

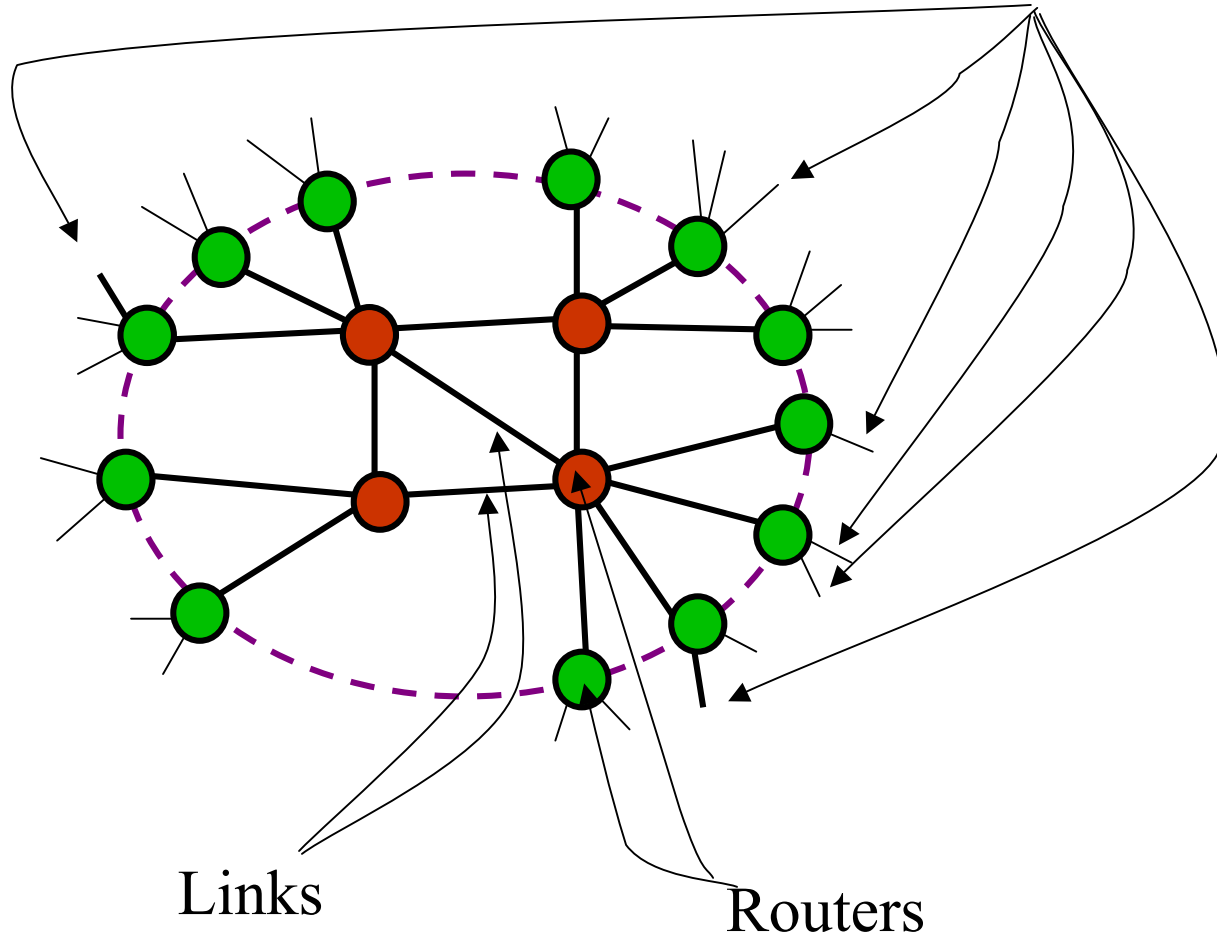
Network Measurements and Sampling

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IP Network

The Edge of Network



Links

Routers

Some Questions that are hard to answer about IP networks

- ❑ Given a hotspot, how do we change network configuration to fix the problem.
 - ❑ What exactly is the problem? Type of traffic?
- ❑ Traffic usage. Which applications are using the network?
- ❑ How do we design an efficient network?
 - ❑ Where do the traffic want to go?

Traffic Matrix Construction

- ❑ Traffic Matrix
 - ❑ Point to Point Demands
 - ❑ Point to Multi-Point Demands
 - Needed to model in networks with multi-homing and peering. (e.g., ISPs etc.)
- ❑ Input for many tasks
 - ❑ Network Design
 - ❑ Reroute traffic
 - ❑ Failure analysis
 - ❑ OSPF weight optimization (Thorup et al.)

Measurement Options

- ❑ SNMP
 - ❑ Counting packets on interfaces
- ❑ Packet sniffers/Probes
 - ❑ Whole packet header/contents
- ❑ Flow measurements
 - ❑ Router support
 - ❑ Network-wide measurements
- ❑ Packet sampling (sFlow)
- ❑ Trajectory sampling
- ❑ Etc.

Traffic Matrix: SNMP based methods

- ❑ Network Tomography
 - ❑ From link measurement determine traffic matrix, using temporal correlations.
- ❑ Network Tomogravity
 - ❑ Starts with a model of the traffic matrix from edge measurements.
 - ❑ Uses internal measurements to find a consistent solutions that is close to the traffic matrix that the model predicted.

Traffic Matrix: Flow based methods.

- Detailed measurement where the traffic enter and determine from the destination IP address, where the traffic will exits the network
 - Need Prefix level routing information to determine the exit point

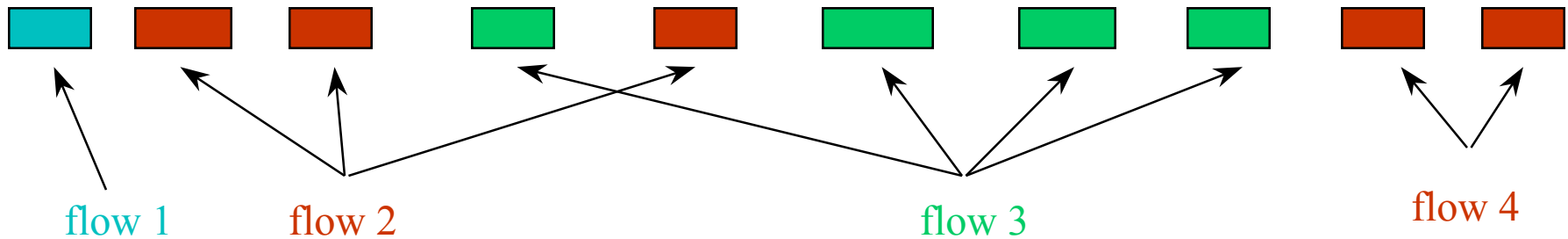
Traffic Matrix: Method Comparison

- ❑ SNMP based
 - ❑ Less accurate
 - ❑ Harder to deal with multi-point destinations
 - Tomography do not.
 - Tomogravity do try to model it.
 - ❑ Measurement instrumentation/gathering is standard.
- ❑ Flow based
 - ❑ More accurate
 - ❑ Deal with the multi-point destinations
 - ❑ Measurement instrumentation/gathering is not standard.
 - ❑ Need to deal with huge amount of detailed measurements

Outline of the rest of the talk

- Context
 - What are Flows?
 - Measurement Infrastructure
- The main idea
 - Size dependent sampling
 - Optimal sampling
- How do this compare to size independent sampling?
- Billing application

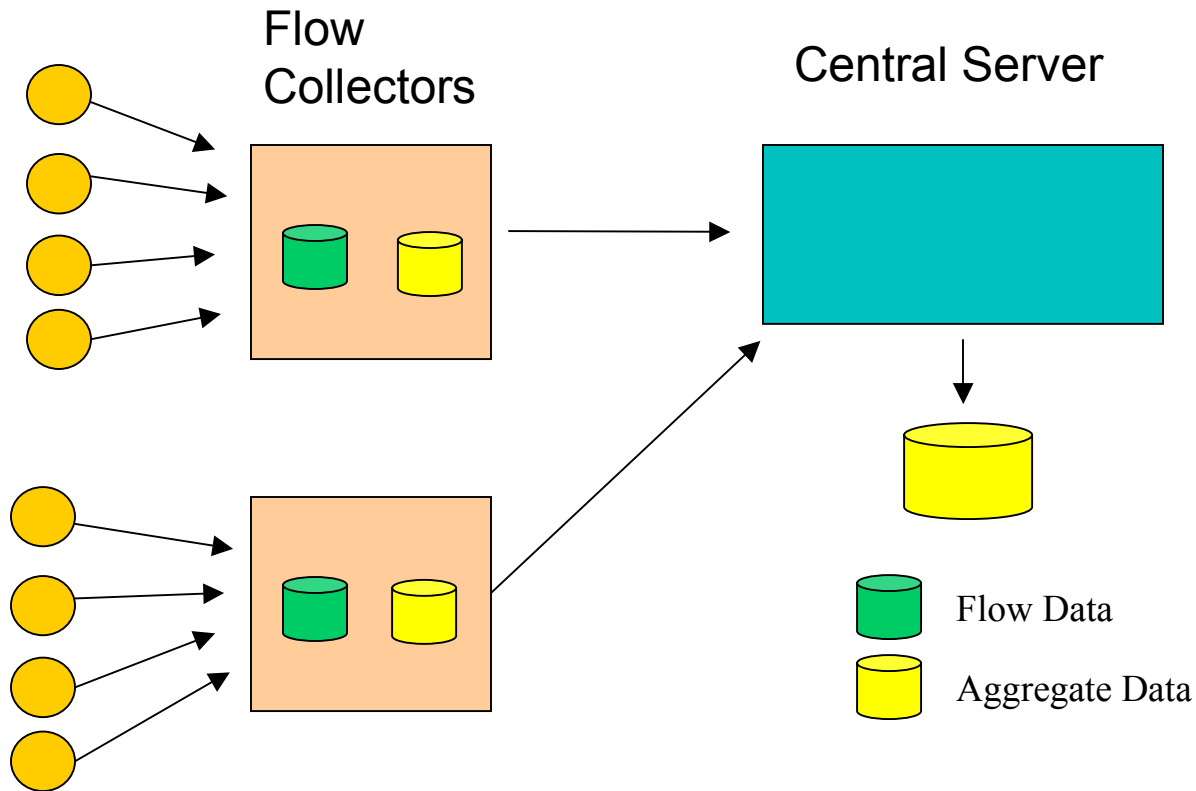
IP Flow Abstraction



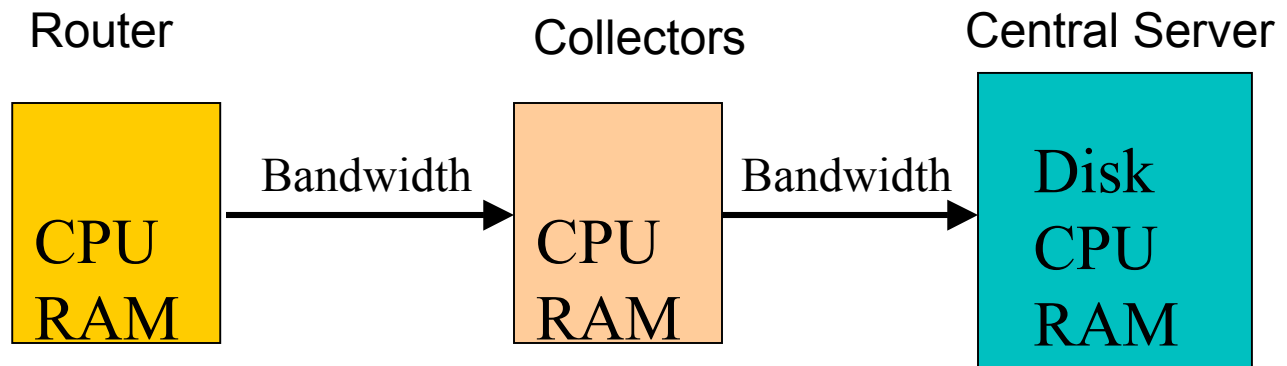
- ❑ IP flow abstraction
 - ❑ set of packets identified with “same” address, ports, etc.
 - ❑ packets that are “close” together in time
- ❑ IP flow summaries
 - ❑ reports of measured flows from routers
 - flow identifiers, total packets/bytes, start and end times
- ❑ Several flow definitions in commercial use

Collection System

Routers



Resources in the Measurement System



Measure/Export All Traffic Flows?

- ❑ Flow volumes
 - ❑ one OC48 (2.4 Gbps Trunk) \Rightarrow several GB flow summaries per hour
- ❑ Cost
 - ❑ network resources for transmission
 - ❑ storage/processing at the collection system

Flow Sampling?

- ❑ Sampling
 - ❑ statisticians reflex action to large datasets
- ❑ Export selected flows
 - ❑ reduce transmission/storage/processing costs
- ❑ Sufficiently accurate?
 - ❑ Depends on application.
 - Traffic Engineering (where do traffic flow)
 - Traffic Analysis (application usage, etc.)
 - Billing
 - risk of overcharging (\Rightarrow irate customers)
 - risk of undercharging (\Rightarrow irate shareholders)

Packet Sampling and Flow Sampling

- ❑ Packet Sampling
 - ❑ when router can't form flows at line rate
 - scaling at a single router
- ❑ Flow sampling
 - ❑ managing volume of flow statistics
 - scaling across downstream measurement infrastructure
- ❑ Complementary
 - ❑ could combine
 - e.g. 1 in N packet sampling + flow sampling

Usage Estimation

- Each flow i has
 - "size" x_i
 - bytes or packets
 - "color" c_i
 - combination of IP address, port, ToS etc that maps to billable stream (= customer + billing class)
- Goal
 - to estimate total usage $X(c)$ in each color c

$$X(c) = \sum_{i: c_i=c} x_i$$

Basic Ideas

- ❑ Match sampling method to flow characteristics
 - ❑ high fraction of traffic found in small fraction of long flows
 - sample long flows more frequently than short flows
 - large contributions to usage more reliably estimated
- ❑ Show how to relate sampling and accuracy
 - ❑ simple rules to achieve desired accuracy

Size independent flow sampling bad

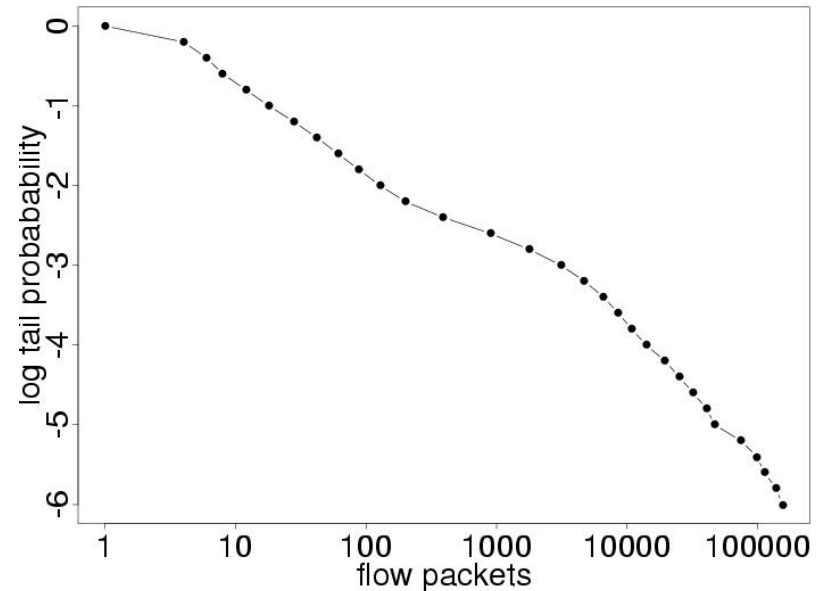
- Sample 1 in N flows

- estimate total bytes by N times sampled bytes

- Problem:

- long flow lengths

- estimate sensitive to inclusion or omission of a single large flow



Size dependent flow sampling

- Sample flow summary of size x with prob. $p(x)$
- Estimate usage X by

$$X' = \sum_{\text{sampled flows}} \frac{x}{p(x)}$$

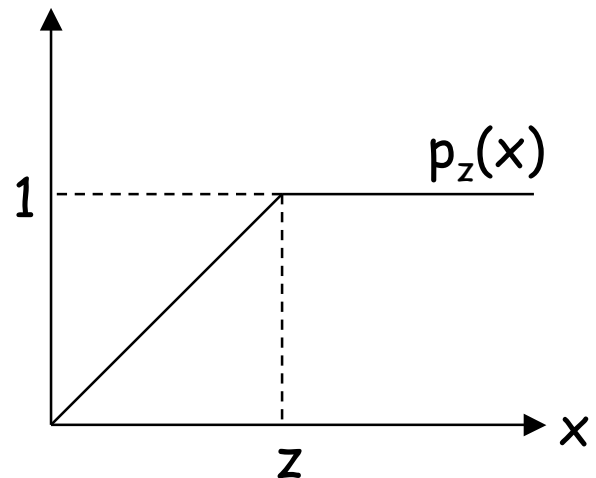
- boost up size x by factor $1/p(x)$ in estimate X'
 - compensate against chance of being sampled
- Chose $p(x)$ to be increasing in x
 - longer flows more likely to be sampled
 - compare size independent sampling: $p(x) = 1/N$

Statistical Properties

- Fixed set of flow sizes $\{x_1, x_2, \dots, x_n\}$
 - we only consider randomness of sampling
- X' is unbiased estimator of actual usage $X = \sum_i x_i$
 - $\mapsto X' = X$: averaging over all possible samplings
 - holds for all probability functions $p(x)$
- Proof:
 - $X' = \sum_i w_i x_i / p(x_i)$
 - w_i random variable
 - $w_i = 1$ with prob. $p(x_i)$, 0 otherwise
 - $\mapsto w_i = p(x_i)$ hence $\mapsto X' = \sum_i w_i x_i / p(x_i) = \sum_i x_i = X$

What is best choice of $p(x)$?

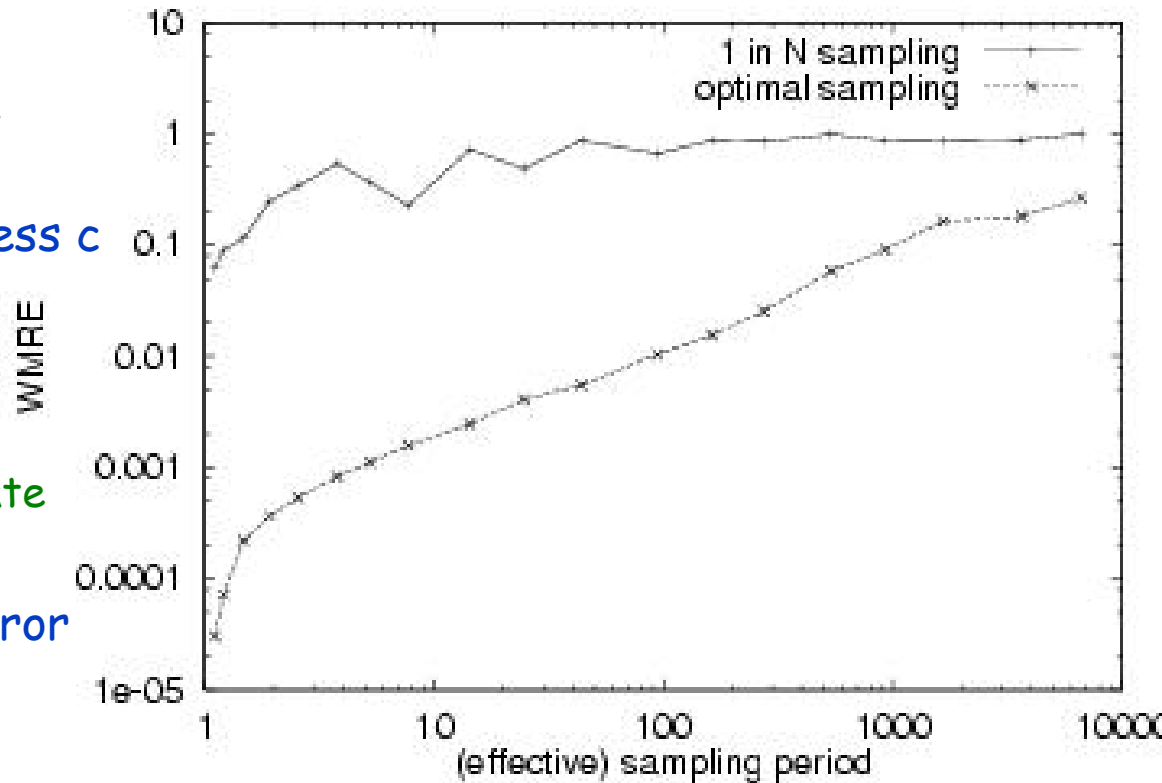
- ❑ Trade-off accuracy vs. number of samples
- ❑ Express trade-off through **cost function**
 - ❑ $\text{cost} = \text{variance}(X') + z^2$ average number of samples
 - parameter z : relative importance of variance vs. # samples
- ❑ Which choice of $p(x)$ minimizes cost?
- ❑ $p_z(x) = \min \{ 1, x/z \}$
 - ❑ flows with size $\geq z$: always selected
 - ❑ flows with size $< z$: selected with prob. proportional to their size
- ❑ Trade-off
 - ❑ smaller z
 - more samples, lower variance
 - ❑ larger z
 - fewer samples, higher variance
- ❑ Will call sampling with $p_z(x)$ "optimal"



Optimal vs. size independent sampling

- NetFlow traces
 - 1000's cable users, 1 week
- Color flows
 - by customer-side IP address c
- Compare
 - 1 in N sampling
 - optimal sampling
 - same average sampling rate
- Measure of accuracy
 - weighted mean relative error

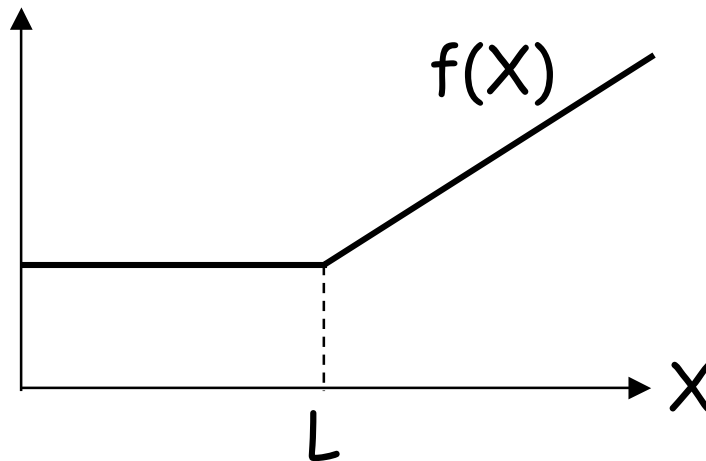
$$\frac{\sum_c |X'(c) - X(c)|}{\sum_c X(c)}$$



- Heavy tailed flow size distribution is our friend!
 - allows more accurate encoding of usage information

Charging and Sampling Error

- Optimal sampling
 - no sampling error for flows larger than z
- Exploit in charging scheme
 - fixed charge for small usage
 - usage sensitive charge only for usage above insensitivity level L
- Charge according to estimated usage
$$f(X'(c)) = a + b \max\{L, X'(c)\}$$
 - coefficients a, b and level L could depend on color c



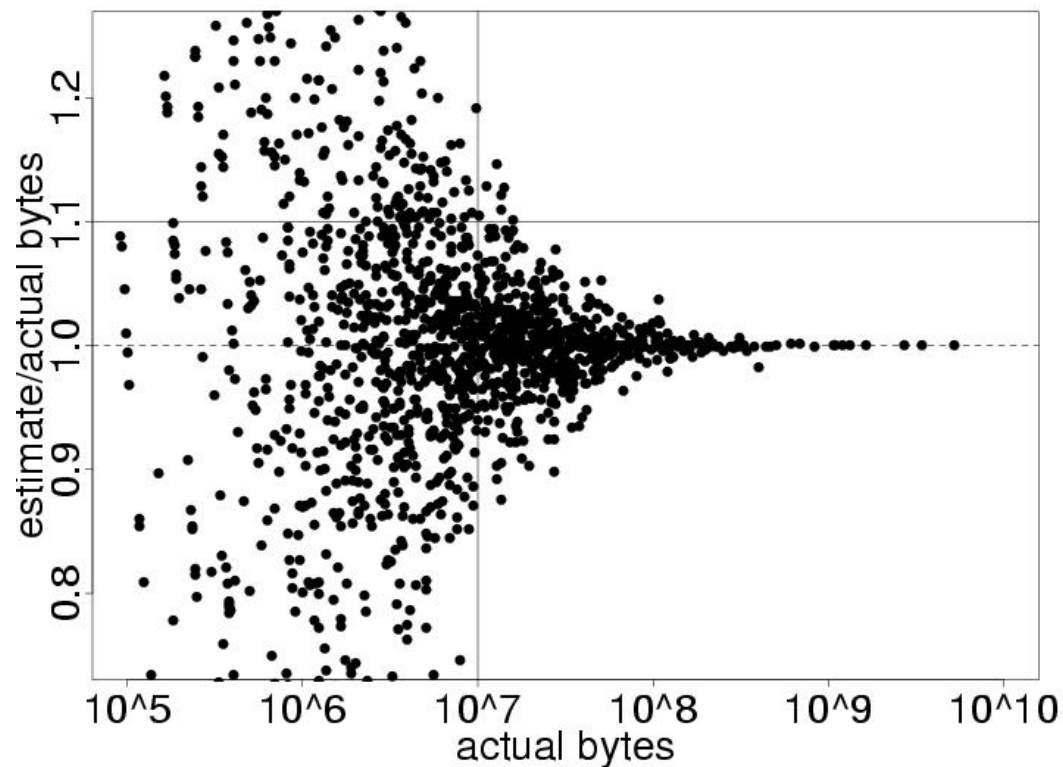
- Only usage above L needs reliable estimation

Accuracy and Parameter Choice

- Given target accuracy
 - relate sampling threshold z to level L
- Theorem
 - $\text{Variance}(X') \leq z X$ (tight bound)
 - now assume: $z \leq \varepsilon^2 L$
 - $\text{Std.Dev. } X' \leq \varepsilon X$ if $X \geq L$
 - bound sampling error of estimated usage $> L$
 - $\text{Std.Dev. } f(X') \leq \varepsilon f(X)$
 - bound error of charge based on estimated usage
- Bounds hold for any flow sizes $\{x_i\}$
 - no assumption on flow size distribution
 - just choose $z \leq \varepsilon^2 L$

Example

- Target parameters
 - $L = 10^7$, $\varepsilon = 10\% \Rightarrow z = 10^5$
- Scatter plot
 - ratio estimated/actual usage vs. actual usage
 - each color c
 - observe better estimation of higher usage
- Want to avoid
 - ratio $> 1 + \varepsilon = 1.1$
and
usage $> L = 10^7$
- Less than 1 in 1000 "bad" points



Compensating variance for mean

□ Aim:

- reduce chance of overestimating usage

□ Method:

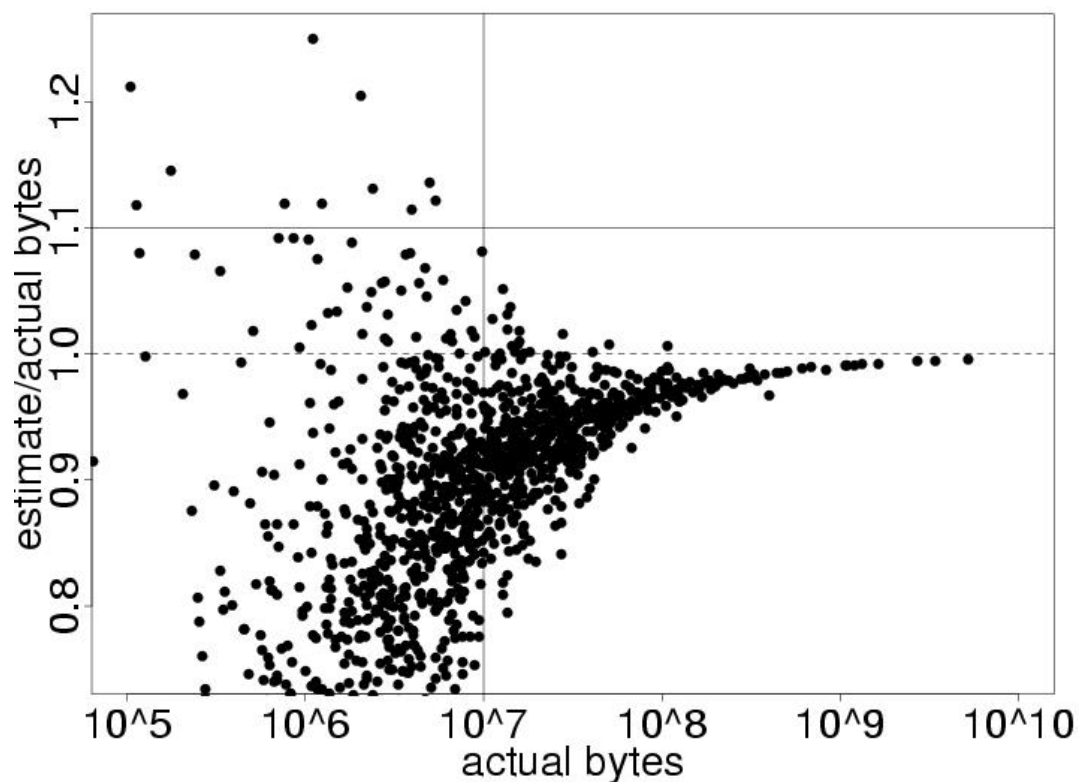
- theorem gave bound: $\text{Var}(X') \leq z X$
- anticipate upwards variations in X' by subtracting off multiples of std. dev.
 - charge according to

$$X_s' = X' - s\sqrt{zX'}$$

- again: no assumptions on flow size distribution

Example: $s=1$

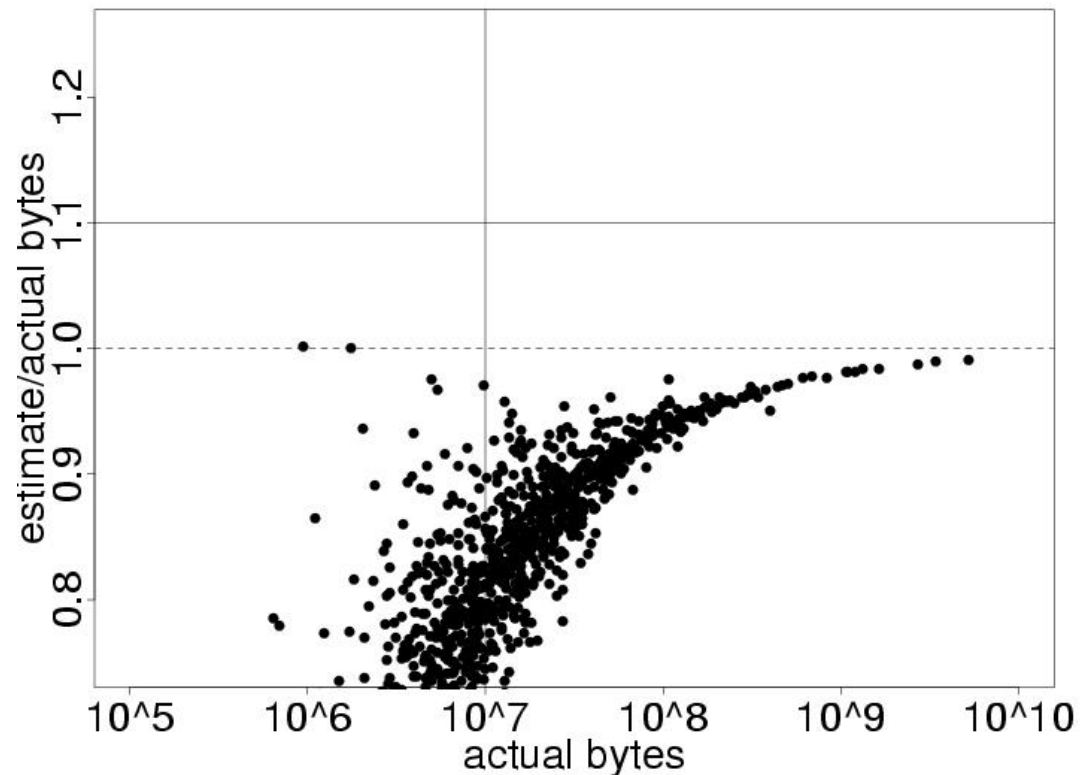
- ❑ Scatter pushed down:
 - ❑ no points with ratio > 1.1 and usage $> 10^7$
- ❑ Drawback
 - ❑ more unbillable usage
 - when $X'_s < X$
- ❑ Small unbillable usage for heavy users
 - ❑ ratio $\rightarrow 1$
 - ❑ $\text{Std.Dev.}(X')/X'$ vanishes as X grows



Example: $s=2$

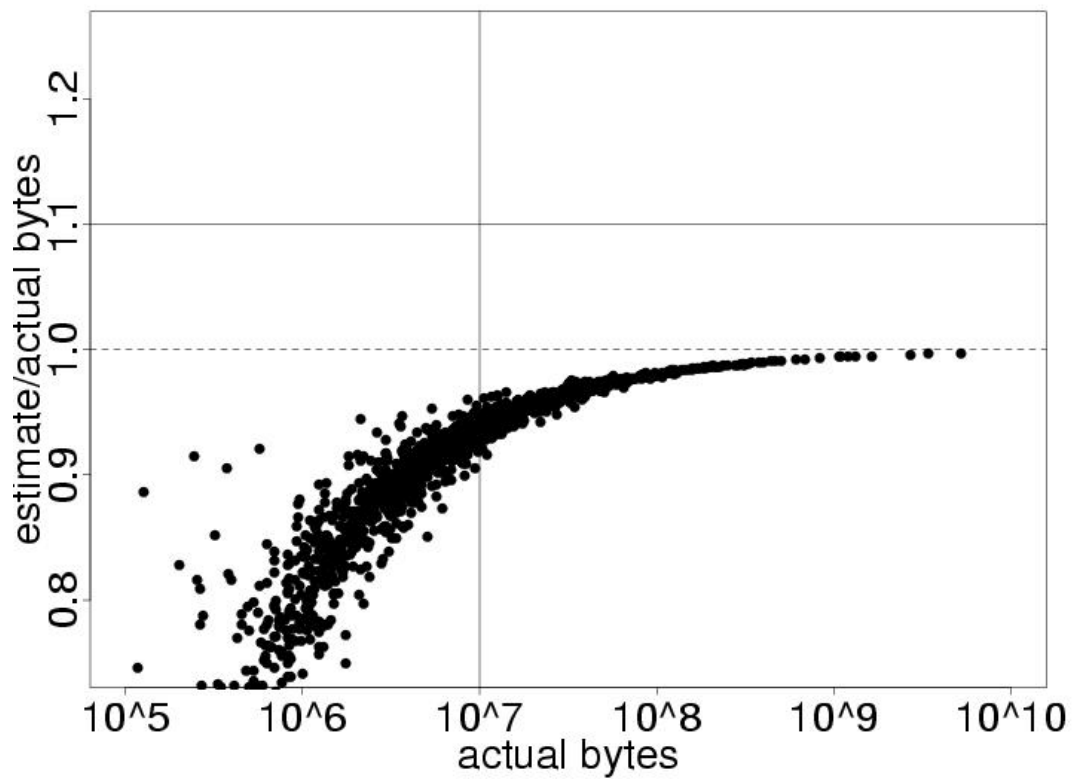
- Scatter pushed down further:
 - no points with ratio > 1
- Trade off
 - unbillable usage vs. overestimation

| s | unbill. bytes | $X'_s > X?$ |
|-----|---------------|-------------|
| 0 | -0.1% | 50% |
| 1 | 3.1% | 3% |
| 2 | 6.2% | 0% |



How to reduce unbillable usage?

- Make sampling more accurate
 - reduce z !
- For unbillable fraction $< \eta$
 - chose s $z \leq \eta^2 L$
- Example:
 - $s = 2, \eta = 10\%$
 - reduce z
 - from 10^5 to 10^4
- Alternative
 - increase coefficient a in charge $f(X)$ to cover costs



Tension between accuracy and volume

- Want to reduce z
 - better accuracy, less unbillable usage
- Drawback
 - increased sample volume
- Solution
 - make billing period longer instead
 - usage roughly proportional to billing period
 - allows increased charge insensitivity level L
 - sampling production rate controlled by threshold z
 - rate $r \sum_x f(x)p_z(x)$
 - flow arrival rate r , fraction $f(x)$ of flows size x
- Need only $z = \varepsilon^2 L$
 - larger L allows smaller error ε for given z

Summary

- Size dependent optimal sampling
 - preferentially sample large flows
 - more accurate usage estimates for given sample volume
 - sample flow of size x with probability $p_z(x)$
- Charging from measured usage X'
 - charge $f(X') = a + b \max\{L, X'\}$
 - fixed charge for usage below insensitivity level L
 - only need to reliably estimate usage above L
- Sampling/charging accuracy
 - choose $z = \varepsilon^2 L$ to get standard error ε
- Variance compensation
 - replace X' by $X'_s = X' - s\sqrt{zX'}$
- Longer billing cycle
 - increases L , better accuracy (ε) at given sampling rate (z)

Papers

- <http://www.research.att.com/projects/flowsamp>