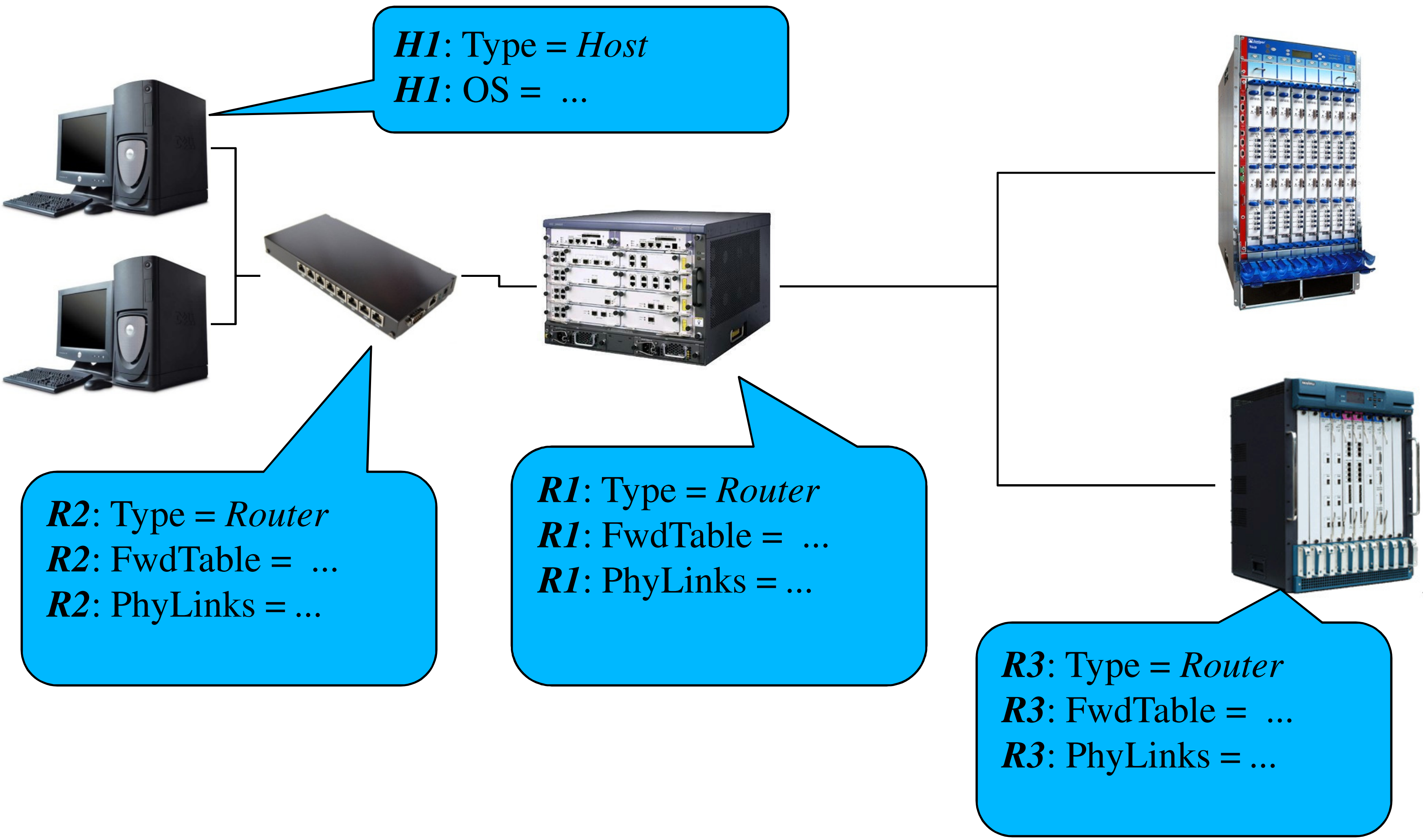
Goals

- A system to check if a network possesses a property of interest
- Goals:
  - Trustworthy
  - Privacy-preserving
  - Scalable
  - Federated
  - Extensible

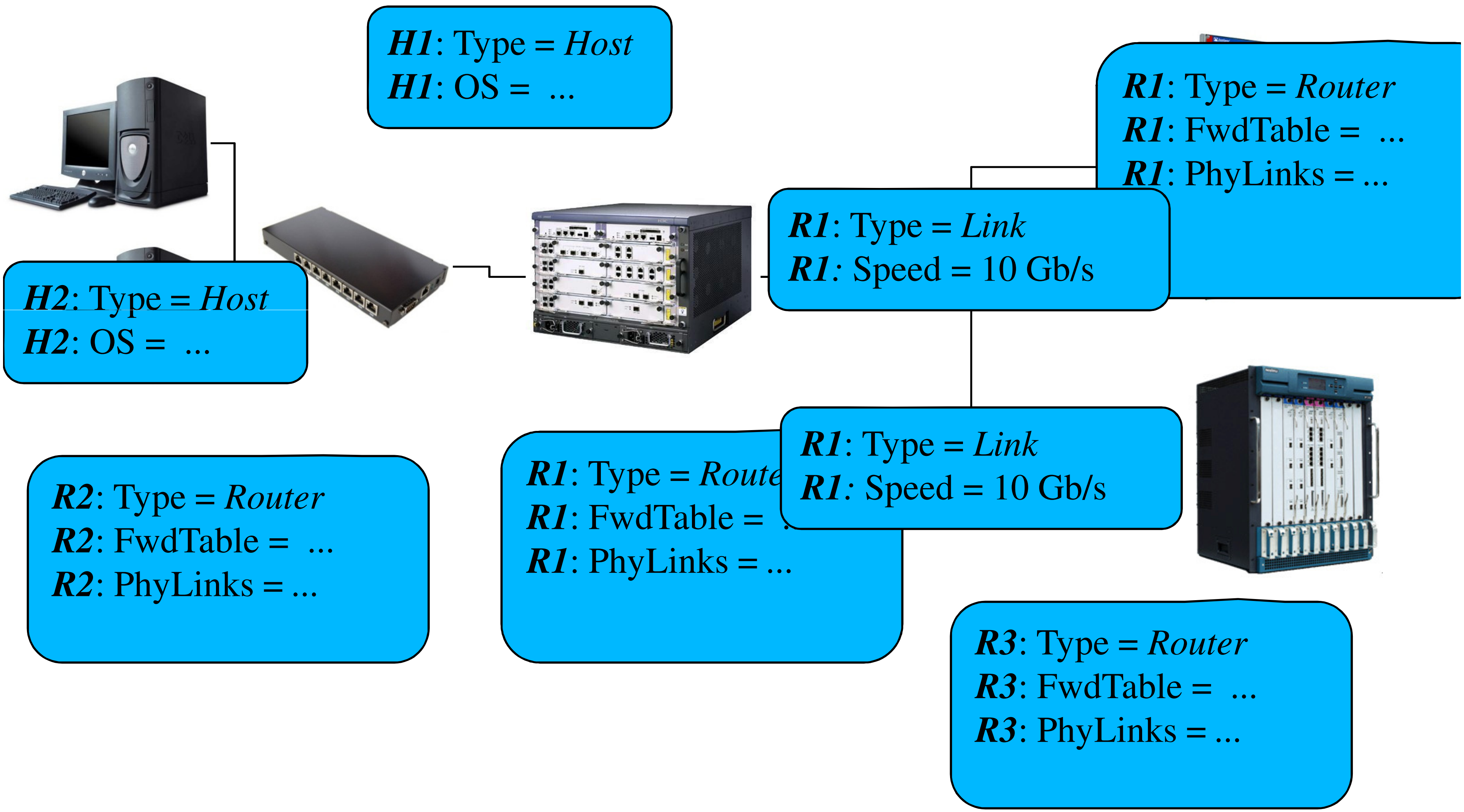
A Knowledge Plane

- A knowledge plane provides an interface and protocol for querying the network for meta-information
- A global, federated tuple-store that contains information about network elements
  - Physical devices, e.g. routers, switches, hosts, etc.
  - Virtual entities, e.g. flows, principals, ASes, etc.
- Information about each network element is stored in an associated **tuple**

Tuplespace Example



Tuplespace Example



Tuple Abstraction

- A tuple contains **factoids**, attribute-value pairs with an attribution to a source principal

Attribute name **Attribute value**

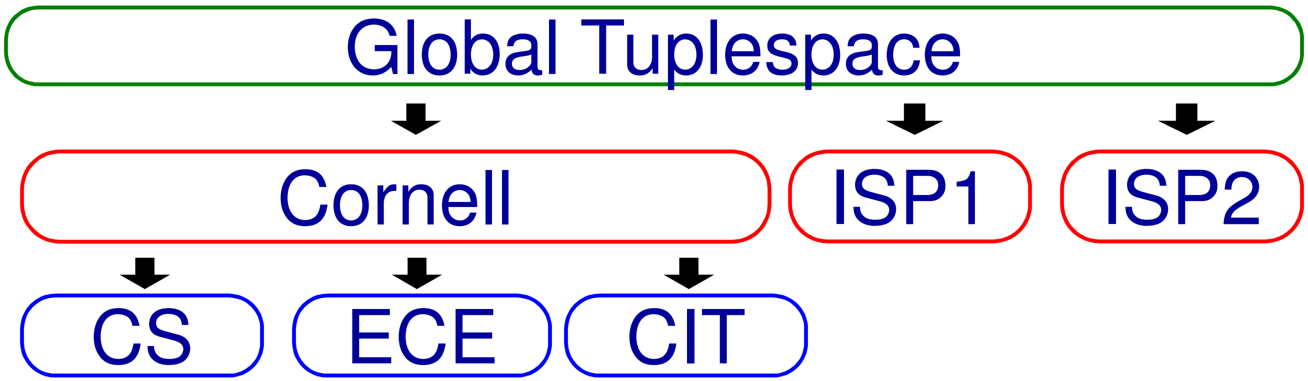
Principal $\boldsymbol{S}$: MachineType = *Router*

- Tuples are identified by a TupleID
  - Attribute values may reference other tuples

- Standard schemas define the base attributes for classes of network elements, e.g. routers, hosts, links, flows, etc

Tuplespace Implementation

- Tuplespace is federated



- A tuplespace server is just a server at an IP:PORT
  - Provided to devices at boot time
  - TupleIDs are simply IP:PORT:ID, a TupleID is sufficient to retrieve the tuple for that device
- Portions of the space can be delegated to other servers
  - All the way down to individual devices, if desired

Factoid Origins

- Factoids come from a variety of sources
  - NetQuery-aware devices provide their own factoids
  - An SNMP-bridge synthesizes tuples for legacy SNMP devices
  - Network administrators can manually create factoids
  - Third-parties can add factoids post-facto
- Why would anyone trust factoids?
- Why would anyone export factoids?

Trusting Factoids

- Secure coprocessors, such as the Trusted Platform Module, are cheap and ubiquitous

- TPMs can provide an **attestation chain** to back a statement about an attribute value
  - Generated by a secure coprocessor, with an embedded secret key

Attestation Chains

EK/AIK

ATMEL *says* TPM *speaksfor* Atmel on TPM.PlatformHash

OS

TPM *says* TPM.PlatformHash = Hash(IOS)

Factoid

IOS *says* IOS.LossRate(*Link1*) = *0.0032*

Trusting TPMs

- TPMs provide unforgeable attribution to a key
  - They do not make the platform any more trustworthy than it used to be
  - But they unforgeably identify the platform
  - So a consumer of an attestation chain can make an informed decision
- "Potemkin attacks" are possible
  - But there are countermeasures
- Applications can specify which principals they trust in an **import policy**

Collecting Factoids

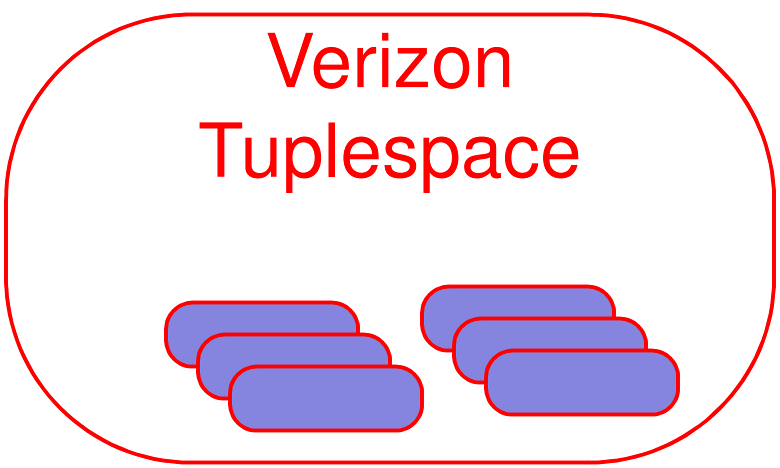
- Factoids are retrieved from the tuplespace servers by **queries**
- **Triggers** enable applications to be notified of changes to an attribute
  - Query-and-Set-Trigger for atomicity
- Received factoids that pass the import policy are loaded into a logic framework

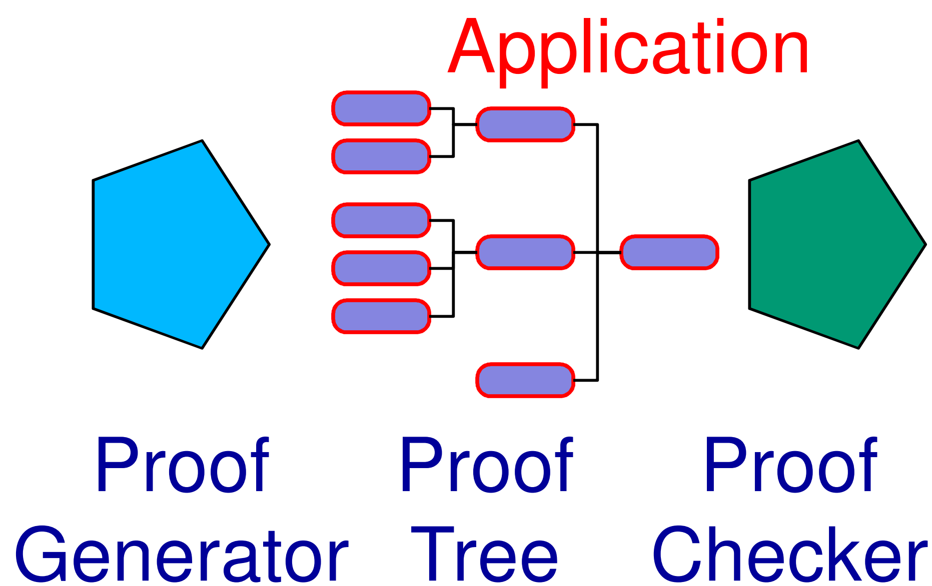
Reasoning with Factoids

- Applications are typically interested in a **characteristic**, a high-level property
  - E.g. do I have a good VOIP path?
- There are many ways to satisfy a desired characteristic using factoids from the network
  - E.g. "Trusted router reports low loss" or "I have an SLA with this AS"
- NetQuery applications import factoids from the tuplespace into a logical framework, and construct a proof of the characteristic

Factoid Confidentiality

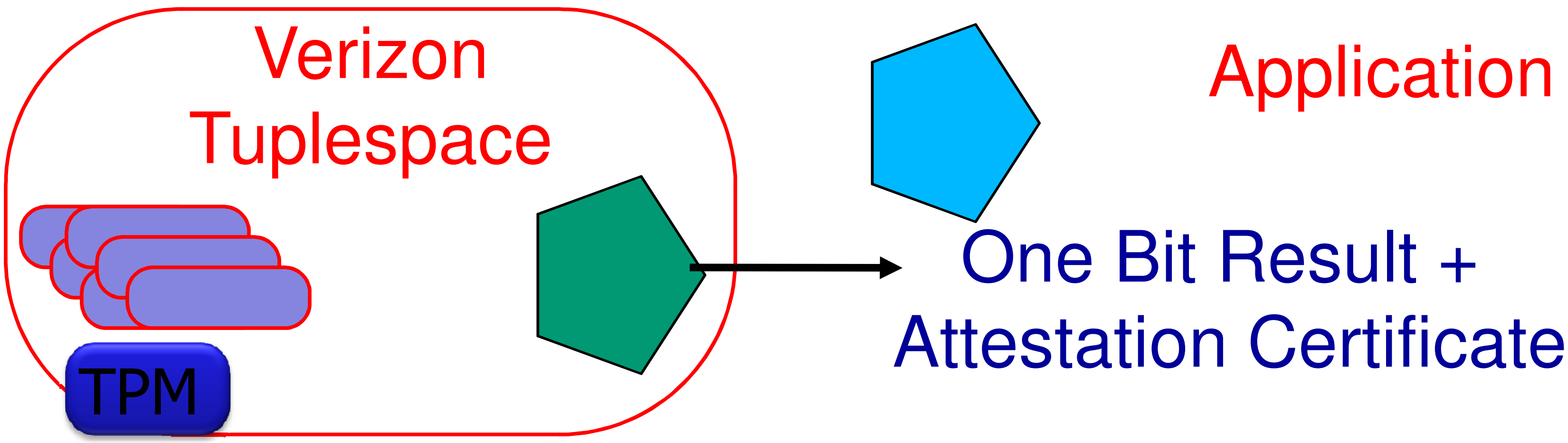
- ISPs do not like to reveal details of their internal operation
  - **Export policy** to restrict principals' access to factoids
  - **Secure remote evaluation** to confidentially create and check a proof, without leaking any factoids





Factoid Confidentiality

- ISPs do not like to reveal details of their internal operation
  - **Export policy** to restrict principals' access to factoids
  - **Secure remote evaluation** to confidentially create and check a proof, without leaking any factoids



NetQuery Prototype

- NetQuery client library
- Tuplespace server
- Logic framework and proof checker
- Devices
  - Host
  - Ethernet switch
  - BGP router
  - SNMP proxy
- Applications and proof generators

Example applications

- Network access control
- Topology quality
  - Over-subscription
  - Maximum capacity
  - Failover capacity
  - AS hop count
  - Wi-Fi access point quality
  - Network redundancy
- BGP configuration and peering
  - Mutual backup

NetQuery Prototype

Libraries	
Server & client	18,286
Logic Framework	2,254

Devices	
Host	543
Ethernet switch	1,853
Quagga router	777
SNMP proxy	1,578

Applications	
Network access control	787
L2/L3 traceroute	483
Oversubscription	356
Maximum capacity	316
Redundancy	333

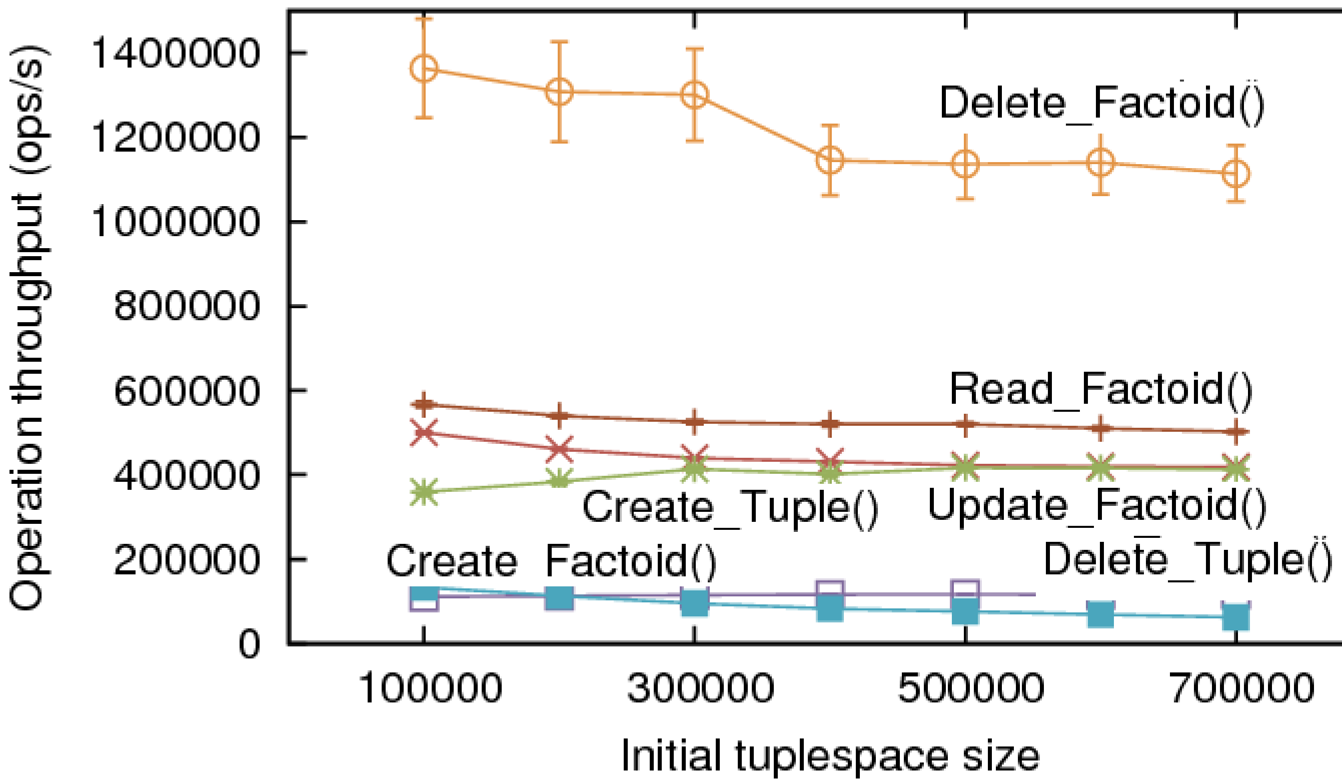
Testbed and datasets

- Compute cluster
  - 8-core 2.5 GHz Intel Xeon
  - 1 Gb/s Ethernet
- Departmental network
  - 73 L2/L3 switches (HP & Cisco)
  - >700 end hosts
- RouteViews BGP traces
- RocketFuel router-level topology

Feasibility evaluation

- Tuplespace performance
  - Is query rate suitable for applications?
  - What is the overhead for a typical device?
- Case studies and end-to-end performance
  - ISP topology
  - Deployment in department network

Query microbenchmark



Tuplespace server achieves high throughput

Analysis performance and overhead: CS department network

	Completion time (seconds)	Network cost (sent/recv'd)
L2/L3 traceroute	0.16 s	247 KB
Oversubscription	(pre-processing) 7.9 s (per-switch) 0.1 s	17 MB 0 KB
Best-case capacity	0.16 s	247 KB
Redundancy	12.65 s	24 MB

Analyses are suitable for service selection, slow changing topology

ISP topology

Play back RouteViews BGP update traces against BGP router

- Initialization: Load full BGP table (270K prefixes)
- Steady state: Average completion time of update

	Initialization	Steady state
Original	5.7 s	62.2 ms
With NetQuery	13.5 s	63.4 ms

Tuplespace servers can scale to typical POP size

Minimal impact on BGP convergence time.

Summary

- A federated, distributed knowledge plane that:
  - disseminates network properties through a uniform interface
  - incorporates attestation certificates
  - supports reasoning based on certified properties

- Enables many new applications that are not possible today

Proof checking speed: Network Access Control

- Check host process list against policy before allowing access
- Proof size:
  5 from host, 3 attestations — 8 factoids
- Check completion time: — 67 ms
  Dominated by verifying digital signatures on attestations

Completion time is appropriate for connect-time policy enforcement

ISP topology

Simulated IGP failures in RocketFuel topology

- Simulated whole POP on one machine
- 5% link failure rate

Global convergence time increase:

Mean	0.24s
Median	0.14s

Convergence time within ISPs' operational goals (< 1s)