Project: Incorporating Blockchain/P2P Technology into an SDN-Enabled Cybersecurity System to Safeguard Fossil Fuel Power Generation Systems

Project Number: DE-FE0031742

University of North Dakota
College of Engineering and Mines

Annual Technical Review (Spring 2021)
May 19th, 2021

Project Description and Objectives

Overview

- **This project aims to strengthen the security protection of software defined networking (SDN) for facilitating its deployment in fossil fuel power generating systems.**
  - The security protection solution makes use of the blockchain and the peer-to-peer (P2P) technologies.
  - This project is in response to Area of Interest 2 of DE-FOA-0001991.
  - AOI 2: "*investigate how cutting-edge network technologies such as blockchain may be leveraged and integrated into industrial monitoring and process control systems for optimized, cybersecure operation of electricity generating units.*"
- **This project aims to produce two deliverables:**
  - A cloud-based networking platform for prototyping and experimenting various designs of safeguarding the software-defined networks deployed in electric power systems.
  - A blockchain/P2P-based technology for detecting the compromised controllers in a software defined network.
    - The application will operate in the cloud-based networking platform.
- **The outcomes of this project will serve in**
  - Meeting the general security requirements of the electric power generating systems.
  - Mitigating the security risks targeting the vulnerabilities of SDN-enabled operational networks.

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Project Description and Objectives

Strategic Alignment of Project to Fossil Energy Objectives (1)

- **Serving for Meeting the General Security Requirements of Electric Power Systems**
  - Safe operations of power systems rely on the fundamental security mechanisms
    - Authentication, Authorization, and Anti-spoofing.
- **Serving for Facilitating the Deployment of SDN-Enabled Operational Networks**
  - Software Defined Network (SDN) technologies will be increasingly adopted to support data communications in electric power systems.
  - The Department of Energy had sponsored research projects on
    - Applying SDN technology to support the device-to-device communications;
    - Prototyping a dashboard application for providing the operators with a global view of the SDN-enabled operational networks.
- **Serving for Addressing the Threats Targeting the SDN-Enabled Operational Networks**
  - SDN paradigm faces new security threats and attacks.
  - Our project addresses the security risks targeting SDN technology and the protection solutions.

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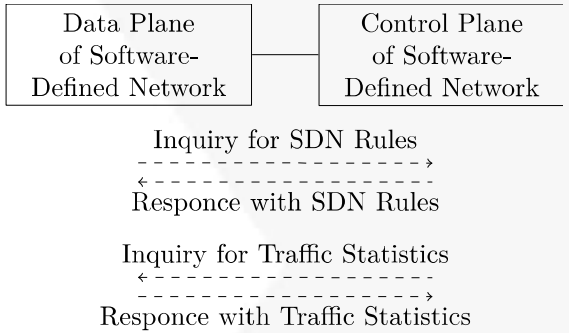
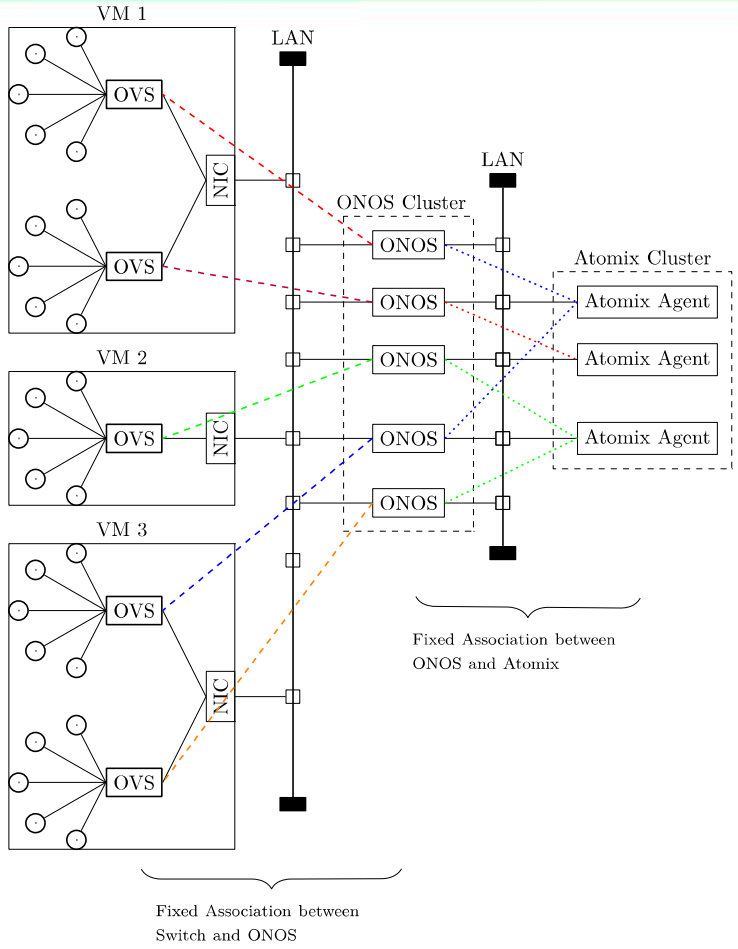
Project Description and Objectives

Strategic Alignment of Project to Fossil Energy Objectives (2)

System Diagrams of traditional Software-Defined Network





- Key vulnerabilities
  - Lack of detection on security breaching.
  - Lack of effective mechanism for excluding compromised SDN controllers from a SDN.

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Project Description and Objectives

Technology Benchmarking (1)

- This project aims to construct
  - A cloud-based networking platform which can be used for
    - Studying the threats targeting SDN-enabled operational networks deployed in electric power systems, and
    - Prototyping security protection solutions thwarting the attacks targeting the control plane, the forwarding plane, and the communications between the control plane and the forwarding plane.
  - A blockchain/P2P-based technology for detecting the compromised controllers in software defined networks.
- Industry/input or validation
  - This project is in collaboration with *Minnkota Power Cooperative.*
  - *Minnkota Power Cooperative* helps to facilitate decision-makings on the scientific and technical direction of the project and will be a user of the cloud-based networking platform.

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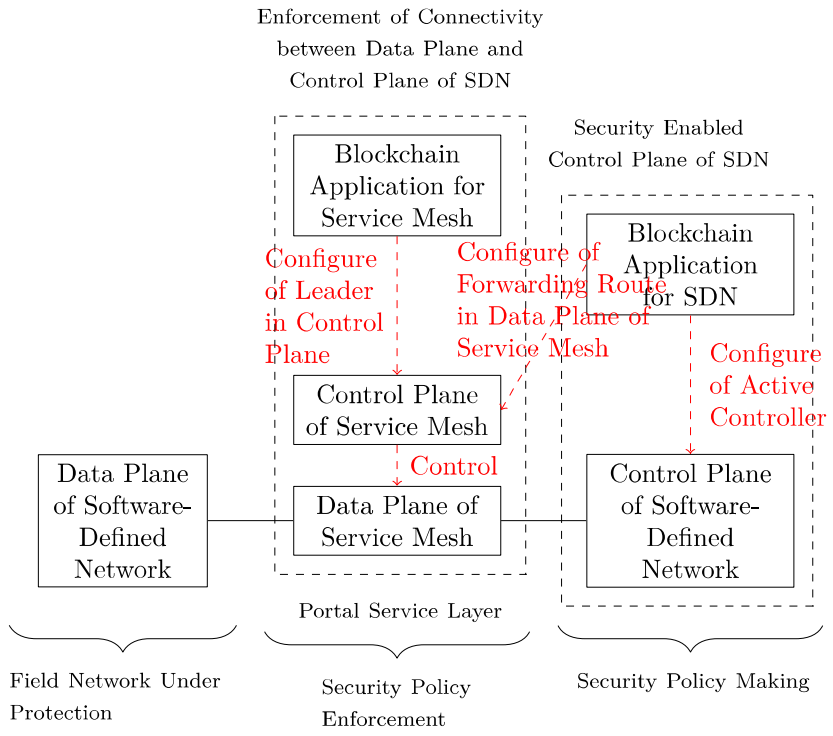
Project Description and Objectives

Technology Benchmarking (2)

- This project aims to enable security protection for SDN.
  - Enabling detection of compromised SDN controllers by constructing blockchain applications.
  - Enabling exclusion of compromised SDN controllers by decoupling the direct and fixed connectivity between the data plane and control plane in SDN.
    - A portal service layer is used to decouple the two planes.



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Project Description and Objectives

Overview of Major Efforts

- We have conducted 4 efforts in this project.
  - Determined the overall structure of the security-enabled SDN system.
  - Constructed a private cloud platform over 3 Dell servers.
    - The testbed operates in the private cloud.
    - The testbed supports simultaneous run of multiple SDN simulations.
  - Constructed the SDN with a controller cluster.
    - Mininet is used for simulating the data plane of the SDN (DP-SDN).
    - A cluster of ONOS controllers is used for the control plane of the SDN (CP-SDN).
  - Constructed the portal service layer to bridge the data plane and the control plane of an SDN.
    - The portal service layer is materialized in the form of a service mesh which consists of
      - A data plane (DP-SM): a set of *Envoy* proxies.
        - Forwarding traffic between DP-SDN and CP-SDN.
        - The forwarding paths are determined by CP-SM.
      - A control plane (CP-SM): a set of *Consul* agents.
        - Determine the forwarding paths in DP-SM.

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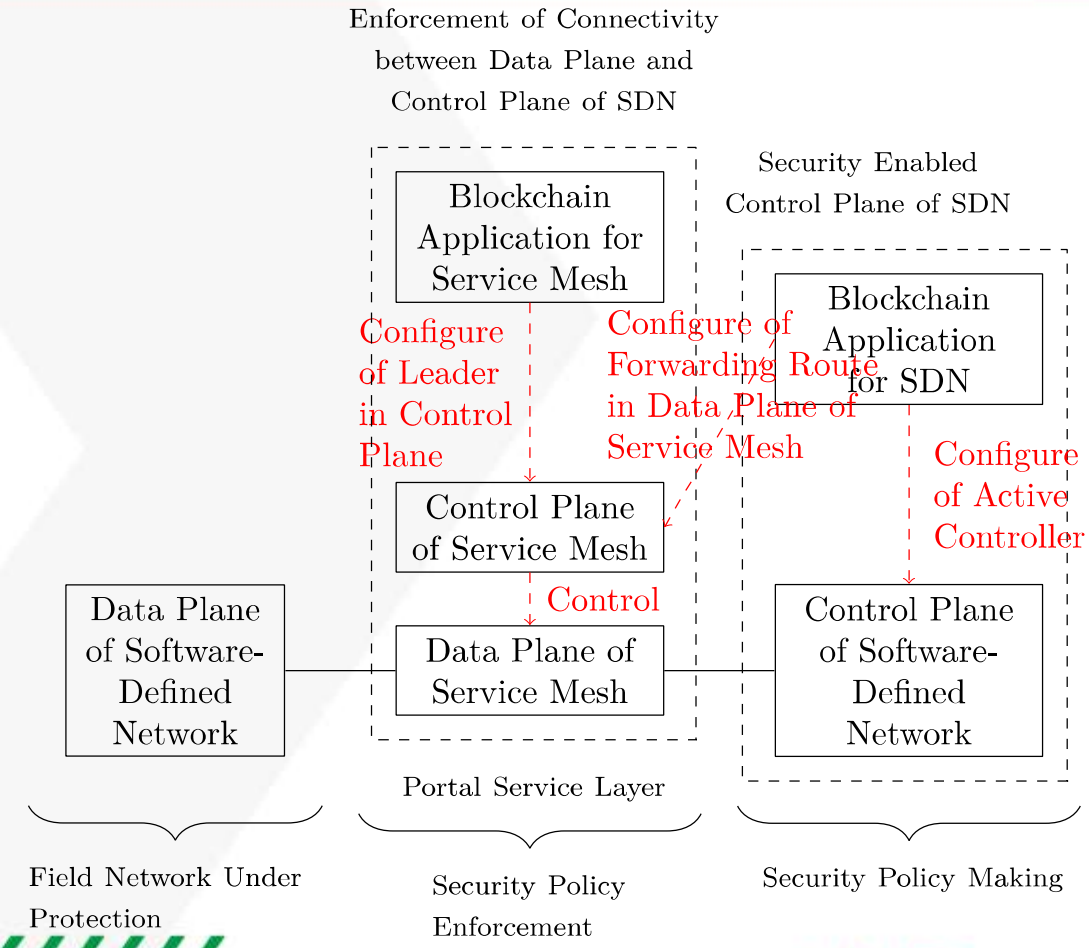
Project Description and Objectives

Overall Structure of Security-Enabled SDN System (1)



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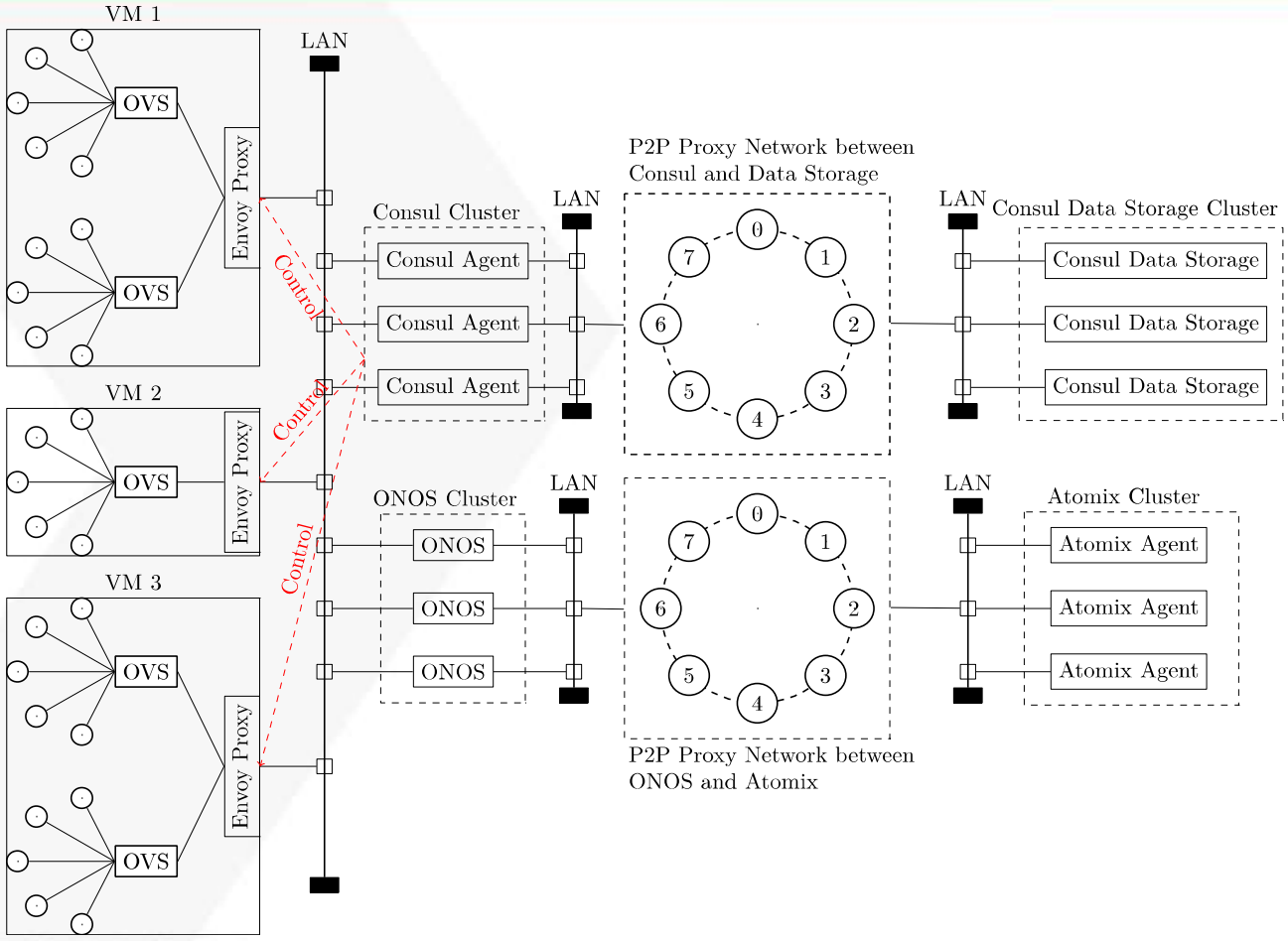
Project Description and Objectives

Overall Structure of Security-Enabled SDN System (2)



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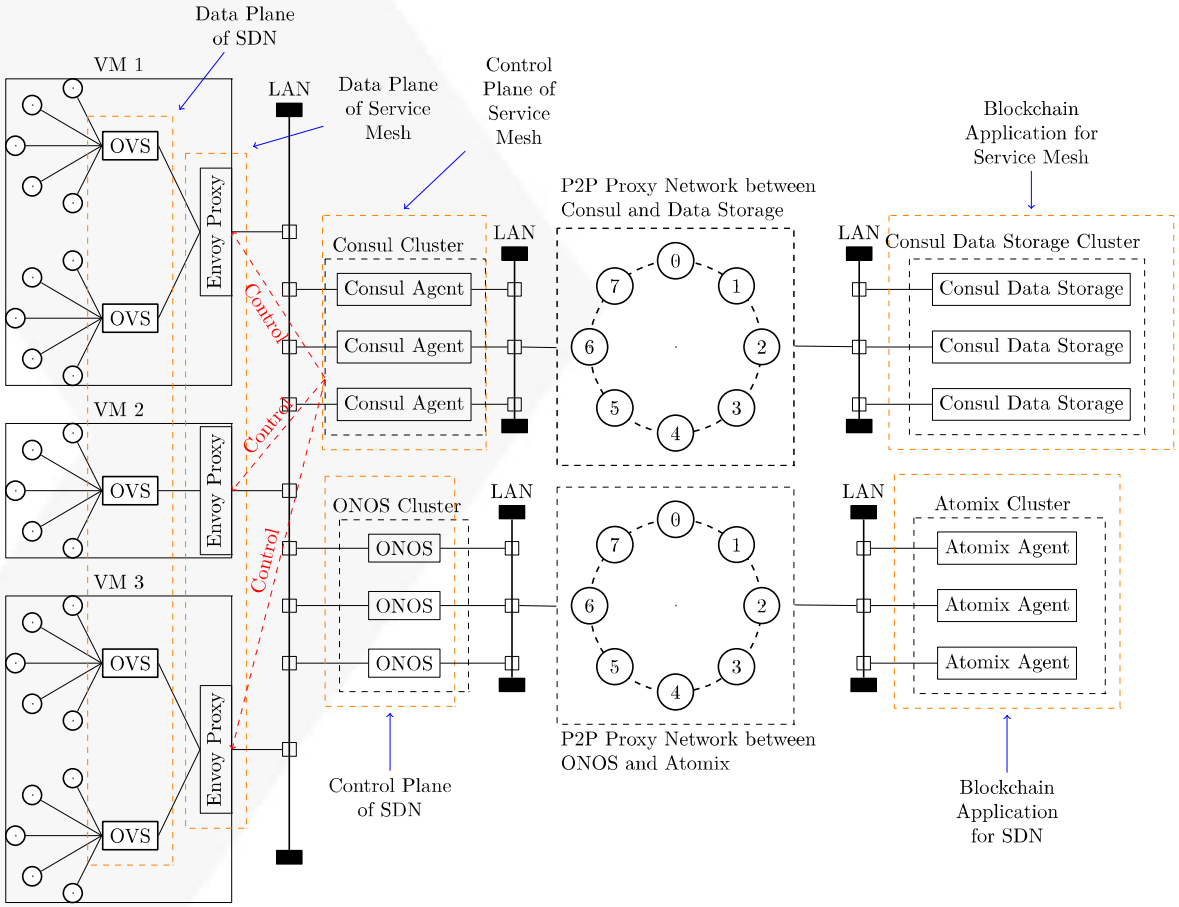
Project Description and Objectives

Overall Structure of Security-Enabled SDN System (3)



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Project Description and Objectives

Current Status of Project

- This project started on September 1st, 2019 for a 3 years duration.
- This project , and there is no available comparison with known benchmark.
- There is no major change in the project goals/objectives.
- We have made some changes in the actual implementation of the tasks.
  - We have decided to construct the originally proposed testbed in the form of a cloud-based networking platform.
  - We have decided to adopt the proof-of-reputation consensus model for detecting the compromised network controllers in SDN networks.

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Project Description and Objectives

Current Status of Project

- This project started on September 1st, 2019 for a 3 years duration.
- Timeline of major tasks and milestones:

Task Description	Planned		Achieved	
	Start Date	End Date	Start Date	End Date
Task 1.0 -- Update project management plan	9/1/19	9/30/19	9/1/19	9/30/19
Task 2.0 -- Demonstration of Sample Runs of an SDN System	10/1/19	4/30/20	10/1/19	5/30/20
Subtask 2.1 -- Demonstration of Installation of Software on Controllers and Switches	10/1/19	11/30/19	10/1/19	12/31/19
Subtask 2.2 -- Demonstration of Traffic Flows Between SDN Switches	12/1/19	1/30/20	12/1/19	2/28/20
Subtask 2.3 -- Demonstration of Query for Rules	2/1/20	2/28/20	2/1/20	3/31/20
Subtask 2.4 -- Demonstration of Traffic Flow Handling Based on Rule Specifications	3/1/20	4/30/20	3/1/20	5/30/20
Task 3.0 -- Demonstration of a P2P Inquiry Platform in the SDN System	5/1/20	4/30/21	5/1/20	4/20/21
Subtask 3.1 -- A Justification Report of the Choice of a P2P Open-Source Package	5/1/20	5/30/20	5/1/20	6/15/20
Subtask 3.2 -- Demonstration of Querying Rules from the P2P System	6/1/20	11/30/20	6/1/20	4/20/21
Subtask 3.3 -- Making SDN Forwarding Switches to Query Rules from the Inquiry Platform	12/1/20	4/30/21	12/1/20	4/20/21
Task 4.0 -- Demonstration of Use Case of Identifying a Compromised Controller	5/1/21	8/31/22	2/1/21	
Subtask 4.1 -- Demonstration of a Blockchain System Running on Top of a P2P System	5/1/21	10/1/21	2/1/21	
Subtask 4.2 -- Demonstration of Replicated Rules in Blockchain System	11/1/21	1/30/22		
Subtask 4.3 -- Demonstration of Storing Replicated Data Chunks in Blockchain System	2/1/22	6/1/22		
Subtask 4.4 -- Demonstration of Identifying a Compromised Controller	7/1/22	8/30/22		

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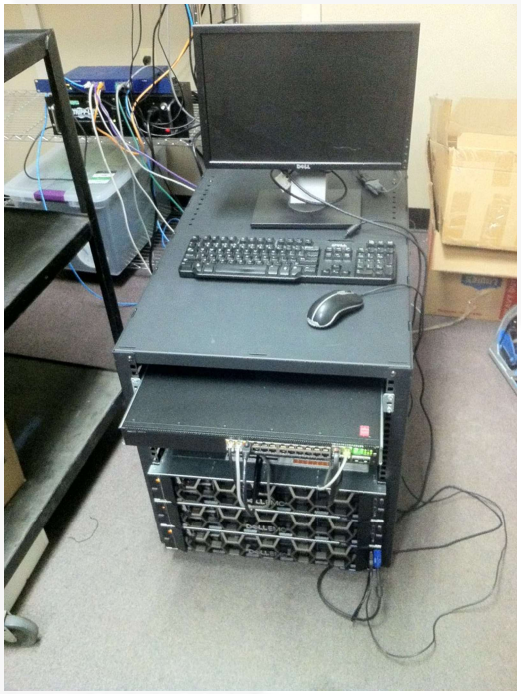
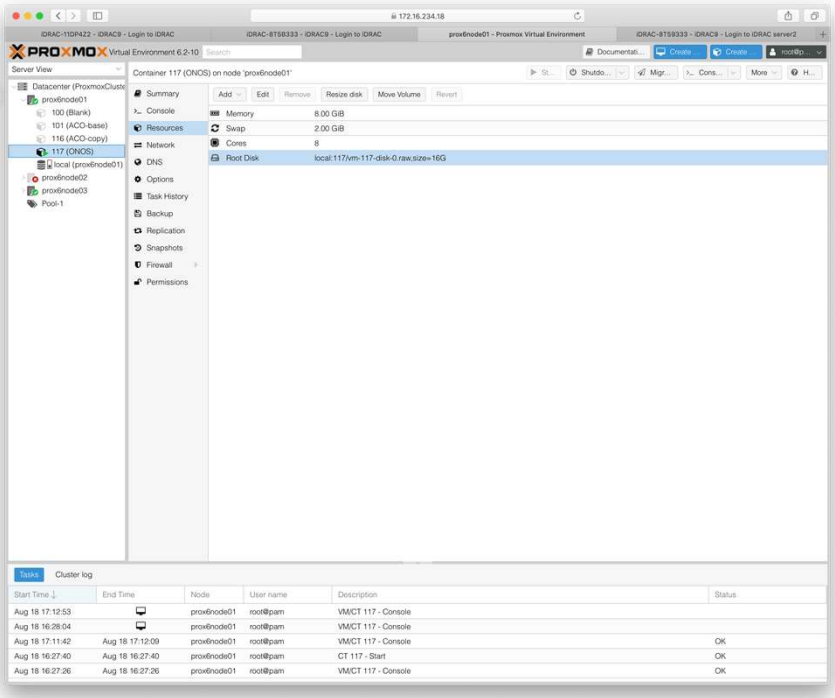
Project Description and Objectives

Accomplishments Before 2020 Review Meeting (1)

- Deployment of a cloud infrastructure running across 3 servers
  - Hardware: 3 high-end Dell servers (Model PowerEdge R540).
  - Software: Proxmox Virtual Environment (PVE) and OpenStack.





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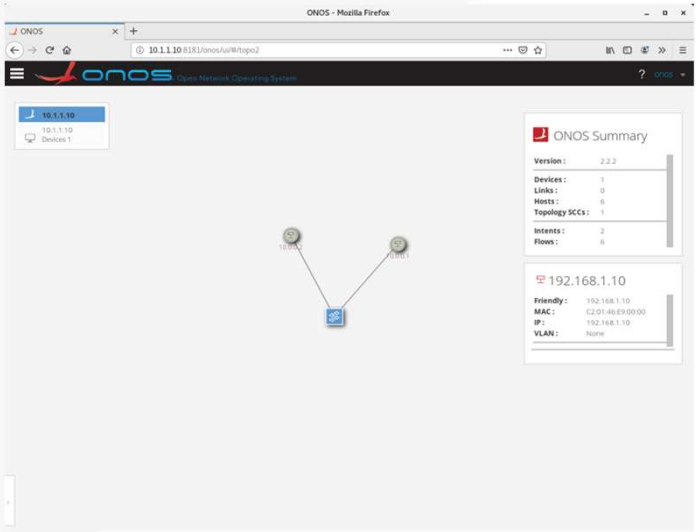
Project Description and Objectives

Accomplishments Before 2020 Review Meeting (2)

- Deployment of an Openflow-based SDN environment
  - Data plane: *mininet* is used to emulate OpenvSwitch (OVS) switches
  - Control plane: *Open Network Operating System (ONOS)* is used to emulate an OVS controller.
  - Running Openflow networks in the cloud environment.



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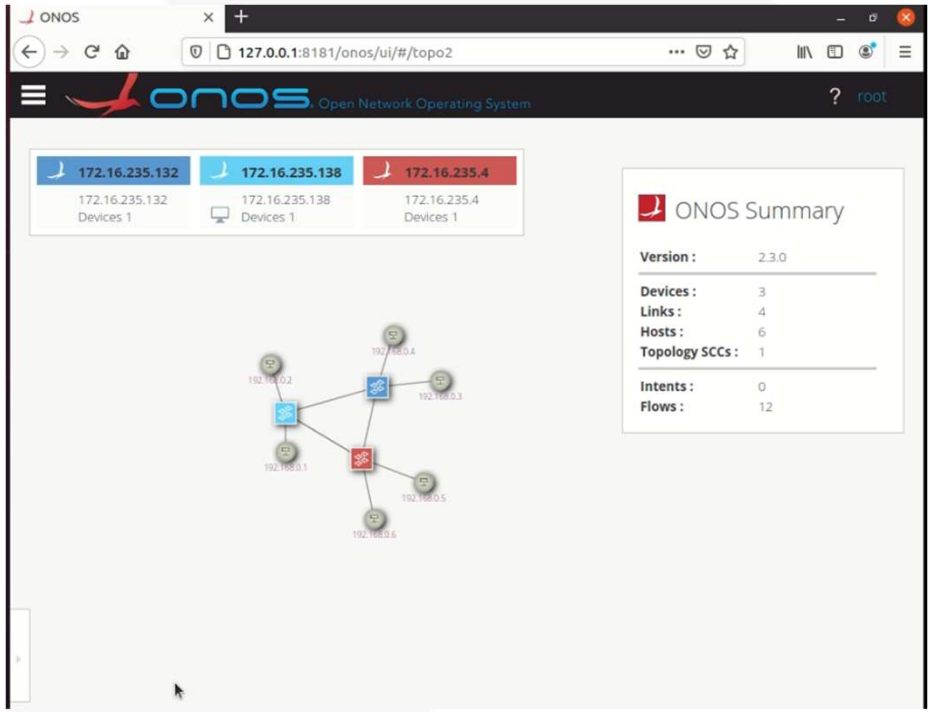
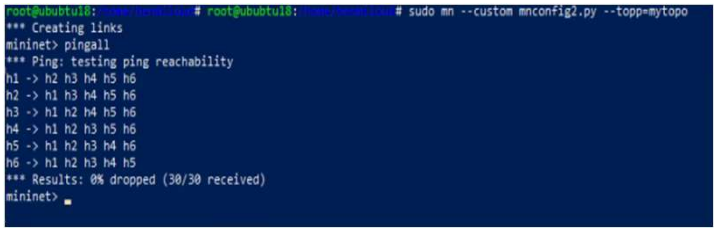
Project Description and Objectives

Accomplishments Since 2020 Review Meeting (1)

- Constructed the SDN with a controller cluster.
  - Mininet is used for simulating the data plane of the SDN (DP-SDN).
  - A cluster of ONOS controllers is used as the control plane of the SDN (CP-SDN).
  - A cluster of Atomix agents is needed for forming a cluster of ONOS controllers.





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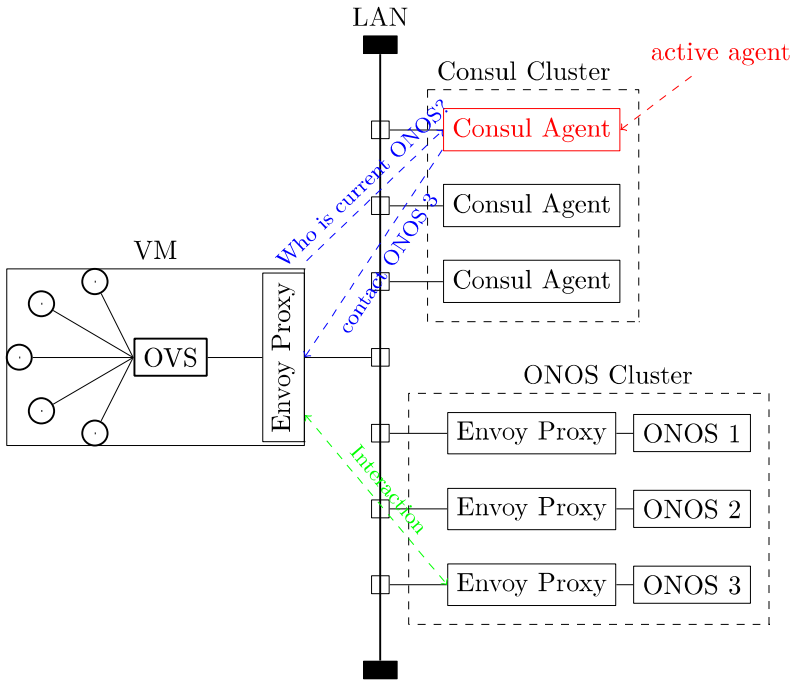
Project Description and Objectives

Accomplishments Since 2020 Review Meeting (2)

- Constructed the portal service layer to bridge the data plane and the control plane of an SDN.
  - The portal service layer is materialized in the form of a service mesh which consists of
    - A data plane (DP-SM): a set of *Envoy* proxies.
      - Forwarding traffic between DP-SDN and CP-SDN.
      - The forwarding paths are determined by CP-SM.
    - A control plane (CP-SM): a set of *Consul* agents.
      - Determine the forwarding paths in DP-SM.
  - In the demo of a SDN with a cluster of ONOS controllers shown on the previous slide, OVS switches interact with ONOS cluster through the portal service layer.
    - Manual configuration of the portal service layer as of now.
    - We will continue to enable automatic configuration by enabling the xDS service in Consul cluster.



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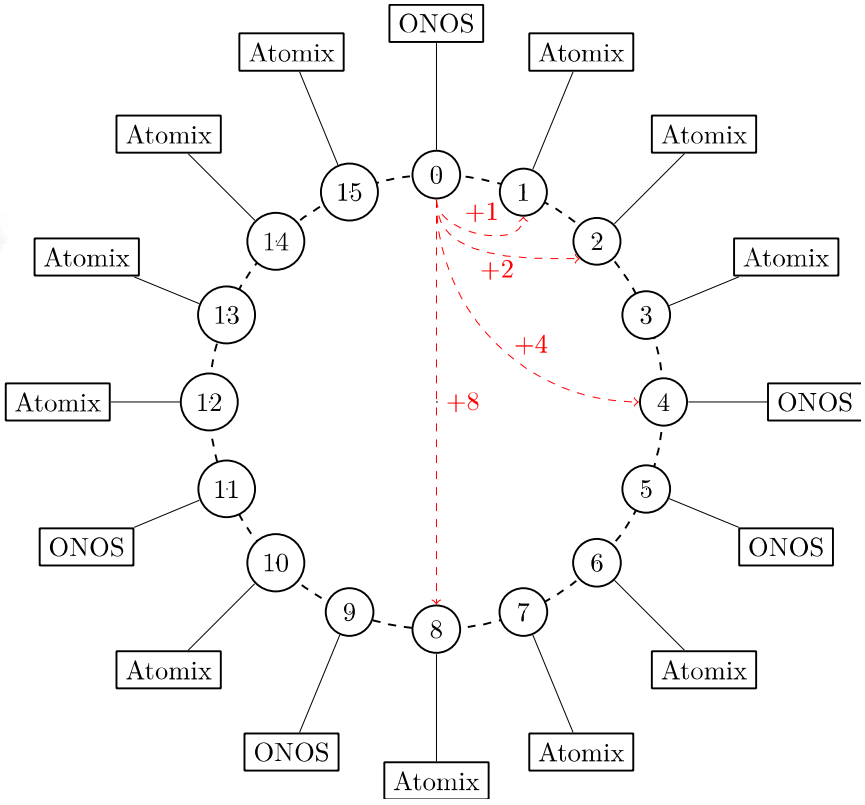
Project Description and Objectives

Accomplishments Since 2020 Review Meeting (3)

- Constructed the peer-to-peer (P2P) network to bridge between .
  - A cluster of ONOS controllers is used as the control plane of the SDN (CP-SDN).
  - A cluster of Atomix agents is needed for forming a highly available (HA) cluster of ONOS controllers because the formation of a HA cluster requires a Raft protocol to be run in the Atomix cluster.
  - A P2P network is used to bridge between a cluster of ONOS controllers and a cluster of Atomix agents.
    - An ONOS controller acts as an inquirer.
    - An Atomix agent acts as a data storage.



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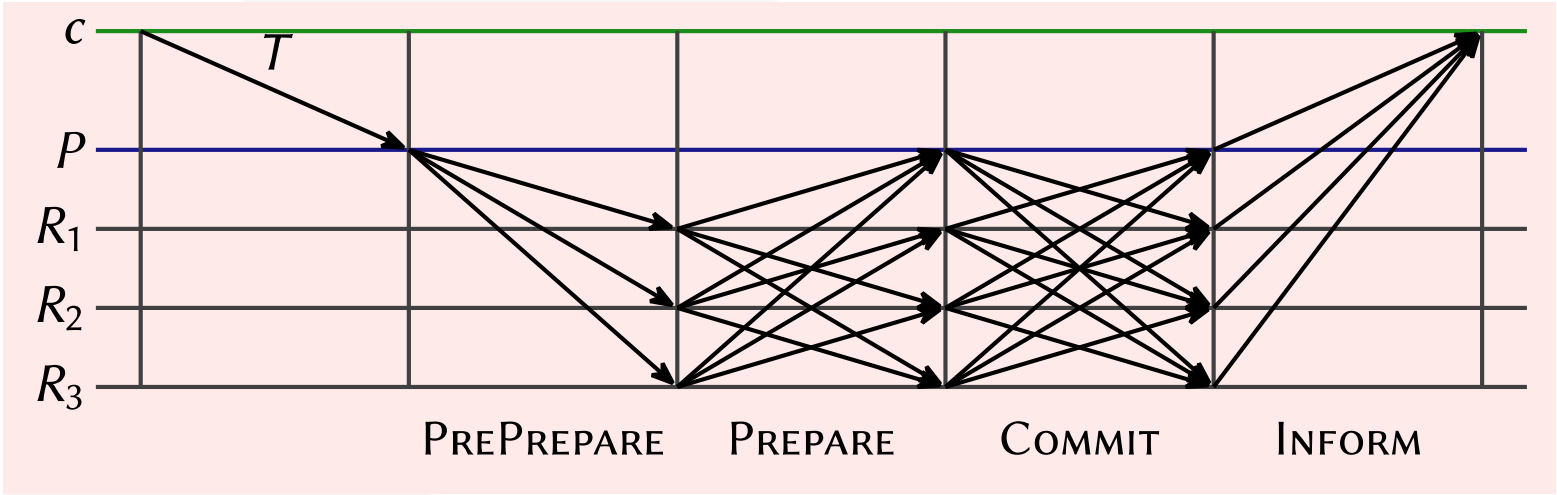
Project Description and Objectives

Accomplishments Since 2020 Review Meeting (4)

- Started to construct a BFT data storage with reduced communication overhead.
  - Raft protocol runs in Atomix data storage to support high availability of replicated data stores.
  - Raft protocol only tolerates fail-stop or fail-recover failures, but it does not tolerate Byzantine failures.
  - Practical BFT consensus can tolerate Byzantine failures and requires to transmit $3*n+2*n^2$ messages.
- Our goal: a BFT consensus algorithm in which a 3PC only produces a linear communication overhead.



(Figure is from a lecture note on practical BFT.)

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Project Description and Objectives

Next Steps (1)

- Develop a BFT consensus algorithm with linear communication overhead.
  - We are close to finish developing a 2-rounds group key agreement protocol which allows a group of participants to agree upon a common secret value.
  - The communication overhead of this group key agreement protocol is linear in the number of participants.
  - We plan to convert this group key agreement protocol into a BFT consensus algorithm.
- Prototyping the BFT consensus algorithm by modifying the Raft code in Atomix.
- Risk:
  - Prototyping the BFT consensus algorithm may be risky and time consuming.
- Risk mitigation:
  - We will also find open-source implementation of practical BFT (pBFT) algorithm and integrate the open-source pBFT implementation with Atomix, while we will attempt to prototype our low-overhead BFT consensus algorithm.
  - Bottom line: we will ensure pBFT with quadratic communication overhead to be used to provide BFT consensus in Atomix data storage.

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Project Description and Objectives

Next Steps (2)

- To develop a blockchain application (called blockchain-1) for detecting and excluding a compromised ONOS controller.
  - The blockchain application runs on top of Atomix data storage which provides BFT consensus.
  - Detection: A compromised ONOS controller is the one which had issued inconsistent rule to OVS switches.
  - Exclusion: The blockchain application configures the xDS in the Consul cluster to exclude a compromised ONOS controller after the detection.
- To develop a blockchain application (called blockchain-2) for detecting and excluding a compromised Consul agent.
  - It is also important to detect and exclude a compromised Consul agent since the Consul agent enforces the decision made by blockchain-1 application.

Project Description and Objectives

Next Steps (3)

- To continue the work on the P2P networks
  - The current work on P2P networks is highly simplified for demonstrating that an ONOS cluster can also be formed after a P2P network is used to bridge between a cluster of ONOS controllers and a cluster of Atomix agents.
  - We will continue to work on configuring the partitions in the P2P network by adding more peers.
- To construct the coordinated executions of multiple subsystems adopted in the testbed.
  - Currently, different subsystems have to be run piece-by-piece manually without being able to make a coordinated execution through running a single launching instruction.
- Many auxiliary tools have to be implemented for collecting experiment data in the simulation of an SDN.

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Acknowledgment

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