Traffic Measurement and Analysis (1)

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measurement goals

- for operations
  - trouble shooting
  - diagnosis and tuning of performance, reliability
  - usage report
  - long-term planning of capacity, equipment, cost evaluation
- for protocol/software/hardware engineering
  - trade-off in design (e.g., buffer size vs. cost)
  - to verify things are working as designed
  - to look for unexpected (important in Internet)
- for scientific interests (new discoveries)
  - characteristics of delay, throughput, loss
  - modeling (e.g., TCP, web traffic)
  - self-similarity/fractal traffic
    - abundant data, simulation tools

measurement needs combined skills

- goals could be operational, engineering, scientific
  - all unseparable, all skills required
    - knowledge of operational environment
    - engineering of measurement tools
- output can be facts, findings, new ideas
  - new ideas are not always necessary
  - facts, especially long-term measurement, are valuable
- but you should have clear goals
  - better to start with real problems to solve
    - there are many issues and problems but some are more important than others

why traffic measurement of Internet is so hard?

- massive, diverse and changing traffic
- mechanisms at different layers in different time scale
  - interact with each other
- dynamics
  - Internet mechanisms are adaptive and resilient
  - traditional measurement techniques are often not applicable
- pathological traffic is not unusual
  - by bugs, misconfigurations, errors, mismatches, accidents
- we still don’t have good understanding

massive volume of traffic

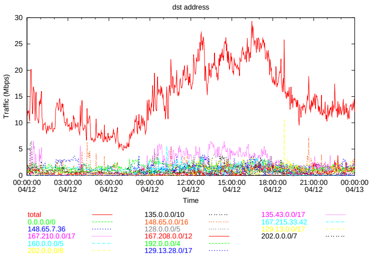
- unprecedented scale with unprecedented growth
  - e.g., traffic volume: 100Mbps traffic
    - 12MB/sec 715MB/minute 42GB/hour 1TB/day
- far more data than we can analyze
  - techniques needed to reduce data size
    - filtering: e.g., record only TCP SYN packets
    - aggregation: e.g., flow-based accounting
    - sampling: e.g., record 1 in n packets
- still, details matter
  - a big impact often comes
    - from small fraction
    - from minor differences

diverse traffic

- large variation in traffic mix between sites
- backbone vs. access links
  - access line types: fiber, ADSL, modem, wireless, satellite
    - differences in bandwidth, delay, loss
- typical traffic doesn’t exist!

constant change of traffic pattern

- daily, weekly traffic pattern
- trend changes over time
  - web completely changed traffic pattern
- hard to predict future!



time scale of traffic management

- long-term
  - capacity planning
- day
  - pricing (off-time rate discount)
- session
  - service pricing, admission control, routing
- round-trip time
  - end-to-end flow control, various timeout mechanisms
- packet time
  - packet scheduling
- less than packet time
  - link layer dependent

Internet dynamics

- dynamics
  - packet switching
    - statistical multiplexing
    - queueing
  - feedback mechanisms
    - at different layers in different time scale
    - e.g., TCP congestion control
- scaling property
  - Internet traffic is bursty
    - corelation, long-range dependences
  - traditional measurement techniques often not applicable
    - e.g., independent (memoryless) events, random sampling
  - median and 90th-percentile more useful than mean and stddev
    - try log-scale plots to see scaling property

other issues

- problems often occur at boundaries of different networks
  - cooperation needed but not easy
- operators vs. researchers
  - different interests and culture
  - build good relationship
- cost: measurement doesn’t come free
  - willingness to invest
- privacy in traffic data
- companies often do not publish results

commonly-used management tools

- quick overview
  - ping
    - reachability, round-trip time
  - traceroute
    - path detection
  - tcpdump
    - packet capturing
  - SNMP
    - usage monitoring

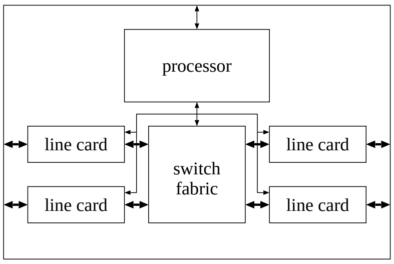
ping

- a popular and widely-available tool to check connectivity
- ICMP-echo request/reply

- limitations
  - ping responses do not mean network is working correctly
  - ICMP is not representative of host/network performance

router architecture

- ○ fast path: hardware assisted processing
- ○ slow path: software processing



ping sample output

```
% ping -c10 www.ait.ac.th
PING www.ait.ac.th (202.183.214.46): 56 data bytes
64 bytes from 202.183.214.46: icmp_seq=0 ttl=113 time=220.550 ms
64 bytes from 202.183.214.46: icmp_seq=1 ttl=113 time=241.832 ms
64 bytes from 202.183.214.46: icmp_seq=2 ttl=113 time=228.779 ms
64 bytes from 202.183.214.46: icmp_seq=3 ttl=113 time=220.574 ms
64 bytes from 202.183.214.46: icmp_seq=4 ttl=113 time=219.312 ms
64 bytes from 202.183.214.46: icmp_seq=5 ttl=113 time=217.608 ms
64 bytes from 202.183.214.46: icmp_seq=6 ttl=113 time=218.355 ms
64 bytes from 202.183.214.46: icmp_seq=7 ttl=113 time=221.564 ms
64 bytes from 202.183.214.46: icmp_seq=8 ttl=113 time=218.330 ms
64 bytes from 202.183.214.46: icmp_seq=9 ttl=113 time=219.085 ms

--- www.ait.ac.th ping statistics ---
10 packets transmitted, 10 packets received, 0% packet loss
round-trip min/avg/max/stddev = 217.608/222.599/241.832/7.084 ms
```

traceroute

- □ exploit TTL (time-to-live) of IP
  - ○ router returns ICMP TIME EXCEEDED to the sender when TTL becomes 0
- □ limitations
  - ○ path may change over time
  - ○ path may be asymmetric
  - ○ reports one of the interfaces of router

traceroute sample output

```
% traceroute www.ait.ac.th
traceroute to www.ait.ac.th (202.183.214.46), 64 hops max, 44 byte packets
 1  entry (133.138.1.2)  0.350 ms  0.308 ms  0.297 ms
 2  foundry2.otemachi.wide.ad.jp (133.138.0.1)  0.961 ms  1.603 ms  1.553 ms
 3  cisco5.otemachi.wide.ad.jp (203.178.140.220)  181.694 ms  203.383 ms  199.252 ms
 4  210.132.94.77 (210.132.94.77)  1.807 ms  1.953 ms  1.713 ms
 5  gsr-ote1.kddnet.ad.jp (203.181.96.37)  1.872 ms  1.663 ms  2.350 ms
 6  tr-ote109.kddnet.ad.jp (203.181.96.74)  2.362 ms  2.198 ms  2.147 ms
 7  210.132.93.186 (210.132.93.186)  214.827 ms  218.536 ms  215.359 ms
 8  202.47.253.145 (202.47.253.145)  218.988 ms  217.795 ms  216.383 ms
 9  202.47.252.190 (202.47.252.190)  216.720 ms  217.435 ms  217.882 ms
10  202.183.160.121 (202.183.160.121)  216.964 ms  216.934 ms  216.781 ms
11  www.ait.ac.th (202.183.214.46)  219.197 ms  229.315 ms  217.640 ms
```

tcpdump

- □ packet capture tool
  - ○ capture the first N bytes of packets
- □ flexible filtering
  - ○ e.g., capture only TCP SYN from host X
- □ enables detailed analysis
- □ limitations
  - ○ huge volume
  - ○ difficult to capture high-speed links

tcpdump sample output

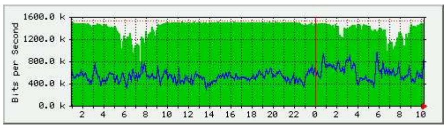
```
14:53:24.878901 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: S 1758089118:1758089118(0) win 57344
    <mss 1440,nop,wscale 0,nop,nop,timestamp 77899233 0>
14:53:24.882544 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: S 959813947:959813947(0) ack 1758089119 win 16384
    <mss 33160,nop,wscale 0,nop,nop,timestamp 0 77899233>
14:53:24.882597 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: . ack 1 win 58548 <nop,nop,timestamp 77899233 0>
14:53:24.904230 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: P 1:451(450) ack 1 win 58548 <nop,nop,timestamp 77899236 0>
14:53:24.910081 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: P 1:324(323) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.912819 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 324:1764(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.912846 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: . ack 1764 win 56785 <nop,nop,timestamp 77899236 0>
14:53:24.919719 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 1764:3204(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.920949 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 3204:4644(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.920988 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: . ack 4644 win 53905 <nop,nop,timestamp 77899237 0>
14:53:24.921624 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: . ack 4644 win 58001 <nop,nop,timestamp 77899237 0>
14:53:24.922177 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 4644:6084(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.929047 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 6084:7524(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.929086 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: . ack 7524 win 55668 <nop,nop,timestamp 77899238 0>
14:53:24.930272 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 7524:8964(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.931643 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 8964:10404(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.931692 linus.csl.sony.co.jp.4804 > www.wide.ad.jp.http: . ack 10404 win 52788 <nop,nop,timestamp 77899238 0>
14:53:24.936876 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 10404:11844(1440) ack 451 win 16384 [flowlabel 0xec414]
14:53:24.938104 www.wide.ad.jp.http > linus.csl.sony.co.jp.4804: . 11844:13284(1440) ack 451 win 16384 [flowlabel 0xec414]
```

SNMP (Simple Network Management Protocol)

- SNMP allows a remote user to
  - query information, store information, set traps
  - by UDP (unreliable)
- standardized set of traffic statistics
  - supported by most of routers, switches, host OS
  - many management/monitoring products
- MIB (Management Information Base)
  - tree structured database of SNMP objects
    - e.g., interfaces.ifTable.ifEntry.ifOutOctets
    - standard MIBs and private MIBs
  - get, set, get-next to access MIB
- limitations
  - supported statistics are limited
    - most counter statistics are hard-coded: e.g., interface counters
  - accessing to MIB objects is expensive

MRTG

- popular tool to show SNMP data
- time series data aggregated over time
  - daily, weekly, monthly
- inbound/outbound traffic
  - can be used for other types of time series data
- RRDtool: successor of MRTG

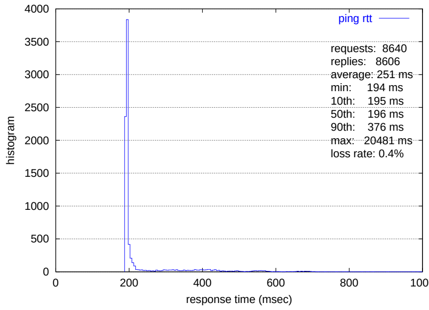


real-world data

- one day ping measurement
  - from home in Tokyo to university in East Coast
- facts
  - 8640 queries, 8606 replies, 0.4% loss
  - average rtt: 251ms
  - stddev: 391ms
  - min rtt: 194ms
  - 10th: 195ms
  - 50th: 196ms
  - 90th: 376ms
  - max: 20481ms

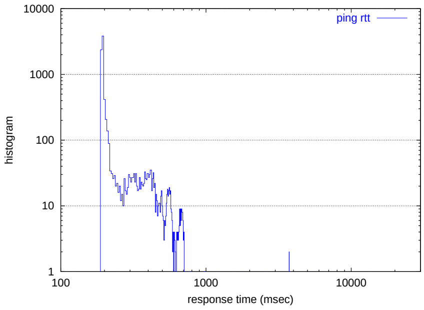
ping round-trip time histogram

- most replies: 194-196ms



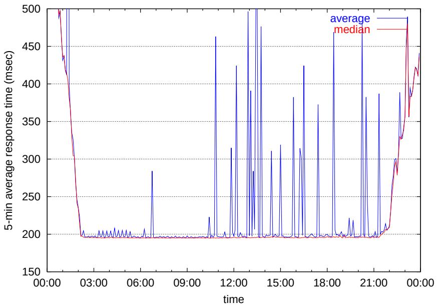
ping round-trip time histogram in log scale

- log-plot to see scaling property
  - no scaling property in data



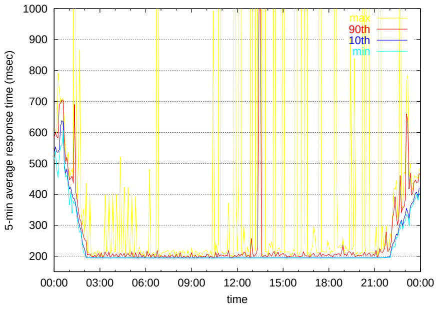
daily plot (mean and median)

- median more stable than mean
- service degrades during 22:00 - 26:00



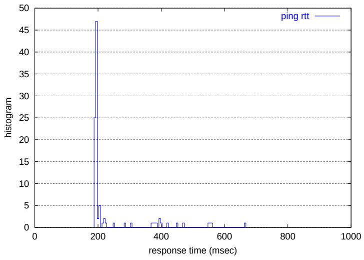
tails of distribution

- ○ daily plot (min, 10th, 90th, max)
  - ▹ minimum, maximum
  - ▹ 10th-percentile, 90th-percentile to remove outliers



limitations of histogram

- □ needs appropriate bin size
  - ○ too small: each bin doesn’t have enough samples (e.g., empty bins)
  - ○ too large: only few regions available
- □ enough samples needed
  - ○ histogram with 100 samples

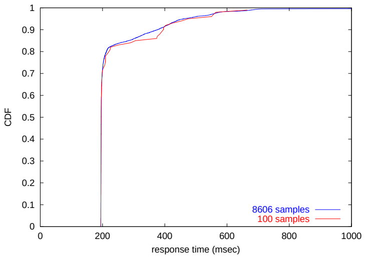


cumulative distribution function (CDF)

- ○ density function: probability of observing x

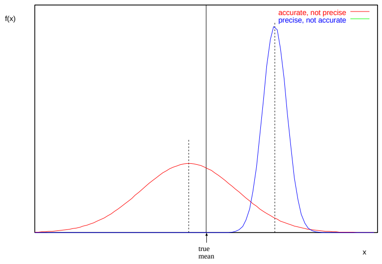
  f(x) = P[X = x]
- ○ cumulative distribution function: probability of observing x or less

  F(x) = P[X <= x]
- ○ better than histogram when
  - ▹ sample count is not enough or outliers are not negligible



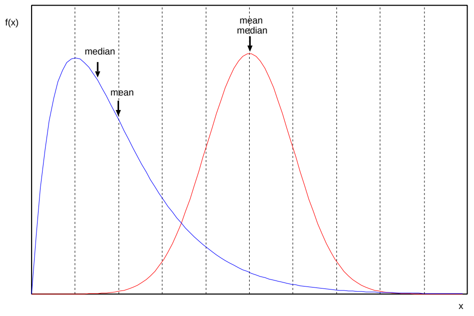
sample average revisited

- □ accuracy
  - ○ how close to true (population) mean
- □ precision
  - ○ variance in data



mean and median

- □ not equal if distribution is asymmetric



average (mean)

average over n sample values

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

variance

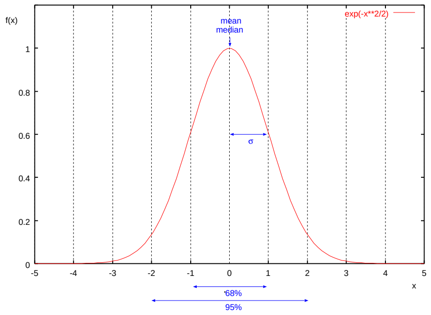
$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

standard deviation s (in the same unit as mean)

- ○ sample mean (for large samples) follows normal distribution
  - ▹ central limit theorem (see statistics textbook)

normal distribution

- ○ 68% within (mean-stddev, mean+stddev)
- ○ 95% within (mean-2*stddev, mean+2*stddev)



confidence interval

□ confidence interval for the mean

- ○ provides probabilistic bounds
- ○ tells how much uncertainty in the estimate

$$Prob\{c_1 \leq \mu \leq c_2\} = 1 - \alpha$$

(c1, c2): confidence interval
100(1 - α): confidence level

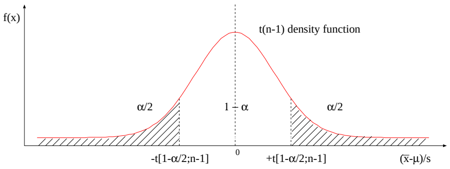
- ○ e.g., with 95% confidence, the population mean is between c1 and c2
  - ▹ traditionally, 95 or 99% is used for confidence level

confidence interval (cont'd)

- ○ from central limit theorem
  - ▹ if observations are independent and samples come from the same population with mean μ and standard deviation σ
  - ▹ then, sample mean for large samples is normal distribution with mean μ and standard deviation σ /sqrt(n)

$$\bar{x} \sim N(\mu, \sigma/\sqrt{n})$$

  - ▹ increase sample size to get more accuracy
- ○ (x- μ)/(s/sqrt(n)) for samples from normal populations
  - ▹ follows t(n-1) distribution



how to use confidence interval for mean

□ applications

- ○ provide confidence interval to show possible range of mean
- ○ from sample mean and stddev, compute how many trials are needed
  - ▹ to satisfy a given confidence interval
- ○ repeat measurement until a given confidence interval is reached

□ summary:

- ○ be careful when you use average
- ○ sometimes, average is not so useful in Internet measurement

measurement techniques

□ management tools are useful but not designed for measurement

□ next lecture:

- ○ types of measurement
  - ▹ throughput, delay, path, routing
- ○ data reduction techniques
  - ▹ filtering, aggregation, sampling
- ○ clock and timestamp

summary

□ overview of measurement issues

- ○ operational, engineering, scientific skills are needed

□ popular management tools

- ○ ping, traceroute, tcpdump, SNMP

□ using real ping data

- ○ histogram, CDF

□ mean and confidence interval