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Department of Informatics
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Application of Network Calculus Models on Programmable Device Behavior

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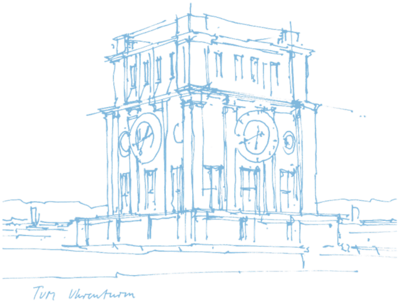

Motivation

Programmable device workflow

Generic Programmable Device + Program = Programmed Device

Software-Defined Networking

OpenFlow or P4

Device for specific usecase
e.g. latency requirement

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Dynamic modeling workflow

Generic Device Model + Selection of Functionality Models = Model of Programmed Device

Collection of
Network Calculus models

Service curves
for logical functions

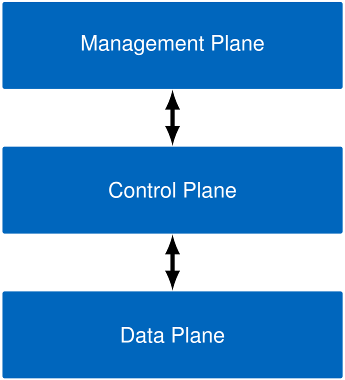
Derive worst-case
latency bounds

Background

SDN

Software-defined Networking (SDN)

- Separation of concern for networks
- Three distinct planes with specific tasks:
  - Management and configuration
  - High-level network algorithms
  - Packet forwarding tasks
- Two well-known implementations of the SDN concept
  - OpenFlow (on the control plane)
  - P4 (on the data plane)



Background

OpenFlow vs. P4

OpenFlow

- Introduces programmability to the *control* plane
- Used for the manipulation of *existing protocols*
- Allows comparatively *high-level* packet manipulation

P4

- Introduces programmability to the *data* plane
- Creation of entirely *new protocols*
- Allows *low-level* packet manipulation

Shared design between P4 & Openflow

- Packet processing pipeline applies the match-action principle:
  - User define patterns (matches) to execute packet processing tasks (actions)

Challenges

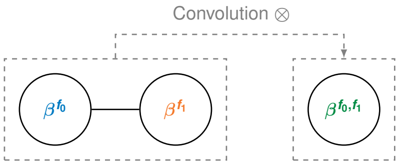
- Device performance changes significantly depending on the programmed network task
- Conceptual differences between both languages hinder their direct comparison

Background

Performance Bounds in Networks

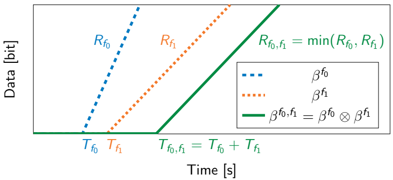
Network Calculus

- Calculate worst-case delay bounds in networks
- Represents nodes and data flows as wide-sense increasing functions
- Combines these functions to calculate bounds



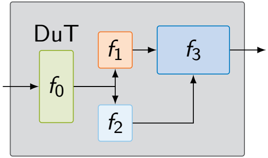
Service Curve

- Wide-sense increasing function describing a node, depends on arrival and departure times of flow datums
- Multiple nodes can be combined into one node by convolving their service curves



Modeling Concept

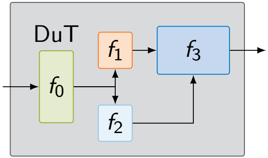
Modeling Concept

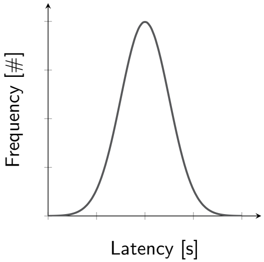


Device Model

- Logical funtions f_n in the Device under Test (DuT)
- Baseline function f_0 needed to operate device
- Feed-forward network of additional functions

Modeling Concept





Device Model

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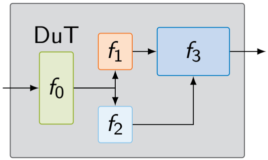
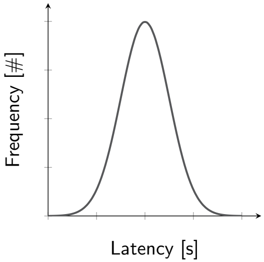
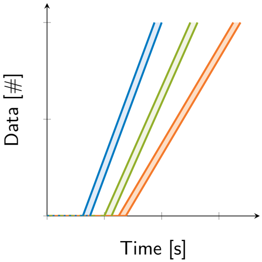
Measurements

- Goal: measure each logical function in isolation
- Measure baseline function f_0
- Measure each logical function pair $f_0 + f_i$

Modeling Concept







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- Measure baseline function f_0
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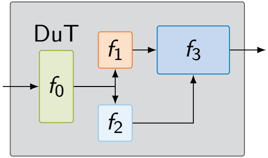
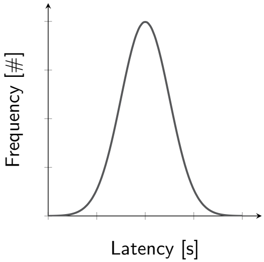
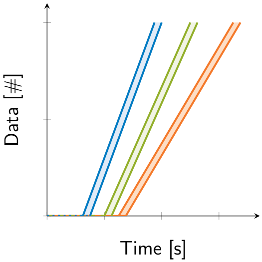
Service Curve Model

- Approximate service curve parameters for each logical function using measurements of function pairs
- Subtract influence of baseline function
- Latency parameter for service curve of f_1: $T^{f_1} = T^{f_0+f_1} - T^{f_0}$

Modeling Concept







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Model any combination of logical functions while minimizing required measurements

Evaluation

Evaluation

Investigated Platforms

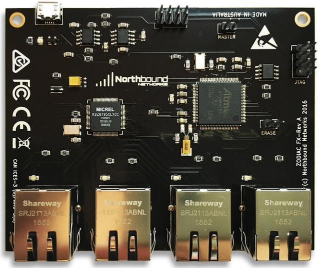


Figure 1: Zodiac FX

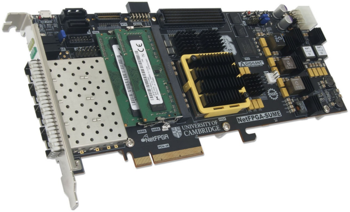


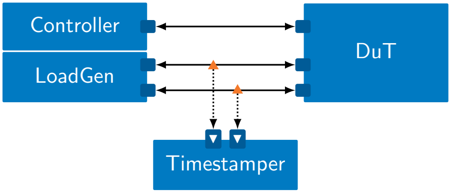
Figure 2: NetFPGA SUME

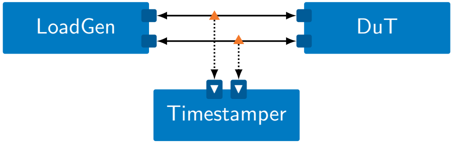
- 4 × 100 Mbit/s Ethernet ports
- low-cost, embedded hardware
- supports OpenFlow (realized as software)

- 4 × 10 Gbit/s Ethernet ports
- powerful hardware
- supports P4 programming language

Evaluation

Setup





OpenFlow / Zodiac FX

- OpenFlow controller required for switch management
- external timestamper monitoring network traffic via splitter

P4 / NetFPGA

- standalone P4 implementation using prefilled tables
- external timestamper monitoring network traffic via fiber-optical splitter

Evaluation

Differences between Platforms

Why did we choose the different plattforms?

- Demonstrate the applicability of our framework, despite obvious differences:
  - OpenFlow (control plane programability) vs. P4 (data plane programability)
  - 100 Mbit/s vs. 10 000 Mbit/s
  - Embedded platform (Zodiac FX) vs. high-performance platform (NetFPGA)

Goal:

- Apply NC to programmable network devices
- Find a common framework applicable to vastly different platforms
- Therefore, we create and measure common test scenarios for both platforms

Evaluation

Investigated Test Scenarios

Parameter	Values
num. rules	1
packet size	64 B
match types	**port**, tp-dst, dl-dst, masked-nw-dst, **five-tuple**, all
action types	**output**, set-dl-src, **strip-vlan**, set-vlan-id, set-nw-src, set-nw-tos, **set-tp-src**

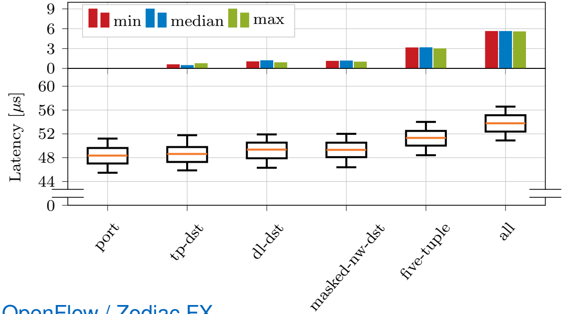
Table 1: Investigated match-action scenarios

- We use the match-action principle of P4 and OpenFlow as a common foundation for our comparison
- We investigate different match types and action types separately
- We start with the most basic forwarding scenarios (port & output) and gradually increase the complexity of the forwarder selecting the given match and action types

Evaluation

Comparison of Match Performance

- Variable match, fixed action
- Latency measurements and their comparison to the baseline function



OpenFlow / Zodiac FX

- Latencies scale with amount of data to be matched
- Maximum deviation from baseline is $\approx 6\,\mu s$

Evaluation

Comparison of Match Performance

- Variable match, fixed action
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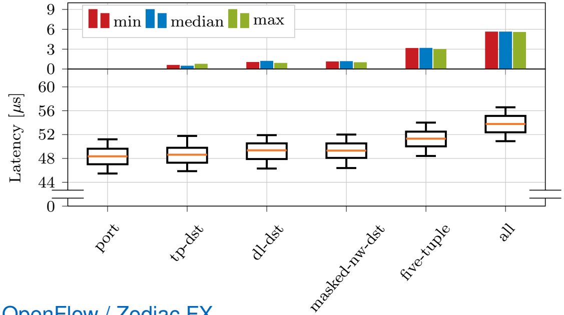
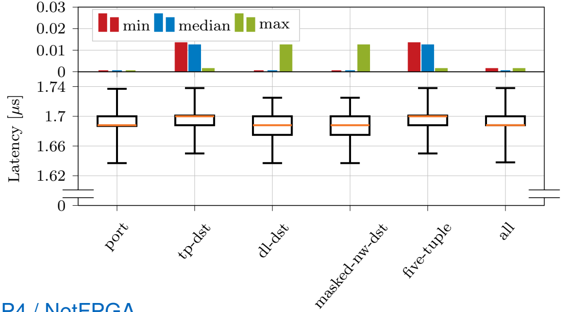




OpenFlow / Zodiac FX

- Latencies scale with amount of data to be matched
- Maximum deviation from baseline is ≈ 6 µs

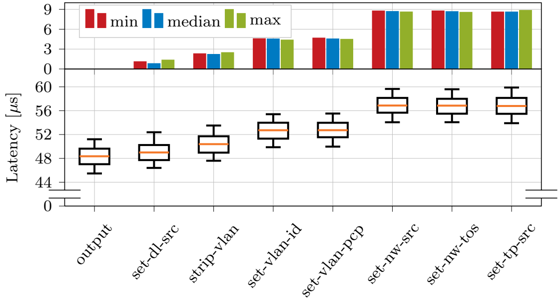
P4 / NetFPGA

- Maximum deviation from baseline is ≈ 0.01 µs
- Time resolution of hardware is 0.0125 µs

Evaluation

Comparison of Action Performance

- Variable action, fixed match



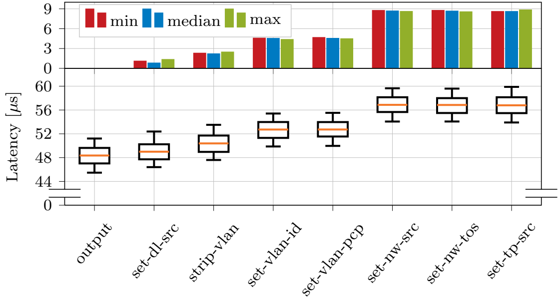
OpenFlow / Zodiac FX

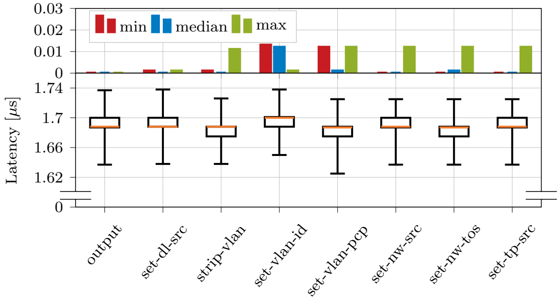
- Deviations of 2 µs to 5 µs for lower layer manipulations (MAC, VLAN)
- Deviations of ≈ 9 µs for network and transport layer manipulations

Evaluation

Comparison of Action Performance

- Variable action, fixed match





OpenFlow / Zodiac FX

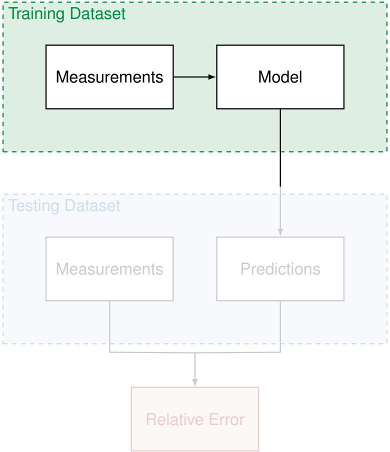
- Deviations of 2 μs to 5 μs for lower layer manipulations (MAC, VLAN)
- Deviations of ≈ 9 μs for network and transport layer manipulations

P4 / NetFPGA

- Maximum deviations ≈ 0.01 μs for any action

Evaluation

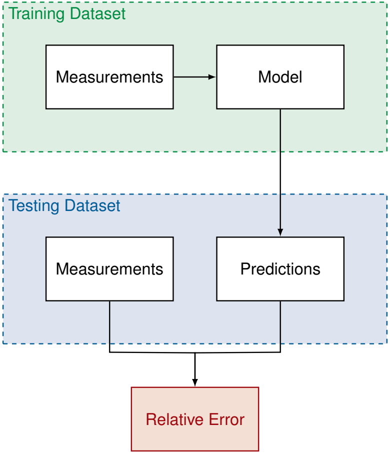
Evaluating the Predictive Power of our Model



- Use measurements to derive model of other logical function combinations for both devices
- Calculate latencies for the combinations
- Perform measurements for the new combinations
- Compare them to the model results and calcuate the relative error

Evaluation

Evaluating the Predictive Power of our Model



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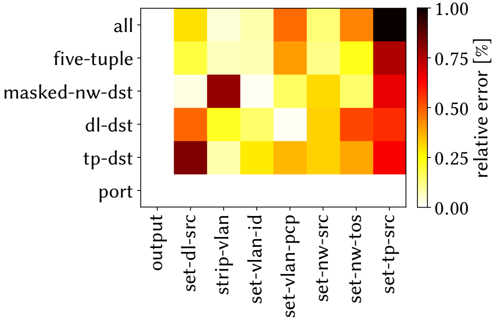
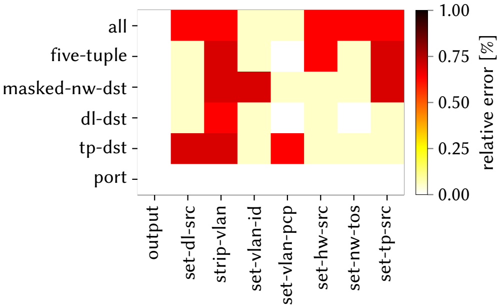
Evaluation

Predictive Quality Evaluation (Worst Case)





OpenFlow / Zodiac FX

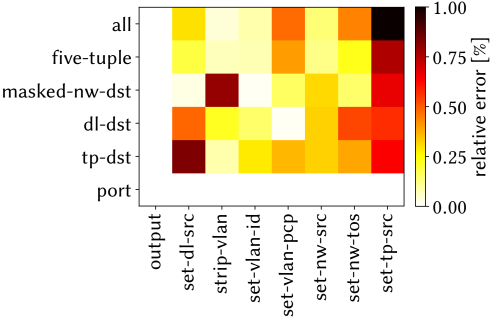
- Relative error below 1%
- Relatively high variance between function combinations

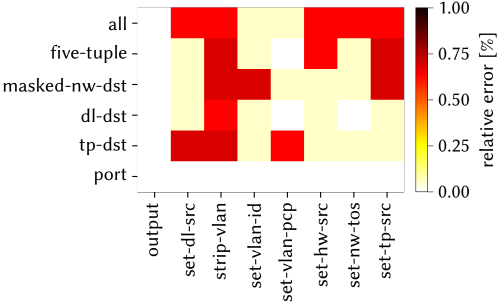
P4 / NetFPGA

- Relative error below 0.75%
- Comparatively low variance

Evaluation

Predictive Quality Evaluation (Worst Case)





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Model exhibits a reasonable predictive power.
No high correlation between error and types of function in combinations indicates good overall performance.

- Relatively high variance between function combinations
- Comparatively low variance

Conclusion

Summary & Contributions

Summary

- Measurements demonstrate (expected) performance gaps between platforms
- Dynamic models show low error for both platforms respectively

Contributions

- We successfully applied NC to describe programmable network devices
- We applied the same methodology to entirely different classes of programmable network devices

In the Paper

- Detailed description of service curve parameter approximation
- Details on measurement methodology and gathered data
- Evaluation of model considering best- and median-case latencies

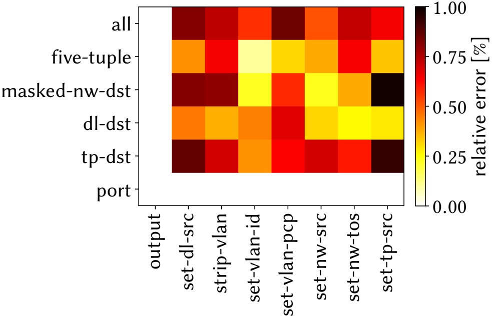
Future Work

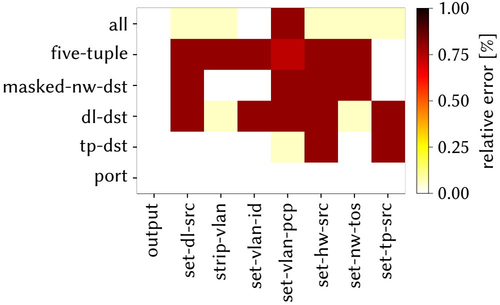
- Exact service curve derivation based on inversion of the min-plus convolution
- More complex service curve shapes

Backup Slides

Backup Slides

Predictive Quality Evaluation (Best Case)





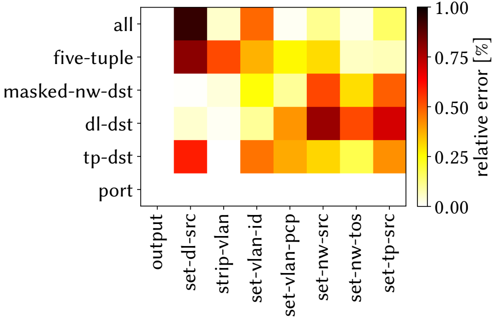
OpenFlow / Zodiac FX

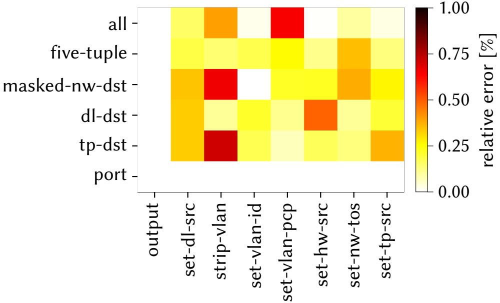
- Similar behavior

P4 / NetFPGA

- Similar behavior

Predictive Quality Evaluation (Median Case)





OpenFlow / Zodiac FX

- Similar behavior

P4 / NetFPGA

- More variance between different function combinations