Internet Infrastructure Measurement: Challenges and Tools

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Outline

- Motivation
- Challenges
- Tools
- Conclusion

Why Measure ?

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- Internet, with all its quirks, has prevailed in spite of the exponential growth witnessed in the last decade
- So, why bother measuring various aspects of it then ?

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- Topology Properties
  - Various levels – Autonomous Systems (AS), Points of Presence (PoP), Routers, Interfaces
- Traffic Properties
  - Delays (Transmission, Propagation, Queuing, Processing etc.), Losses, Throughput, Jitter

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  - Help us to better understand why it works the way it does
  - Help us to diagnose known problems and lead us one step closer to their solutions
  - Help us to design new features that the Internet should provide to enable next-generation application requirements

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Simply put, "Internet Measurements is key to the design of the next-generation Internet"

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The answer to all of these questions is NO

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- Reasons for this:
  - Core Simplicity
  - Layered architecture
  - Hidden Pieces
  - Administrative Barriers

Core Simplicity

- Keep It Simple Stupid (KISS) design principle
- Stateless nature w.r.t connections/flows
- End-to-End argument

As network elements do not track packets individually, interaction of traffic with the network is hard to observe

Layered Architecture

- IP hourglass model hides details of lower level layers
- While this provides abstraction improving interoperability, it impedes detailed visibility of lower layers
- Hence, even detailed measurements such as packet capture cannot detect differences between two types of links

Hidden Pieces - Middleboxes

- Firewalls – provide security
- Traffic Shapers – assist in traffic management
- Proxies – improve performance
- NAT boxes – utilize IP address space efficiently

Each of these impedes visibility of network components.

E.g.:

- firewalls may block active probing requests
- NATs hide away the no. of hosts and the structure of the network on the other side

Administrative Barriers

- Owing to the competition-sensitive nature of the data required (topology, traffic etc.), ISPs actively seek to hide these details from outside discovery
- Information that they do provide are often simplified.
  - E.g.: Instead of publishing router-level topologies, ISPs often publish PoP-level topologies

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Tools Classification

- Active Measurement
- Passive Measurement
- Fused/Combined Measurement
- Bandwidth Measurement
- Latency Measurement
- Geolocation
- Others

Active Measurement Tools

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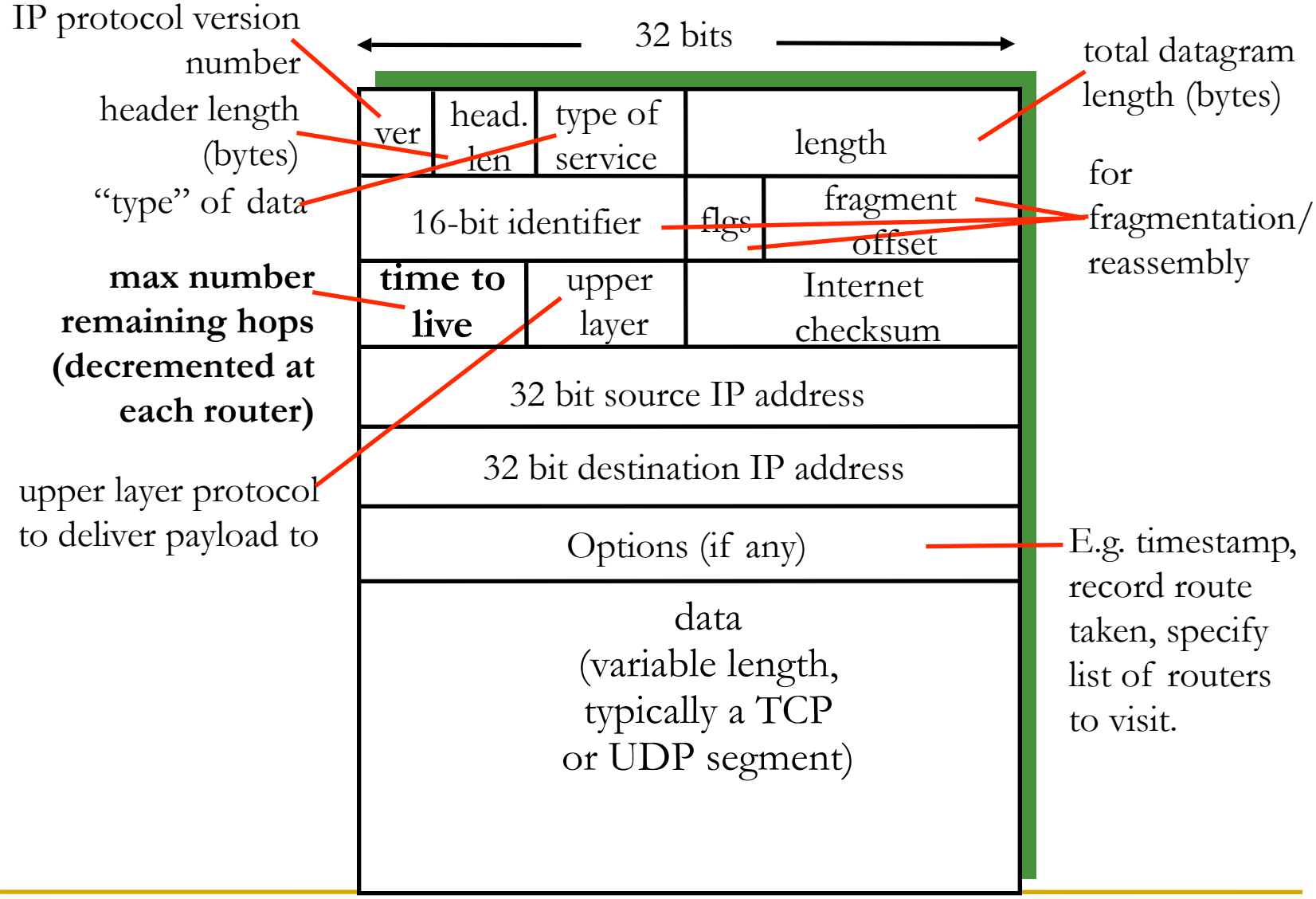
OWAMP: A daemon running on the target which listens for and records probe packets sent by the sender

- Useful for measuring one-way delay
- Requires both sender and receiver to be under experiment control
- Requires synchronized clocks or a method to remove clock offset

Traceroute

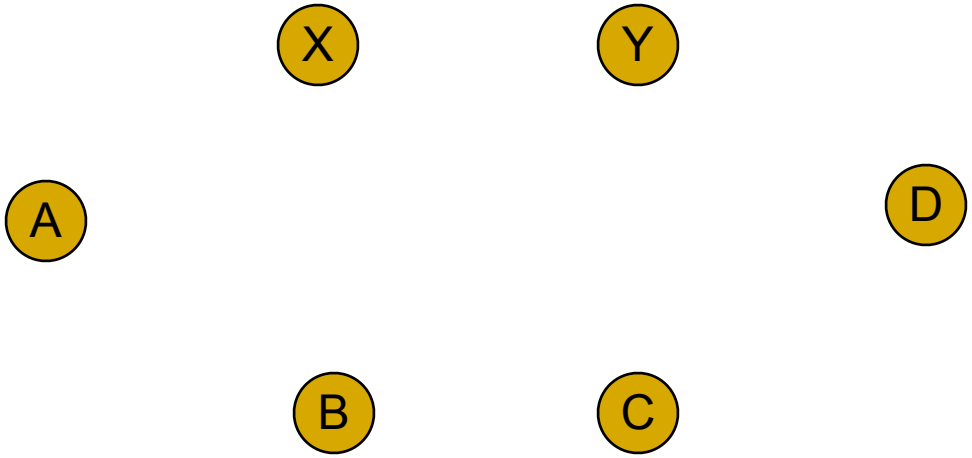
- Useful for determining path from a source to a destination
- Uses the TTL (Time To Live) field in the IP header in a clever but distorted way
- A large scale measurement system called *skitter* uses traceroute to discover network topology

IP Header and the TTL field

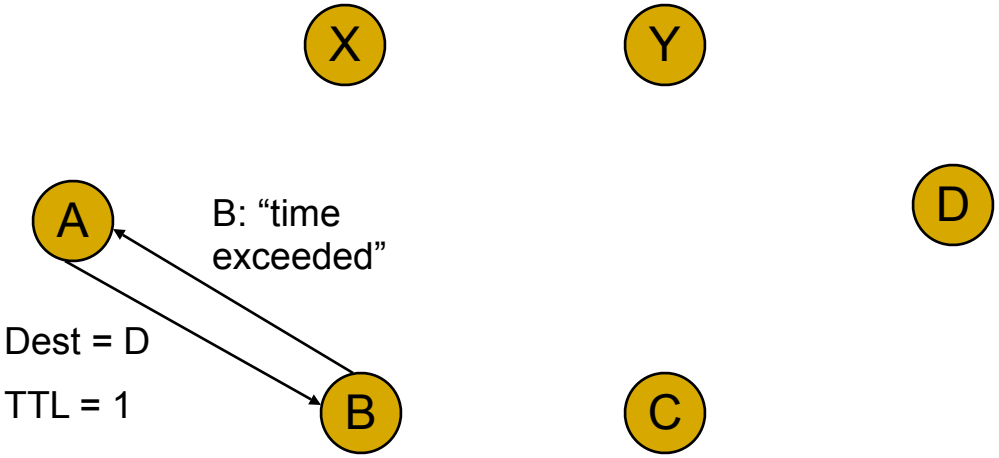


Traceroute Problem

- Suppose the path between A and D is to be determined using traceroute



Traceroute Process



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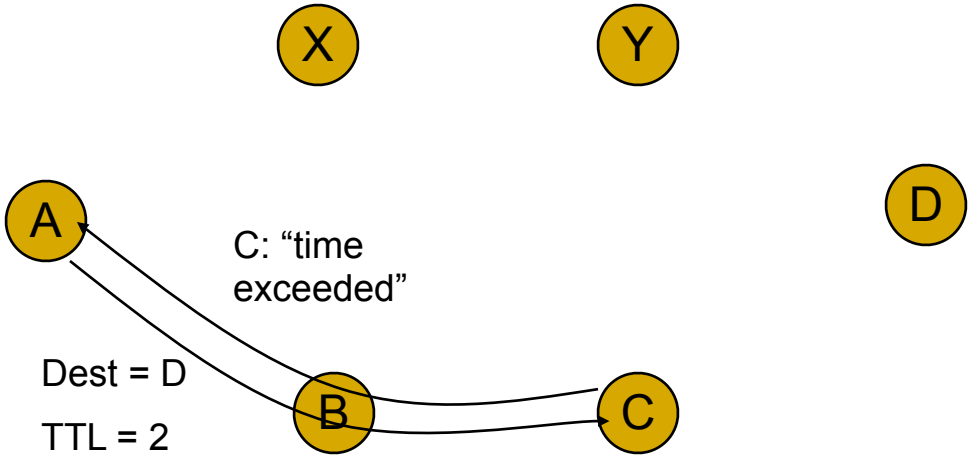

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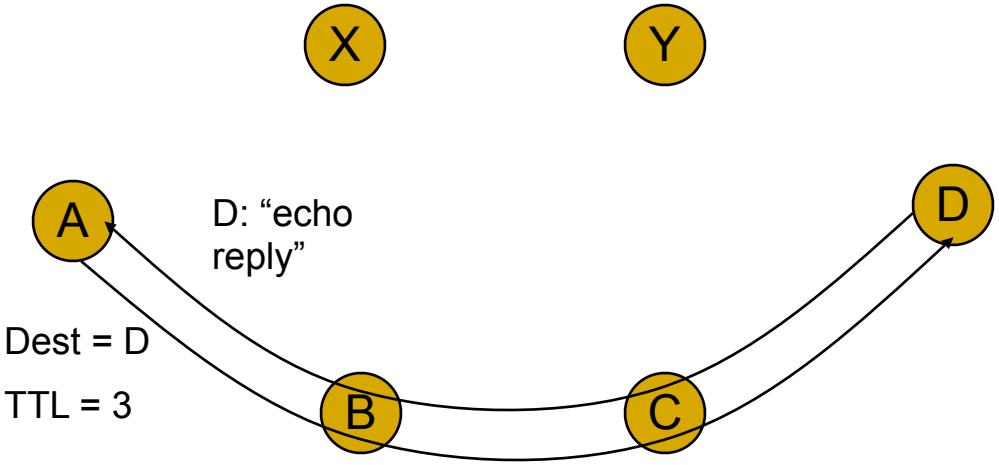
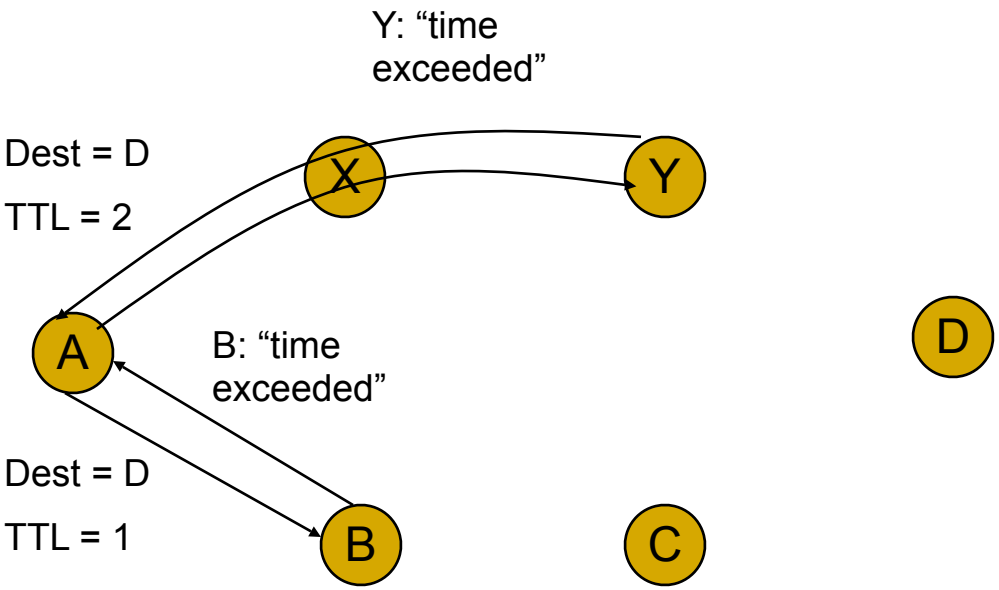


Traceroute issues

- Path Asymmetry (Destination -> Source need not retrace Source -> Destination)
- Unstable Paths and False Edges
- Aliases
- Measurement Load

Unstable Paths and False Edges

Inferred path: A -> B -> Y



Aliases

- IP addresses are for interfaces and not routers
- Routers typically have many interfaces, each with its own IP address
- IP addresses of all the router interfaces are aliases
- Traceroute results require resolution of aliases if they are to be used for topology building

Measurement Load

- Traceroute inserts considerable load on network links if attempting a large-scale topology discovery

- Optimizations reduce this load considerably

E.g.:

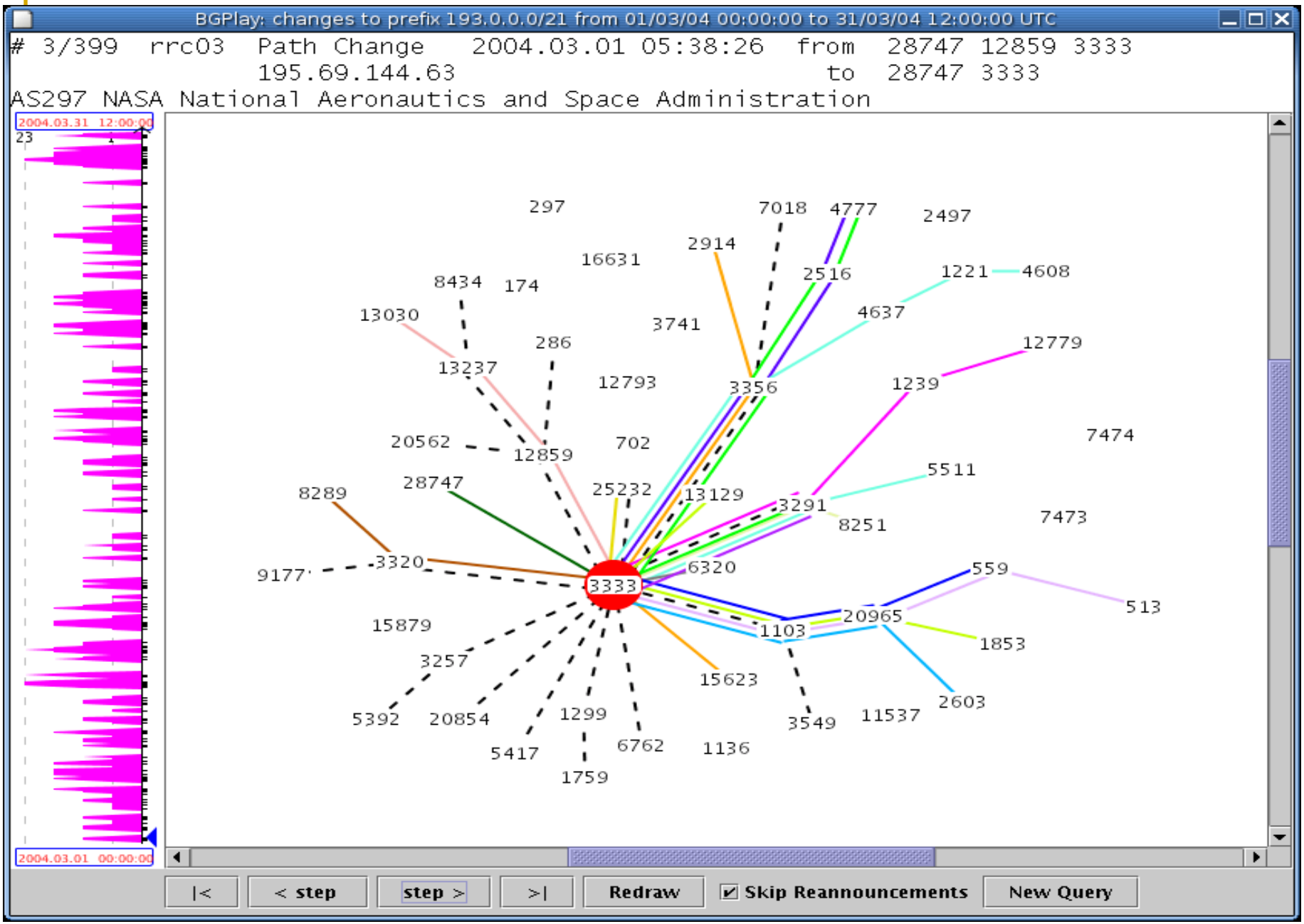
  - If single source is used, instead of going from source to destination, a better approach is to retrace from destination to source
  - If multiple sources and multiple destinations are used, sharing information among these would bring down load considerably

System Support

- Efficient packet injection and accurate measurement of arrival and departure times are best done at kernel level
- Using Scriptroute, unprivileged users can inject and capture packets
- Periscope's API helps define new probing structures and inference techniques for extracting results from arrival patterns of responses
- Unrestricted access to the network interface raises security concerns

Passive Measurement

- Methods that capture traffic generated by other users and applications to build the topology
- Routeview repository collects BGP views (routing tables) from a large set of ASes
- Similarly, OSPF LSAs can be captured and processed to generate router graphs within an AS


BGPlay: changes to prefix 193.0.0.0/21 from 01/03/04 00:00:00 to 31/03/04 12:00:00 UTC
3/399 rrc03 Path Change 2004.03.01 05:38:26 from 28747 12859 3333
195.69.144.63 to 28747 3333
AS297 NASA National Aeronautics and Space Administration
2004.03.31 12:00:00
2004.03.01 00:00:00
297
7018
4777
2497
2914
16631
2516
1221
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8434
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Skip Reannouncements
New Query

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- However, especially using BGP views, there could be potential loss of cross-connections between ASes which are along the path
- Secondly, route aggregation and filtering tends to hide some connections
- Also, multiple connections between ASes will be shown as a single connection in the graph

Bandwidth Measurement

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- Three kinds of bandwidth –
  - *capacity:* max throughput a link can sustain,
  - *available bandwidth:* capacity – used bandwidth and
  - *bulk transfer capacity:* rate that a new single long-lived TCP connection would obtain over a path

Bandwidth Measurement Methods

- These focus on observing how packet delay (queuing and transmission) is affected by link properties

Four types:

- Packet-pair Methods
- Size-delay Methods
- Self-induced Congestion
- Bulk Transfer Capacity Measurement

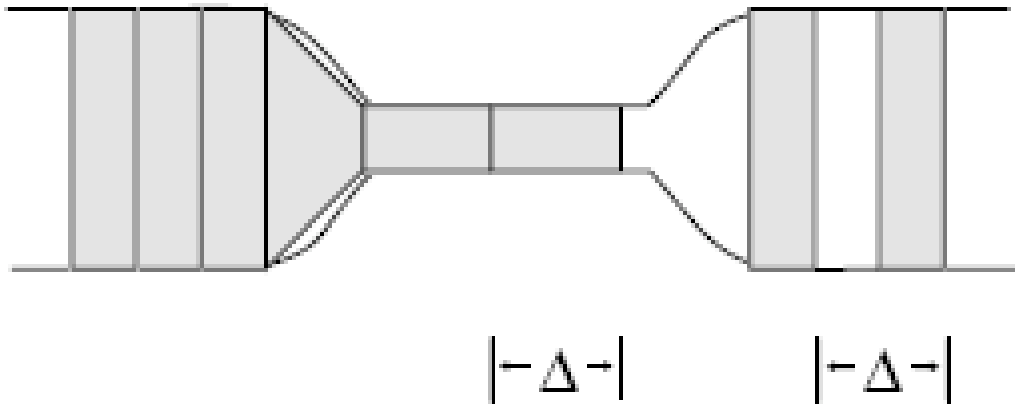
Packet-Pair Methods

- Methods to measure capacity and available bandwidth
- Involve sending probe packets with known inter-packet gaps and measuring the same gap downstream
- Capacity is calculated using the eqn:

  C = L / max delta,

  where C is the capacity, L is the length of probe packets, max delta is the maximum inter-packet gap measured downstream
- Assumes there is no cross-traffic

Packet-Pair Methods



$$\Delta_{H+1} = \max_{i \in 0,\ldots,H} \left(\Delta_i, \frac{L}{C_i} \right) = \frac{L}{\min_{i \in 0,\ldots,H} C_i} = \frac{L}{C}$$

Size Delay Methods

- Useful for measuring link capacities on each link along a path
- Based on the observation that transmission delay is affected by link capacity and packet size
- The idea is to send many different sized packets and measure the difference in delays affected by packet size.
- Then the capacity of each link will be a function of these differences
- Method assumes there is no cross-traffic, no queuing delays, no variation in packet size
- Measurements become less accurate if the length of the path grows

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- FIFO order is not guaranteed in wireless links
- Layer 2 devices can cause underestimation of a IP hop's capacity by introducing additional transmission delays

Geolocation

- Given the network address of a target host, what is the host's geographic location ?
- The answer to this is useful for a wide variety of social, economic and engineering purposes
- The actual location of network infrastructure sheds light on how it relates to population, social organization and economic activity

Geolocation methods

- Name Based Geolocation – Extracting location details from ISPs domain names
- Delay Based Geolocation – two types:
  - Best Landmark
  - Constraint-based

Landmark based geolocation

- In best landmark approach, minRTT between each of the identified landmarks is measured and stored.

$$\vec{\ell_i} = [d(\ell_i, \ell_1),\ d(\ell_i, \ell_2), \ldots,\ (\ell_i, \ell_N)].$$

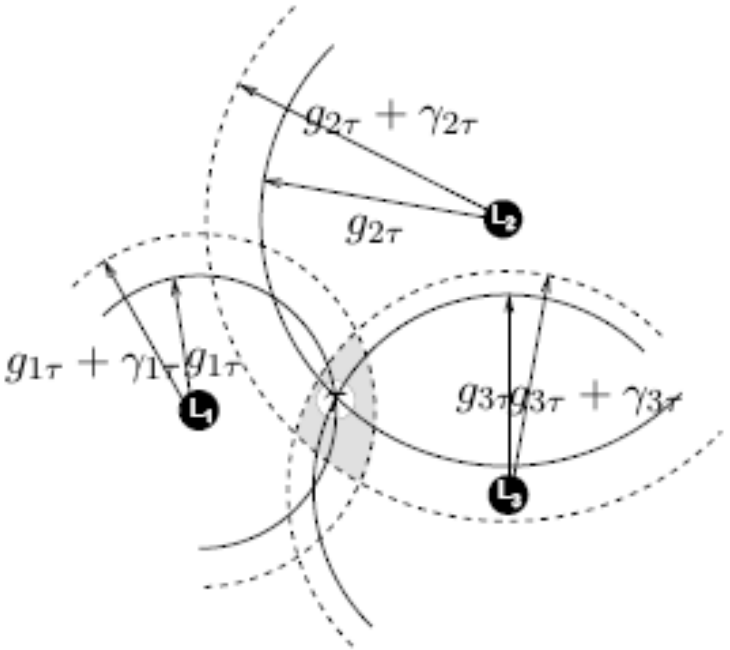
- Then the same metric is calculated between the node in question and each of the landmarks.

$$\vec{\tau} = [d(\tau, \ell_1),\ d(\tau, \ell_2), \ldots,\ (\tau, \ell_N)].$$

- The landmark with the best matching values of minRTT is the closest to the node

Constraint based geolocation

- In constraint-based approach, the distances of target location from sufficient number of fixed points are calculated and using multilateration, the position is determined

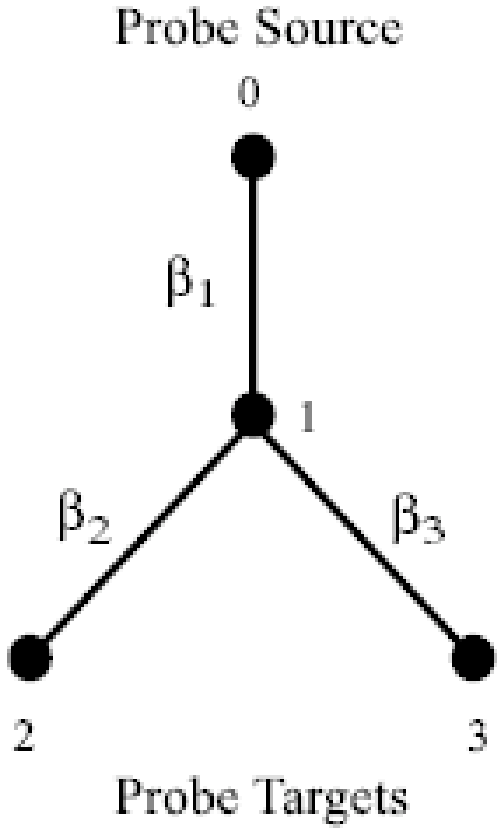


Network Tomography

- A process of inferring network topology, delays, packet losses etc. using only end-to-end measurements
- One needs to make many assumptions about the behavior of the underlying network

Network Tomography – Multicast based method

- Multicast based method e.g. to figure out the loss rates



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Internet Measurements are anything but straightforward…

- Internet Measurement is key to designing the next generation communication network
- Fundamental design principles of the current internet make it harder for measuring various aspects of it
- Preliminary research has resulted in a set of basic tools and methods to measure aspects like topology, traffic etc.
- Accuracy of such methods is still an open question
- There is still a lot of ground to cover in this direction and this is where researchers like you come into the equation!

TTL normal usage

- TTL is initialized by the sender and decremented by one each time the packet passes through a router
- If it reaches zero before reaching the destination, IP protocol requires that the packet be discarded and an error message be sent back to the sender
- Error message is an ICMP “time exceeded” packet