Analytical Delay Modeling of an OpenFlow Switch

Uzzam Javed

Outline

- Background
- Problem Statement
- Motivation
- Literature Review
- Implementation and Results
- Stochastic Modeling
- Conclusion and Future Work

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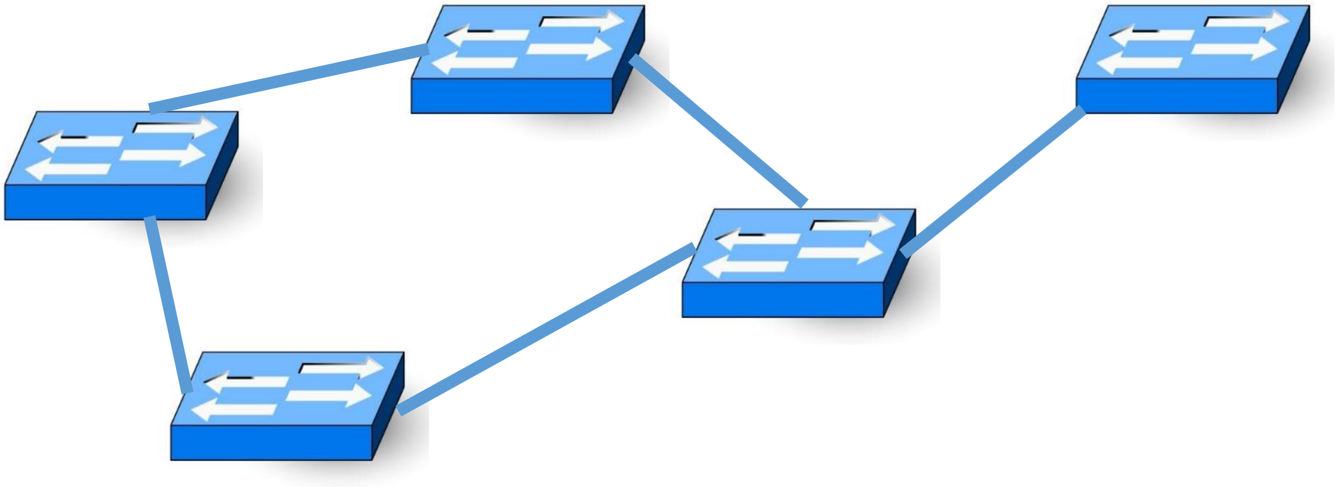
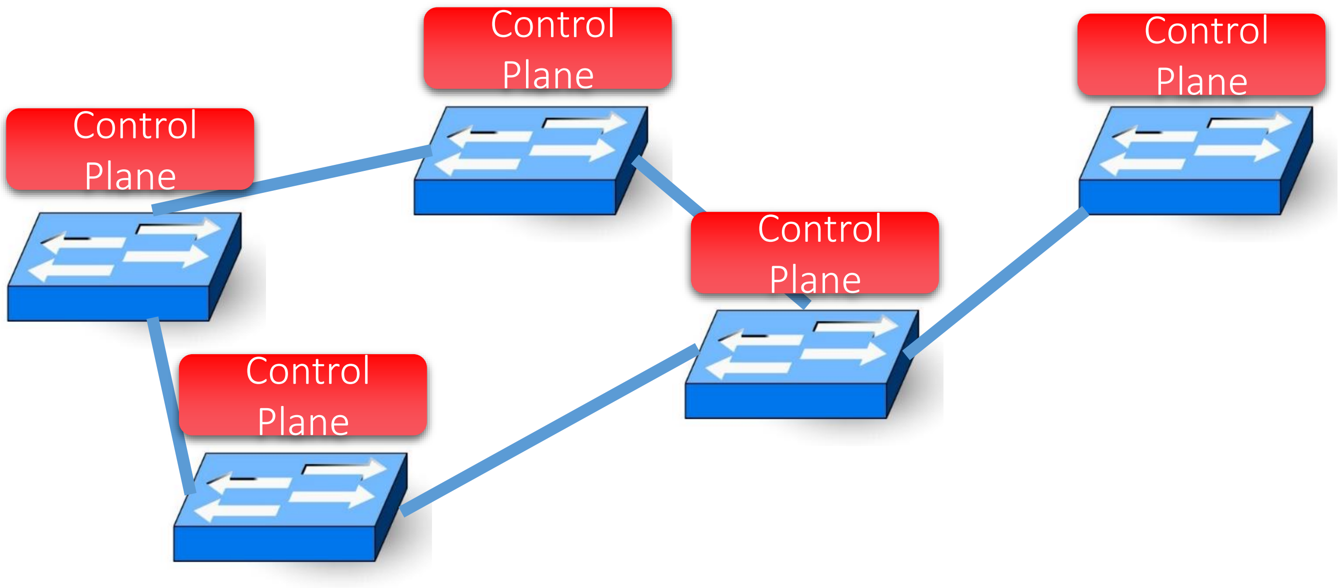
Planes in Networking

- **Data Plane**
  - Forward traffic according to the logic implemented at the control plane.



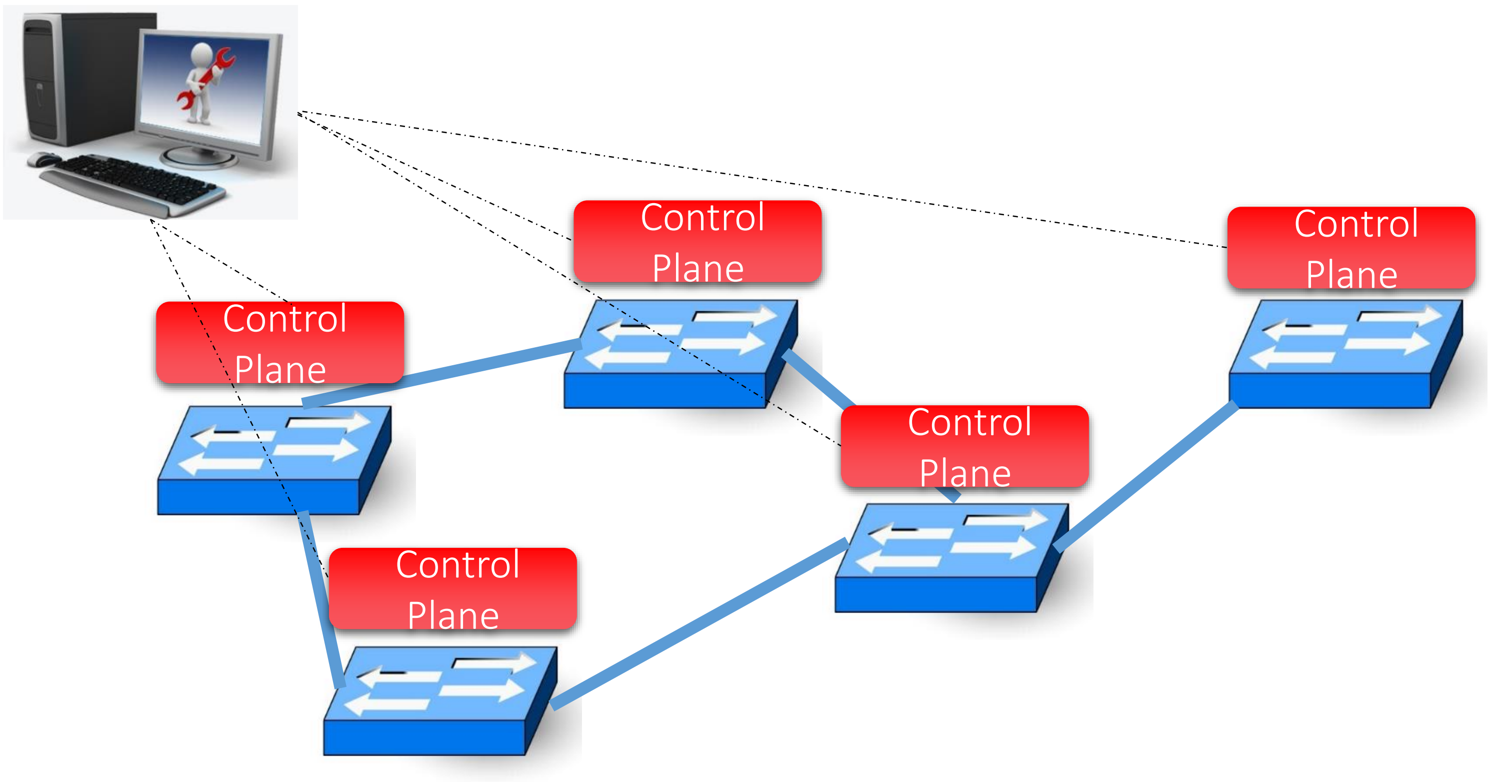
Planes in Networking

- **Control Plane**
  - Control plane is the brain of the network, providing logic for the forwarding plane.
  - It learns about the structure of the network by communicating to its peers in other devices.



Planes in Networking

- **Management Plane**
  - For management and configuration of the network devices.

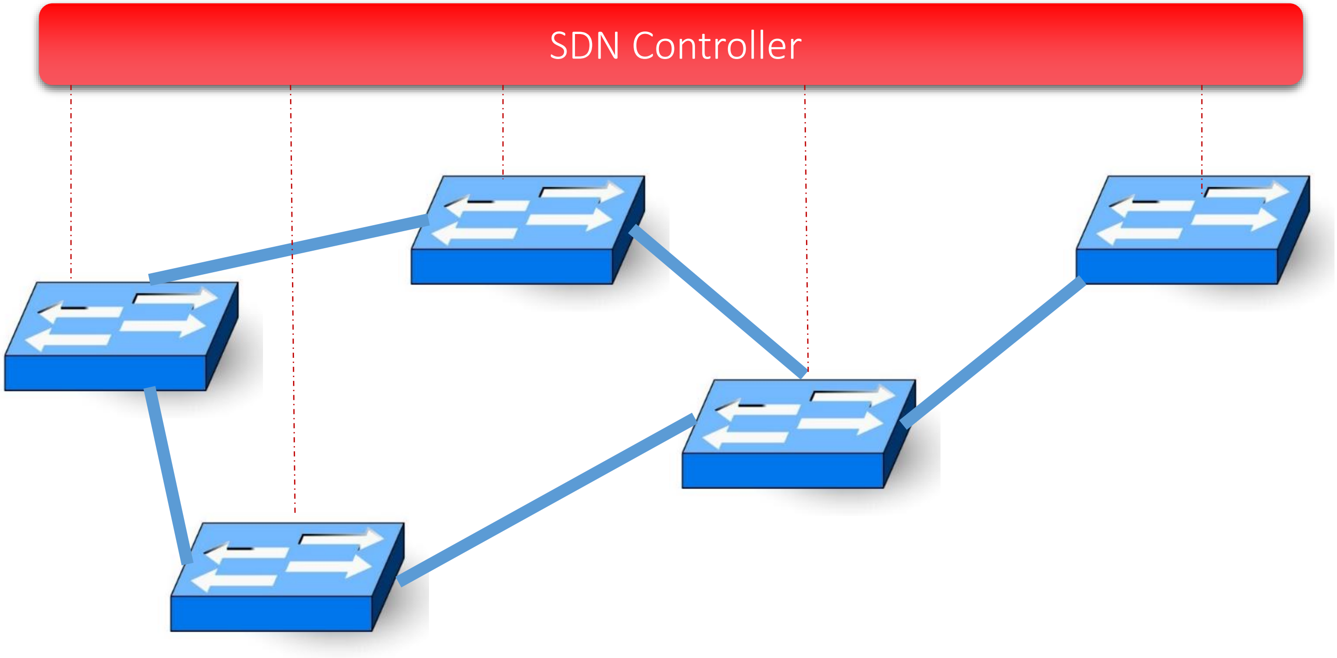


Traditional Networks

- In traditional networks all three planes reside within the firmware of switches and routers.
- Making the management of large scale networks difficult.

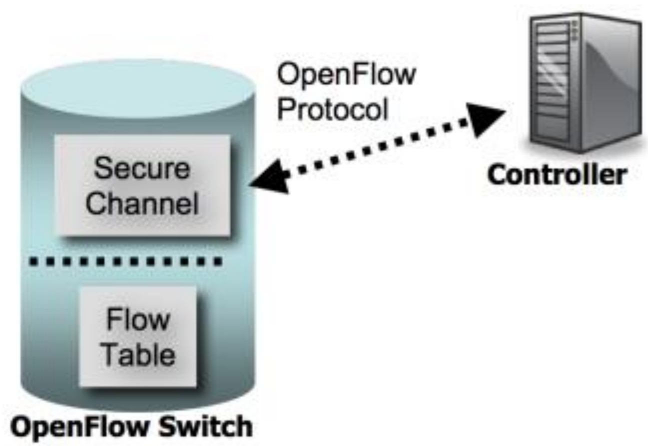
Software Defined Networking (SDN)

- Software Defined Networking (SDN) decouples control plane from data plane.
- Providing a control plane abstraction for the whole network.



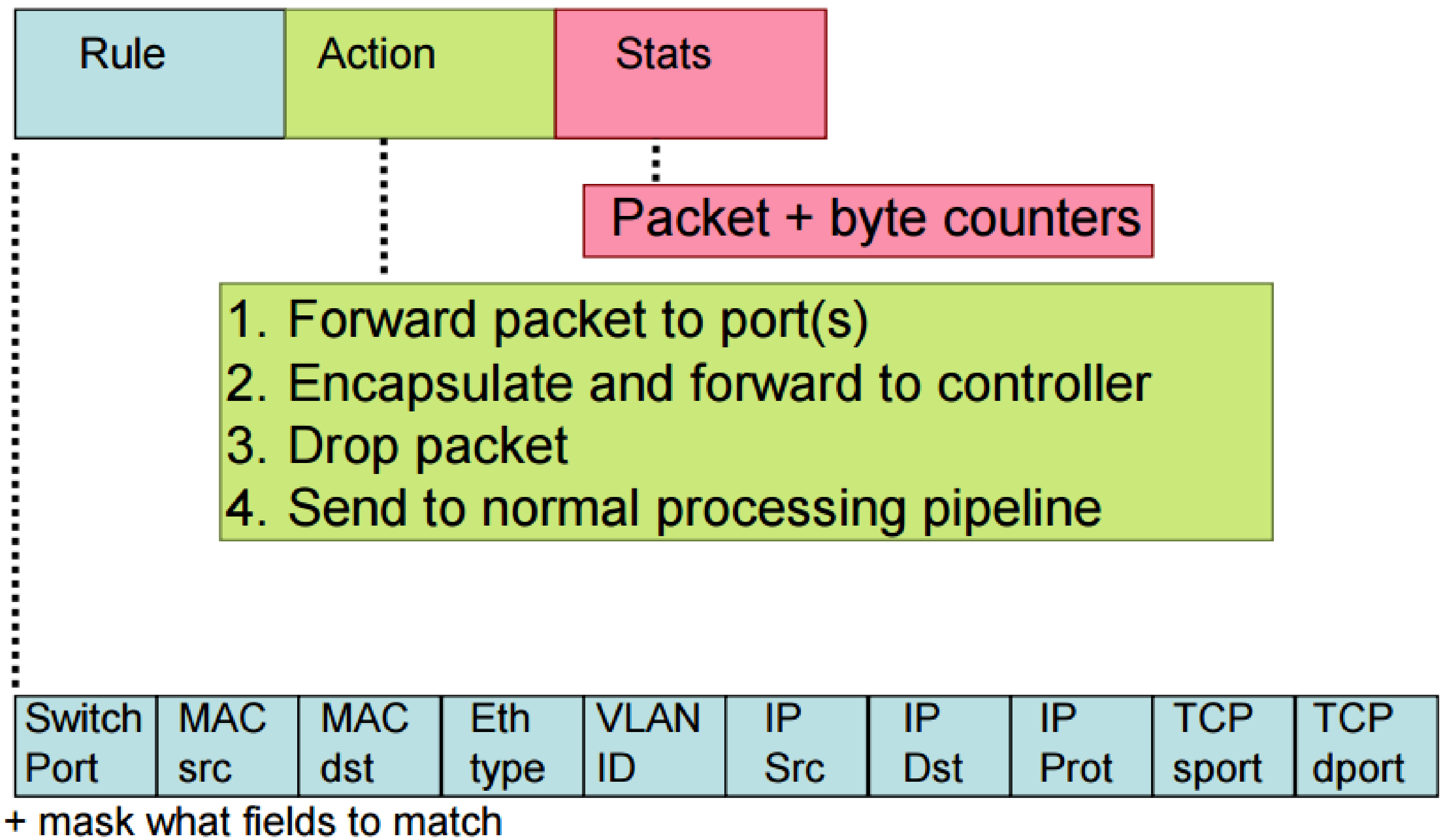
OpenFlow

- Virtually separated planes interact through different APIs (interfaces).
- OpenFlow is an interface to communicate between the control plane and the data plane promoted by Open Networking Foundation (ONF).



https://www.opennetworking.org/images/stories/downloads/sdn-resources/onf-specifications/openflow/openflow-spec-v1.0.0.pdf

OpenFlow Switch Flow Table



http://www.slideshare.net/Cameroon45/ppt-4515906

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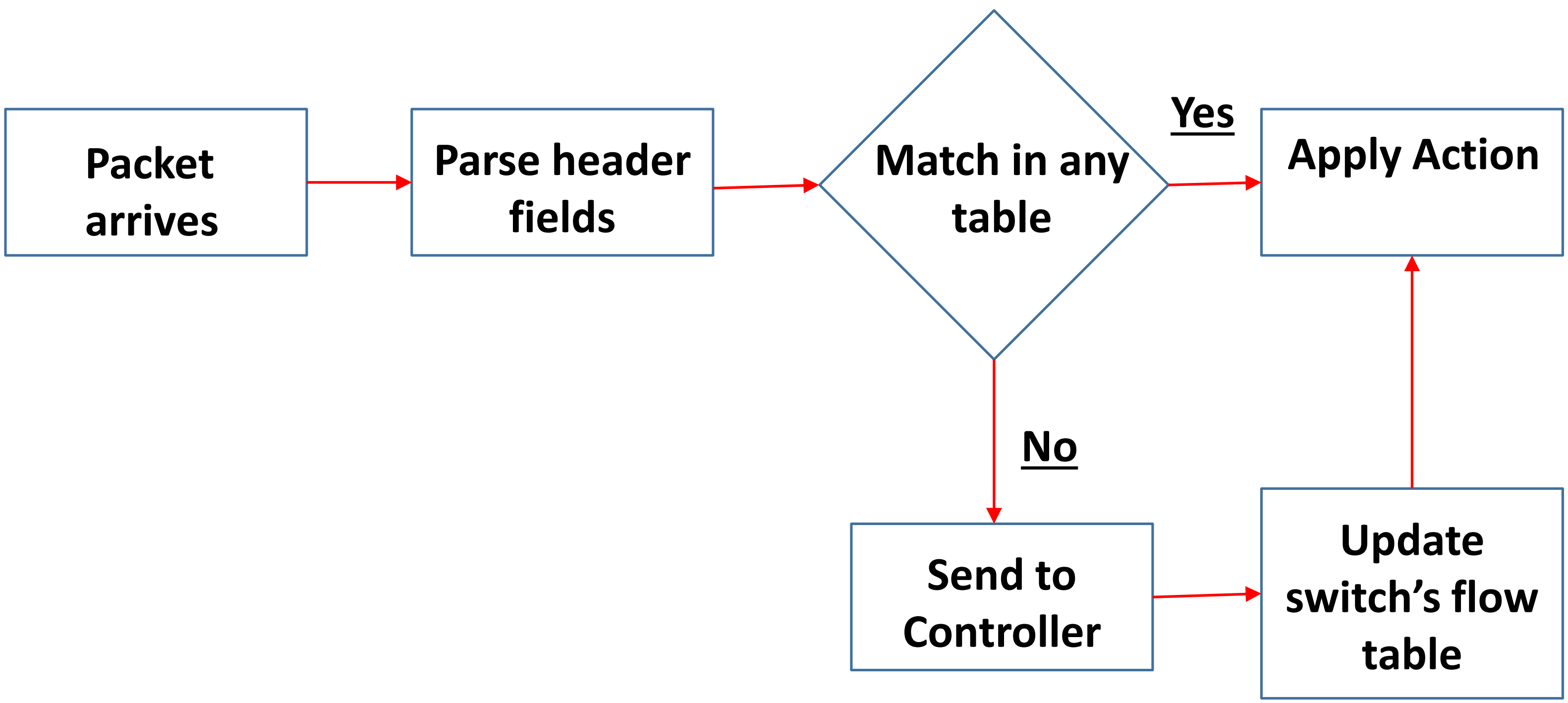
Packet Flow in OpenFlow Switch



https://www.opennetworking.org/images/stories/downloads/sdn-resources/onf-specifications/openflow/openflow-spec-v1.0.0.pdf

Packet Flow in OpenFlow Switch

- The increase in latency is due to:

1. The propagation delay between OpenFlow switch and control plane,
2. The processing speed of the control plane,
3. The responsiveness of OpenFlow switches in generating flag for a new flow and updating their respective flow tables on receiving signal from the central controller.

Problem Statement

- To derive a model of the packet processing delay of an OpenFlow switch.
- Model is be based on measurements and simulations on different platforms.

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Motivation

- To provide a quick notion and better understanding of how an OpenFlow switch will perform during experiments.
- To analyze how a normal switch performance is affected by switch-controller interaction and its limitation.
- To help understand the delay characteristics of Internet traffic in networks using OpenFlow controlled switches.
- It will help network designers and administrators anticipate expected end-to-end delays Internet links built from OpenFlow switches.

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- Stochastic Analysis of Results
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Literature Review

1. Multiple research papers relating to performance measurements.
2. Models using Queueing theory
   - Simulations were used to verify the derived model.
   - Exponential service time distribution for traffic was assumed.
   - *[Jarschel, Michael, et al. "Modeling and performance evaluation of an openflow architecture." Proceedings of the 23rd international teletraffic congress. International Teletraffic Congress, 2011.]*
   - *[Chilwan, Ameen, et al. "ON MODELING CONTROLLER-SWITCH INTERACTION IN OPENFLOW BASED SDNS."]*

Literature Review

3. Models using Network Calculus
   - Model only provided worst-case bounds on performance metrics.
   - *[Azodolmolky, Siamak, et al. "An analytical model for software defined networking: A network calculus-based approach." Global Communications Conference (GLOBECOM), 2013 IEEE. IEEE, 2013.]*

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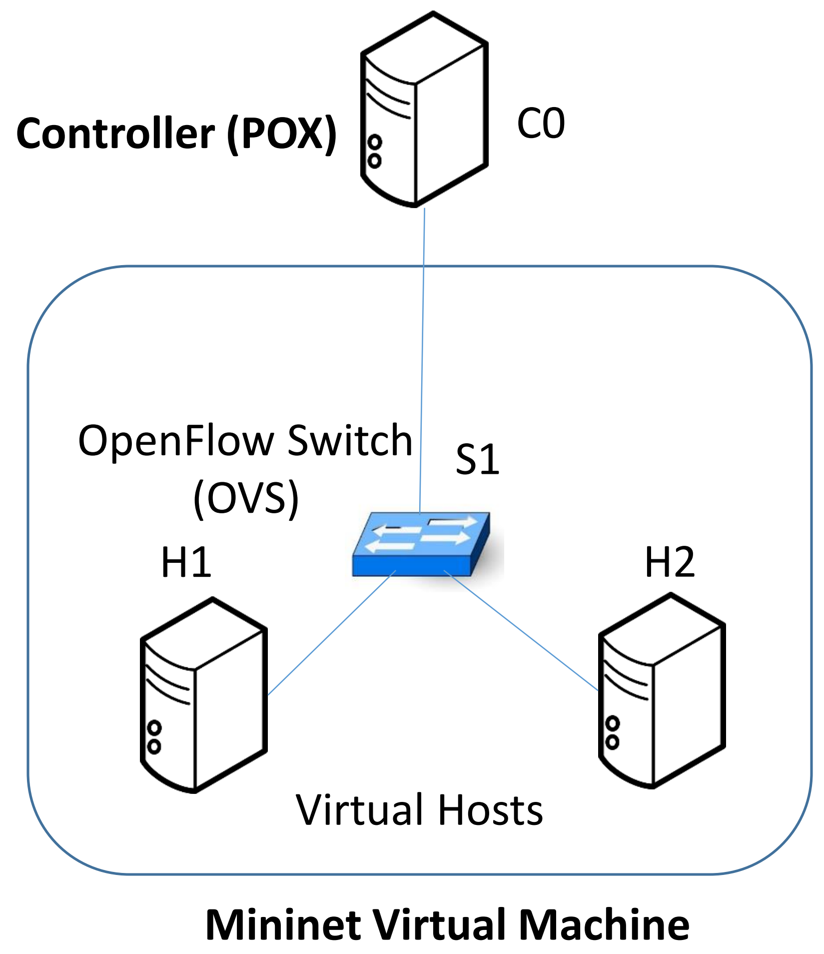
Experimental Setups

- We used the *Distributed-Internet Traffic Generator* (D-ITG) to generate and control repeatable network traffic flows for experiments.
- We measured the Round-Trip Time (RTT), to avoid clock synchronization issues present in measuring one-way delay.
- POX was the controller used on one system.
- OVS was used to enable OpenFlow 1.0 .
- Two hosts were connected with the switch.

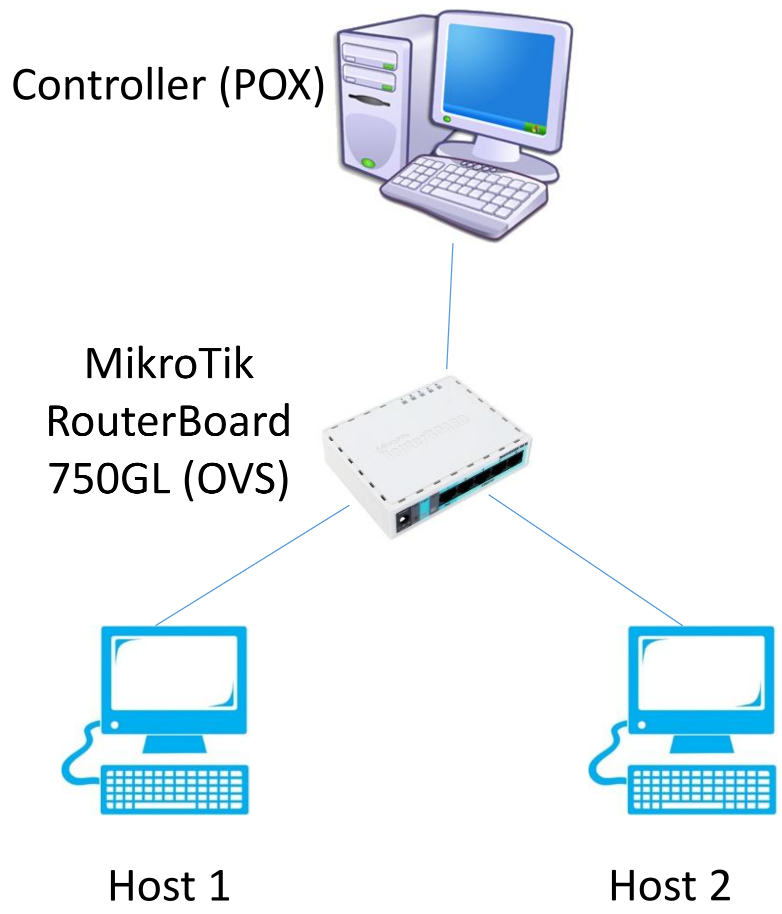
Setup 1 – Mininet 2.2.1

- A Software Defined Networking emulator.
- To explore the behavior of OpenFlow switch delay in an SDN emulator.



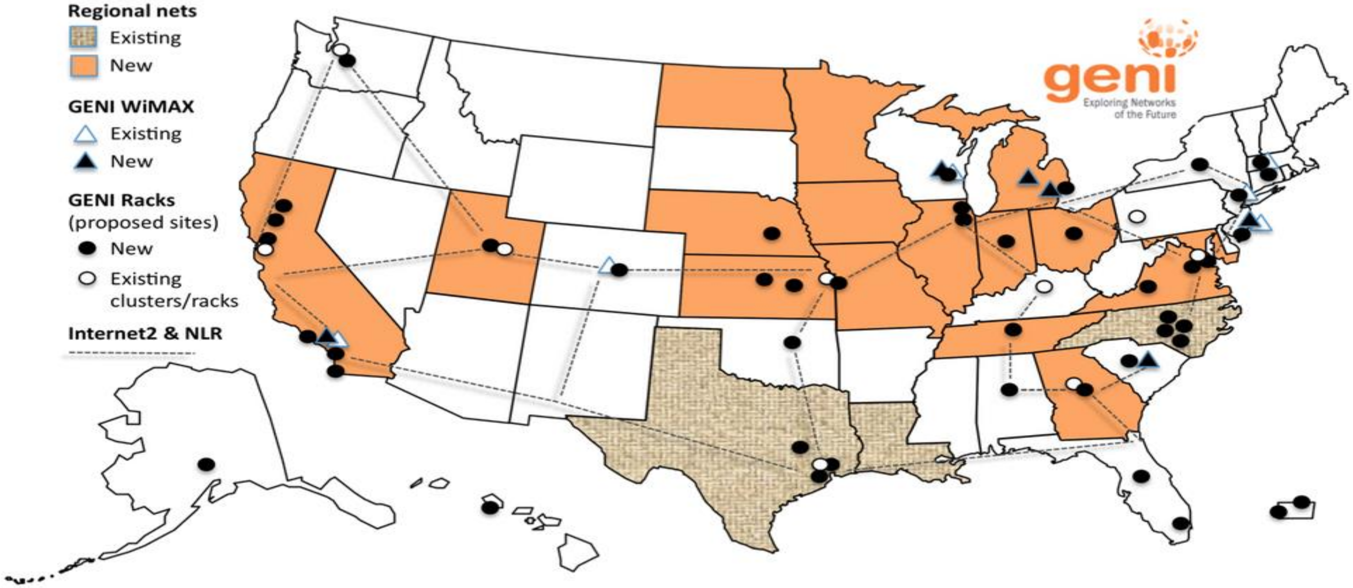
Setup 2 – Laboratory setup

- Experimentation on a Laboratory scale testbed of a single OpenFlow switch.
- Enabling OpenFlow on a commercial router, MikroTik RouterBoard 750GL, for experimentation.
  - Wrote a technical report *'Enabling OpenFlow on MikroTik RouterBoard 750GL: A Tutorial'.*



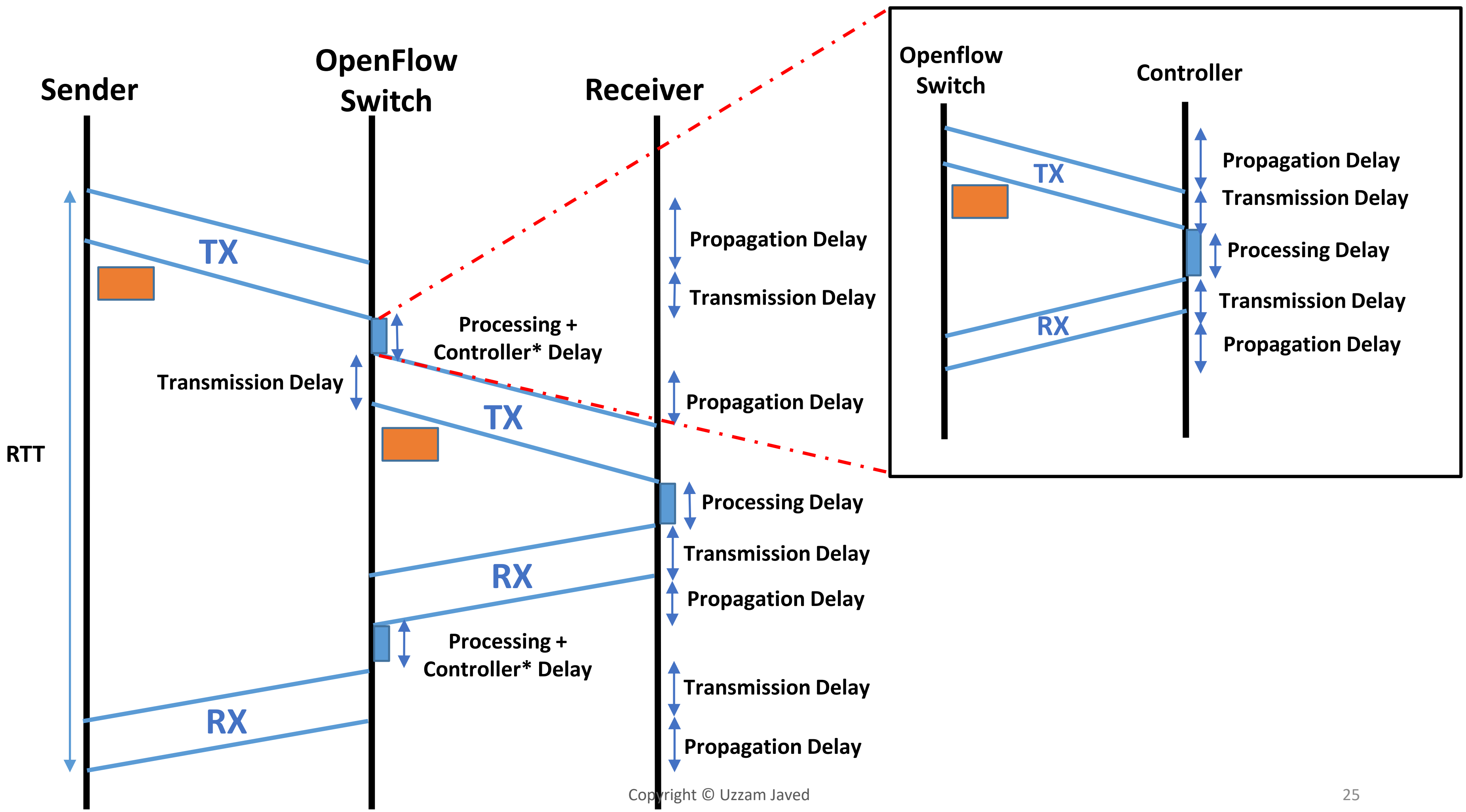
Setup 3 – GENI Testbed

- A large-scale experiment infrastructure.
- Experimentation on widely distributed resources.
- To explore OpenFlow switch behavior at scale.
- Controller was located in Stanford, California while the switch and hosts were located in La Mirada, California.



http://groups.geni.net/geni/wiki/GeniNewcomersWelcome

Delay Components in Experiments



Experimental Setups

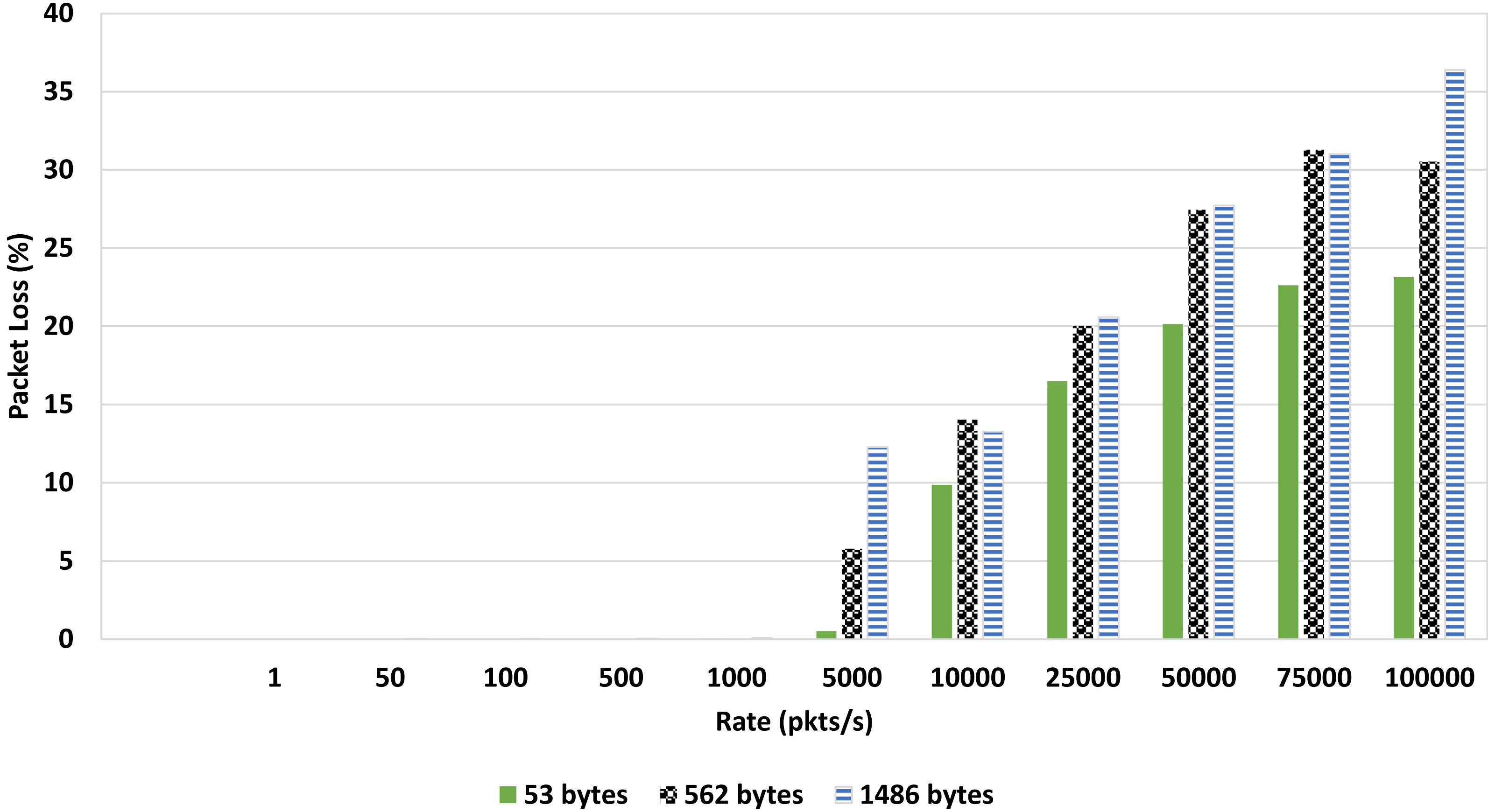
Two scenarios were considered in experiments:

- Proactive - Controller populates the switch's flow table ahead of time.
- Reactive - Switch does not find a flow table entry for an incoming round trip flow and consults the controller.
  - Rules were installed for a MAC addresses.
  - Timeout value for a rule was set to 1 second.
- Three packet sizes were considered 77bytes (small), 562bytes (medium) and 1,486bytes (large) for experiments.

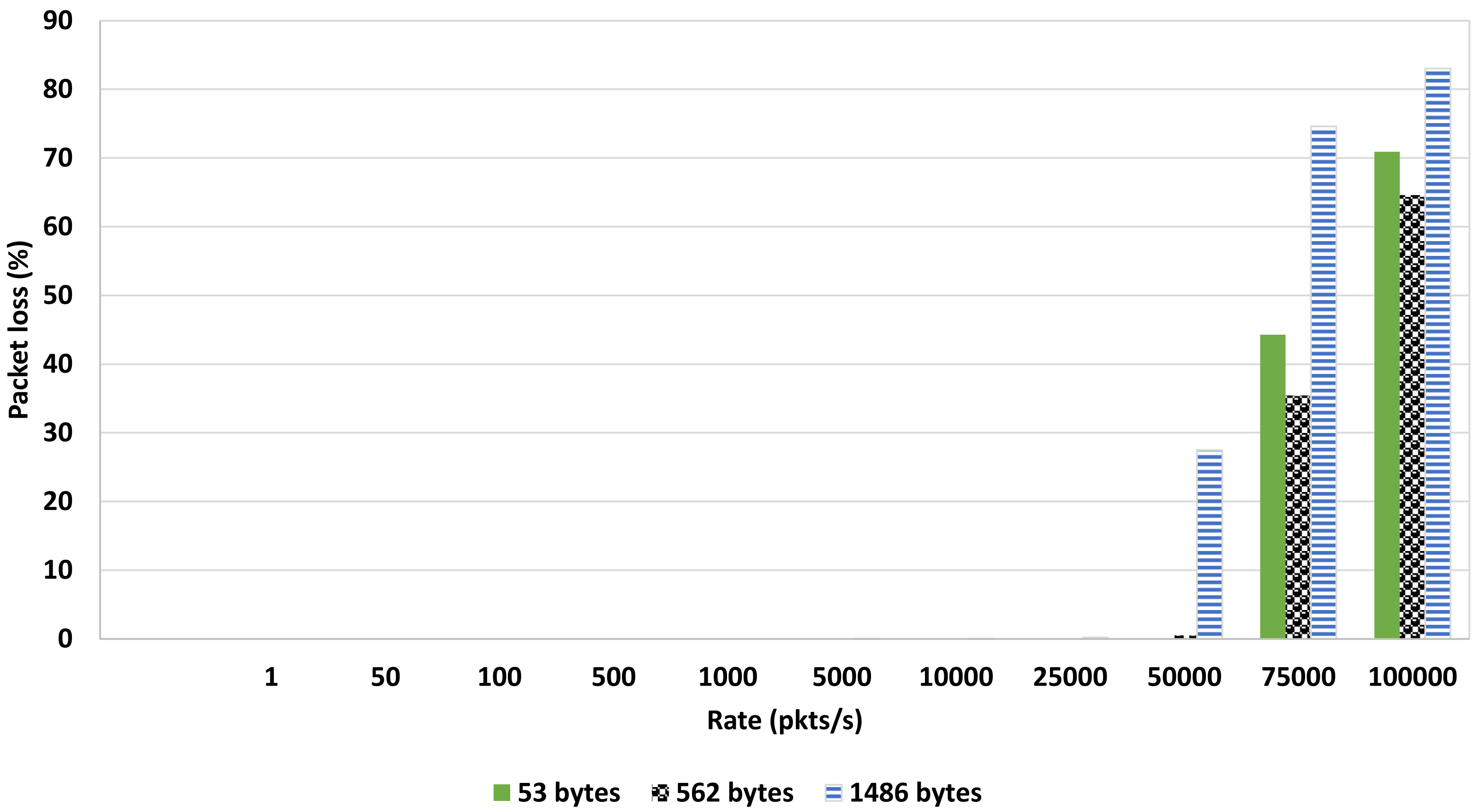
Performance Benchmarking

- Packet loss percentage of UDP traffic was captured at various packet transmission rates.
- Similarly for TCP, retransmission rate was captured.
- The experiment per transmission rate was performed for a 5 minutes capture time.

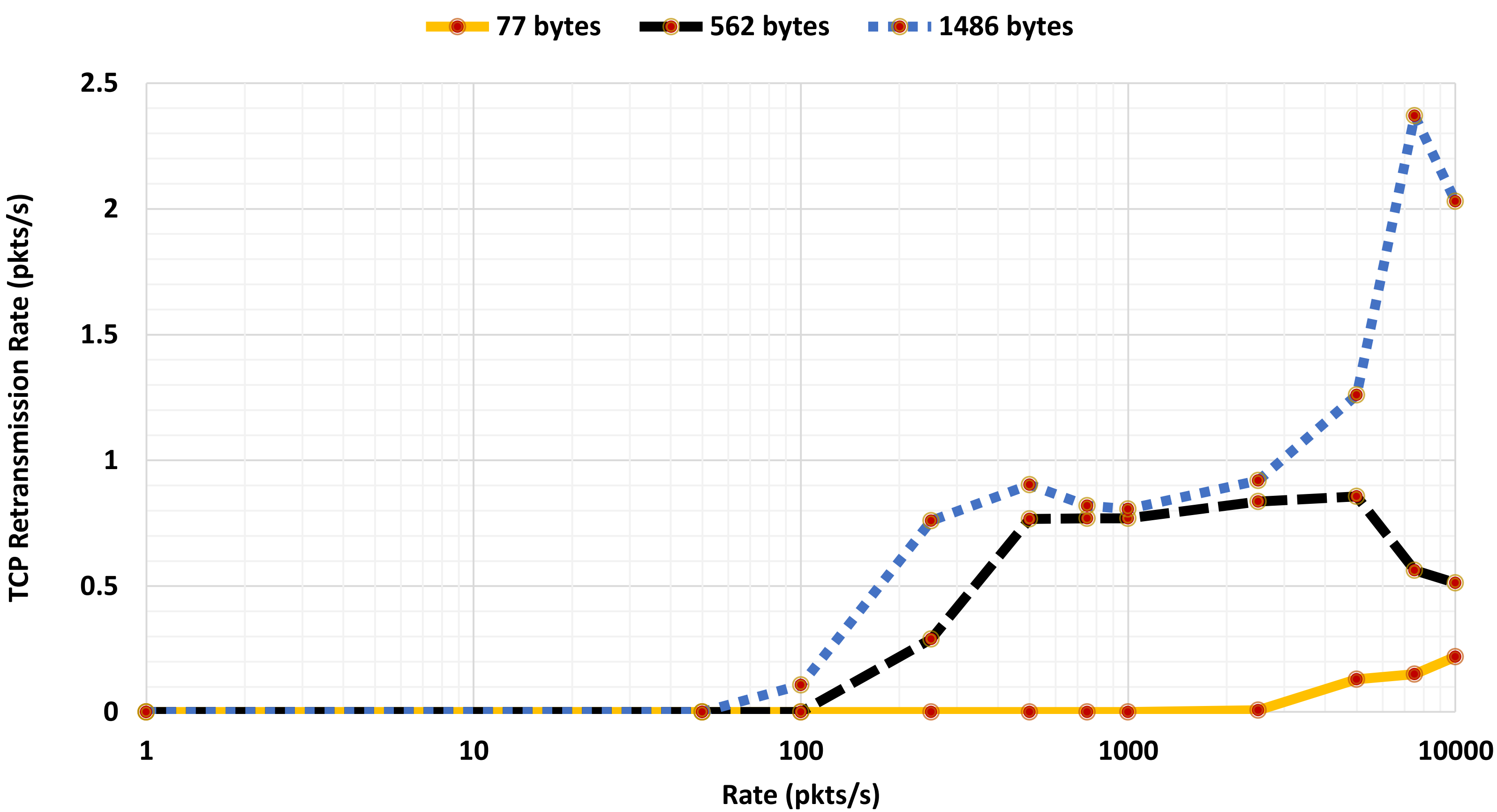
Packet loss rate of UDP traffic in MikroTik RB750GL



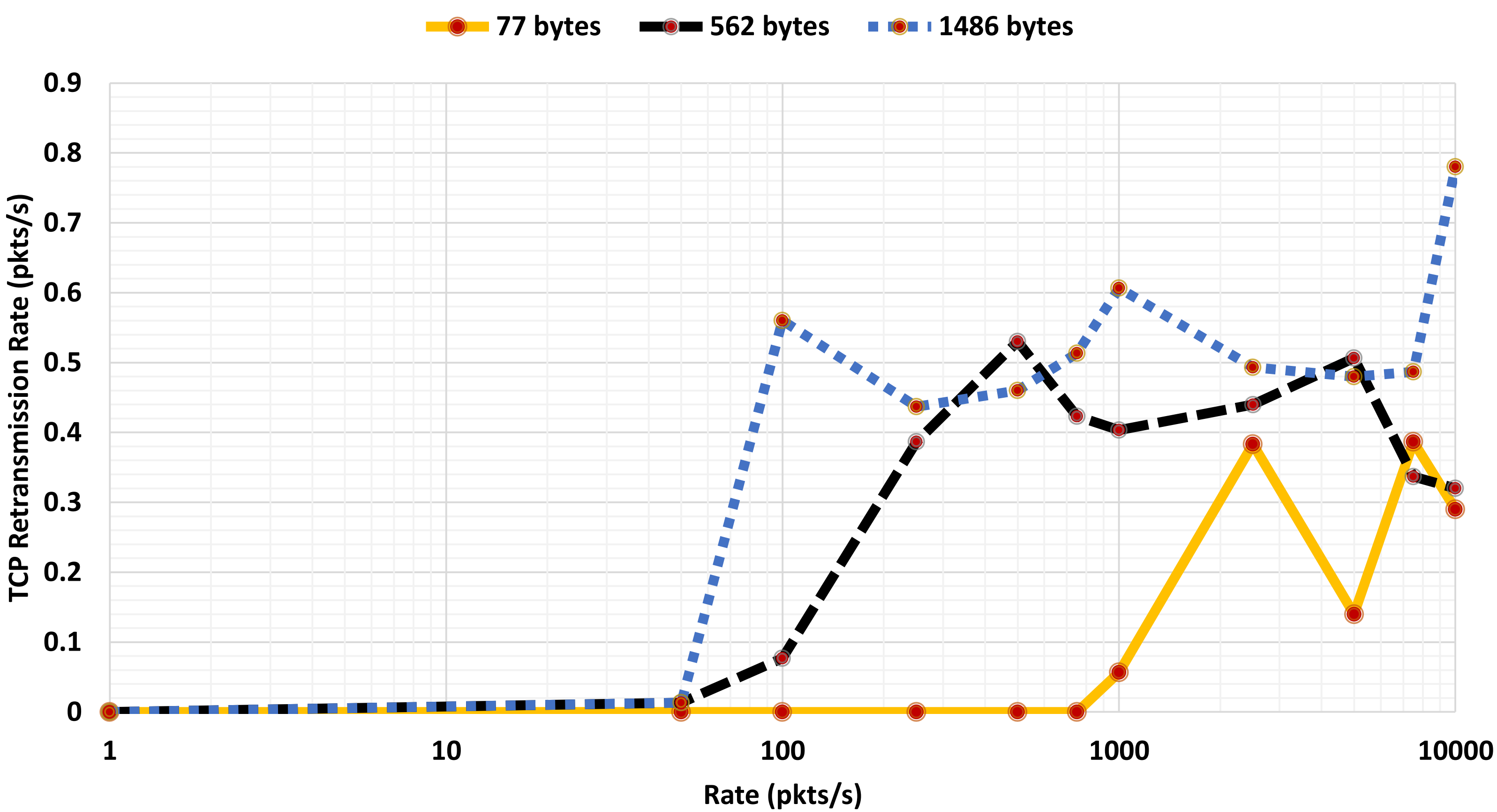
Packet loss rate of UDP traffic in GENI



Retransmission rate in TCP traffic in MikroTik RB750GL



Retransmission rate in TCP traffic in GENI



Maximum Throughput Rate

Platforms	Proactive	Reactive	Controller
MIninet	2.92Gbits/s	2.7Gbits/s	16.8Mbits/s
MikroTik RB750GL	514Mbits/s	477Mbits/s	6.29Mbits/s
GENI	99.5Mbits/s	83.6Mbits/s	6.08Mbits/s

TCP window size = 85.3KBytes

- The measurement was performed using *iperf* client.

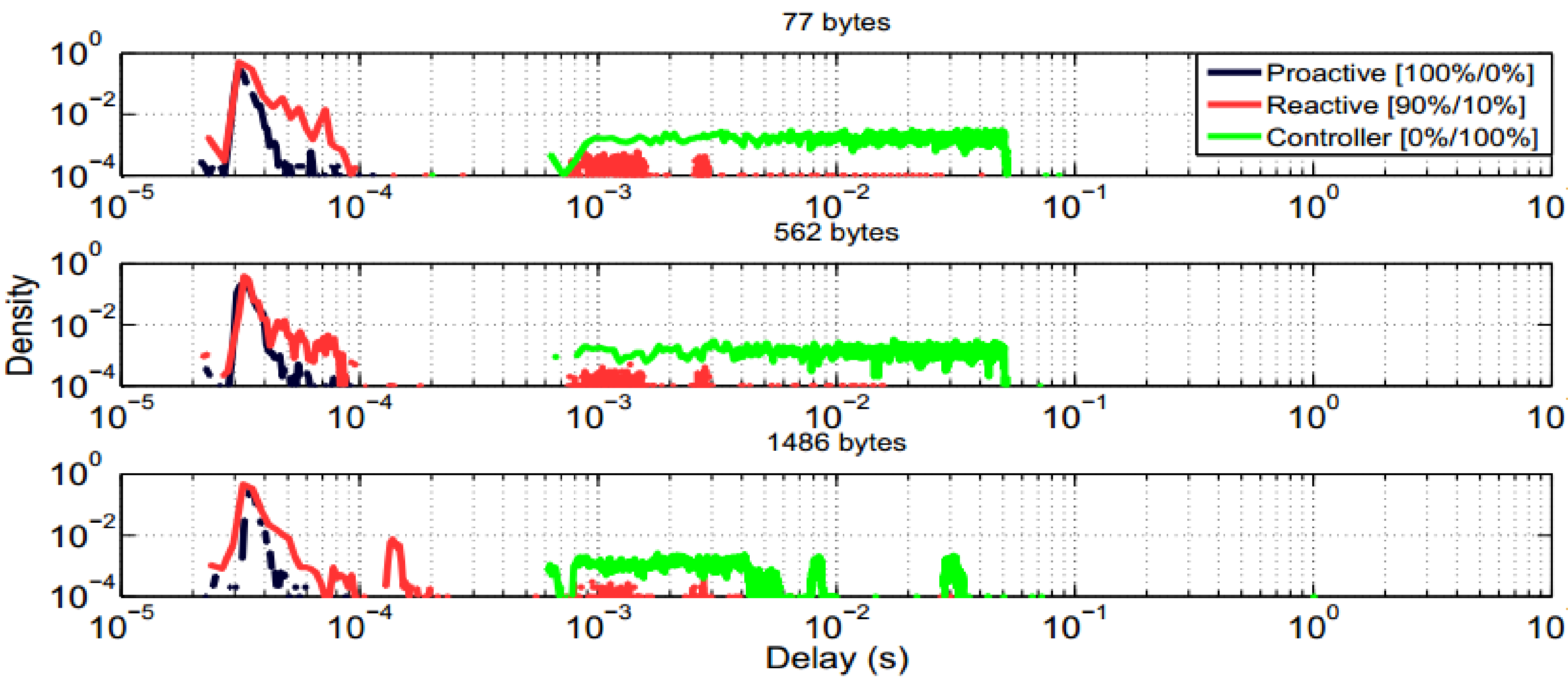
Jitter

Platforms	Proactive	Reactive	Controller
MIninet	0.001ms	4.424ms	4.303ms
MikroTik RB750GL	0.011ms	1.449ms	1.766ms
GENI	0.113ms	5.225ms (1.3% loss)	3.027ms

UDP buffer size = 208KBytes

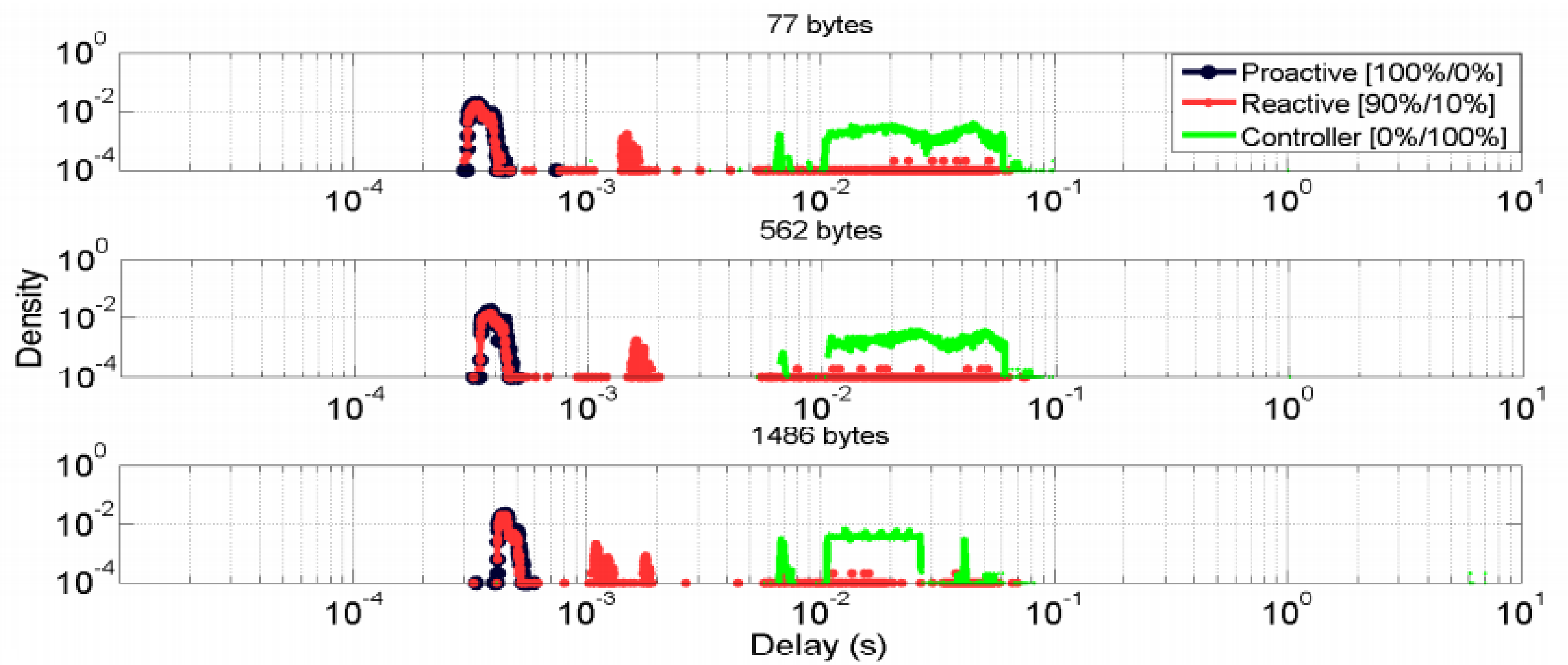
- The measurement was performed using *iperf* client.

RTT Latency vs. Function of Packet Size



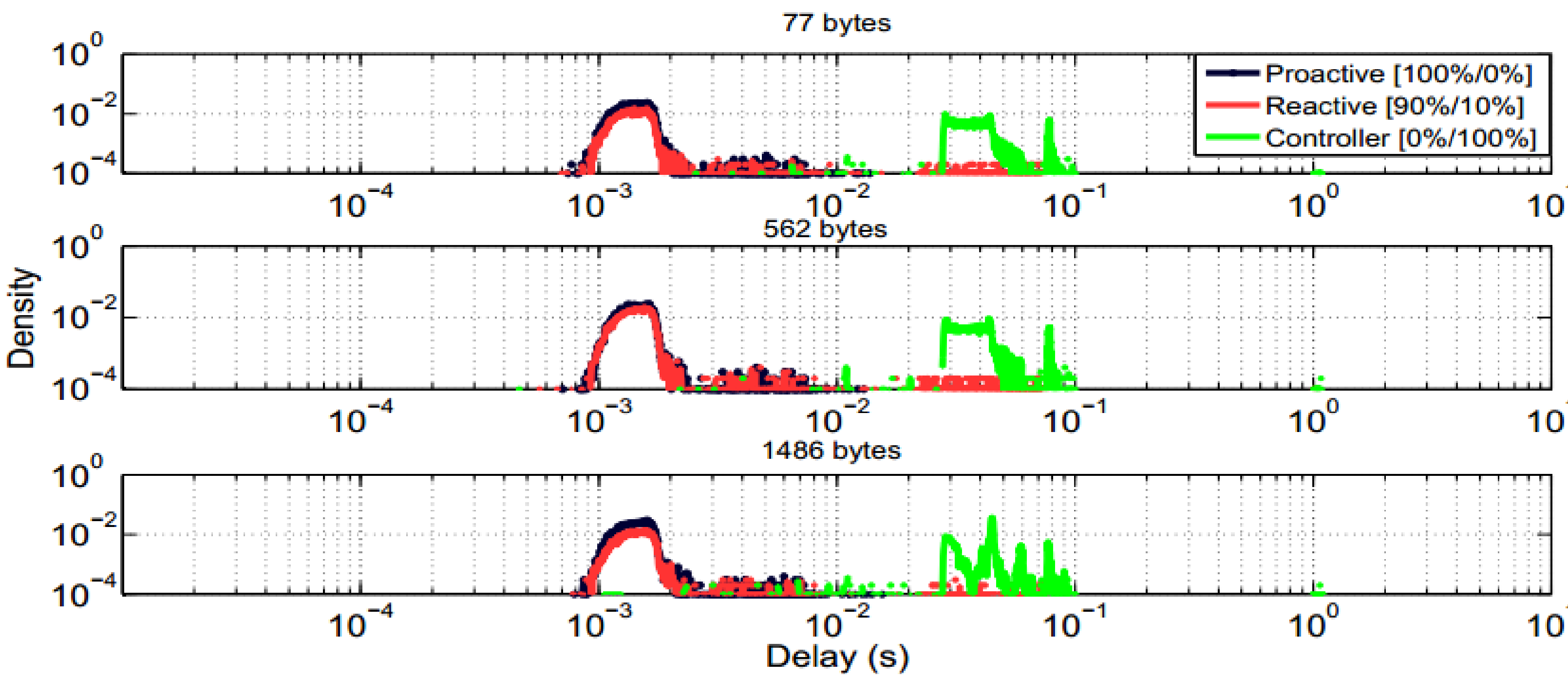
Delay versus packet size in Mininet at a constant 10 pkts/s input traffic rate

RTT Latency vs. Function of Packet Size



Delay versus packet size in MikroTik RB750GL at a constant 10 pkts/s input traffic rate

RTT Latency vs. Function of Packet Size

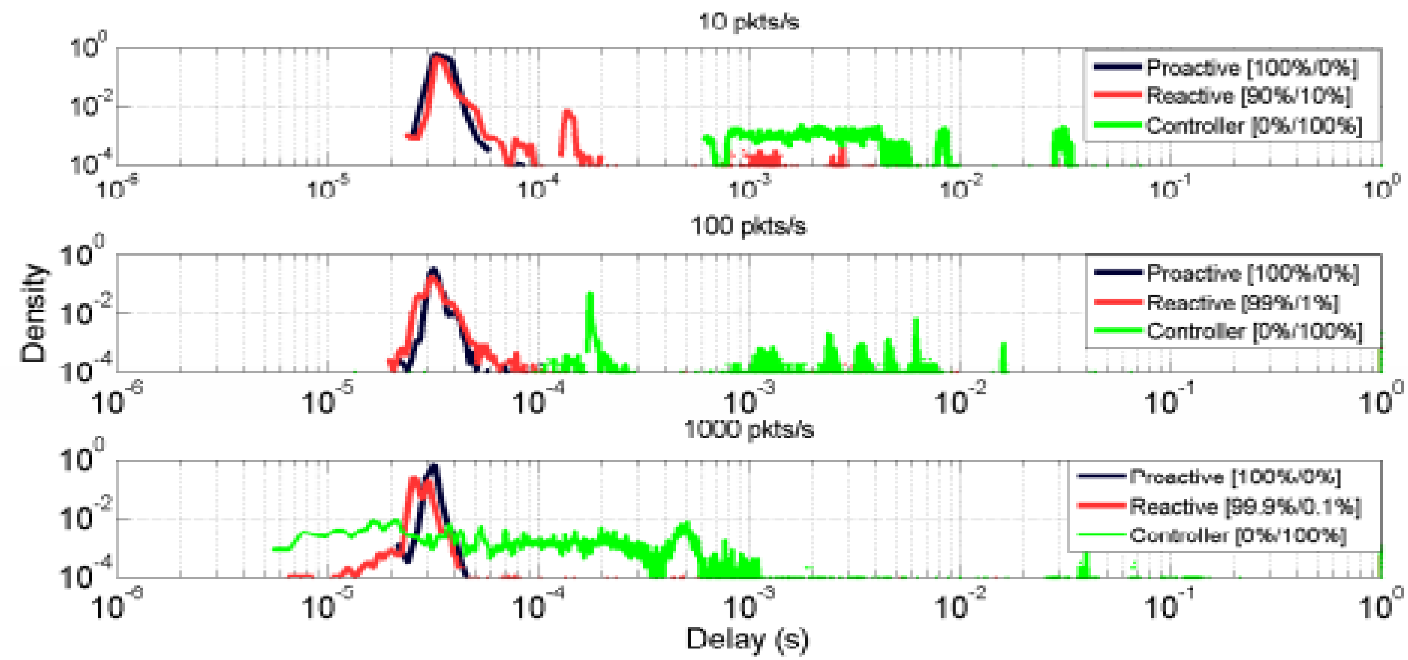


Delay versus packet size in GENI at a constant 10 pkts/s input traffic rate

Observations

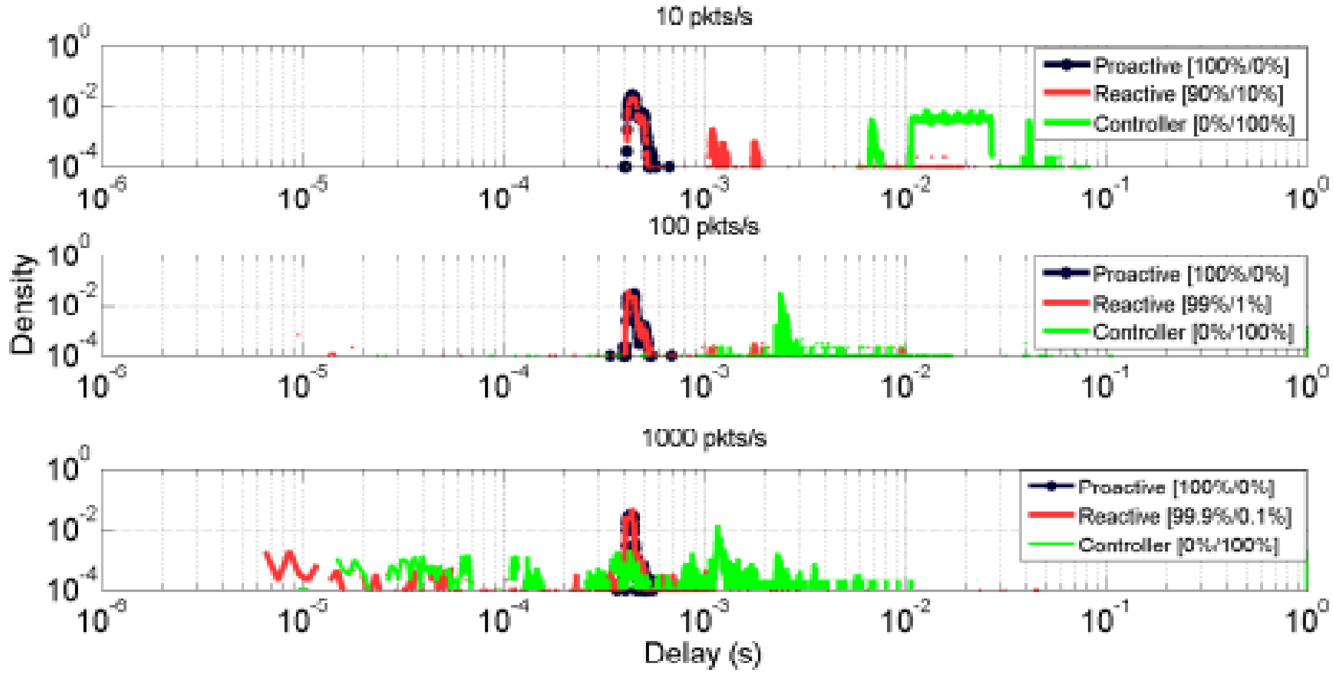
- In proactive case the distribution is unimodal, while in the case of mixed use the distribution is observed to be multimodal.
- The RTT latencies in mixed forwarding modes are concentrated around two clusters:
  1. Lower end represents packets forwarded proactively,
  2. Higher end represents packets forwarded through controller intervention.
- The controller delay is about two orders of magnitudes larger than the processing delay at a switch.
- The order of range of delay for packet sizes increases from Mininet, MikroTik RB750GL to GENI due to increase in propagation delay.
- There is an increase in latency with an increase in packet size in MikroTik RB750GL router, but not in Mininet and GENI.

RTT Latency vs. Packet Transmission Rate (Mininet)



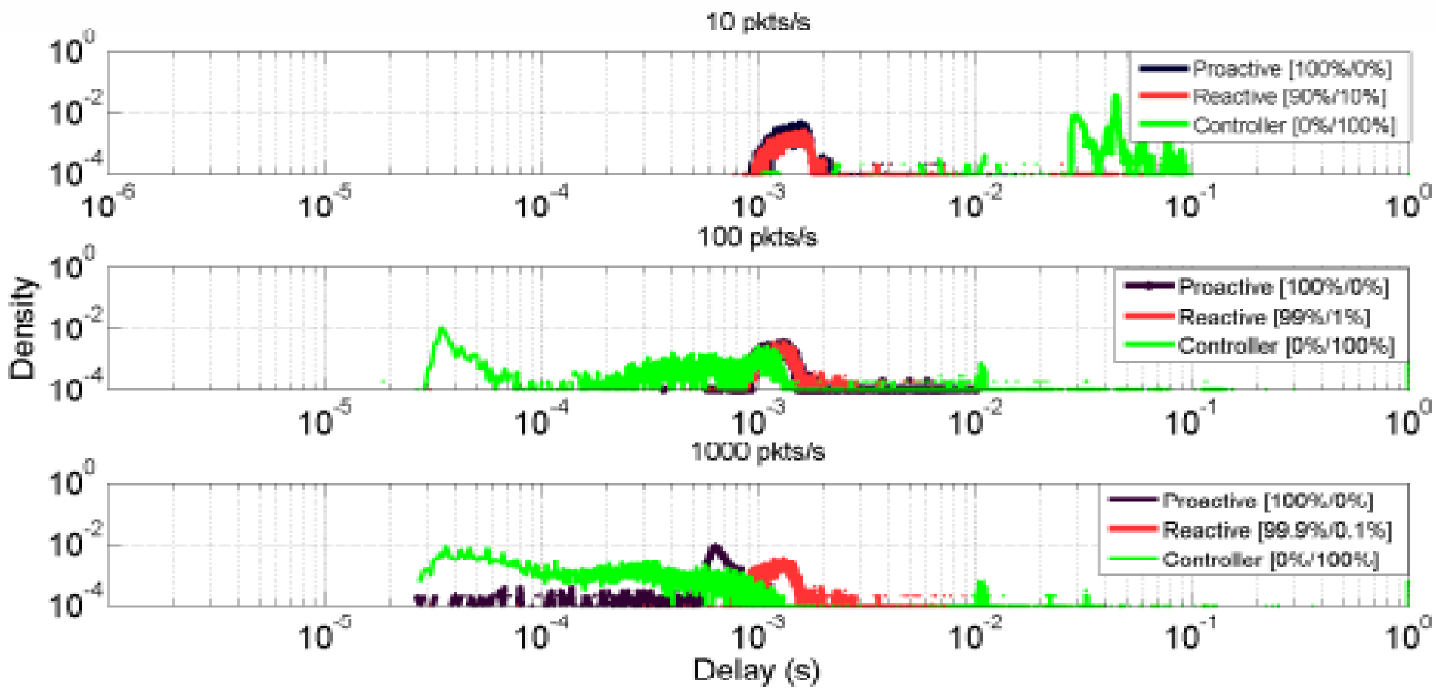
RTT latency vs. input traffic rate (packet size of 1,486 bytes).

RTT Latency vs. Packet Transmission Rate (MikroTik RB750GL)



RTT latency vs. input traffic rate (packet size of 1,486 bytes).

RTT Latency vs. Packet Transmission Rate (GENI)



(b) RTT latency vs. input traffic rate (packet size of 1,486 bytes).

Observations

- Increase in input traffic rate decreases controller interaction in reactively forwarded packets stream.
- This is due to lesser context switching between OVS and non-OVS processes and increase in cache hits.
- The PDF of reactive mode approaches PDF of proactive mode.

RTT Latency vs. Other Variables

- We also measured latency by changing following OpenFlow parameters:
  - ➢ Varying the number of fields against which to match a flow.
  - ➢ Varying the priority level of a matching flow table entry.
  - ➢ Changing the table in which the matching flow table entry is found.
- This is because OVS uses tuple space search classifier, which creates a single hash table for same category of matches.

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Transit Latency in SDN

- It is the end-to-end delay in an OpenFlow SDN.
- Expressed as a sum of two components:
  - Deterministic delay (*D*) + Stochastic delay (*S*)
- Transit latency in terms of network delay components can be expressed as follows:

$$L_T = (D_{trans} + Dprop) + (Ss + I \times Sc)$$

Transit Latency in SDN

- D_{prop} is the propagation delay calculated as $\frac{Distance}{Speed}$, while D_{trans} is the transmission delay calculated as $\frac{Number\_of\_bits}{link\_transmission\_rate}$.

- Propagation and transmission delay contribute to deterministic delay component, while switches and controller contribute to stochastic delay components.

- I (1 or 0) is a Bernoulli random variable (Indicator Function).

- The probability of a state is dependent on the input traffic and the timeout value of the entries.

Probability Distribution Function (PDF) of Transit latency in SDN

- The empirical results show that PDF of RTT latency in SDN are multiple Gaussian distributions on a logarithmic scale.
- This shows that latency distribution in SDN is a **Mixture Model**.

Probability Distribution Function (PDF) of Transit latency in SDN

- Transit latency follows a **log-normal distribution**.

$$f_X(x) = \sum_{i=1}^{K} \lambda_i N\,(\log x\,; \mu_i, \sigma_i{}^2)$$

where, $1 \leq \lambda_i \leq 1$ and $\sum_{i=1}^{K} \lambda_i = 1$

- And $N(x; \mu_i, \sigma^2{}_i)$ for $1 \leq i \ \leq K$ are K Log-normal PDFs of the form,

$$N(\log x\,; \mu, \sigma^2) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\left(-\frac{1}{2}\left(\frac{\log x - \mu}{\sigma}\right)^2\right)}$$

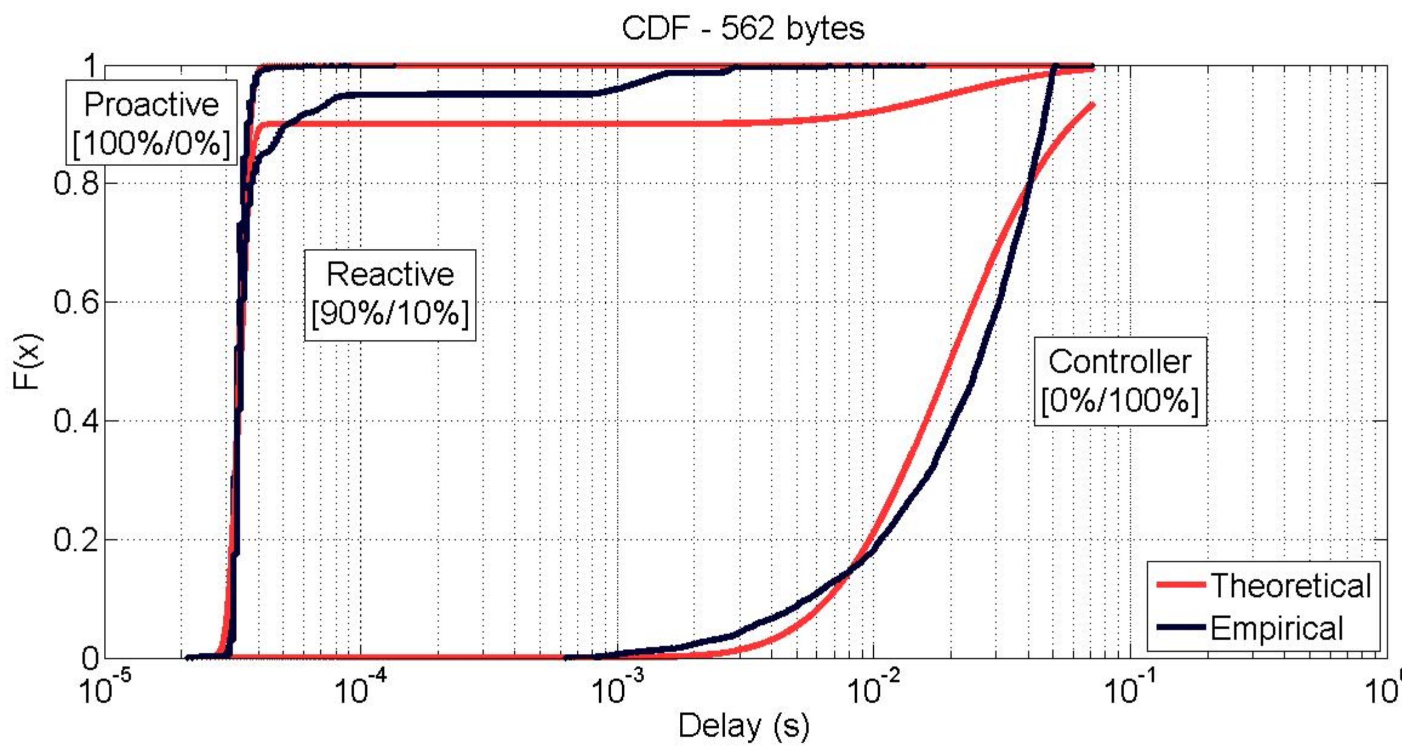
- In our case K=2, one representing switch processing delay and other one representing controller consultation.

Model validation using CDFs

- We compared CDFs of different scenarios of empirical data with theoretical data by finding the Maximum Likelihood Estimates (MLE).
- The comparison of theoretical and empirical data was done by finding the coefficient of determination (R^2):

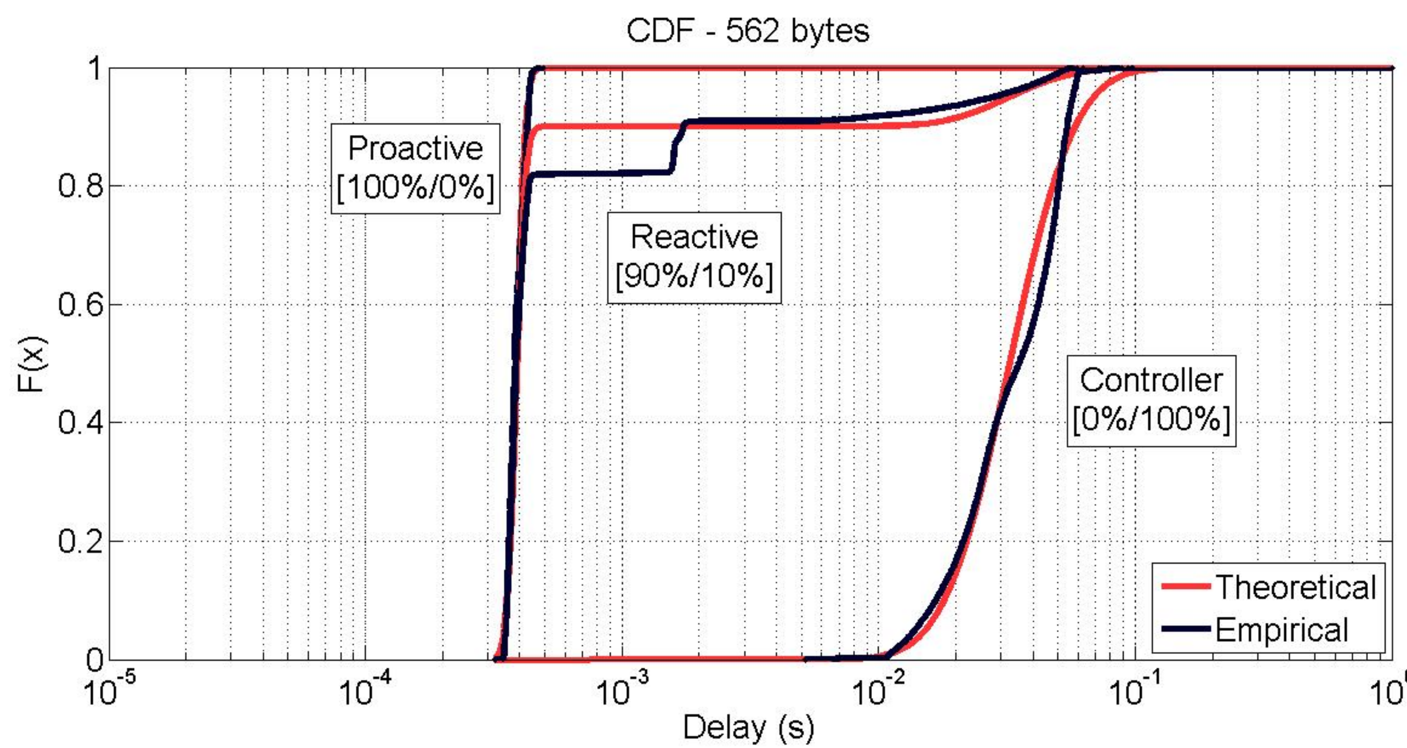
$$R^2 = 1 - \frac{\sum_{i=1}^{n} \left(x_i - fx(x_i)\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Model validation for Mininet



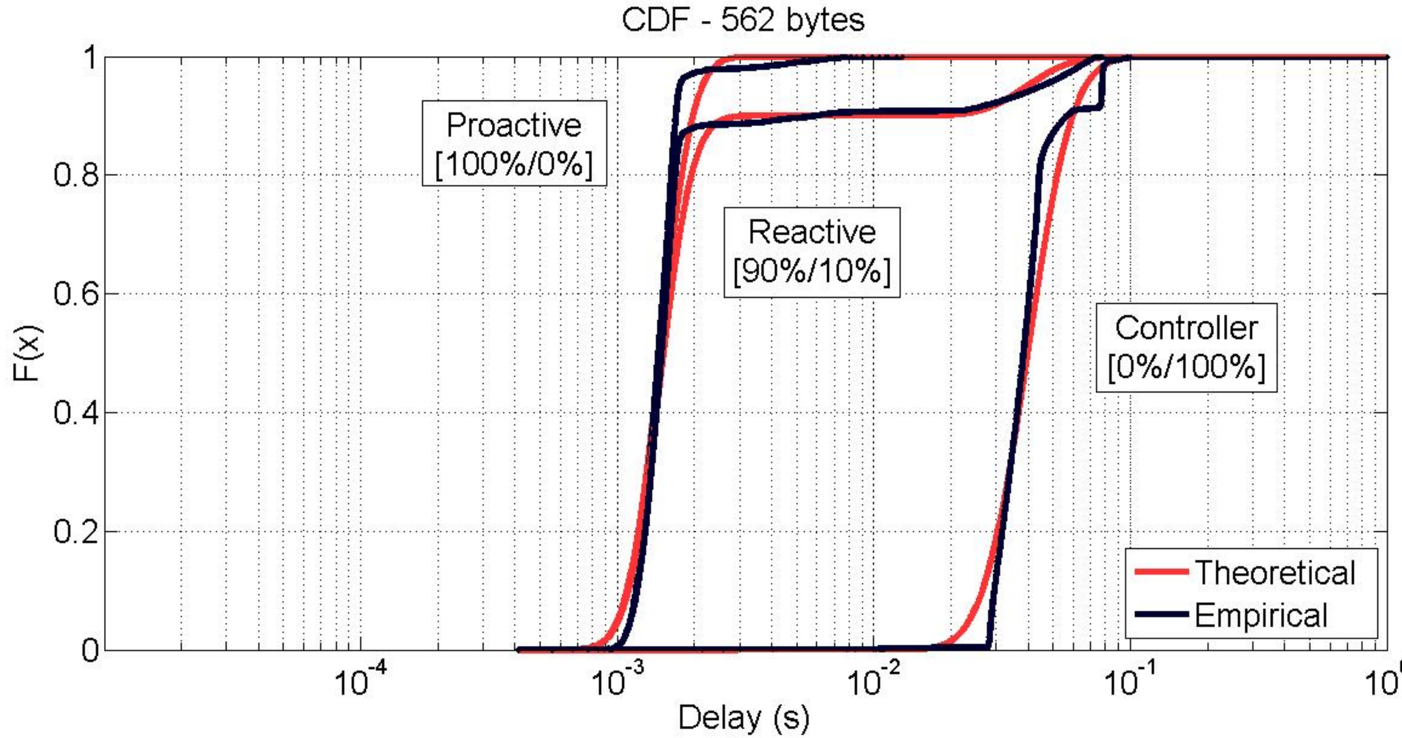
Proactive=0.98, Controller=0.92, Reactive=0.90

Model validation for MikroTik RB750GL



Proactive=0.98, Controller=0.97, Reactive=0.98

Model validation for GENI

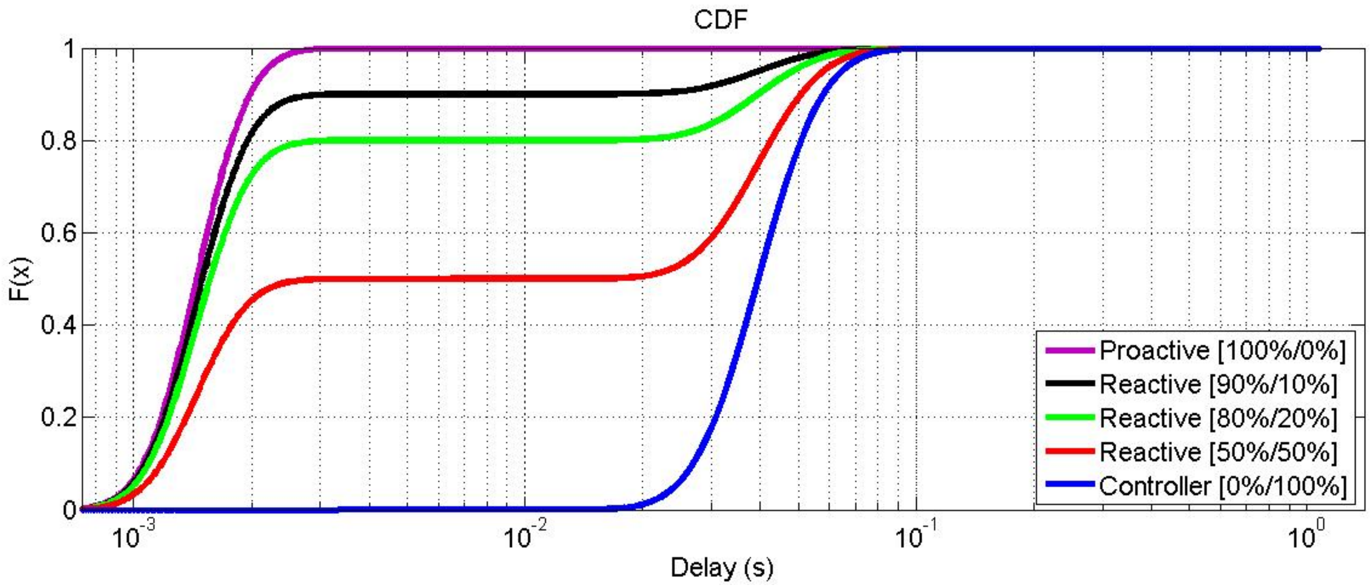


Proactive=0.90, Controller=0.89, Reactive=0.95

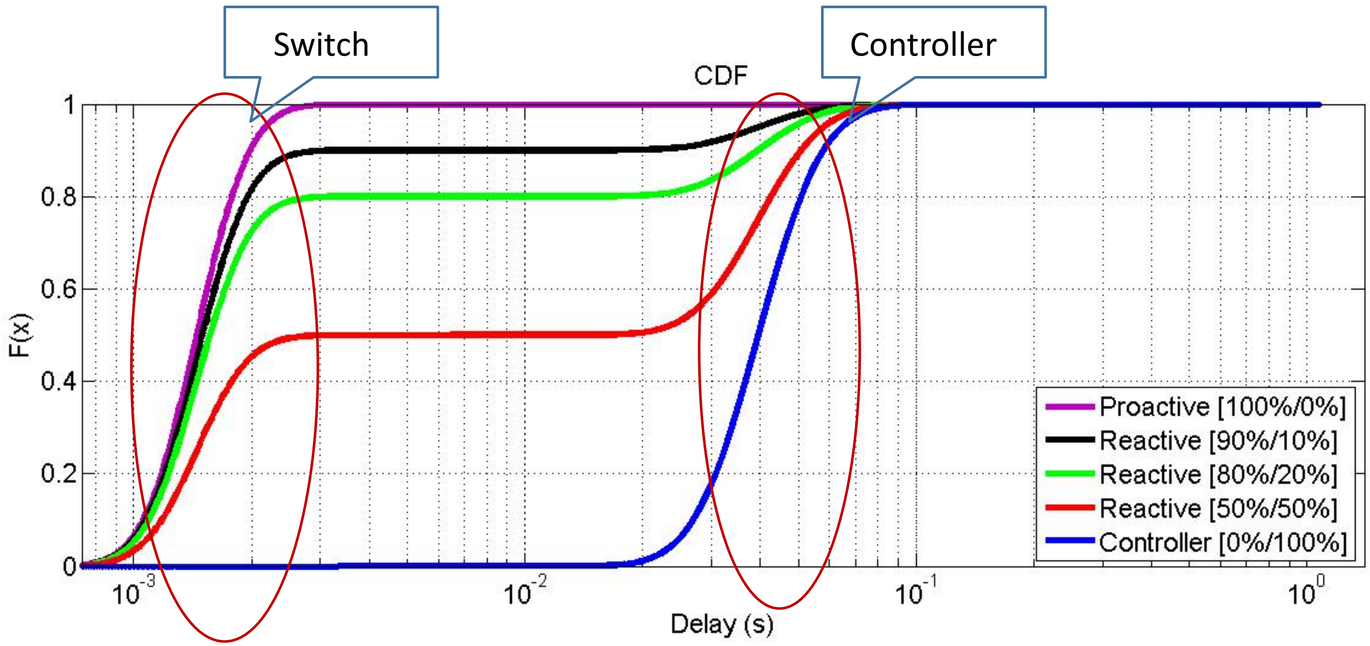
Extension to multiple Switches and Controllers

- Total delay of due to switches ***S,*** can be supposed sum of independent and identically distributed (i.i.d.) random variables S_1, S_2, ..., S_n.
- Total delay due to switches could found through convolution of PDF of a single switch processing time with itself (n-1) times.
- Similarly, total delay of due to controllers ***C,*** can be supposed sum of independent and identically distributed (i.i.d.) random variables C_1, C_2, ..., C_n.
- Total delay due to controllers could found through convolution of PDF of a single controller processing time with itself (n-1) times.

Effect of Switch and Controller interaction on overall distribution of Latency



Effect of Switch and Controller interaction on overall distribution of Latency



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Conclusion and Future Work

- A stochastic model for transit latency in SDNs, based on empirical data using POX controller.
- Transit latency in SDNs follows generally follows a two component log-normal mixture model.
- Model could be extended to network having multiple switches and controllers.
- A more accurate model based on queuing theory would be using log-normal mixture model as the service time.

Publications

- A Stochastic Model for Transit Latency in OpenFlow SDNs - *Elsevier Computer Networks Journal 2017*.
- Enabling OpenFlow on MikroTik RouterBoard 750GL: A Tutorial (*Technical Report*).

Thank You