Network Measurement

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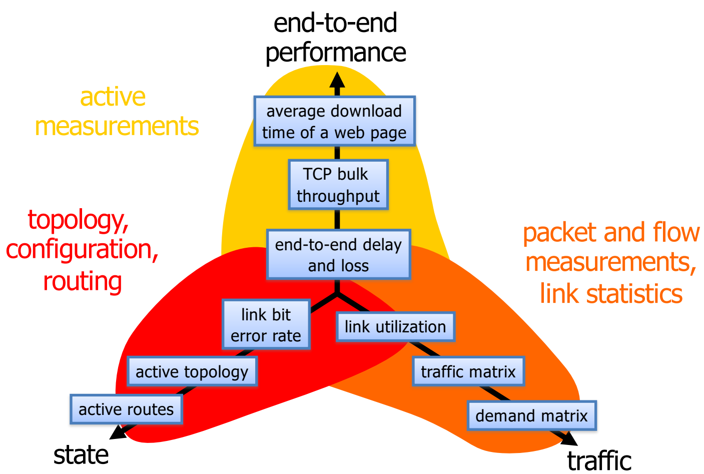
COS 461: Computer Networks

http://www.cs.princeton.edu/courses/archive/spr20/cos461/

Why Measure the Network?

- Scientific discovery
  - Characterizing traffic, topology, performance
  - Understanding protocol performance and dynamics
- Network operations
  - Billing customers
  - Detecting, diagnosing, and fixing problems
  - Planning outlay of new equipment

Types of Measurement

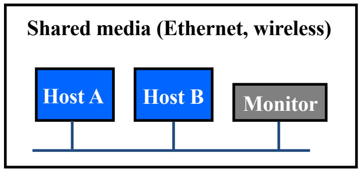


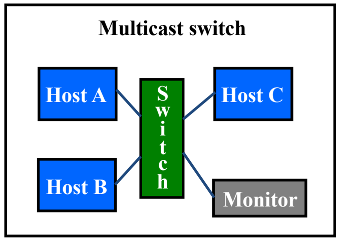
Traffic Measurement

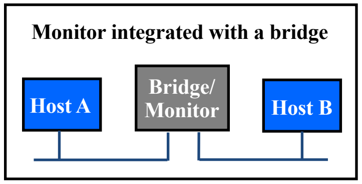
Packet Monitoring

- Definition
  – Passively collecting IP packets on one or more links
  – Recording IP, TCP/UDP, or application-layer traces
- Scope
  – Fine-grain information about user behavior
  – Passively monitoring the network infrastructure
  – Characterizing traffic and diagnosing problems

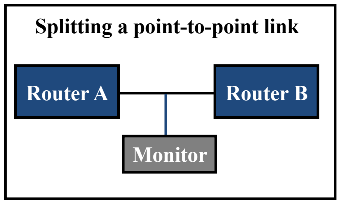
Monitoring a LAN Link

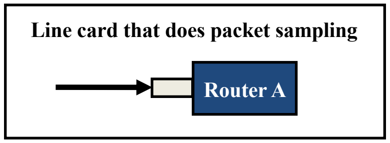






Monitoring a WAN Link





Selecting the Traffic

- Filter to focus on a subset of the packets
  – IP addresses/prefixes (e.g., to/from specific sites)
  – Protocol (e.g., TCP, UDP, or ICMP)
  – Port numbers (e.g., HTTP, DNS, BGP, Napster)
- Collect first n bytes of packet
  – Medium access control header (if present)
  – IP header (typically 20 bytes)
  – IP+UDP header (typically 28 bytes)
  – IP+TCP header (typically 40 bytes)
  – Application-layer message (entire packet)

What to measure to..

- Understand router workload model
  - Distribution of packet sizes
- Quantify web transfer sizes
  - Number of packets/bytes per connection
- Which servers are popular & who heavy clients are
  - Collect source/destination IP address (on port 80)
  - Collection application URLs (harder!)
- If a denial-of-service attack is underway
  - SYN flooding (spoofable)
  - Unusual # requests to particular (expensive) page

Analysis of IP Header Traces

- Source/destination addresses
  - Identity of popular Web servers & heavy customers
- Distribution of packet delay through the router
  - Identification of typical delays and anomalies
- Distribution of packet sizes
  - Workload models for routers
- Burstiness of the traffic on the link over time
  - Provisioning rules for allocating link capacity
- Throughput between pairs of src/dest addresses
  - Detection and diagnosis of performance problems

TCP Header Analysis

- Source and destination port numbers
  - Popular applications; parallel connections
- Sequence/ACK numbers and packet timestamps
  - Out-of-order/lost packets; throughput and delay
- Number of packets/bytes per connection
  - Web transfer sizes; frequency of bulk transfers
- SYN flags from client machines
  - Unsuccessful requests; denial-of-service attacks
- FIN/RST flags from client machines
  - Frequency of Web transfers aborted by clients

Packet Contents

- Application-layer header
  - HTTP and RTSP request and response headers
  - FTP, NNTP, and SMTP commands and replies
  - DNS queries and responses; OSPF/BGP messages
- Application-layer body
  - HTTP resources (or checksums of the contents)
  - User keystrokes in Telnet/Rlogin sessions

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Application-Layer Analysis

- URLs from HTTP request messages
  - Popular resources/sites; benefits of caching
- Meta-data in HTTP request/response messages
  - Content type, cacheability, change frequency, etc.
  - Browsers, protocol versions, protocol features, etc.
- Contents of DNS messages
  - Common queries, error frequency, query latency
- Contents of Telnet/Rlogin sessions
  - Intrusion detection (break-ins, stepping stones)

Flow Measurement (e.g., NetFlow)

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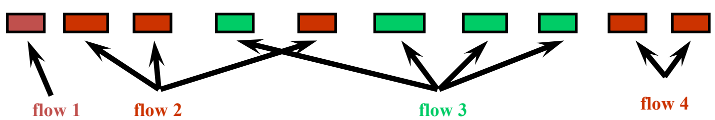
IP Flows



- 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)
- Packets that are "close" together in time
  - Maximum spacing between packets (e.g. 30 sec)
  - E.g.: flows 2 and 4 are different flows due to time

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Flow Abstraction

- Not exactly the same as a "session"
  - Sequence of related packets may be multiple flows
  - Related packets may not follow the same links
  - "Session" is hard to measure from inside network
- Motivation for this abstraction
  - As close to a "session" as possible from outside
  - Router optimization for forwarding/access-control
  - … might as well throw in a few counters

Traffic Statistics (e.g., Netflow)

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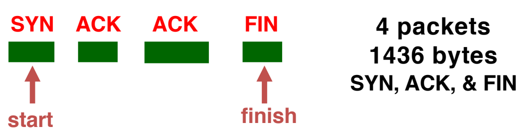
- Packet header info
  - Source and destination addresses and port #s
  - Other IP & TCP/UDP header fields (protocol, ToS)
- Aggregate traffic information
  - Start and finish time (time of first & last packet)
  - Total # of bytes and number of packets in the flow
  - TCP flags (e.g., logical OR over sequence of packets)



Measuring Traffic as it Flows By

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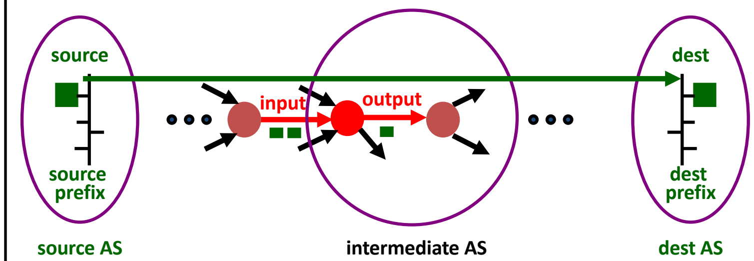

Source and destination: IP header

Source and dest prefix: forwarding table or BGP table

Source and destination AS: BGP table

Collecting Flow Measurements

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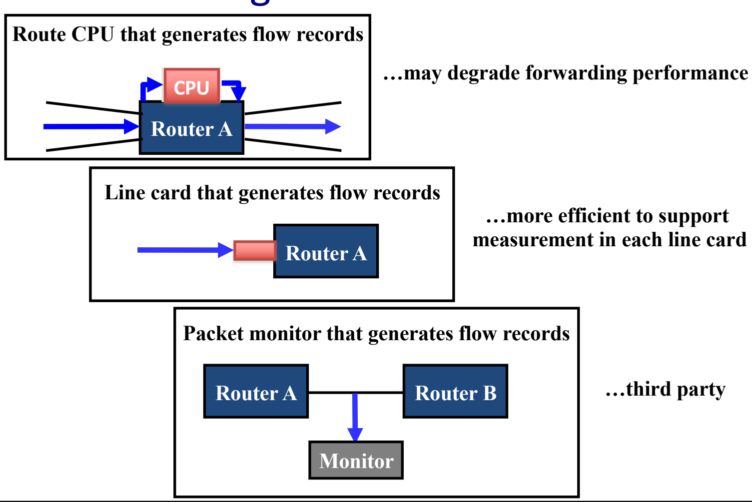

Mechanics: Flow Cache

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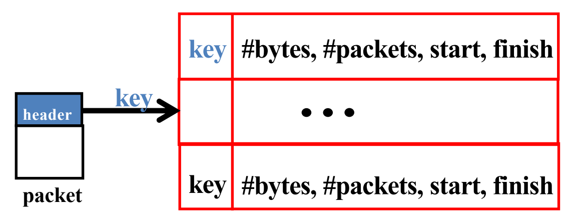
- Maintain a cache of active flows
  - Storage of byte/packet counts, timestamps, etc.
- Compute a key per incoming packet
  - Concatenation of source, destination, port #s, etc.
- Index into the flow cache based on the key
  - Creation or updating of an entry in the flow cache



Mechanics: Evicting Cache Entries

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- Flow timeout
  - Remove flows not receiving a packet recently
  - Periodic sequencing to time out flows
  - New packet triggers the creation of a new flow
- Cache replacement
  - Remove flow(s) when the flow cache is full
  - Evict existing flow(s) upon creating a cache entry
  - Apply eviction policy (LRU, random flow, etc.)
- Long-lived flows
  - Remove flow(s) persisting a long time (e.g., 30 min)

Measurement Overhead

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- Per-packet overhead
  - Computing the key and indexing flow cache
  - More work when the average packet size is small
  - May not be able to keep up with the link speed
- Per-flow overhead
  - Creation and eviction of entry in the flow cache
  - Volume of measurement data (# of flow records)
  - Larger # of flows when # packets per flow is small
  - May overwhelm system collecting/analyzing data

Sampling: Packet Sampling

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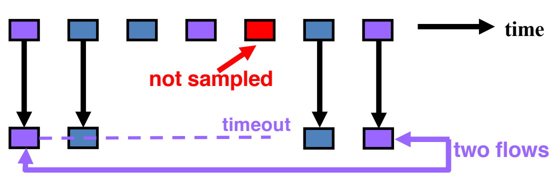
- Packet sampling before flow creation
  - 1-out-of-m sampling of individual packets
  - Creation of flow records over the sampled packets
- Reducing overhead
  - Avoid per-packet overhead on 1 – (1/m) packets
  - Avoid creating records for many small flows



BGP Monitoring

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Motivation for BGP Monitoring

- Visibility into external destinations
  - What neighboring ASes are telling you
  - How you are reaching external destinations
- Detecting anomalies
  - Increases in number of destination prefixes
  - Lost reachability or instability of some destinations
- Input to traffic-engineering tools
  - Knowing the current routes in the network
- Workload for testing routers
  - Realistic message traces to play back to routers

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BGP Monitoring: A Wish List

- Ideally: know what the router knows
  - All externally-learned routes
  - Before applying policy and selecting best route
- How to achieve this
  - Special monitoring session on routers that tells everything they have learned
  - Packet monitoring on all links with BGP sessions
- If you can't do that, you could always do…
  - Periodic dumps of routing tables
  - BGP session to learn best route from router

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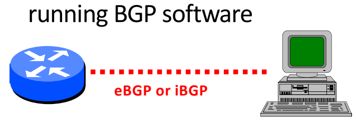
Using Routers to Monitor BGP

Talk to operational routers using SNMP or telnet at command line

(-) BGP table dumps are expensive
(+) Table dumps show all alternate routes
(-) Update dynamics lost
(-) Restricted to interfaces provided by vendors

Establish a "passive" BGP session from a workstation running BGP software



(+) BGP table dumps do not burden operational routers
(-) Receives only best route from BGP neighbor
(+) Update dynamics captured
(+) Not restricted to interfaces provided by vendors

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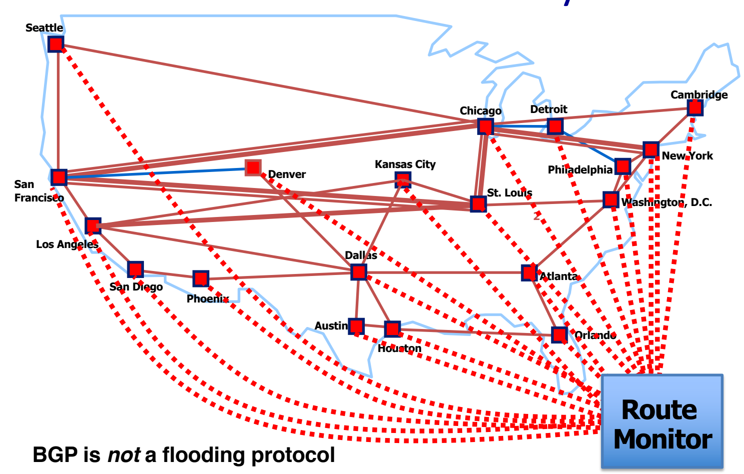
Collect BGP Data From Many Routers



BGP is *not* a flooding protocol

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BGP Table ("show ip bgp" at RouteViews)

	Network	Next Hop	Metric	LocPrf	Weight	Path
*	3.0.0.0	205.215.45.50			0	4006 701 80 i
*		167.142.3.6			0	5056 701 80 i
*		157.22.9.7			0	715 1 701 80 i
*		195.219.96.239			0	8297 6453 701 80 i
*		195.211.29.254			0	5409 6667 6427 335
*>		12.127.0.249			0	7018 701 80 i
*		213.200.87.254		929	0	3257 701 80 i
*	9.184.112.0/20	205.215.45.50			0	4006 6461 3786 i
*		195.66.225.254			0	5459 6461 3786 i
*>		203.62.248.4			0	1221 3786 i
*		167.142.3.6			0	5056 6461 6461 378
*		195.219.96.239			0	8297 6461 3786 i
*		195.211.29.254			0	5409 6461 3786 i

AS 80 is General Electric, AS 701 is UUNET, AS 7018 is AT&T

AS 3786 is DACOM (Korea), AS 1221 is Telstra

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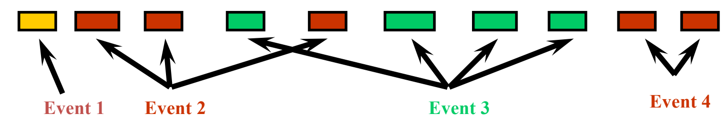
BGP Events



- Group of BGP updates that "belong together"
  - Same IP prefix, originating AS, or AS_PATH
- Updates that are "close" together in time
  - Maximum spacing between packets (e.g. 30 sec)
  - E.g.: events 2 and 4 are separated in time

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Conclusions

- Measurement is crucial to network operations
  - Measure, model, control
  - Detect, diagnose, fix
- Network measurement is challenging
  - Large volume of measurement data
  - Multi-dimensional data
- Great way to understand the Internet
  - Popular applications, traffic characteristics
  - Internet topology, routing dynamics