

# A Cloud System for Teaching and Research on P4 Programmable Data Plane

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8<sup>th</sup> Annual ICT Annual Educators' Conference 2023  
Western Academy Support and Training Center  
<https://www.wastc.org/wc2023>



Supported by NSF 2118311  
“CyberTraining: Implementation: Small: Cybertraining on P4 Programmable Devices  
using an Online Scalable Platform”



# Agenda

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- Motivation for virtual labs
- Platform
- Libraries
- P4 Tofino library
- Research work

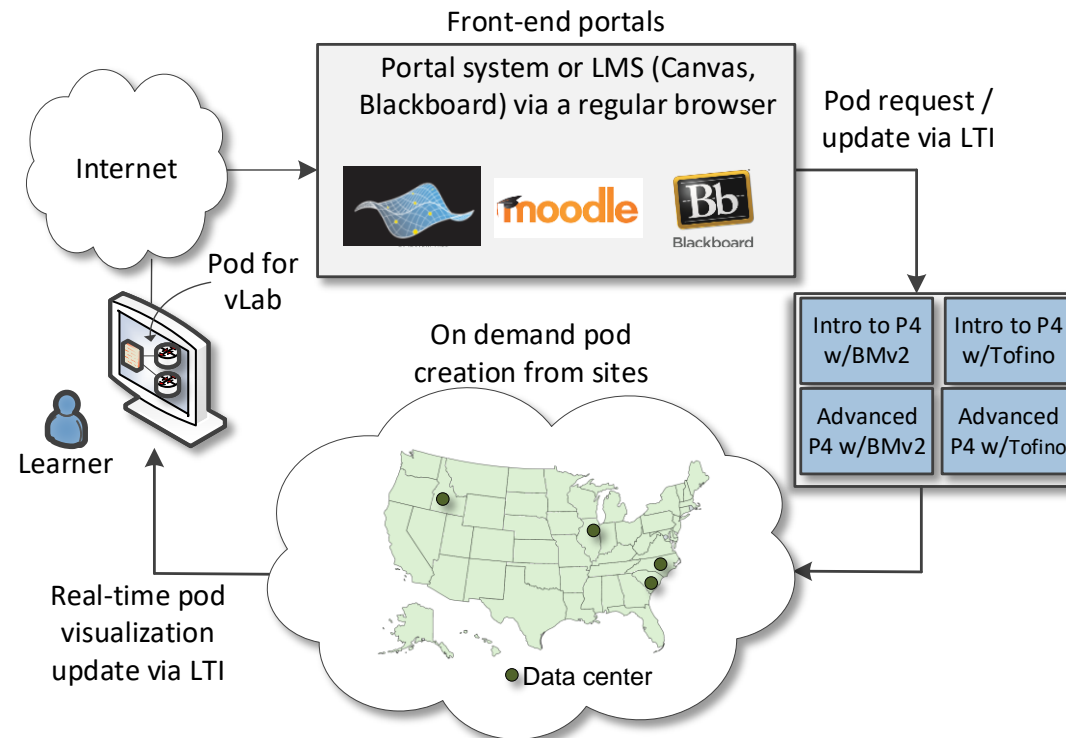
# Motivation for Virtual Labs

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- IT curriculum should emphasize “learning IT core concepts with authentic practice<sup>1</sup>”
  - “It is not enough to simply attend courses and read books”
- Disadvantages of physical labs
  - Difficult to scale
  - Expensive (space, maintenance, staff)
  - Since COVID-19 emerged, the capacity of labs has been further reduced

# Motivation for Virtual Labs

- The University of South Carolina (USC) (SC), the Network Development Group (NDG) (NC), and Stanly Community College (SCC) (NC) have deployed an Academic Cloud
  - Virtual labs on P4, routing, high-speed networks (USC)
  - Remote-access capability to lab equipment via Internet
  - Shared resources (CPU, memory, storage) from four data centers



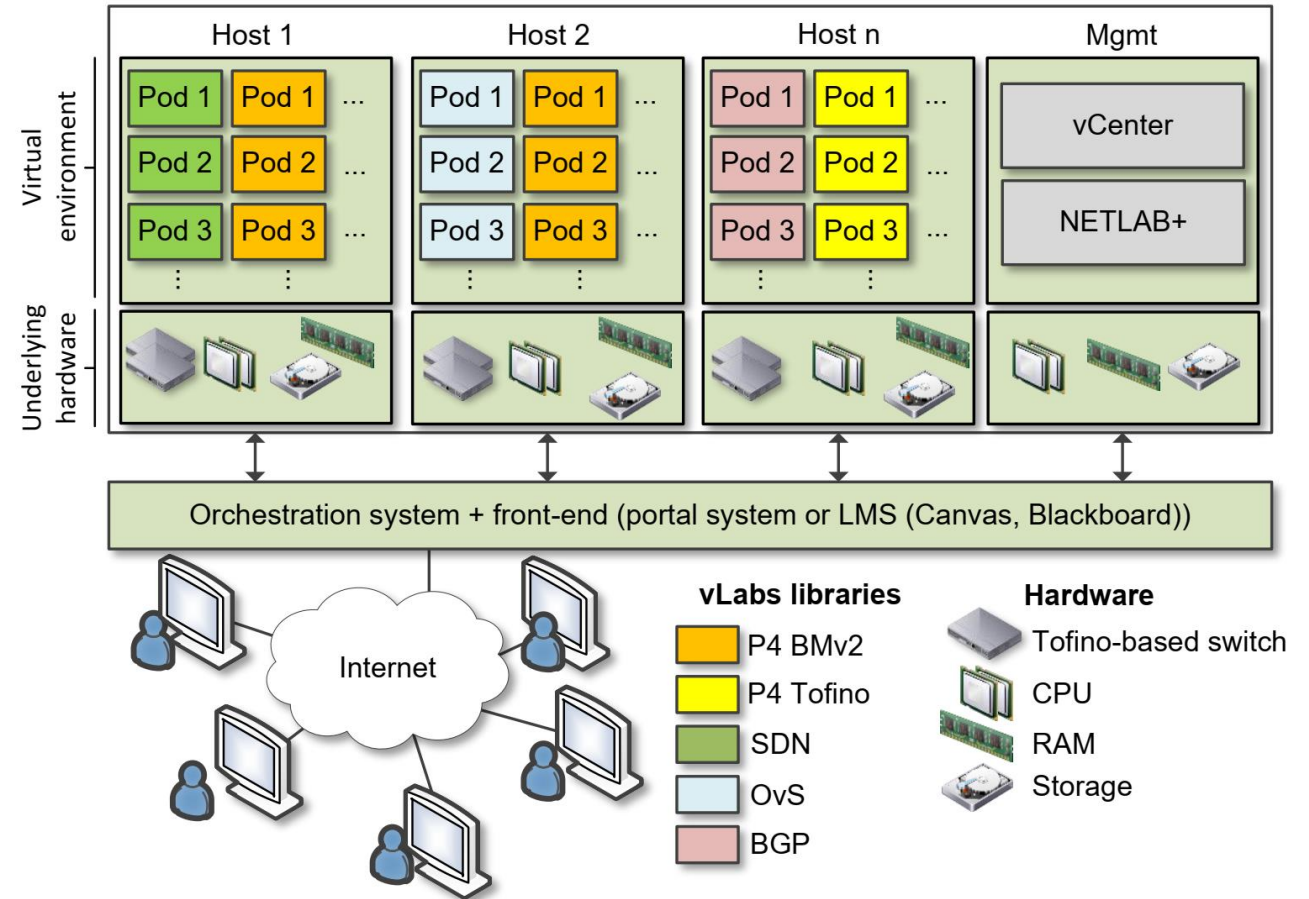
# FABRIC

- [www.whatisfabric.net](http://www.whatisfabric.net)



# Platform - USC Data Center

- Hosts 1-n store virtual machines (VMs) for virtual labs
- Management server runs vCenter, Management Software (NETLAB+)
- Partnership with Network Development Group (NDG)<sup>1</sup>



# Libraries

- A library consists of between 10-20 lab experiments
- Each lab experiment includes a detailed, step by step manual
- Once a learner completes all experiments, the learner acquires significant knowledge and hands-on expertise, and may earn an academic credential or certificate
- Information about libraries are available at <http://ce.sc.edu/cyberinfra/cybertraining.html>

# Library on Introduction to P4 with BMv2

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## Experiments

- Lab 1: Introduction to Mininet
- Lab 2: Introduction to P4 and BMv2
- Lab 3: P4 Program Building Blocks
- Lab 4: Parser Implementation
- Lab 5: Introduction to Match-action Tables (Part 1)
- Lab 6: Introduction to Match-action Tables (Part 2)
- Lab 7: Populating / Managing Match-action Tables
- Lab 8: Checksum Recalculation and Deparsing

## Exercises

- Exercise 1: Building a Basic Topology
- Exercise 2: Compiling and Testing a P4 Program
- Exercise 3: Parsing UDP and RTP
- Exercise 4: Building a Simplified NAT
- Exercise 5: Configuring Tables at Runtime
- Exercise 6: Building a Packet Reflector



# Library on P4 Applications, Stateful Elements, and Custom Packet Processing

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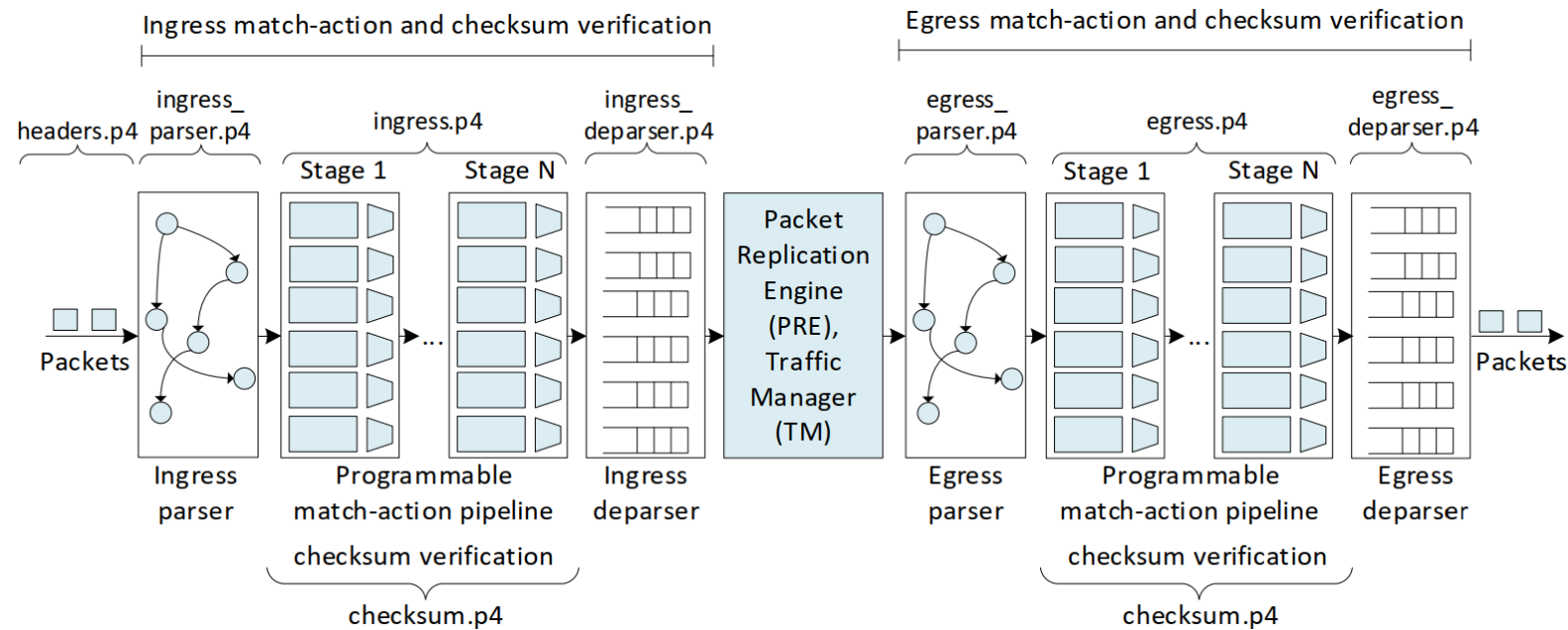
## Experiments

- Lab 1: Introduction to Mininet
- Lab 2: Introduction to P4 and BMv2
- Lab 3: P4 Program Building Blocks
- Lab 4: Defining and processing custom headers
- Lab 5: Monitoring the Switch's Queue using Standard Metadata
- Lab 6: Collecting Queueing Statistics using a Header Stack
- Lab 7: Measuring Flow Statistics using Direct and Indirect Counters
- Lab 8: Rerouting Traffic using Meters
- Lab 9: Storing Arbitrary Data using Registers
- Lab 10: Calculating Packets Interarrival Time w/ Hashes and Registers
- Lab 11: Generating Notification Messages from the Data Plane

# Library on P4 Programmable Data Plane with Tofino

## Experiments

- Lab 1: Introduction to P4 and Tofino
- Lab 2: Introduction to P4 Tofino Software Development Environment
- Lab 3: Parser Implementation
- Lab 4: Introduction to Match-Action Tables
- Lab 5: Populating and Managing Match-Action Tables at Runtime
- Lab 6: Checksum Recalculation and Packet Deparsing



# Library on P4 Programmable Data Plane with Tofino

- <https://netlab2.cec.sc.edu/>

The screenshot shows a web browser window with the URL `https://10.173.85.50/my-netlab-i.cgi`. The page header includes the University of South Carolina logo and navigation links for Home, Schedule, Manage, Help, and a user profile for jcrichigno. The main content area is titled "Scheduled Lab Reservations" and contains a message: "You have no scheduled lab reservations. Select from the Schedule menu above to add reservations." A blue button labeled "+ New Lab Reservation" is visible at the bottom. A dropdown menu is open over the "Schedule" link, listing options: "View or Cancel Lab Reservations", "Schedule Instructor-Led Training", "Schedule Lab for Myself", "Schedule Lab for a Student", and "Schedule Lab for a Team". An orange arrow points from the "You have no scheduled lab reservations" text to the "Schedule Lab for Myself" option in the dropdown menu.

# Library on P4 Programmable Data Plane with Tofino

Not secure | [https://10.173.85.50/makeres-i.cgi?res\\_type=l](https://10.173.85.50/makeres-i.cgi?res_type=l)

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Home jcrichigno

Select Content

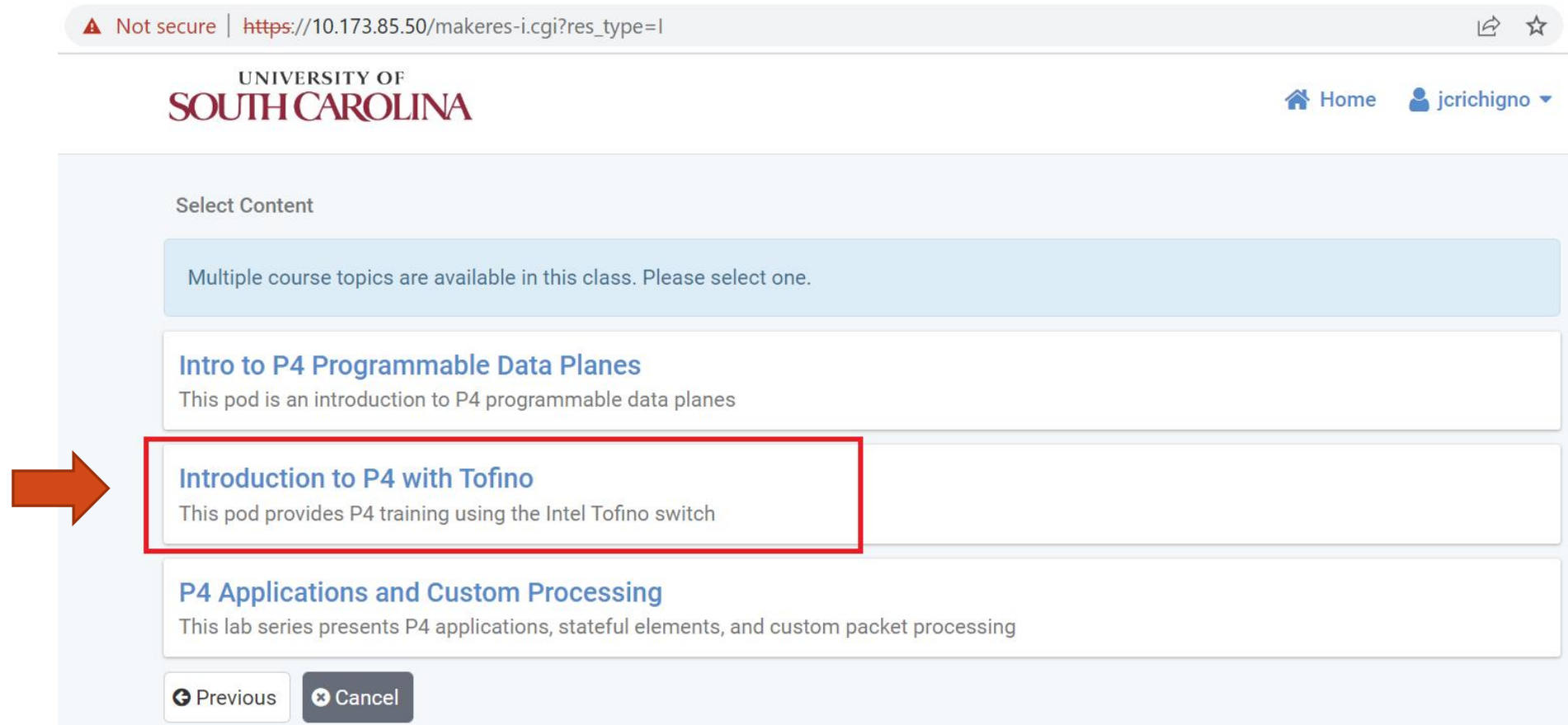
Multiple course topics are available in this class. Please select one.

**Intro to P4 Programmable Data Planes**  
This pod is an introduction to P4 programmable data planes

**Introduction to P4 with Tofino**  
This pod provides P4 training using the Intel Tofino switch

**P4 Applications and Custom Processing**  
This lab series presents P4 applications, stateful elements, and custom packet processing

Previous Cancel



# Library on P4 Programmable Data Plane with Tofino

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Select Content (Introduction to P4 with Tofino) > Select Lab

🔧 This pod provides P4 training using the Intel Tofino switch

Lab Name	Action
<a href="#">Lab 1: Introduction to P4 and Tofino</a>	▾
<a href="#">Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)</a>	▾
<a href="#">Lab 3: Parser Implementation</a>	▾
<a href="#">Lab 4: Introduction to Match-action Tables</a>	▾
<a href="#">Lab 5: Populating and Managing Match-action Tables at Runtime</a>	▾



# Library on P4 Programmable Data Plane with Tofino

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Home jrichigno

Select Content (Introduction to P4 with Tofino) > Select Lab (Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)) >

Reserve Pod

### Pod Scheduler

September 2022

Sun	Mon	Tue	Wed	Thu	Fri	Sat
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	1

Selected Day: September 17, 2022

Current Time: 16:55 Eastern Time (US & Canada)

	Tofino_H1_pod1	Tofino_H1_pod3	Tofino_H2_pod4	Tofino_H2_pod5
16:00				
17:00				

# Library on P4 Programmable Data Plane with Tofino

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Select Content (Introduction to P4 with Tofino) > Select Lab (Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)) > Reserve Pod (Tofino\_H2\_pod4) > Settings

### 📅 Add Reservation

Pod Tofino\_H2\_pod4

Reservation Type Instructor Private Reservation

Reserve For Jorge Crichigno

Lab Exercise Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)

Lab Device Configurations load preset configurations for exercise ⚙️ Settings

Time Zone Eastern Time (US & Canada)

Start Time

End Time  📅






Length of Reservation 2 hrs., 53 mins.

# Library on P4 Programmable Data Plane with Tofino

Not secure | <https://10.173.85.50/my-netlab-i.cgi> 🔍 🔗 ☆

UNIVERSITY OF SOUTH CAROLINA 🏠 Home 📅 Schedule ▾ 🔧 Manage ▾ 🔗 Help 👤 jcrichigno ▾

## 📅 Lab Reservations Search

ID	Date/Time	Description	Pod
298	 2022-09-17 16:57  2022-09-17 20:00  2 hrs., 52 mins.  <a href="#">Enter Lab ▶</a>	<b>Class:</b> P4 Course <b>Lab:</b> Lab 2: Introduction to P4 Tofino Software Development Environment (SDE) <b>Type:</b> Instructor <b>User:</b> Jorge Crichigno	Tofino_H2_pod4 

Showing 1 to 1 of 1 items

[+ New Lab Reservation ▾](#)



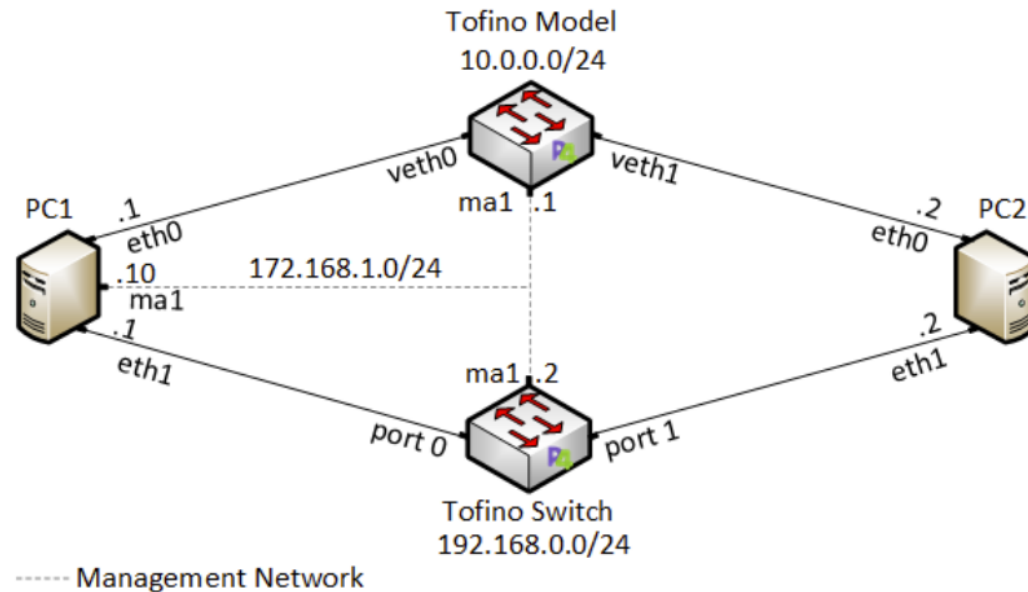
# Library on P4 Programmable Data Plane with Tofino

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Tofino\_H2\_pod4 > Reservation 298 > Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)

Content Status Tofino Switch PC 1 PC 2 Tofino Model



# Library on P4 Programmable Data Plane with Tofino

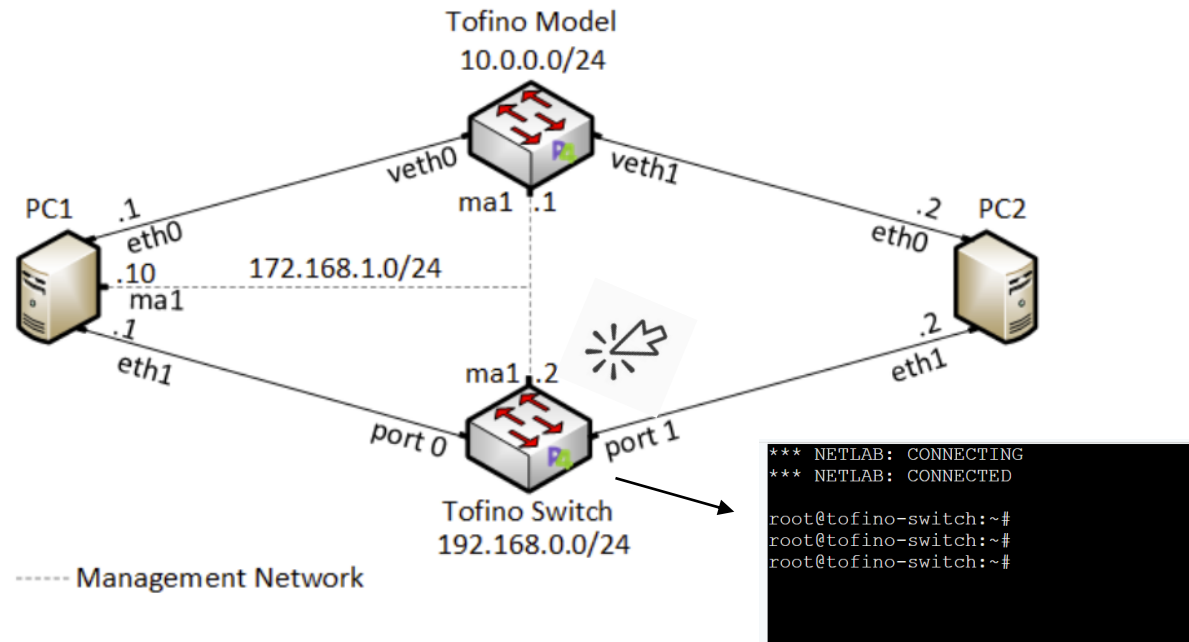
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Home Pod Reser

Tofino\_H2\_pod4 > Reservation 298 > Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)

Content Status Tofino Switch PC 1 PC 2 Tofino Model



# Platform Features

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	Feature	Notes
1	Allocation of resources	Pod granularity
2	Custom pods	Easy to create custom pods, including physical (e.g., Tofino switches) and virtual devices
3	Cost	Cost-effective when used extensively
4	Presentation layer	Topology is graphically presented to the learner using a regular browser
5	Time sharing	Easy to implement time-sharing policies
6	IP addresses	Pods have the same topology / IP addresses (overlapping addresses w/o conflict)
7	Functional realism	Virtual labs have the same functionality as real IT hardware in a real deployment
8	Traffic realism	Devices generate/receive real, interactive network traffic to/from the Internet
9	Management	Devices are managed via out-of-band management connections (i.e., management is not disrupted by experiments)

# Library on P4 Programmable Data Plane with Tofino

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- Topology complexity
  - 6.4 Tbps Tofino programmable switch
  - Tofino model for debugging (trace execution in the data plane)
  - Servers to send/receive data to/from the switch/other servers
  - Multi-mode fiber
  - QSFP28+ transceivers
  - Open Network Linux (ONL) (control plane)
  - Software Development Environment (SDE) from Intel (control plane)
  - Sample P4 codes for each lab (data plane)
  - Laboratory experiments with step-by-step directions (thousands of development hours)

# Research Work

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- “INC: In-Network Classification of Botnet Propagation at Line Rate”
- “P4DDPI: Securing P4-Programmable Data Plane Networks via DNS Deep Packet Inspection”
- “Dynamic Router's Buffer Sizing using Passive Measurements and P4 Programmable Switches”
- “On Offloading Network Forensic Analytics to Programmable Data Plane Switches”
- “Coarse Estimation of Bottleneck Router's Buffer Size for Heterogeneous TCP Sources”
- “Offloading Media Traffic to Programmable Data Plane Switches”
- “Towards a Unified In-Network DDoS Detection and Mitigation Strategy”
- “Enabling TCP Pacing using Programmable Data Plane Switches”
- “An Exhaustive Survey on P4 Programmable Data Plane Switches: Taxonomy, Applications, Challenges, and Future Trends”
- “A Survey on TCP Enhancements using P4-programmable Devices”
- “A Survey on Security Applications of P4 Programmable Switches and a STRIDE-based Vulnerability Assessment”



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