Measurement:
Techniques, Strategies, and Pitfalls

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Many (most) slides in this lecture from
Nick Feamster's measurement lecture

Internet Measurement

- Process of collecting data that measure certain phenomena about the network
  - *Should be a science*
  - *Today: closer to an art form*
- **Key goal:** Reproducibility
- "Bread and butter" of networking research
  - *Deceptively complex*
  - *Probably one of the most difficult things to do correctly*

Types of Data

Active

- traceroute
- ping
- UDP probes
- TCP probes
- Application-level “probes”
  - *Web downloads*
  - *DNS queries*

Passive

- Packet traces
  - *Complete*
  - *Headers only*
  - *Specific protocols*
- Flow records
- Specific data
  - *Syslogs …*
  - *HTTP server traces*
  - *DHCP logs*
  - *Wireless association logs*
  - *DNSBL lookups*
  - *…*
- Routing data
  - *BGP updates / tables, ISIS, etc.*

Outline: Tools and Pitfalls

- Aspects of Data Collection
  - ***Precision:*** *At what granularity are measurements taken?*
  - ***Accuracy:*** *Does the data capture phenomenon of interest?*
  - ***Context:*** *How was the data collected?*
- Tools
  - *Active*
    - Ping, traceroute, etc.
    - **Accuracy pitfall example:** traceroute
  - *Passive*
    - Packet captures (*e.g.*, tcpdump, DAG)
    - Flow records (*e.g.,* netflow)
    - Routing data (*e.g.,* BGP, IS-IS, etc.)
    - **Context pitfall example:** eBGP multihop data collection

Outline (continued)

- Strategies
  - *Cross validate*
    - consistency checks
    - multiple “overlapping” measurements
  - *Examine Zeroth-Order*

- Database as secret weapon

- Other considerations
  - *Anonymization and privacy*
  - *Maintaining longitudinal data*

Active Measurement

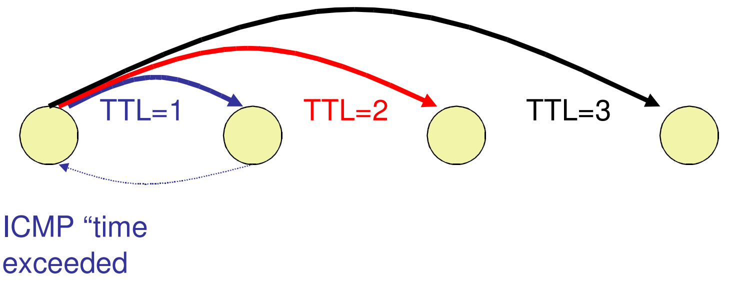
- Common tools:
  - *Ping*
  - *traceroute*
  - *scriptroute (see homework)*

Sample Question: Topology

- What is the topology of the network?
  - *At the IP router layer*
  - *Without "inside" knowledge or official network maps*
  - *Without SNMP or other privileged access*
  -
- Why do we care?
  - *Often need topologies for simulation and evaluation*
  - *Intrinsic interest in how the Internet behaves*
    - "But we built it! We should understand it"
    - Emergent behavior; organic growth

How Traceroute Works

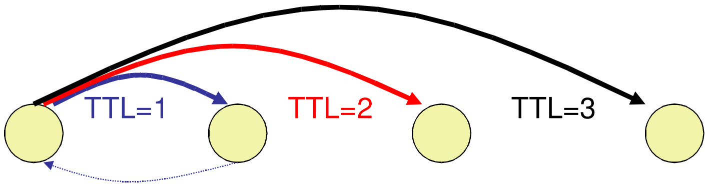
- Send packets with increasing TTL values



- Nodes along IP layer path decrement TTL
- When TTL=0, nodes return "time exceeded" message

Problems with Traceroute

- Can’t unambiguously identify one-way outages
  - *Failure to reach host : failure of reverse path?*
- ICMP messages may be filtered or rate-limited
- IP address of “time exceeded” packet may be the *outgoing* interface of the *return* packet



Famous Traceroute Pitfall

- **Question: What ASes does traffic traverse?**
- **Strawman approach**
  - *Run traceroute to destination*
  - *Collect IP addresses*
  - *Use “`whois`” to map IP addresses to AS numbers*
- Thought Questions
  - *What IP address is used to send “time exceeded” messages from routers?*
  - *How are interfaces numbered?*
  - *How accurate is whois data?*

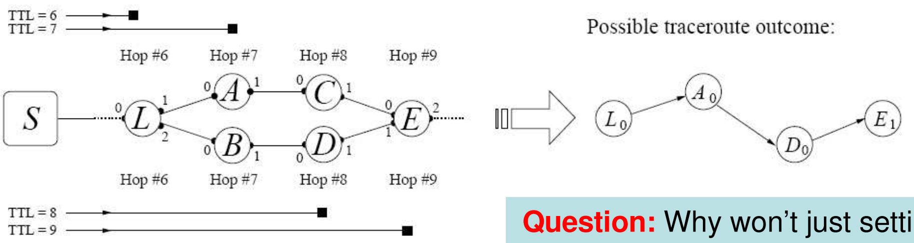
More Caveats: Topology Measurement

- Routers have multiple interfaces
- Measured topology is a function of vantage points

- **Example:** Node degree
  - *Must "alias" all interfaces to a single node (PS 2)*
  - *Is topology a function of vantage point?*
    - Each vantage point forms a tree
    - See Lakhina *et al.*
- *(preview of homework! :)*

Less Famous Traceroute Pitfall

- Host sends out a sequence of packets
  - *Each has a different destination port*
  - *Load balancers send probes along different paths*
    - Equal cost multi-path
    - Per flow load balancing



Question: Why won't just setting same port number work?

Soule *et al.*, "Avoiding Traceroute Anomalies with Paris Traceroute", *IMC 2006*

Designing for Measurement

- What mechanisms should routers incorporate to make traceroutes more useful?
  - *Source IP address to "loopback" interface*
  - *AS number in time-exceeded message*
  - *??*
- More general question: How should the network support measurement (and management)?

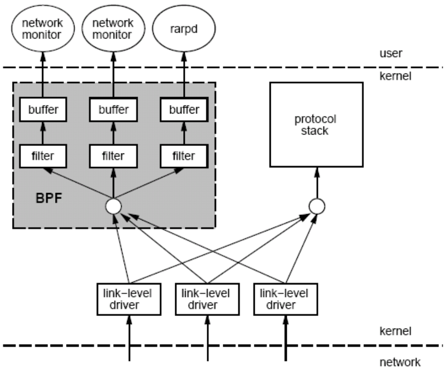
Passive Measurement

Two Main Approaches

- Packet-level Monitoring
  - *Keep packet-level statistics*
  - *Examine (and potentially, log) variety of packet-level statistics. Essentially, anything in the packet.*
  - ***Timing***
- Flow-level Monitoring
  - *Monitor packet-by-packet (though sometimes sampled)*
  - *Keep aggregate statistics on a flow*

Packet Capture: tcpdump/bpf

- Put interface in promiscuous mode
- Use bpf to extract packets of interest



Accuracy Issues

- Packets may be dropped by filter
  - Failure of tcpdump to keep up with filter
  - Failure of filter to keep up with dump speeds

Question: How to recover lost information from packet drops?

Traffic Flow Statistics

- *SNMP (Simple Network Management Protocol)*
  - Get # of packets across interface per 5min
  - or other similar very coarse stats
  -
- *Flow monitoring* (*e.g.*, Cisco Netflow)
  - *Statistics about groups of related packets (e.g., same IP/TCP headers and close in time)*
  - *Records header information, counts, and time*
  - *May be sampled*

What is a flow?

- **Source IP address**
- **Destination IP address**
- **Source port**
- **Destination port**
- **Layer 3 protocol type**
- TOS byte (DSCP)
- Input logical interface (ifIndex)

Flow Record Contents

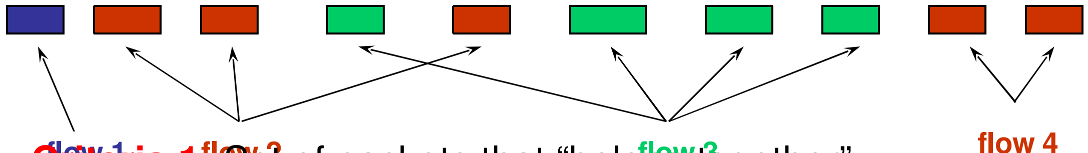
Basic information about the flow…

- Source and Destination, IP address and port
- Packet and byte counts
- Start and end times
- ToS, TCP flags

…plus, information related to routing

- Next-hop IP address
- Source and destination AS
- Source and destination prefix

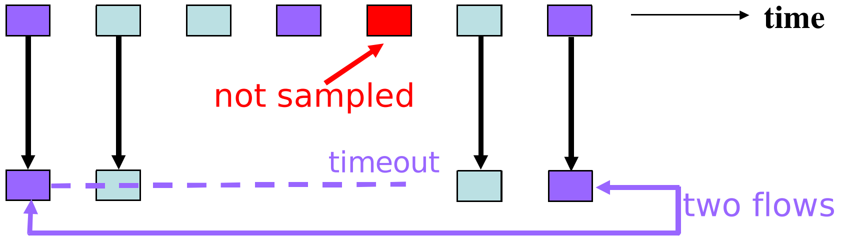
Aggregating Packets into Flows



- **Criteria 1:** Set of packets that "belong together"
  - *Source/destination IP addresses and port numbers*
  - *Same protocol, ToS bits, …*
  - *Same input/output interfaces at a router (if known)*
- **Criteria 2:** Packets that are "close" together in time
  - *Maximum inter-packet spacing (e.g., 15 sec, 30 sec)*
  - ***Example:** flows 2 and 4 are different flows due to time*

Packet Sampling

- Packet sampling before flow creation (Sampled Netflow)
  - *1-out-of-m sampling of individual packets (e.g., m=100)*
  - *Create of flow records over the sampled packets*
- Reducing overhead
  - *Avoid per-packet overhead on (m-1)/m packets*
  - *Avoid creating records for a large number of small flows*
- Increasing overhead (in some cases)
  - *May split some long transfers into multiple flow records*
  - *… due to larger time gaps between successive packets*



time

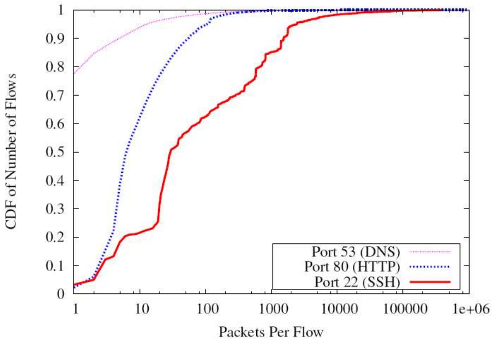
not sampled

timeout

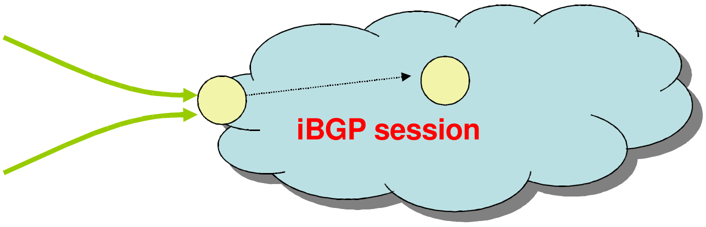
two flows

Problems with Packet Sampling

- Determining size of original flows is tricky
- Flow records can be lost
- Small flows may be eradicated entirely
- Flow sampling can provide better accuracy
  - *But requires measuring every packet still*
- Lots of research looking at sampling techniques, etc.



Routing Data



- IGP
- BGP
  - *Collection methods*
    - eBGP (typically “multihop”)
    - iBGP
  - *Table dumps: Periodic, complete routing table state (direct dump from router)*
  - *Routing updates: Continuous, incremental, best route only*

Why Trust Your Data?

- Measurement requires a degree of suspicion
  - *Why should I trust your data? Why should you?*
- Resolving that...
  - *Use current best practices*
    - e.g., paris-traceroute, CAIDA topologies, etc.
  - *Don't trust the data until forced to*
    - Sanity checks and cross-validation
    - Spot checks (when applicable)

Context Pitfall: AS-Level Topologies

- **Question:** What is the Internet’s AS-level topology?
- **Strawman approach**
  - *Routeviews routing table dumps*
  - *Adjacency for each pair of ASes in the AS path*

- Problems with the approach?
  - ***Completeness:*** *Many edges could be missing. Why?*
    - Single-path routing
    - Policy: ranking and filtering
    - Limited vantage points
  - ***Accuracy***
  - ***Coarseness***

Context Pitfall: Routing Instability

- **Question:** Does worm propagation cause routing instability?
- **Strawman approach:**
  - *Observe routing data collected at RIPE RIRs*
  - *Correlate routing update traffic in logs with time of worm spread*
  - *Finding: Lots of routing updates at the time of the worm sprreading!*
  - ***(Bogus) conclusion:*** *Worm spreading causes route instability*

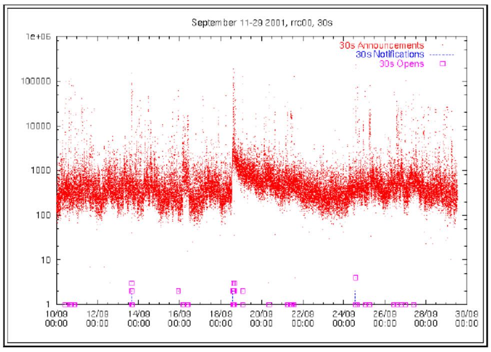


Figure 5: A zoom-in on the BGP message storm of 18–22 September.

Cowie *et al.*, “Global Routing Instabilities Triggered by Code Red II and Nimda Worm Attacks”

Missing/Ignored Context: Instability + eBGP multihop …

Strategy: Examine the Zeroth-Order

- Paxson calls this “looking at spikes and outliers”
- **More general:** Look at the data, not just aggregate statistics
  - *Tempting/dangerous to blindly compute aggregates*
  - *Timeseries plots are telling (gaps, spikes, etc.)*
  - *Basics*
    - Are the raw trace files empty?
      - Need not be 0-byte files (*e.g.*, BGP update logs have state messages but no updates)
    - Metadata/context: Did weird things happen during collection (machine crash, disk full, etc.)

Strategy: Cross-Validation

- Paxson breaks cross validation into two aspects
  - *Self-consistency checks (and sanity checks)*
  - *Independent observations*
    - Looking at same phenomenon in multiple ways

- What are some other examples of each of these?

Example Sanity Checks

- Is time moving backwards?
  - *Paxson's probing example*
  - ***Typical cause:** Clock synchro*
- Has the the speed of light increased?
  - *E.g., 10ms cross-country latencies*
- Do values make sense?
  - *IP addresses that look like 0.0.1.2 indicate bug*

Cross-Validation Example

- Traceroutes captured in parallel with BGP routing updates
- **Puzzle**
  - *Route monitor sees route withdrawal for prefix*
  - *Routing table has no route to the prefix*
  - *IP addresses within prefix still reachable from within the IP address space (i.e., traceroute goes through)*
- Why?
  - *Collection bugs … or*
  - *Broken mental model of routing setup: A default route!*

Databases: Secret Weapon

- Easy way to get lots of summary statistics
  - *Regular first-order stats (cf. Paxson's recommendation)*
    - Latest timestamp, number of updates, etc.
  - ***Cross-validation** becomes easier (quick and dirty SQL)*
  - ***Joint analysis** of diverse datasets is a common need*

- **Caveats!**
  - *Insertion must be done properly*
    - Always, always save raw data

Horror Story #1: Buggy Postprocessing

- Logs maintained at each host
- Files collected and merged to compute one-way delays

Example RON Monitoring Logs

```
1103659228.224614 S 14b13270 0 8 18.7.14.168 66.26.83.103
1103659228.252509 R 14b13270 1 8 18.7.14.168 66.26.83.103
1103659229.388441 S 55a4b9a1 0 8 18.7.14.168 192.249.24.10
1103659229.611096 R 55a4b9a1 1 8 18.7.14.168 192.249.24.10
1103659231.200177 S bf1207a0 0 8 18.7.14.168 12.46.129.20
1103659231.270053 R bf1207a0 1 8 18.7.14.168 12.46.129.20
1103659233.109900 S 55e244c0 0 8 18.7.14.168 112.12.8.0
1103659234.308722 S 8ba24c76 0 8 18.7.14.168 18.97.168.219
```

- If corresponding ends of logfile missing: set receive time to zero.

"Does the extra effort matter?" (Paxson)

- What if the log files don't match up in time properly?
- What about missing log files?

Longitudinal measurement hard

- Accurate distributed measurement is tricky!
- Lots of things change:
  - *Host names, IPs, software*
- Lots of things break
  - *hosts (temporary, permanently)*
  - *clocks*
  - *links*
  - *collection scripts*
- Paxson's "master script" can help a bit

Anonymization

- Similar questions arise here as with accuracy
- Researchers always want full packet captures with payloads
  - *…but many questions can be answered without complete information*
- Common methods:
  - *Nulling out low-order IP bytes*
  - *hashing IP addresses*

- Privacy / de-anonymization issues

PlanetLab for Network Measurement

- Nodes are largely at academic sites
  - *Other alternatives: RON testbed (disadvantage: smaller, less software support)*
- Repeatability of network experiments is tricky
  - *Proportional sharing*
    - Minimum guarantees provided by limiting the number of outstanding shares
  - *Work-conserving CPU scheduler means experiment could get more resources if there is less contention*