Intelligent SDN based Traffic (de)Aggregation and Measurement Paradigm (iSTAMP): Theory

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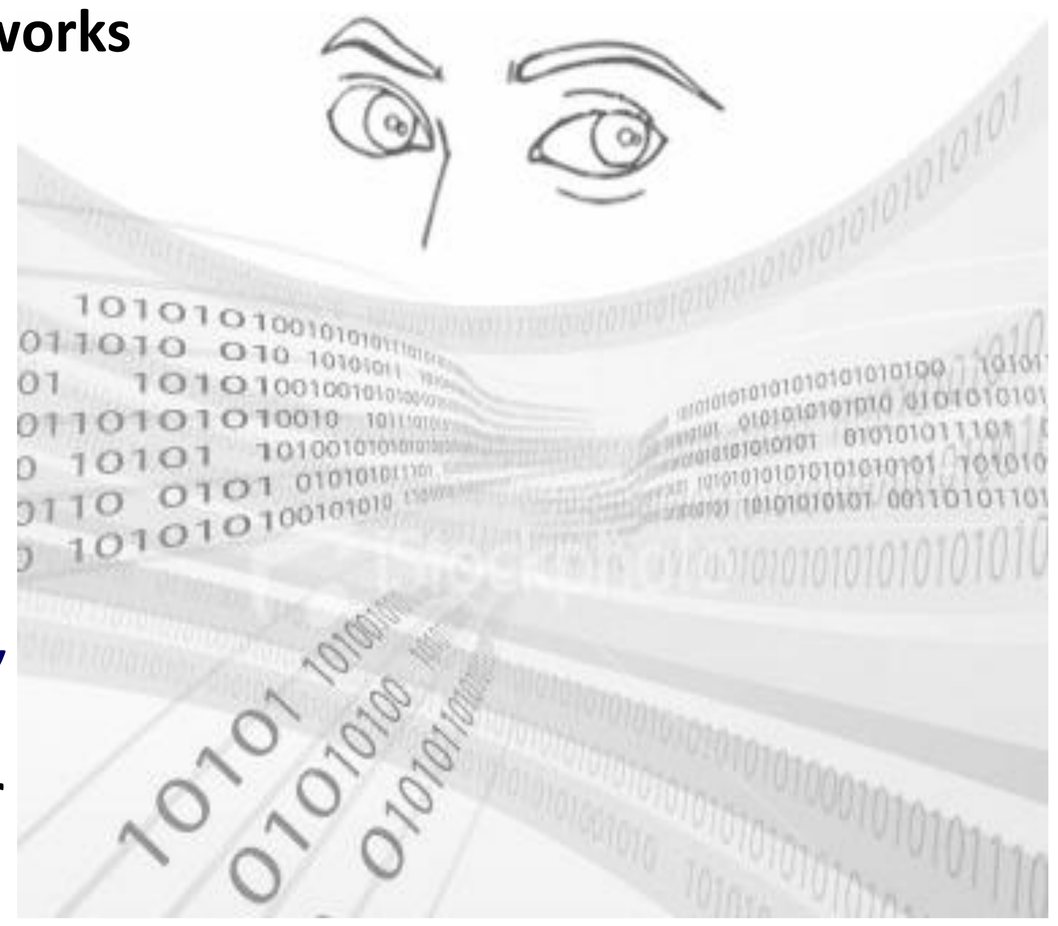
Network Measurement

Direct and indirect network measurement techniques provide essential information for network design, network monitoring and management and network security

Network Measurement: Limitations and Challenges

- Feasibility and Complexity of the measurement process
- Exploding Traffic Volume
- Limited Measurement and/or Processing Resources
- High computational complexity in large-scale networks
- Limited performance accuracy
- Sensitivity to noise and failures



Solution

Efficient and Intelligent Software Defined Network Measurement & Inference under Resource Constraints

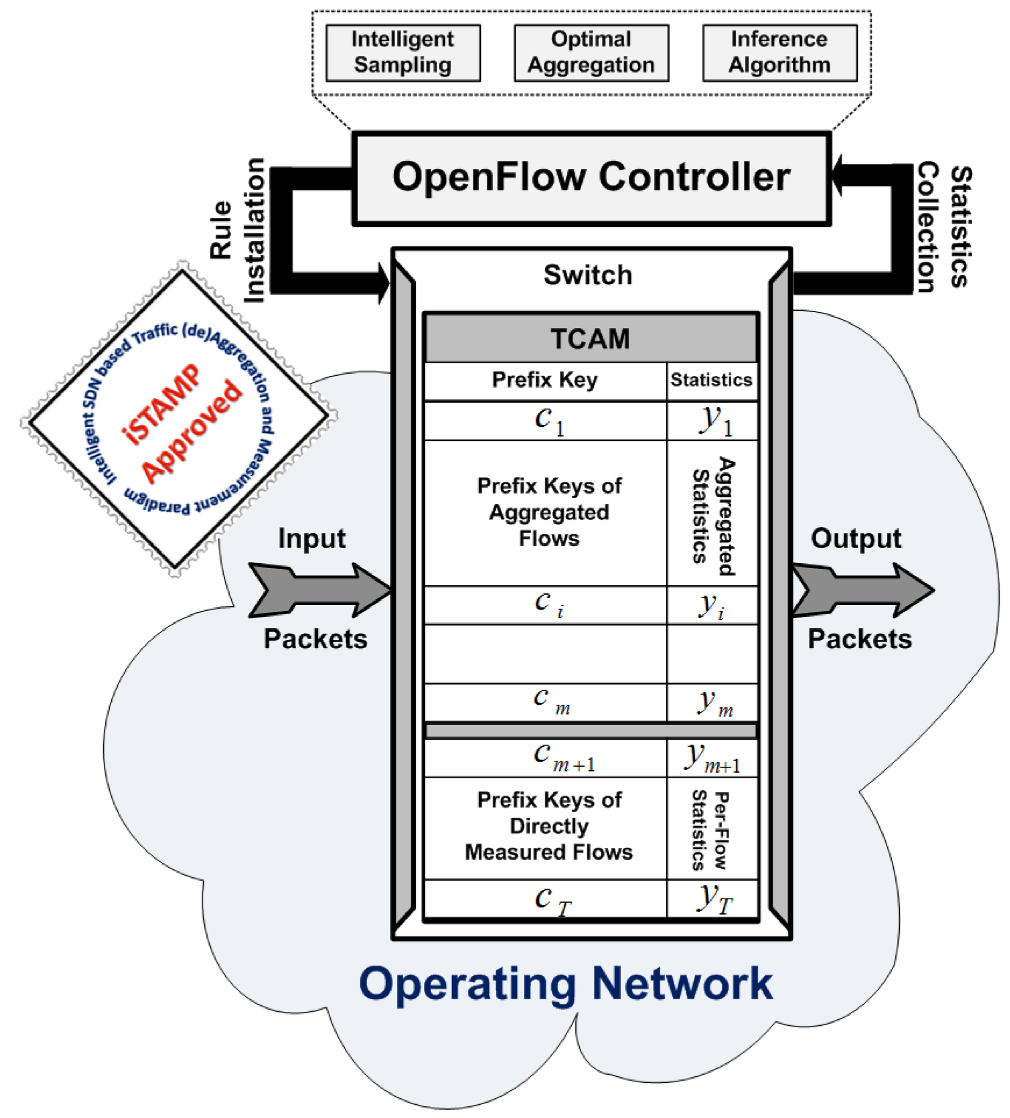
where

- Measurement Resources are ***optimally*** & ***adaptively*** allocated
- Powerful inference techniques are ***efficiently*** used for estimating the attribute of interests

iSTAMP: Framework

iSTAMP leverages OpenFlow to dynamically partition the TCAM entries of a switch/router into two parts for optimal aggregation and direct flow sampling. iSTAMP has three main components:

- ❑ An Optimal aggregation technique to produce a well-compressed aggregated flow measurements that can lead to the best estimation accuracy via network inference process
- ❑ An intelligent sampling algorithm to sample the most informative traffic flows
- ❑ An efficient compressive sensing inference technique to accurately estimate highly fluctuated flows over time/space



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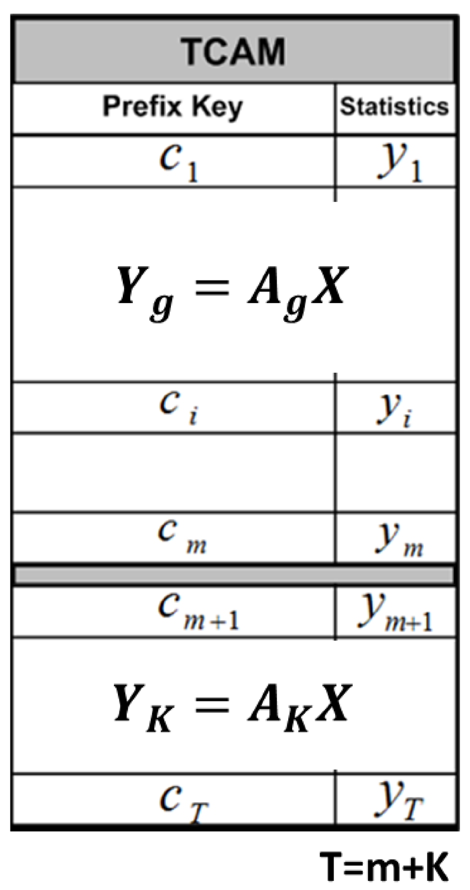
iSTAMP: Formulation

Design the aggregation matrix A which provides both optimal aggregated and per-flow direct measurements

Definitions:

- X: An $n \times 1$ vector of unknown flows denoted
- $A = \begin{bmatrix} A_g \\ A_K \end{bmatrix}$: An m$\times$ n binary matrix aggregation matrix
- Y: An m$\times$ 1 vector of observations

$$Y = AX \Rightarrow Y = \begin{bmatrix} Y_g \\ Y_K \end{bmatrix} = \begin{bmatrix} A_g \\ A_K \end{bmatrix} X$$



Main Optimization Framework:

$$\hat{X} = \underset{X}{\text{minimize}} \, \|Y_g - A_g X_g\|_2^2 + \lambda \|X_g\|_1$$

$$\text{s.t.} \quad X_k = A_k X_k, \quad X_g \geq 0$$

Example:

$$Y = \begin{bmatrix} Y_g \\ Y_K \end{bmatrix} = \begin{bmatrix} x_1 + x_2 \\ x_4 + x_6 \\ x_3 \\ x_5 \end{bmatrix} \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix}$$

TCAM Rules (Flow ID's bit map)

0	0	X	---
0	1	X	---
1	1	0	---
1	1	1	---

3 most significant bits

x_1: 000.---
x_2: 001.---
x_3: 110.---
x_4: 010.---
x_5: 111.---
x_6: 011.---

iSTAMP: Optimal Aggregation & Per-Flow Measurement Matrix Design

Measurement matrix design depends on the size of matrix and estimation technique

❑ Optimal Compressive Sensing Flow Aggregation

$$\hat{X} = \underset{X}{min} \|X\|_1 \quad \text{s.t.} \quad Y_g = A_g X \Rightarrow \underset{A_g}{\text{minimize}} \left\| A_g^T A_g - \phi \right\|_F^2$$

Formulated as a Linear Integer Optimization Problem

❑ Optimal Sampling and Exponential Aggregation Technique

Algorithm Modified Upper Confidence Bound (MUCB)

Input: Time horizon T_c and parameter α.
Output: At each epoch t, the set of sorted indicies of incoming flows (I^t) in descending order where $I^t = I_k^t \bigcup I_g^t$.
while True **do**
- Set $t = 1$, measure all n flows $\{x_j\}_{j=1}^n$ using all T entries of TCAM over $\lceil \frac{n}{T} \rceil$ epochs, and set $t_c = n$.

while $t < T_c$ **do**
- Compute flow indicies $I_j^t = \alpha \bar{x}_j + \sqrt{\frac{2ln(t_c)}{t_j(t_c)}}$ for all flows $j = 1, ..., n$ where $\bar{x}_j$ is the average flow size for j^{th} flow, $t_j(t_c)$ is the number of times flow j has been measured upto time t_c and t_c is the overall number of measurements done so far.
- Sort the set I^t and report indicies in descending order as $I^t = I_k^t \bigcup I_g^t$.
- Allocate k measurement entries to the k flows with indicies in I_k^t and measure them.
- $t = t + 1$, $t_c = t_c + K$.

end while
end while

Algorithm 2 Exponential Aggregation Technique (EAT)

Input: Aggregation parameters ρ and δ.
Output: Aggregation Matrix A_g^t .
Initialization: Set $i_c = 0$ and $A_g^t = 0_{m \times n}$.
for i = m **to** 1 **do**
- $r = \lceil \rho(n - K)\frac{1}{\delta^i} \rceil + 1$

for j = 1 **to** r **do**
- $A_g^t(i, I_g^t(i_c + j)) = 1$

end for
- $i_c = i_c + r$

end for