Packet Sampling for Flow Accounting: Challenges and Limitations

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April 29, 2008

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CISCO SYSTEMS

This work was funded by Cisco Systems as part of the VEGAS project.

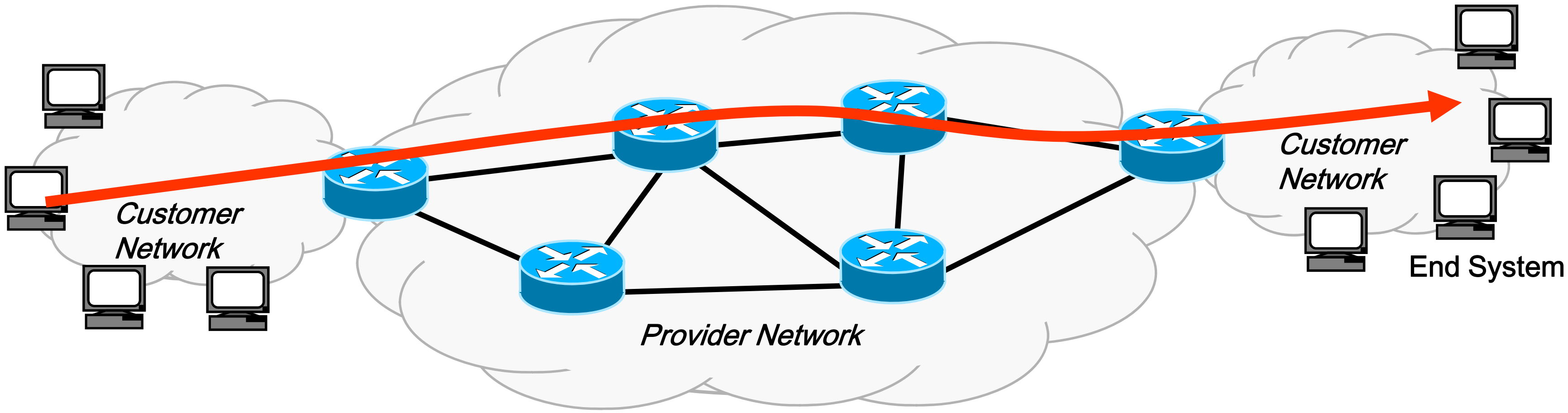
Outline

- Problem statement
- Packet selection techniques
- Accuracy assessment in theory
- Accuracy assessment in practice
- Experimental results
- Standardization (IPFIX/PSAMP)
- Conclusion

Usage-based Accounting

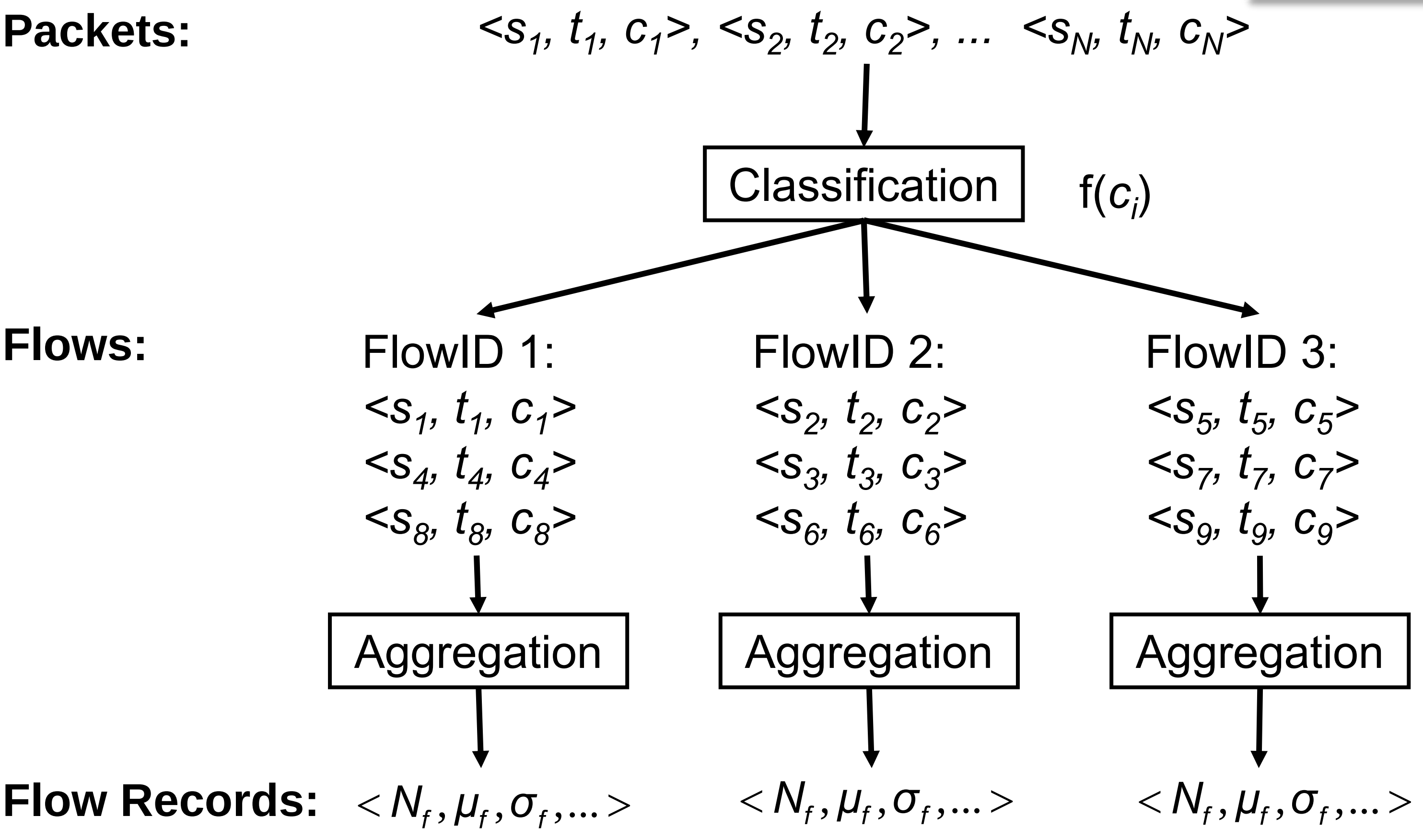
- Accounting based on flow volume (transferred bytes)
- Requires flow measurements
  - all packets from network A
  - all packets with DSCP=x
  - all VoIP packets
  - …

Flow:= *packets with common properties*



Flow Measurements

Packet Attributes at Observation Point
s_i, –sequence number
t_i – arrival time
c_i – content (header, payload)



Packets: $<s_1, t_1, c_1>, <s_2, t_2, c_2>, \ldots <s_N, t_N, c_N>$

Classification f(c_i)

Flows:

FlowID 1:
$<s_1, t_1, c_1>$
$<s_4, t_4, c_4>$
$<s_8, t_8, c_8>$

FlowID 2:
$<s_2, t_2, c_2>$
$<s_3, t_3, c_3>$
$<s_6, t_6, c_6>$

FlowID 3:
$<s_5, t_5, c_5>$
$<s_7, t_7, c_7>$
$<s_9, t_9, c_9>$

Aggregation

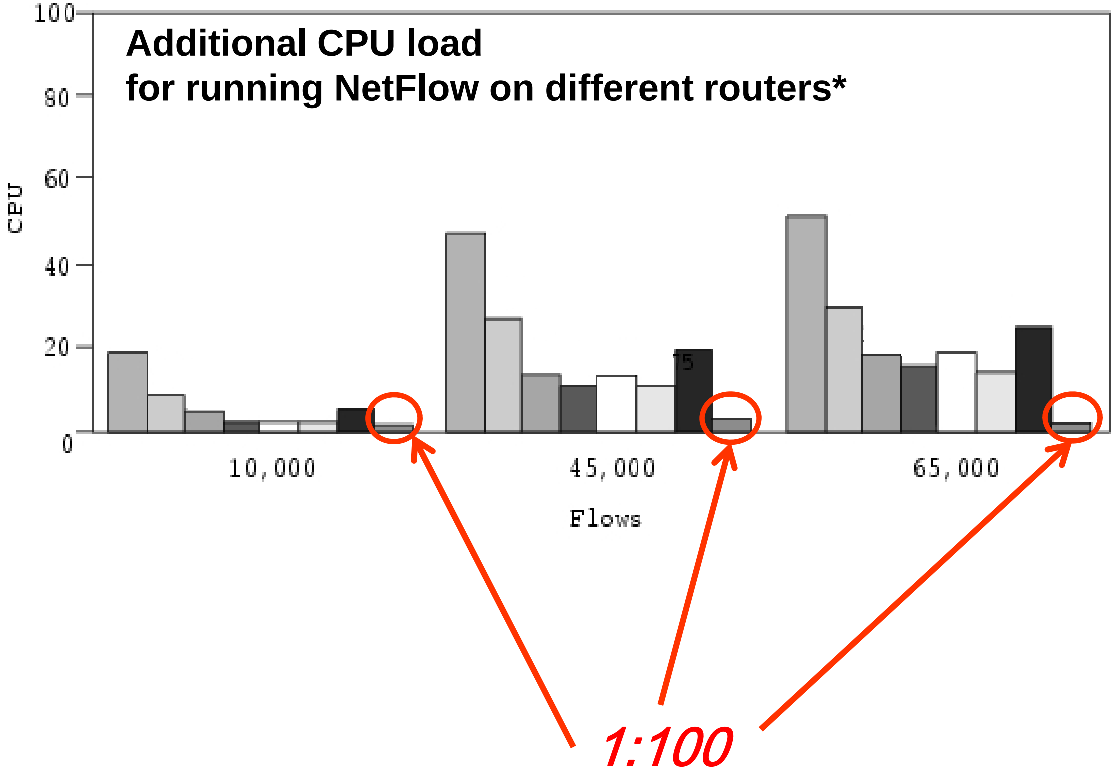
Aggregation

Aggregation

Flow Records: $< N_f, \mu_f, \sigma_f, \ldots >$ $< N_f, \mu_f, \sigma_f, \ldots >$ $< N_f, \mu_f, \sigma_f, \ldots >$

Problem: Resource Consumption

- Resource Limitations
  - Processing power
  - Transmission
  - Storage
- Demand depends on
  - Data rates
  - Required granularity
- Solutions
  - Dedicated Hardware
  - Improved Algorithms
  - Data Selection

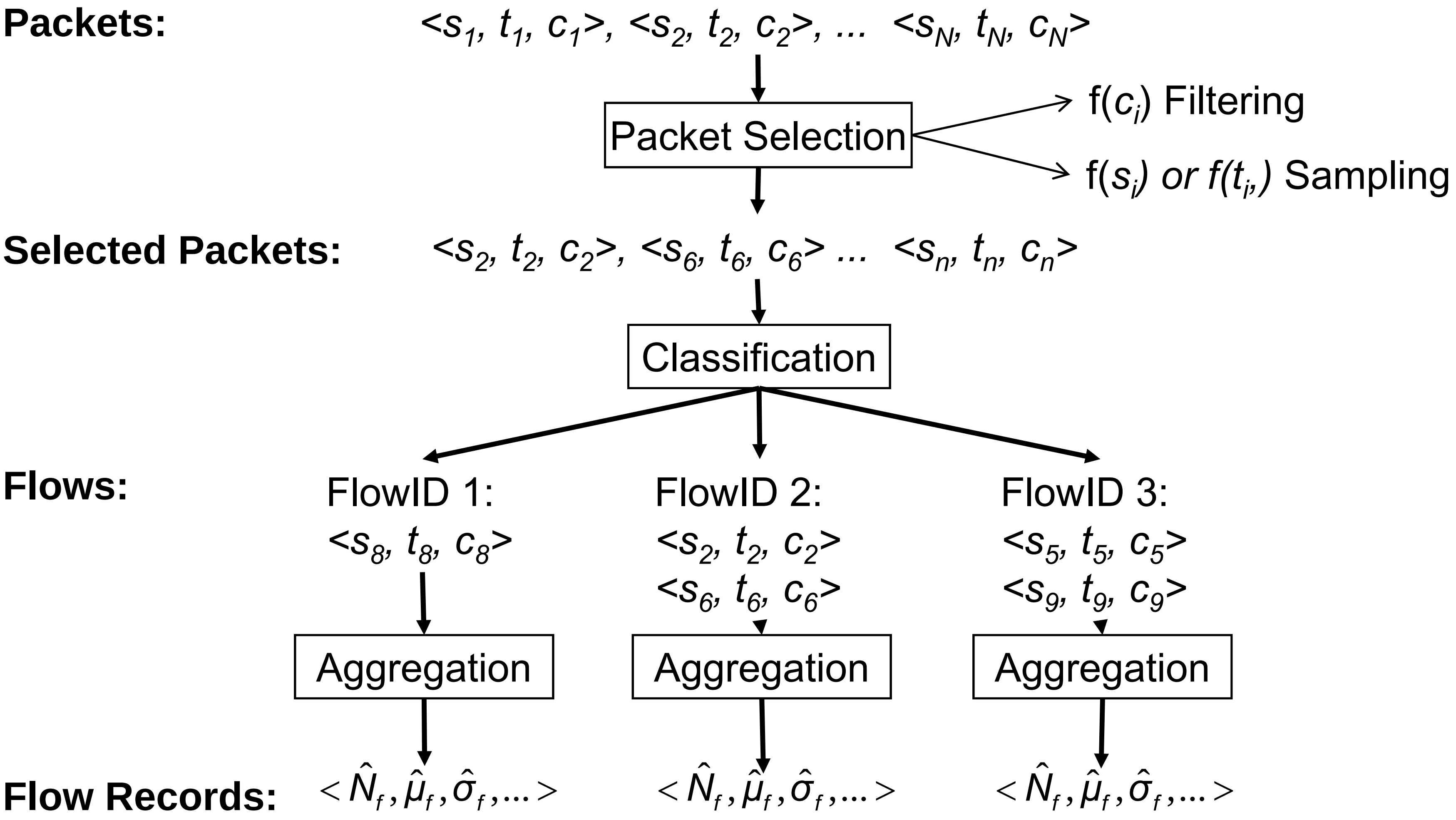


Additional CPU load
for running NetFlow on different routers*

1:100

*source: NetFlow Performance Analysis, Cisco white paper

Packet Selection



Packets: $<s_1, t_1, c_1>, <s_2, t_2, c_2>, \dots <s_N, t_N, c_N>$

Packet Selection

f(c_i) Filtering

f(s_i) *or f(t_i,)* Sampling

Selected Packets: $<s_2, t_2, c_2>, <s_6, t_6, c_6> \dots <s_n, t_n, c_n>$

Classification

Flows:

FlowID 1:
$<s_8, t_8, c_8>$

FlowID 2:
$<s_2, t_2, c_2>$
$<s_6, t_6, c_6>$

FlowID 3:
$<s_5, t_5, c_5>$
$<s_9, t_9, c_9>$

Aggregation

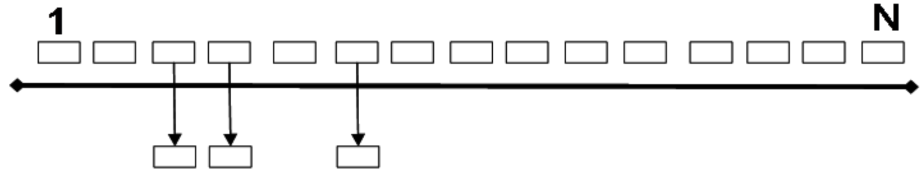
Aggregation

Aggregation

Flow Records: $< \hat{N}_f, \hat{\mu}_f, \hat{\sigma}_f, \dots >$ $< \hat{N}_f, \hat{\mu}_f, \hat{\sigma}_f, \dots >$ $< \hat{N}_f, \hat{\mu}_f, \hat{\sigma}_f, \dots >$

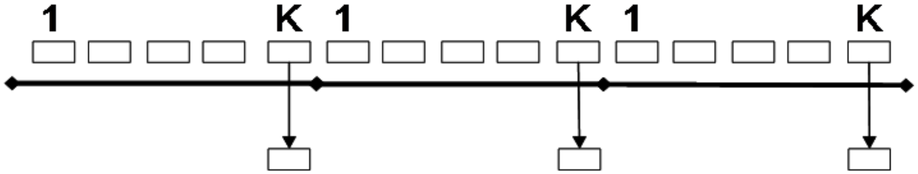
Packet Selection Techniques (Examples)

Random n-out-of-N:



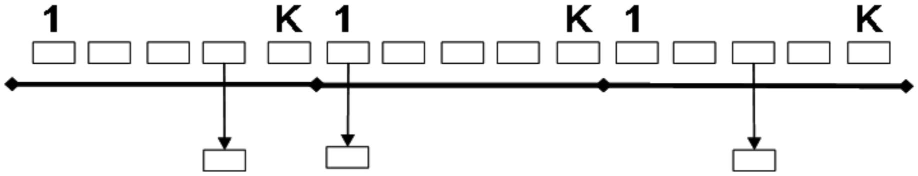
MI with N elements
n-of-N selected
N=15, n=3

Systematic:



MI with N elements
every Kth selected
N=15, K=5, n=N/K=3

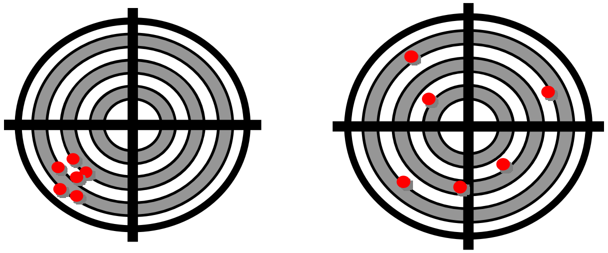
Random 1-in-K:



L subintervals with K elements
L x 1-of-K selected
N=15, K=5, L=N/K=3, n=L=3

Problem: Accuracy Assessment

Accuracy Assessment required



- Achievable accuracy depends on
  - Sampling and estimation method
  - Sampling parameters
  - Population characteristics 🡐 **unknown and highly dynamic**
- Accuracy assessment **during** measurement
  - For each measurement interval
  - For each flow
  - Based on sampled data

Theoretical Model

Case: n-out-of-N, sampling ***before*** classification

N	Packets in MI
n	Packets in sample
Sum_f	Volume in flow f
N_f	Number of packets in flow f
n_f	Sampled packets from flow f
μ_f	Mean packet size in flow f
$\sigma^2_{x_f}$	Packet size variance in flow f
$x_{f,i}$	Bytes in i-th packet

Estimation of Flow Volume: $\hat{S}um_f = \frac{N}{n} \cdot \sum_{i=1}^{n_f} x_{f,i}$

Variance of Estimate: $V[\hat{S}um_f] = V[\frac{N}{n} \cdot \sum_{i=1}^{n_f} x_{f,i}] = \frac{N^2}{n^2} \cdot V[\sum_{i=1}^{n_f} x_{f,i}]$

random variables

Estimation accuracy for flow f :

$$StdErr_{rel} = \frac{1}{N_f \cdot \mu_f} \cdot \sqrt{\frac{N\, N_f \cdot (\sigma_f^2 + \mu_f^2)}{n} - \frac{N_f^2 \cdot \mu_f^2}{N}}$$

Flow Characteristics:

Number of packets from flow f in MI

Packet size variance in flow f

Packet size mean in flow f

Sampling Parameters:

Number of all packets in MI (population size)

Number of selected packets in MI (sample size)

Accuracy Assessment in Practice

- Flow characteristics unknown
  - Estimation from sampled data
- Storing per-packet information too costly
  - Storing aggregates
- NetFlow Records
  - Number of packets stored
  - Sum of packet sizes stored
  - Calculation/estimation of mean packet size possible
  - **BUT:** calculation/estimation of packet size variance not possible

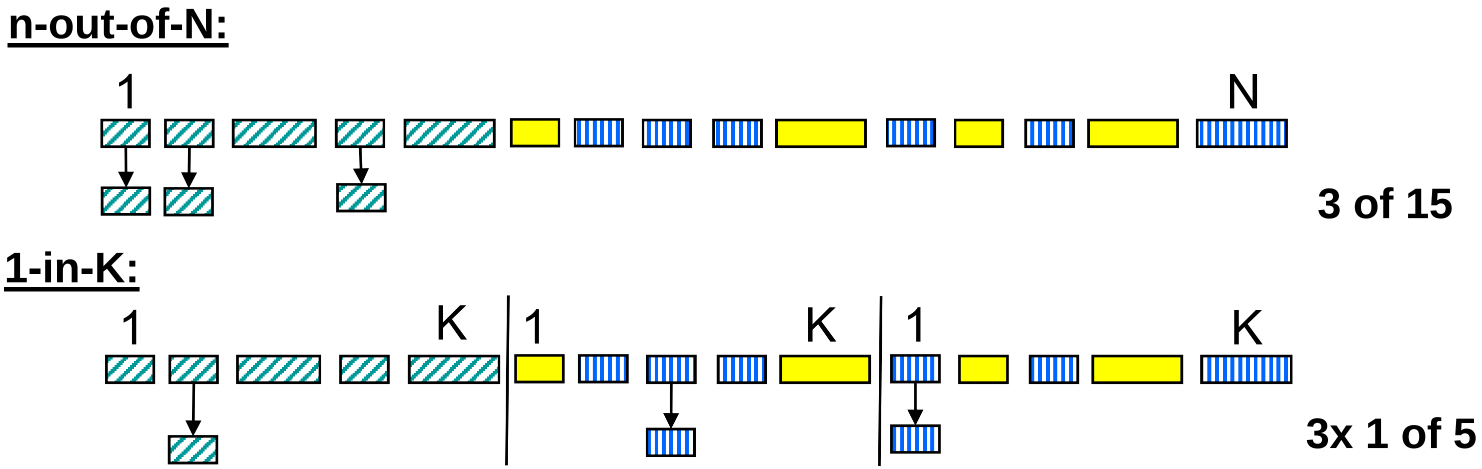
NetFlow Records: $N_f, \sum x_f \; , \sum x_f^2$

Store sum of squares !

1-in-K Sampling (Cisco)

- 1-in-K: Count-based **stratification** with **equal allocation**
  - Packet selection limited to 1 packet per subinterval
  - Theoretical Model ➔ see paper
- Stratification gain
  - Depends on variance of packet sizes from flow f in strata
  - 1 packet per sub-interval selected

  ➔ not sufficient to estimate variance in sub-interval



n-out-of-N:

1

N

3 of 15

1-in-K:

1

K

1

K

1

K

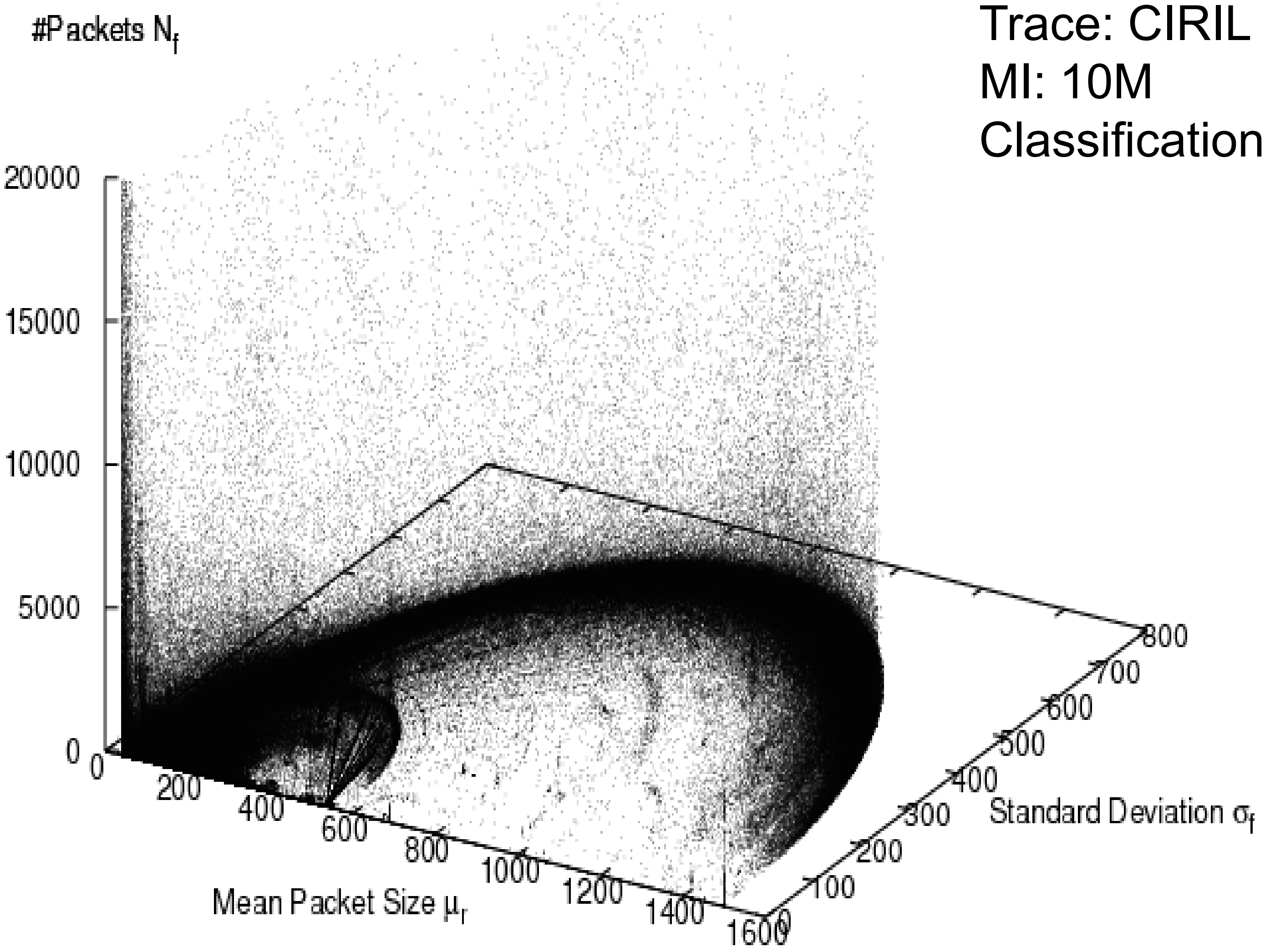
3x 1 of 5

Experiments

- Setup
  - Traces from three different networks
  - Different sampling schemes
  - Different classification schemes
  - Different measurement interval lengths
  - Sampling before and after classification

- Accuracy Calculation
  - based on theoretical model
  - using real flow characteristics

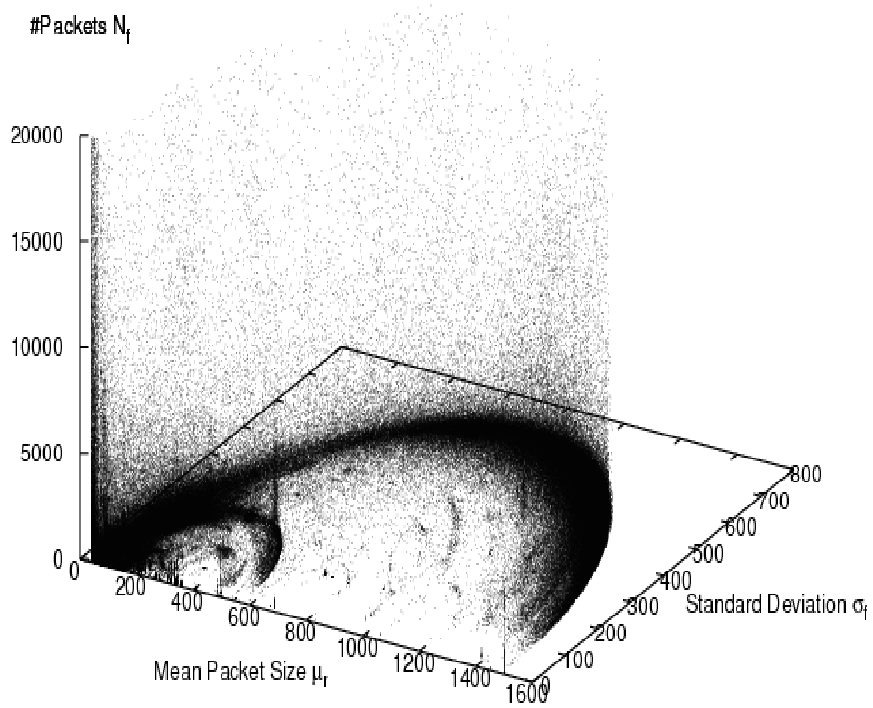
Flow Characterstics



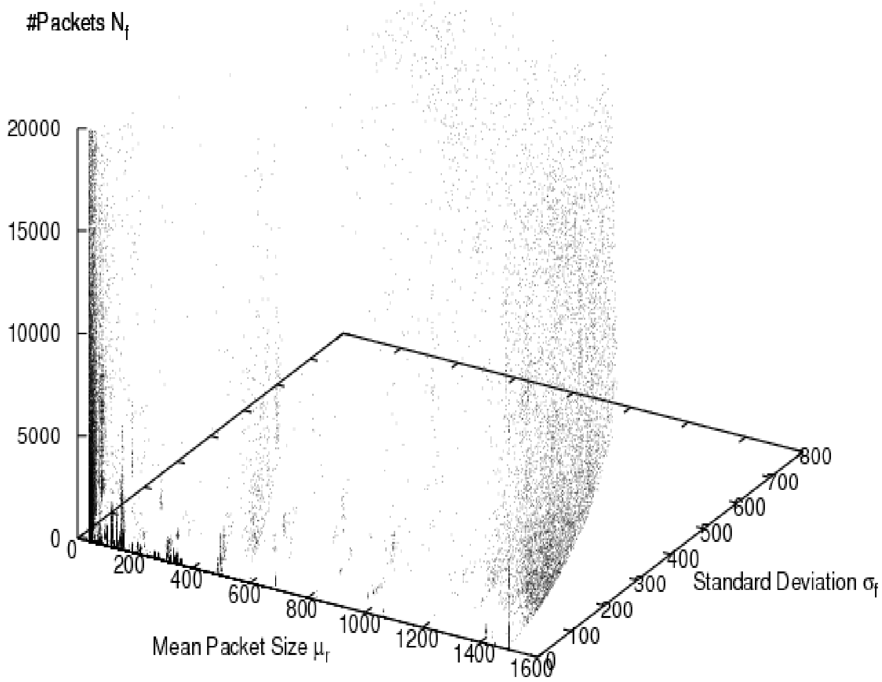
Trace: CIRIL
MI: 10M
Classification S24D00

Conformant Flows

Sampling fraction: 5%, StdErr ≤0.05



Sampling ***after*** classification



Sampling ***before*** classification

Sampling Experiments

- 1000 sampling runs per experiment
- Different sampling rates
- Calculation of bias and standard error
- Comparison of schemes
  - n-out-of-N
  - 1-in-K
  - systematic

Conformant Flows

Trace: NZIX
MI: 1M
Classification S24D00
Sampling fraction =5%

Max rel. StdErr	Error/CL	n-of-N	1-in-K	Systematic
0.003876	0.01/99%	0	0	0
0.005102	0.01/95%	0	0	0
0.019380	0.05/99%	64	64	62
0.025510	0.05/95%	72	72	83
0.051020	0.1/95%	473	475	567
0.076531	0.15/95%	1406	1425	1580
0.102041	0.2/95%	2316	2568	2860
0.1531	0.3/95%	5146	5397	5799
>0.1531	-	79383	79383	79383

Results

- Comparison of schemes
  - n-out-of-N close to n-out-of-N model
  - 1-in-K close to n-out-of-N model
  - Systematic sampling
    - Better results for some flows
    - But unpredictable (high variance of results)
    - Differs from model
- Higher accuracy achievable with
  - Larger sample fraction
  - Longer observation periods (if flow characteristics remain)
  - Coarse grained classification
  - Aggregation of flows

IPFIX/PSAMP IEs

- IP Flow Information Export (IPFIX)
  - Standard for flow information export (RFC5101)
  - Information elements (RFC5102)
- Packet Sampling (PSAMP)
  - Packet selection techniques (filtering, sampling)
  - Packet export using IPFIX

Parameter	**IPFIX/PSAMP IEs**
Number *N* of packets in measurement interval	`samplingPopulation`
Number *n* of packets in sample	`samplingSize`
Number of packets from flow *f* in sample	`packetTotalCount`
Sum (bytes in sampled packets)	`octetTotalCount`
Sum of squares (bytes in sampled packets)	`octetTotalSumOfSquares`

Conclusion

- Accuracy Assessment in theory and practice
  - n-out-of-N (before/after classification) ➔ store sum of squares
  - 1-in-K ➔ not possible in practice (although model exists)
- Experiments
  - Small flows ➔ poor accuracy for sampling before classification
  - 1-in-K close to n-out-of-N
  - Accuracy depends on settings (obs. period, classification)
  - Alternative: Flow selection based on expected accuracy
- IPFIX provides required information elements
- Work in progress:
  - Sampling for other metrics (e.g. for anomaly detection)
  - Hash-based selection

Thank you!

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FOKUS Open Source IPFIX Library:

http://net.fokus.fraunhofer.de/libipfix/

Measurement data always welcome at:

http://www.ist-mome.org/

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