Flow Table: Network devices maintain flow tables that define how incoming packets should be processed. These tables contain rules (flows) that dictate packet handling based on fields like source/destination IP addresses, ports, VLAN tags, etc.

It may have the following challenges:

- **Security:** Centralized control introduces potential security vulnerabilities, requiring robust security measures to protect the controller and network.
- **Integration:** Integrating OpenFlow into existing network infrastructures can be complex and requires careful planning.

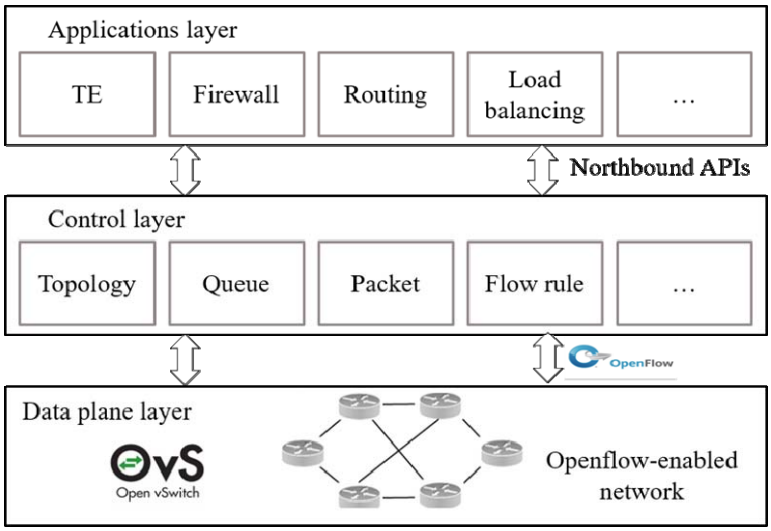

Figure 1. Software Defined Networks Architecture.

4.2. *Trema*

Trema serves as a toolkit for developers working with OpenFlow controllers and SDN applications. It facilitates the creation of custom network control software, allowing developers to manage and monitor network flows dynamically.

To use Trema effectively, developers typically follow these steps:

- **Installation**: Start by installing Trema and its dependencies on your development environment.
- **Development**: Write SDN applications using Trema's Ruby-based APIs, implementing control logic and flow management.
- **Testing**: Use Trema's tools to test and debug your applications, ensuring they perform as expected under different network conditions.
- **Integration**: Integrate Trema with OpenFlow-compatible switches and network hardware to manage and control network traffic according to your application's requirements.

The key features of Trema include;

- **Ease of Use**: The Ruby API makes it easy for developers to create and manage OpenFlow applications.
- **Modularity**: Trema's modular architecture allows for easy extension and customization.
- **High Performance**: The C core ensures efficient packet processing and low-level operations.
- **Comprehensive Documentation**: Trema offers extensive documentation and examples to help developers get started quickly.

4.3. *Plant UML*

PlantUML[12] is a tool that allows you to create diagrams from plain text descriptions. It's particularly useful for generating UML diagrams in an easy-to-read format, which can then be integrated into various documentation and codebases. The PlantUML code will generate a diagram illustrating the key elements of the system, how they interact, and the flow of the process from learners participating in exercises to receiving help through the analysis provided by the system.

To run PlantUML, we need a Java Runtime Environment (JRE) installed on our system, as PlantUML is a Java-based tool. Here's a detailed list of the requirements and steps to get started with PlantUML:

1. J Java Runtime Environment (JRE):
    - PlantUML requires Java to be installed on your system. You can download it from the official Java website.
    - Verify your Java installation by running java -version in your command prompt or terminal.
2. PlantUML Jar File:
    - Download the PlantUML jar file from the official PlantUML website.

5. System Implementation

The objective of this paper is to assist learners in identifying errors during network construction exercises by providing useful clues. To achieve this goal, we incorporated a standard output function (comprising prefix, line number, and clock) into all statements of the controller program.

In the proposed system, users first submit the network configuration information and controller program for their exercise. The data collection function then initiates packet capture and Trema, logging the user's communication test activities. Upon completion of the communication test and the user's termination request, the data collection function halts packet capture and Trema, retrieves packets, OpenFlow messages, and execution history, and stores them in the log DB as packet information, OpenFlow information, and executable statement information.

Following the conclusion of data collection, the system sequentially executes the time series flow table reproduction function, route selection imitation function, and transmission route estimation function, generating and saving the time series flow table, route selection history, and transmission route information in the log DB. The clue generator function extracts the necessary information from the log DB and provides the user with the clues to help identify and resolve errors. Figure 2 shows an example output of the system.

6. Experiment

In this system, we set a communication network with three different controller programs as sample exercises with one testbed network topology in Figure 2. The achievement condition is all host can communication with ping each other. The evaluation environment includes Host OS: Windows 10, Host CPU: Intel(R) Core (TM) i7-6500U CPU @ 2.59GHz, Virtual Machine: VMware Workstation 15 Player, Guest OS: Ubuntu 16.04LTS and Guest memory assignment is 1GB. The visualizer is implemented with Ruby and C language, Plant UML is used to convert the description to graphics. It might make it possible for us to achieve our goals. The system output result is shown in Figure 2 and the analysis result is in table 1.

Table 1. Analysis result

Controller Program	Controller Evets	Network Reachability	Packet Information (KB)	Openflow Information	Executed Statement Information
1	High	Yes	18	38	2
2	Medium	Yes	22	24	3
3	Low	Yes	25	20	4

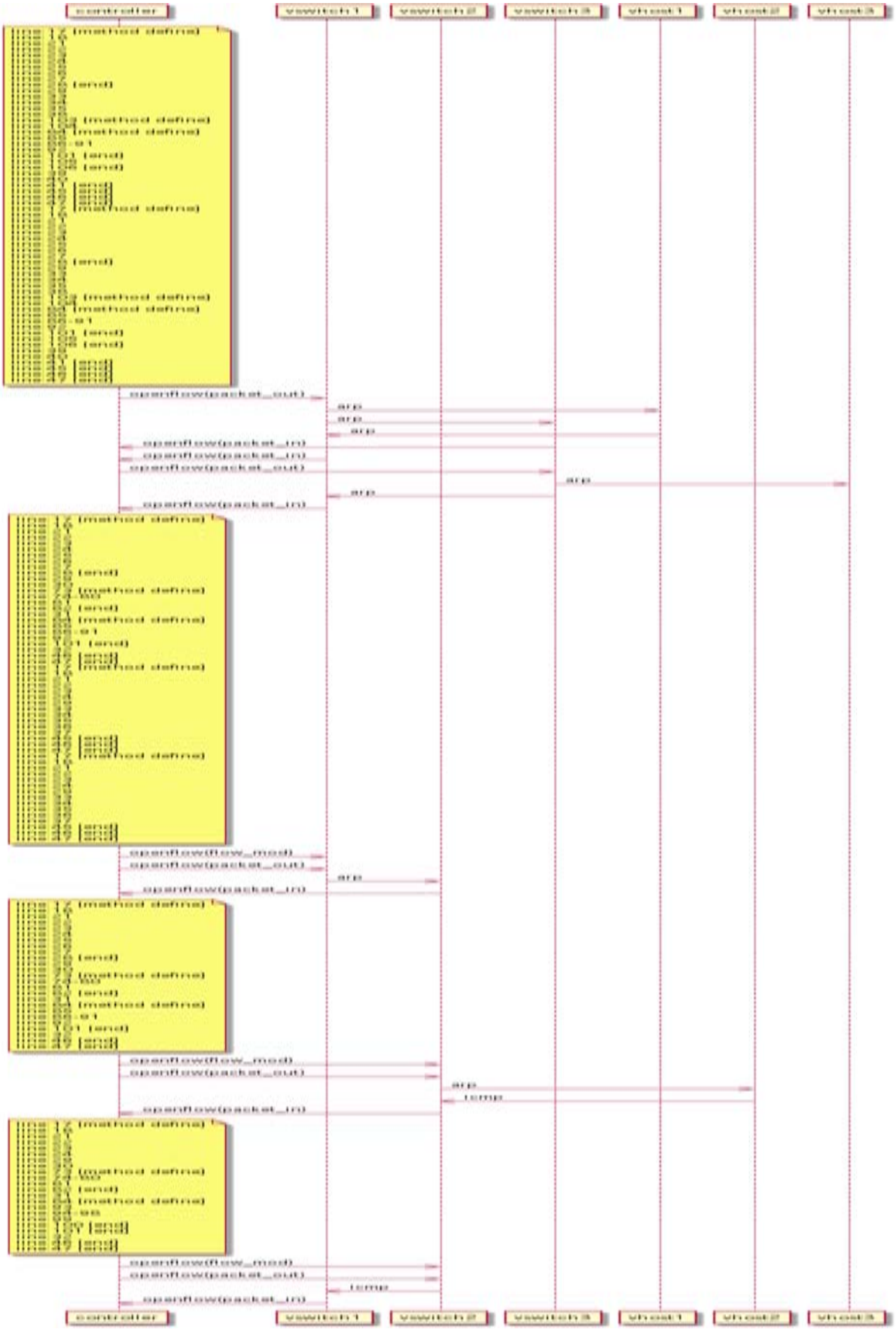

Figure 2. Output of the system

7. Conclusion and Future Work

In our system, we have conducted an analysis of the dependency between communication activities in SDN construction exercises to help learners easily identify missettings. Utilizing the OpenFlow controller Trema, we implemented the simulator with Ruby and C [11], while the visualizer is created with the Plant UML Library [12]. This configuration allows us to effectively achieve our objectives.

Our work proposes a system for analyzing dependency in communication activities within SDN construction exercises using Trema. Learners often cannot identify missettings in SDN controllers due to various reasons, such as ping not finding delivery routes including switches, and switches not having the function to log rules. For learners facing difficulties in narrowing down errors, the proposed system provides three valuable clues from the dependency analysis: identifying rules, narrowing down switches, and pinpointing executed statements that lead to incorrect communication. Additionally, we evaluated the system's performance and effectiveness in aiding students' debugging processes.

Conflict of Interest

Declared conflicts of interest do not exist for the authors. There are no financial conflicts to disclose,

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