Measuring network with packets: delay,loss, bandwidth and other network properties

Lecture slides for S-38.183

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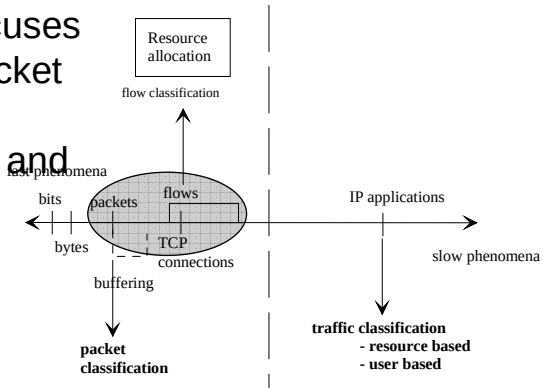
Timescales of different events

- This course focuses primarily on packet and flow level measurements and analysis



Contents

- Basic network events
- Purpose of packet measurements
- Passive measurements
- Active measurements

Goals of this lecture

- After this lecture you should be able to
  - Understand the basic phenomena to be measured in a network
  - Understand the difference between active and passive measurements
    - And the results they produce
  - Be able to explain (in detail) various active measurement types (BW, Loss, Delay)
  - List some of the applications for active and passive measurements with packets

Packet

- (IP) packet is the basic event that most measurements (in this course) are based on
  - Packet has a header and payload
  - Measurement analysis is (usually) interested in using headers to group packets
    - Done with filters/masks
  - Interesting packet measures include:
    - #packets (per time unit, per trace, etc.)
    - Packet sizes (to determine capacity usage, to detect different types of applications)
    - Packet interarrival times (to determine arrival process characteristics)

Purpose of packet measurements

- Develop traffic models
- Find traffic dynamics and directionality (for routing)
- Detect of various network phenomena (currently focus is on detecting malicious traffic and network anomalies)
- TCP studies (congestion detection)
- With passive measurements, no additional traffic introduced into the network
  - However, needs access to the measurement point
  - Choice between collecting statistics on the fly or capturing packet (or parts of it) and analyzing it later

Network phenomena to measure

- Networks deliver packets (Paxson)
  - As we asked (bandwidth)
  - Not at all (packet loss)
  - Significantly late (delay), significantly meaning that a retransmission might occur
  - Out-of-order
    - Due to routing and queue management problems resulting in uneven path delays
  - Replicated
    - Due to bugs/design faults in router/L2 implementations/design
  - Corrupted
    - Neglected CRC-checks (core routers?)

Packet data to collect

- Arrival time (absolute or relative) or lack thereof (packet loss)
- Header info
  - 5-tuple (addresses, proto, ports)
    - Remember address sanitation
  - Ports present only in protos 6 and 17 (TCP and UDP)
    - Others indicated by protocol id.
- Packet size
- Packet contents for protocol/content analysis
- Packet data collected at several points results in traffic matrices

Passive measurements

- Information determined
  - Bit/byte/packet rates, bandwidth
  - Packet IAT/timing information
  - Queue levels (indicating packet loss/delay)
  - Traffic/protocol mixes from packet captures

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Passive measurement objectives

- Arrival process characterization
  - Packets, flows, applications
- Network status & traffic profiles
- General measures
  - Utilization, traffic trends etc.
- Detecting network anomalies
  - Malicious traffic characteristics

Passive measurements in action

- Capture data, discard unusable parts/payload
- Sanitize
  - Preserve as much information as possible
    - IP address mapping
    - IP address hierarchy
    - TCP ports
- Save and archive

Passive vs. Active

- Passive measurements are accurate
  - Based on historical data
  - Depend upon active users and existing traffic
- Active measurements
  - Measure the network here and now
  - May disturb the network
  - Sampling error may be hard to estimate

Active measurements

- Insert additional traffic, probes, into the network
  - Requires the source and the sink(monitor); these can be the same machine
- Information monitored
  - Bandwidth (current, available, bottleneck)
  - Delay and jitter
  - Packet loss

Active measurement pitfalls

- Inserted traffic interferes and disturbes ”real” traffic
  - Need to carefully determine probe insertion rate
- To get proper results the probe packets should be similarly classified in the network (and be similar to real traffic properties (IAT, packet length etc.)

Bandwidth measurements

- Bottleneck bandwidth is the minimum of bandwidths of the links in the route
  - Also known as Path Capacity
- Available Bandwidth is the unused bandwidth in the link
  - May be unused because of bottleneck link
  - Aka as Hop Capacity
- Bandwidth Asymmetry is the relative difference of the BW within the same path to different directions

Hop capacity

- Send probes deeper into the network step by step (utilize TTL)
  - Get echo-packets back, measure for RTT
- RTT consists of
  - Propagation delay
  - Queuing delay
  - Processing delay
    - ICMP may also be restricted

Path capacity

- Packet pair –technique
  - Send two packets back-to-back (make note of the interval) to the other end which echoes the packets back
  - Measure the difference at the other end and determine the bandwidth based on the added transmission delay
  - Cross-traffic has a big effect
  - To get true results
    - Send several packet pairs at various times
    - Send longer back-to-back packet trains
  - Packet pairs determine bottleneck capacity
- Several tools available
  - Pathchar, pathrate, pathload, pchar etc.

Delay in the network

- Delay is caused by
  - Bugs in router implementations.
    - Packet loss
  - Speed of EM waves in media.
  - CPU Power (e.g. routing updates).
    - Packet loss
  - Packets on the slow path.
  - Congestion (Queuing).
    - Packet loss
  - Packet sizes.
  - Noisy channels.
  - Route flapping.

Delay variation, jitter

- No commonly accepted definitions exist for delay variation
  - PPDV – packet to packet delay variation
    - Easy to measure
  - Jitter envelope
    - Track the max and min delay compared to short term average delay
- Delay is (usually) caused by several network elements

Timing compression

- Packets arrive earlier than they should
  - Queues usually store(delay) packets
  - Sometimes packets are earlier packets are held up in the network and later packets have time to catch up

Delay measurement methods

- Obtain a good timing source, synchronize clocks
- Basic Active (multipoint) measurement
  - Send measurement probes, record send and receive times
- Basic Passive (multipoint) measurement
  - Payload CRC acts as a signature
    - CRC recorded at the source and checked at the receiver -> match packets and record timestamps -> off-line analysis
- Basic (onepoint) delay measurements may be based on RTT observations (ping)
    - Are delays(routes) symmetrical?
    - 2-point measurements are preferable
      - Synchronize site clocks, send measurement probes

Packet loss in the network

- Unavoidable in packet switched networks
  - With complex traffic characteristics
- TCP bases some of its congestion detection on packet loss
  - Large buffers would lead to very large delays
- Packet loss happens (usually) in just one (congested, faulted) place in the network

Measuring for packet loss

- A packet lost is a packet lost
  - A packet lost in capture is not packet lost in the network!
- A packet lost might be just an acknowledgement lost!
  - Route asymmetry
- Need to keep record of sent packets and arrived packets
  - And packets dropped by the measurement device

BW, Delay, Drops inter-related

- Available BW is depends up on transmission speed, queue status and router processor capacity
- Delay is a result of transmission speed, processing limitations and subsequent storage of packets in a buffer
- When buffers overflow packet drops occur

Other active measurements

- Inject packets into the network from multiple points and evaluate the delay/latency
  - Packets sent to pre-selected targets
- Network topology discovery
  - Determine path properties and status

The next step

- Most of the techniques presented progress towards using longer and longer packet trains
- Packet trains have the following properties
  - Length
  - Direction
- Packet trains are called flows and play an important part in understanding network and traffic characteristics

Packet measurement summary

- Passive packet measurements
  - To characterize traffic and obtain info on network status
  - Huge amounts of data to analyze
  - Give an accurate view on the past network status
- Active packet measurements
  - Probe the network for bandwidth, delay and loss
  - Determine network topology
  - Increases the amount of traffic in the network
  - Give an accurate view of the current network status