Internet of Things: Sensing, Systems, and Networking

Muhammad Shahzad (www4.ncsu.edu/~mshahza/)

Research Interests

- Human Sensing
- Connectivity
- Measurements & Modeling
- Infrastructure
- Multi-tenancy

Human Sensing

- WiFi based human sensing
- Light based human sensing

Connectivity

- Optimizing existing wireless protocols for IoT
- Visible Light Communication
- Medium Access Control
  - Out of band methods

Measurements and Modeling

- Modeling, design, and analysis of probabilistic protocols to measure fundamental network performance metrics such as latency, jitter, throughput, and packet loss
- Characterizing the performance of WiFi, Zigbee, and IEEE 802.15.4 in dense IoT networks

Infrastructure

- Sizing buffers of IoT access routers
  - maximize link utilization
  - minimize packet loss rate
  - minimize energy consumption
- Fog computing

Multi-tenancy

- Device Level
  - Enabling multiple users to use the same IoT devices
- Network Level
  - Providing customized view of the network to tenants

Accurate and Efficient Per-flow Latency Measurement without Packet Probing and Time Stamping

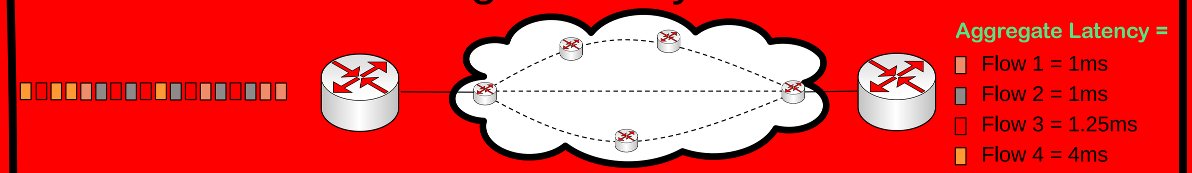
Latency Matters

- Applications
  - Financial Trading
  - High Performance Computing
- Architectures
  - CDNs
  - Datacenters

comcast. verizon at&t

Types of Latency Measurements

- Aggregate Latency Measurement
  - Measure average latency

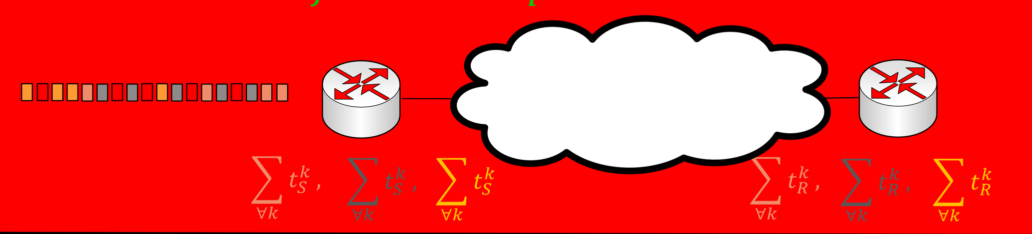


- Guaranteeing average ≠ Guaranteeing each
- Per-flow Latency Measurement
  - Measure latency of each flow

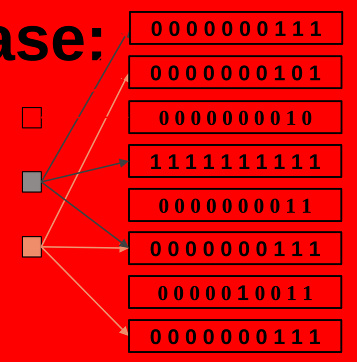
Basic Idea

- Total latency of a flow with n packets is

$$\sum_{k=1}^{n}(t_R^k - t_S^k)$$
$$= \sum_{k=1}^{n} t_R^k - \sum_{k=1}^{n} t_S^k$$
$$= \textit{sum of timestamps at receiver} - \textit{sum of timestamps at sender}$$



Recording Phase: COLATE



- Many-Many mapping
- When a packet comes
  - Select random number $j \in [1, m]$
  - Evaluate hash $H(f_{id}, j) \in [1, n]$
  - Add time stamp to counter $H(f_{id}, j)$
  - Dump when sum of counters exceeds a threshold
- Cost per packet:
  - One hash computation
  - One memory update

Querying Phase

- Latency of Flow ?

Extract $\sum_{\forall k} t_S^k$

$$E[\text{Counter}] = E[\square + \square + \square] + E[\square]$$
$$= \frac{T - \sum_{\forall k} t_S^k}{n} + \frac{\sum_{\forall k} t_S^k}{m}$$

Extract $\sum_{\forall k} t_R^k$

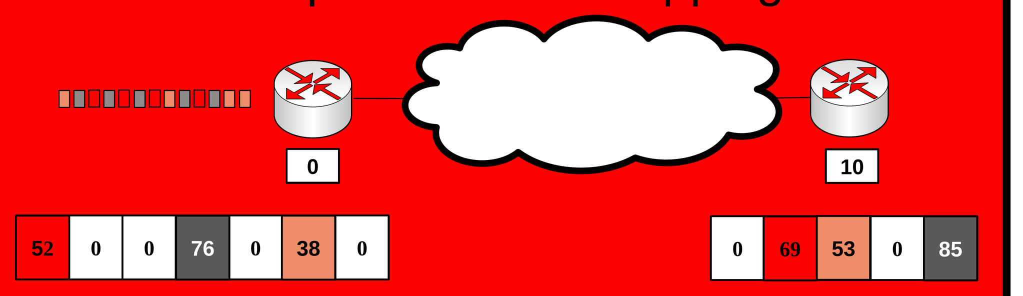
Latency $= \sum_{\forall k} t_R^k - \sum_{\forall k} t_S^k$

Problem Statement

- Input
  - Relative error $\beta > 0$
  - Success probability $\alpha \in [0,1)$
- Output
  - An estimate $\tilde{\mu}$ of average latency μ such that
    - $P\{(1-\beta)\mu \le \tilde{\mu} \le (1+\beta)\mu\} \ge \alpha$
  - An estimate $\tilde{\sigma}$ of standard deviation in latency σ such that
    - $P\{(1-\beta)\sigma \le \tilde{\sigma} \le (1+\beta)\sigma\} \ge \alpha$

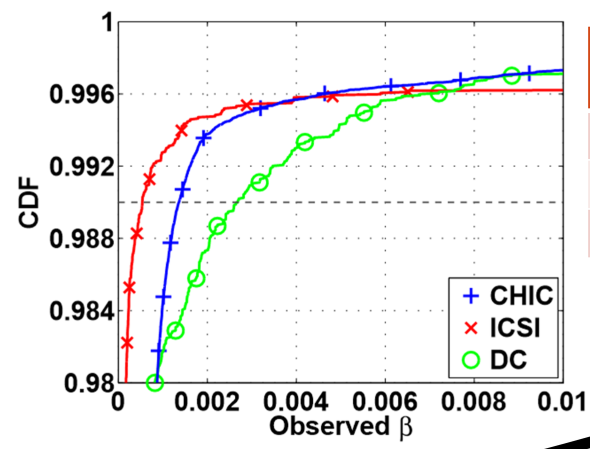
Recording Phase: a naïve solution

- One counter per flow: 1-1 mapping



- Problem
  - Overflow vs. Underutilization
- Reason
  - 1-1 mapping: flows ⟷ counters

Performance Evaluation



Trace	Duration	No. of Packets	No. of Flows
CHIC	5 mins	37.3M	3.01M
ICSI	41.1 hrs	46.9M	0.387M
DC	1.08 hrs	19.9M	0.439M

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