Graphical User Interface for Software Defined Network Cloud Simulator

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Graphical user interface development for software defined network simulation in cloud environments

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ABSTRACT

With the prosperity of cloud computing, various simulation tools, such as CloudSim, are developed to experiment ever-changing user requirement and system supply before deploying a system into real-world scenarios. However, there is no existing cloud simulation tool to support Software Defined Network (SDN), which provides programmable networking paradigm. To implement SDN into the cloud simulation environment, this project develops a visualised extension based on the CloudSim framework that supports SDN simulation in cloud environment and provides graphical user interface for networking topology management.

Declaration

I certify that

- this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person where due reference is not made in the text,
- where necessary I have received clearance for this research from the University's Ethics Committee and have submitted all required data to the Department,
- the thesis is less than 6,000 words in length excluding text in images, table, bibliographies and appendices.

Signature___________________

Date___________________

Acknowledgement

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1 INTRODUCTION

Cloud computing is deemed to represent the next-generation computing paradigm in addition to cluster computing and grid computing. It is treated as 5th utility following after water, electricity, gas, and telephony [1], which works like commodity, and delivers computing as service based on pay-as-you-go schema. By using cloud computing, users can be provided with a variety of services without considering technical issues such as hardware construction, software installation, system maintenance and management. These services can be tailored elastically and dynamically at different levels, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), to fulfil varied requirements. In order to implement cloud computing, virtualization technology is applied to dynamically partition every single server into multiple isolated virtual machines, resulting in increased hardware utilization, minimised cost and reduced energy consumption.

However, due to the diverse criteria of a system and the ever-changing user requirements, the performance assessment of resource allocation policies and application scheduling algorithms under cloud environments is often challenging and complicated [2]. In this case, various simulation tools are developed to conduct performance assessment in a cost effective, efficient, and elastic way. CloudSim is such simulation platform which provides powerful and comprehensive components and features to model cloud, virtual machine (VM), and cloud market [2]. There are many extensions developed on the top of the CloudSim framework to fulfil diverse simulation tasks. For example, CloudAnalyst is a visualised extension developed based on CloudSim. It provides graphical user interface (GUI), real time analysis, and dynamic configuration, which largely simplifies the simulation procedure and performance evaluation process [3]. CloudAnalyst also enables the users who have no experience on programming to perform simulation tasks.

1.1 Motivation

Currently, with the best of our knowledge, there is no simulation tool for cloud infrastructure, which has the functionalities to support Software Defined Networking (SDN). It is thus desirable to develop a visualized extension based on the CloudSim framework that supports SDN simulation and provides graphical user interface for networking design. As a virtualised and programmable network, SDN represents the next generation networking management paradigm [4]. In traditional network, the forwarding device is tightly coupled with controller by providing limited management interface, which leads to manual, complex and time-consuming reconfiguration. While SDN separates the software controller from forwarding devices, which provides unified programmable interface for different types of network devices such as switches and routers. By using this interface, the network engineer can develop applications to achieve automatic reconfiguration. SDN has been widely used in many fields. Especially in cloud computing, SDN provides effective methodology for scalable, efficient, and virtualised network resource management. By implementing SDN, virtual machines can automatically conduct management for updating, reconfiguration, and failure recovery [5]. Particularly, it is helpful for energy conservation by reducing traffic switches consumption and virtual machine (VM) migration [4].

1.2 Software Target

With the motivation, the following targets come up that make us to begin this project.

- Visualised network topology generator
    - Can we tailor a graphical library or framework dedicated to simplify cloud-based, including SDN, simulation process?
    - Can we use graphical graph editor to manage network topology without typing into text editor directly?
    - Can we use unified format to improve reusability of network topology?
- Simple and unified graphical user interface (GUI)
    - Can we provide user friendly graphical interface?
    - Can we simplify simulation execution by using drag-and-drop mode?

This project aims to develop a visualised extension built on the top of the CloudSim framework that supports the SDN simulation in cloud environment and provides the graphical user interface for networking topology design. Particularly, this development makes following contributions.

- Integrating the visualized SDN features into cloud simulation platform.
- Building a GUI which simplifies and accelerates the process of physical and virtual network topology design especially for people with no knowledge of programming.
- Provisioning convenient graphical editor to create, modify, save and load network topology.
- Reducing the learning cost and facilitating the toolkit popularity.

2 RELATED WORK

As a promising next-generation computing paradigm, Cloud computing has been widely accepted by research communities, governments and industries. Many mature cloud computing products and platforms built including Amazon EC2, Google AppEngine, Microsoft Azure and Manjrasoft Aneka [6]. It aims to provide cost friendly, elastic, scaling and pay-on-demand computing resources for fulfilling various types of user requirements. That is, the computing resources, such as compute, storage, and networking, are to be delivered and paid on the basis of usage. Although the idea of Cloud computing has been widely recognized, it is still an evolving technology. One major concern or gap that needs to be addressed is effective and scalable network resource management [7].

There are several challenging issues existing in the virtual networking management. The first issue is how to handle the network dynamicity. Typical cloud networking architectures provide a "one size fit all" paradigm for meeting the diverse requirements of a cloud. However, there is an increasing requirement of the cloud users to specify their own bandwidths for improving the user flexibility. Besides, the change of the network management requirement may also be caused by dynamic network configuration, the design of network topology, different forwarding protocols, and multiple security policies. To deal with these changing requirements, the development of a programmable network paradigm is highly required. The second issue is how to solve the connectivity problem between data centres. It is necessary when an enterprise user needs to work with multiple cloud providers. To solve this problem, the network paradigm should orchestrate the coexistence among several cloud and network providers. The third issue is how to deal with the limitations of the existing networking protocols. The widely used protocols, including Spanning Tree Protocol (STP), Shortest-Path Bridging (SPB), Routing Information Protocol (RIP), Border Gateway Protocol (BGP), Open Shortest Path First (OSPF), and Intermediate System to Intermediate System (IS-IS) are not scalable enough for dynamic network management and Virtual Machine (VM) migration among multiple cloud networks. Thus, a network paradigm with high scalability and programmability is essentially needed.

To address the challenging issues in the virtual networking management, Software Defined Network (SDN), as an emerging network paradigm and promising solution that enables networks programmable, easily partitionable, and virtualisable is introduced [8].

2.1 Software Defined Network

The concept of Software Defined Network (SDN) has been introduced since 1996. It is driven by the need to provide user programmable networking management [9]. As defined by Open Networking Foundation, SDN is "*is a networking architecture where the control and data planes are decoupled, network intelligence and state are logically centralised, and the underlying network infrastructure is abstracted from the applications*" [8]. The SDN architecture involves a control plane, a data plane, and a networking operating system (NOS), as shown in Figure 1.

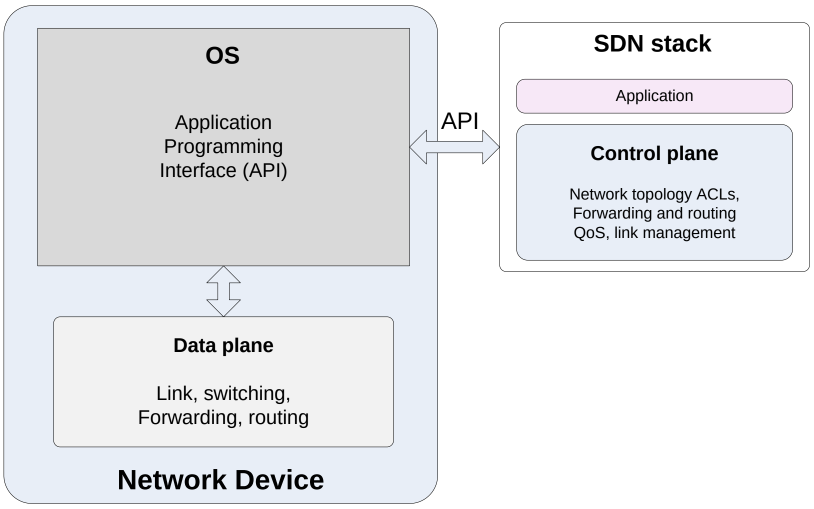

OS
Application Programming Interface (API)
API
SDN stack
Application
Control plane
Network topology ACLs, Forwarding and routing QoS, link management
Data plane
Link, switching, Forwarding, routing
Network Device

Figure 1. SDN architecture.

Different from traditional networks, the control plane in SDN is moved out of the individual network device and into the separate and centralised controller, allowing the network manager to implement control changes by simply changing the control program [10]. This programmable control plane is the most important aspect of SDN. It improves the scalability and flexibility of managing the service user requirements, optimises the routing policies, and enables reactively and proactively control of flow entries.

The main characteristics of SDN include centralisation of the control plane, programmability of the control plane, and standardisation of application programming interface (API) [9] [10]. The centralisation of the control plane allows a global view of the entire network from a single logical point. The control can be dynamically adjusted based on state changes, which is much faster than a distributed control. The programmability of the control plane allows the network to be virtually divided into several sub-networks. The sub-networks share the same hardware infrastructure but implement different policies. The programmability also enables flow-based control, which significantly reduces the traffic between the control plane and data plane. SDN turns the vendor-specific API into standardised API to enable common network services. SDN contains three types of APIs, which are Southbound API, northbound API, and east-west API [11]. Southbound API is the most important API that communicates between the control plane and data plane. Developed by Open Networking Foundation, OpenFlow is one of the most popular and widely applied southbound APIs [8]. It is initially applied into campus network by providing programmable network protocol in different switches and routers [12]. Northbound API is used to communicate between the control plane and application layer. East-west API allows communications between neighbouring control planes.

SDN has shown some advantages in network management, network heterogeneity, and cost control management [13]. Regarding network management, currently, the number of networking devices are growing fast and the networking device itself is getting more complicated by integrating more functionality. SDN greatly simplifies the network design, operation, and network devices by using centralised control. Unlike traditional networking management tools such Simple Network Management Protocol (SNMP), SDN applies policy-based management strategy to manage networking devices in an intelligent, dynamic, and flexible manner. In terms of network heterogeneity, SDN aims to build a unified and heterogeneous network strategy, which allows network products from multiple venders to communicate and co-work with each other. In this case, users or customers will not have to be tightly bound to only one vender. With regard to the cost control management, SDN can reduce the development cost and the network operating cost. By using SDN, complicated control softwares can be extracted from the control plane. Venders will then get free from the development and maintenance of a huge number of code workings. Since SDN allows switching services among multiple venders, it also largely reduces the operating cost.

As a widely accepted network paradigm, SDN can be applied into various fields, including enterprise networks, infrastructure-based wireless access networks, optical networks, home and small business networks, and especially for data centre [4]. As an underlying infrastructure for cloud computing, data centre is developing at a high speed. However, to reconfigure a network in data centre is time-consuming, which poses a challenging issue at networking management in data centre [13]. The networking management should have ability to respond quickly to changing requirements, to recovery from catastrophic events, and to reduce time consumption for VM configuration. SDN is believed having such ability to address this issue by providing programmable, scalable, and intelligent network management. For large-scale data centres, energy consumption is another concern. SDN is able to find the minimum power network subset which will meet the network routing requirements and turns off the unnecessary switches [4].

In order to implement SDN for improving networking management, especially under cloud environment, it is necessary to set up and to tear down experimental platform quickly. To achieve this, simulation is one of the best choices.

2.2 Cloud-based Simulation Tools

As aforementioned, the utilisation of simulation tools is a reasonable solution for conducting large-scale, repetitive, dynamical evolving and expensive experiment [2] [14]. In regard to cloud computing, experiments conducted on real infrastructure are not only extremely expensive due to a huge amount of investment has to be made in purchasing hardware, renting room, building and maintaining data centre, but also time consuming as a lot of time will be used to configure experimental environment and wait for results. In this case, it is desirable to have an efficient, productive, easy-to-deploy, and extensible simulation tool for conducting cloud-based experiments. In this paper, CloudSim, as an outstanding cloud-based simulation tool is used.

Traditional simulators, such as GridSim, SimGrid, OptorSim and GangSim, have been used for many years for grid modelling and simulating platforms [14]. However, none of them fully support cloud computing because cloud is built on the top of virtualisation technology and pay-as-service, including Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Developed for cloud computing simulation, CloudSim provides an open-source, generalised, and extensible simulation framework [15]. Experiments based on CloudSim will concentrate on model building, algorithm design, and data analysis rather than deployment and configuration.

In addition to CloudSim, there are some other existing works should be mentioned, including Mininet [16], Simulation Program for Elastic Computing Infrastructure (SPECI) [17] and iCanCloud [18].

Mininet provides a powerful interactive Command Line Interface (CLI) for developing a virtual network with hosts, links, and switches on a single machine. The single machine can be VM in cloud environment or native laptop or PC. Mininet is compatible with Linux and convenient to migrate to real hardware. It also supports OpenFlow and SDN, by which we can implement software defined switches.

SPECI is a cloud-based simulation platform characterised by providing predictive modelling for large-scale and hierarchical data centre. Cloud services hosted in this type of data centre are connected by the subscription network. Currently, the newest version of SPECI is SPECI-2.

iCanCloud is another cloud-based simulation platform based on OMNET and MPI and written by C++. It supports both graphical modelling and command-line modelling. iCanCloud is devoted to "predicting the trade-off between cost and performance" of applications in specific hardware. In this case, users will be given reasonable output which helps for decision making in purchasing cloud services. By using the global hypervisor function that provided by iCanCloud, users can customise brokering policies. In addition, iCanCloud also supports modelling Amazon instances.

With CloudSim, SDN features could be enabled under cloud simulation environment. To this end, it is essential to integrate SDN into CloudSim by which programmable network management strategies could be implemented. To facilitate SDN implementation, graphical user interface (GUI) should be orchestrated for SDN at the same time. GUI not only provides ability to create and update visualised physical and virtual network topology, but also establishes general and user friendly operation and execution environment. The main objective of this project is to orchestrate specific GUI for visualising and accelerating SDN simulation under cloud environment.

2.3 Java Swing

This project uses Java Swing as the GUI development framework. Swing is part of Oracle's Java Foundation Classes (JFC), which provides a general GUI for Java programs [20]. Compared with its predecessor Abstract Window Toolkit (AWT), Swing aims to provide a more advanced set of GUI components. In addition to common components such as buttons, check boxes and labels, Swing provides several advanced components such as tabbed panel, scroll panes, trees, tables, and lists. Another new feature about Swing is its ability to override the native host operating system (OS)'s GUI controls for displaying itself. Swing 'paints' its controls using the Java 2D APIs, rather than calling a native user interface toolkit. More importantly, Swing is a lightweight, platform-independent, and customizable framework [21]. With this Swing, the developer can customise domain-specific components by overriding the default implementations. Equipped with these advanced features, Swing is selected to tailor and implement SDN-specific or cloud-specific graphical components in this project.

3 DEVELOPMENT OF GUI

Based on the concepts of SDN, CloudSim, and Swing, this project develops a GUI for visualising SDN in order to facilitate the networking topology management and SDN execution. This Section discusses the architecture of the GUI together with the components and methods of implementing the GUI.

3.1 GUI Design

GUI design has three aspects, including high-level architecture design, java graph visualisation library design, and detailed component design.

3.1.1 Architecture Design

Figure 2 shows the GUI architecture developed in this project. The GUI architecture consists of three layers, which are framework layer, business layer, and interface layer. The framework layer defines general, fundamental, reusable, and non-business logic components. It extracts common graphical elements and functions, and encapsulates them into independent classes. Well designed framework will dramatically improve the reusability of SDN and CloudSim and reduce redundant codes. The business layer is responsible for defining software business logic by invoking components from the framework layer. Core software functionality is implemented at this layer such as executing simulation. The top interface layer is used to interact with users by defining a user friendly interface and by optimising the composition of graphical components such as menu, tool bar, and canvas for drawing network topology. Business logic is invoked by the interface layer. The objective of this project is to implement five parts of this architecture, including ‘Graph Visualisation Library’, ‘GraphView’, ‘Execution’, ‘File IO’, and ‘Graphical User Interface’. In particular, the ‘Graph Visualisation Library’ is the key part for drawing network topology.

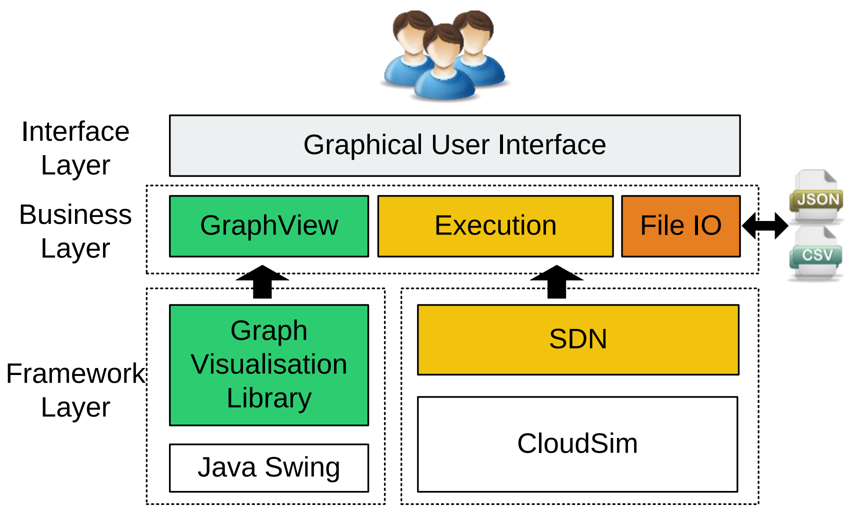


Figure 2. Graphical User Interface architecture.

3.1.2 Java Graph Visualisation Library Design

To develop a reusable graph visualisation library is essential for visualising network topology of SDN. The most commonly method is to import a thirty-party graph visualisation library, such as JGraphX [22], JGraphT [23], JUNG [24] and GraphStream [25].

JGraphX is a Swing-based Java graph visualisation library, which originated from JGraph library. JGraphX facilitates the development of graph applications, including workflow editor, organisational chart, business process modelling tool, UML tool, and network/telecoms visualisation. In addition, it supports import, export, and automatically layout [22].

JGraphT provides a free, simple, and type-safe Java graph library. Compared with JGraphX, JGraphT focuses on providing mathematical graph modelling and graph algorithm. It supports directed and undirected graph with weight, edge multiplicity, ‘read-only’ graph, listenable graph, and sub-graph [23].

JUNG is another prevalent Java universal network/graph framework. It supports graph modelling, analysis, extensibility and visualisation. In addition to support general graph modelling, such as directed and undirected graphs, multi-modal graphs, graphs with parallel edges, and hyper graphs, it also supports annotating graphs, nodes, and relations with metadata, which is beneficial for data analysis [24].

GraphStream is a recommended Java graph visualisation library especially for dynamic graphs. GraphStream supports dynamical graph evolution in time, such as node addition, node deletion, edge addition, edge deletion and attribute management. Besides, it also supports import, export, measure and layout graph elements [25].

Although these existing thirty-party libraries are widely used, some of their features are not suitable for meeting the objective of this project. To develop a lightweight SDN-specific graphical library for fulfilling SDN features under cloud environment, I develop the graph visualisation library by Java Swing. The library is extendable and can be customised to incorporate more functionality.

3.1.3 Framework Layer Design

The framework layer consists of two independent parts which are separated by dotted line, as shown in Figure 2. The right part is composed of two sub-parts, SDN and CloudSim. Developed by CLOUD lab, CloudSim is the cloud-based fundamental simulation framework [15]. Mr. Jongmin Son integrates SDN features into the CloudSim to provide programmable networking management. The left part aims to encapsulate SDN-specific graphical components, including types of nodes, edge, graph and coordinates, and the graph visualisation library built by Java Swing. It aims to implement common graphical components for visualising SDN.

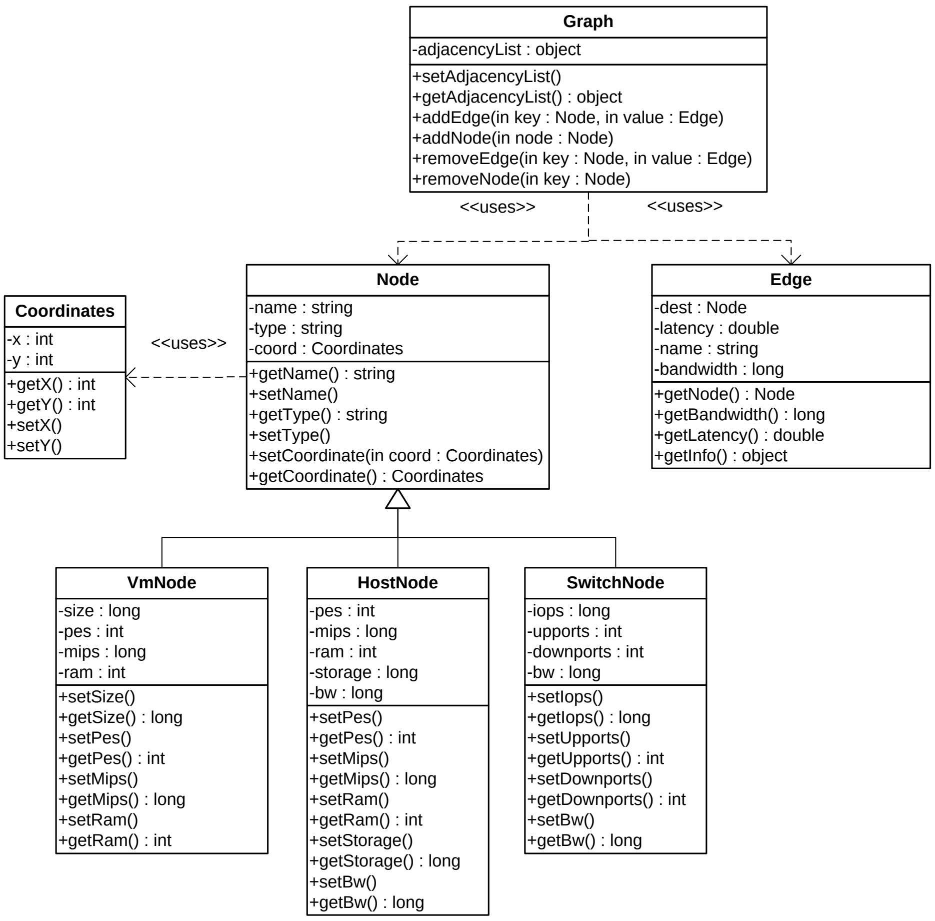


Figure 3. Class diagram of graph visualisation library.

To describe the framework layer, UML class diagram is provided as shown in Figure 3. The class diagram illustrates Java classes and their relationships. Graph class represents the abstraction of network topology, which stores nodes, edges of this graph and is responsible for managing nodes and edges. Edge class represents the abstraction of network connection, which stores attributes and nodes connected with this edge. Node class represents the abstraction of network node. Three types of sub-node are involved, including HostNode, VmNode and SwitchNode, representing host, virtual machine, and switch respectively. By implementing and extending this class diagram, it guarantees the reusability and scalability of the graph visualisation library.

3.1.4 Business Layer Design

As shown in Figure 2, there are three main functions to be defined in business layer, which are GraphView, SDN Execution, and File IO. GraphView is the core part of the GUI, it will draw a visualised network topology by using the graph visualisation library from the framework layer and to render it into canvas. SDN Execution performs SDN simulation and visualises its output. With this function, simulation is operated by drag-and-drop rather than command-line. File IO function supports importing pre-defined files into the GUI, saving defined network topology into files. It is worth mentioning that the three functions are defined separately but working collaboratively.

To describe the business layer, UML sequence diagram is developed as shown in Figure 4. In the sequence diagram, the GUI contains two modes which are "Canvas" and "Execution". The Canvas Mode is the core function of the GUI. It works as a network topology painter, which supports adding node and edge, saving graph into appointed JSON file, and importing outside JSON file into canvas for further processing. The Execution Mode visualises the simulation process and displays results by clicking rather than typing commands. Without the GUI, changing network topology or updating workloads have to be done by modifying source codes. By using the GUI, users can choose files more than once without restarting software, which significantly facilitates the simulation process.

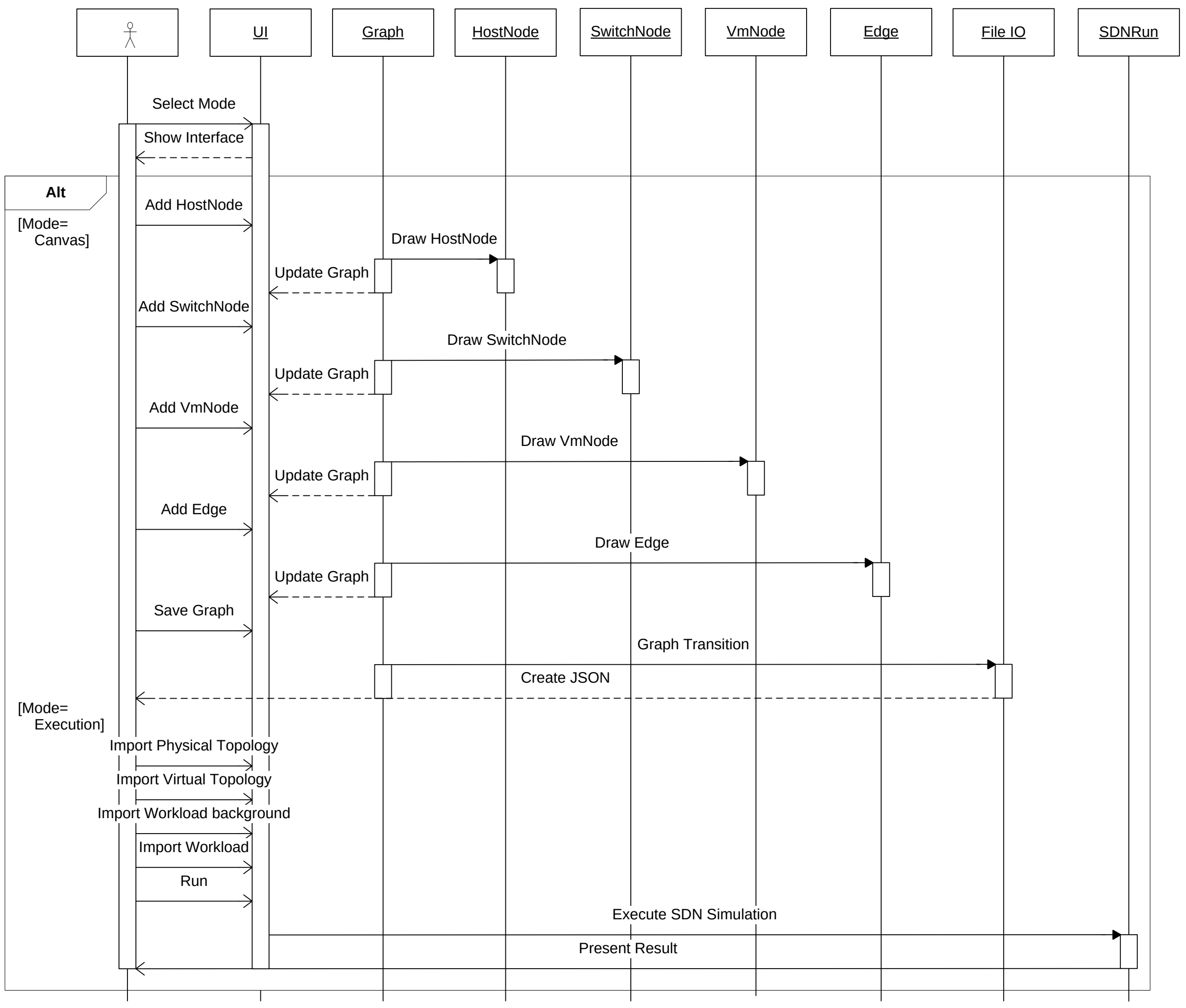


Figure 4. Software sequence diagram.

3.1.5 Interface Layer Design

In order to deliver a user friendly GUI, some principles should be followed, including defining clear entry and exit points, keeping software logic consistent, following widely accepted conventions, responding with proper feedback, prompting assistance and visualising software content [26]. Among them, to design the GUI with consistent logic is relatively more important but not easy to implement. The consistent logic will help user easily identify software logic pattern and accelerate software learning. In addition, it is also necessary to visualise text content to perceptual form, which will provide users with a more friendly and straightforward interface.

3.2 Implementation

The GUI is implemented by using Java Swing to produce user friendly, reusable and SDN-specific functionality. This Section discusses the GUI implementation, including project integrated development environment (IDE), project structure, Graph Visualisation Library, Canvas Mode, and Execution Mode.

3.2.1 GUI Project IDE and Structure

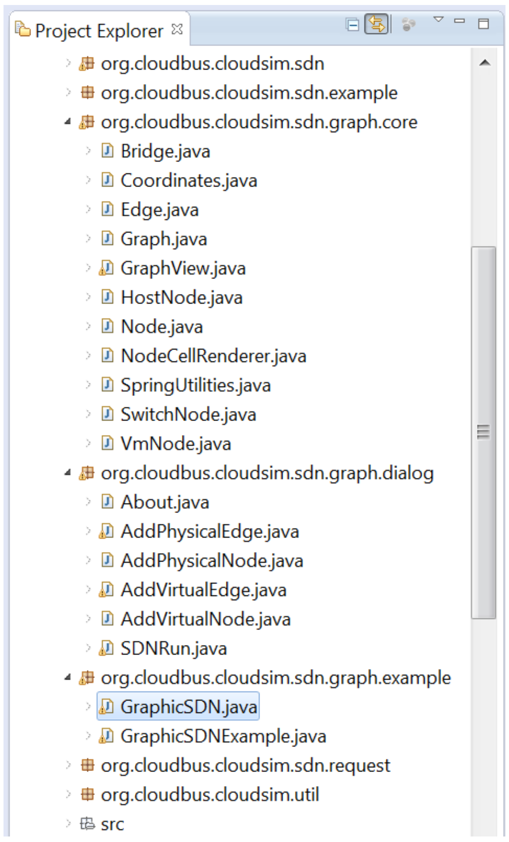
Within java application development, Eclipse Integrated Development Environment (IDE) is the most prevalent Java IDE that provides an open-source, extensible, plug-in based, cross-platform, multilingual programming workspace [27].

Based on the GUI architecture, the following three packages are added into current CloudSim, as shown in Figure 5.

org.cloudbus.cloudsim.sdn.graph.**core**,

org.cloudbus.cloudsim.sdn.graph.**dialog**, and

org.cloudbus.cloudsim.sdn.graph.**example**.



```
Project Explorer
  org.cloudbus.cloudsim.sdn
  org.cloudbus.cloudsim.sdn.example
  org.cloudbus.cloudsim.sdn.graph.core
    Bridge.java
    Coordinates.java
    Edge.java
    Graph.java
    GraphView.java
    HostNode.java
    Node.java
    NodeCellRenderer.java
    SpringUtilities.java
    SwitchNode.java
    VmNode.java
  org.cloudbus.cloudsim.sdn.graph.dialog
    About.java
    AddPhysicalEdge.java
    AddPhysicalNode.java
    AddVirtualEdge.java
    AddVirtualNode.java
    SDNRun.java
  org.cloudbus.cloudsim.sdn.graph.example
    GraphicSDN.java
    GraphicSDNExample.java
  org.cloudbus.cloudsim.sdn.request
  org.cloudbus.cloudsim.util
  src
```

Figure 5. GUI project structure.

The package 'core' defines the types of components for network topology visualisation, including Graph, GraphView, Node, Edge, Coordinates, and Bridge. GraphView is extended from JPanel, which is used to draw network topology. Graph is an abstraction of network topology which is composed of Node and Edge. Coordinates represents the specific location for each node which is used to draw node into canvas. Bridge works as a connection between JSON file and visualised graph, by which the graph entity can be transformed into JSON format and vice versa. The package 'dialog' defines the GUI project functions, including adding node, adding edge and executing simulation. The package 'example' defines the GUI project entry point, by which users can create network topological graph, save graph, load graph and execute simulation in a visualised way.

3.2.2 The implementation of Graph Visualisation Library

The implementation of Graph Visualisation Library is the core part of this project. It implements foundation classes for creating network topology, mainly including Graph, GraphView, Node, Edge, Coordinates and Bridge. GraphView is extended from JPanel, which is used to draw network topology. Graph is an abstraction of network topology which is composed of Node and Edge. Three types of nodes are defined, including HostNode, SwitchNode and VmNode, to represent host, switch and virtual machine respectively. Coordinates represents specific location for each node which is used to draw node into canvas. Bridge works as a connection between JSON file and visualised graph, by which graph entity can be transformed to JSON format and vice versa.

3.2.3 Implementation of Canvas Mode

Based on the design of the business layer presented in Section 3.1.4, the Canvas and Execution modes are implemented into the CloudSim SDN by Java Swing [27]. As shown in Figure 6, the two modes can be displayed under the View function.

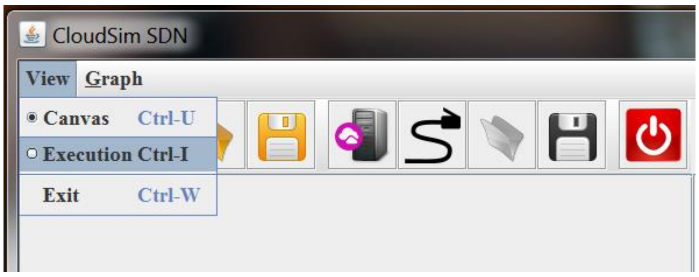


Figure 6. Canvas and Execution mode.

Canvas mode is developed to build network topology, by which user can add node, add edge, save and load network topology. The node represents SDN components, including server, virtual machine and switch, and the edge represents network connection. Figure 7 shows the toolbar of GUI under the Canvas mode. The first four buttons (Add Physical Node, Add Physical Edge, Save, and Load) of the toolbar are used for creating physical network topology. The next four buttons (Add Virtual Node, Add Virtual Edge, Save, and Load) of the toolbar are used for creating virtual network topology.

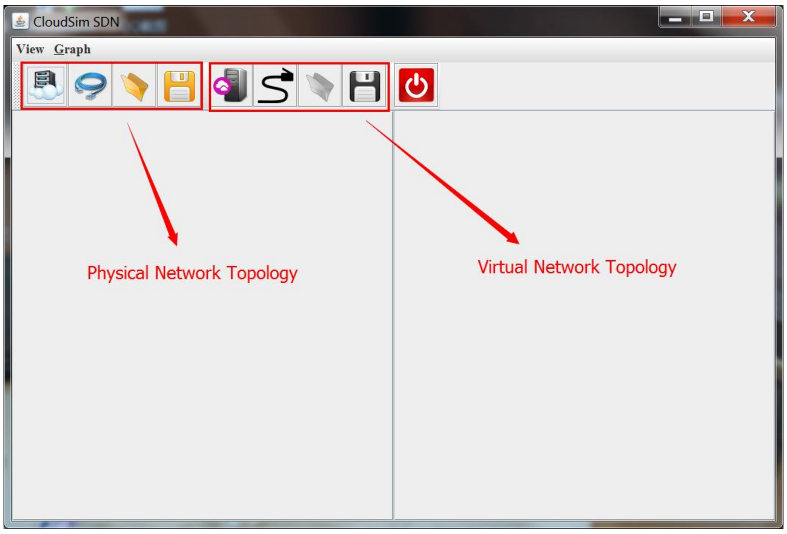


Figure 7. GUI toolbar.

Take creating a physical network topology as an example. The Add Physical Node button will open a dialog, as shown in Figure 8, by which users can add a new node into the network topology. The information in terms of the unique node name, bandwidth, input/output operations per second (IOPS), upports, downports, and node type are required to fill in the dialog. Specifically, the node type includes host (i.e. server host), edge and core (i.e. switch).

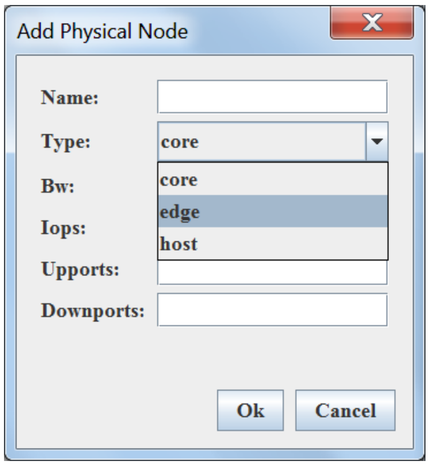


Figure 8. Add Physical Node dialog.

By clicking the Add Physical Edge button, a dialog will appear to allow users to add a new edge in the network topology, as shown in Figure 9. For example, two nodes 'switch2' and 'host2' is selected from the dropdown lists, and the latency of the edge between the two nodes is defined as 1.01. An Edge object will be created and saved in the Graph object. If there is no node, these two dropdown list will show empty.

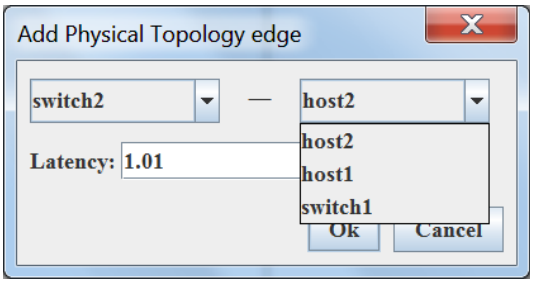


Figure 9. Add Physical Edge dialog.

Figure 10 shows the saving and loading of network topology by using the Save and Load buttons. To convert network topology object into JSON object or vice versa, a ‘bridge class’ is defined. The JSON object is then saved as JSON file.

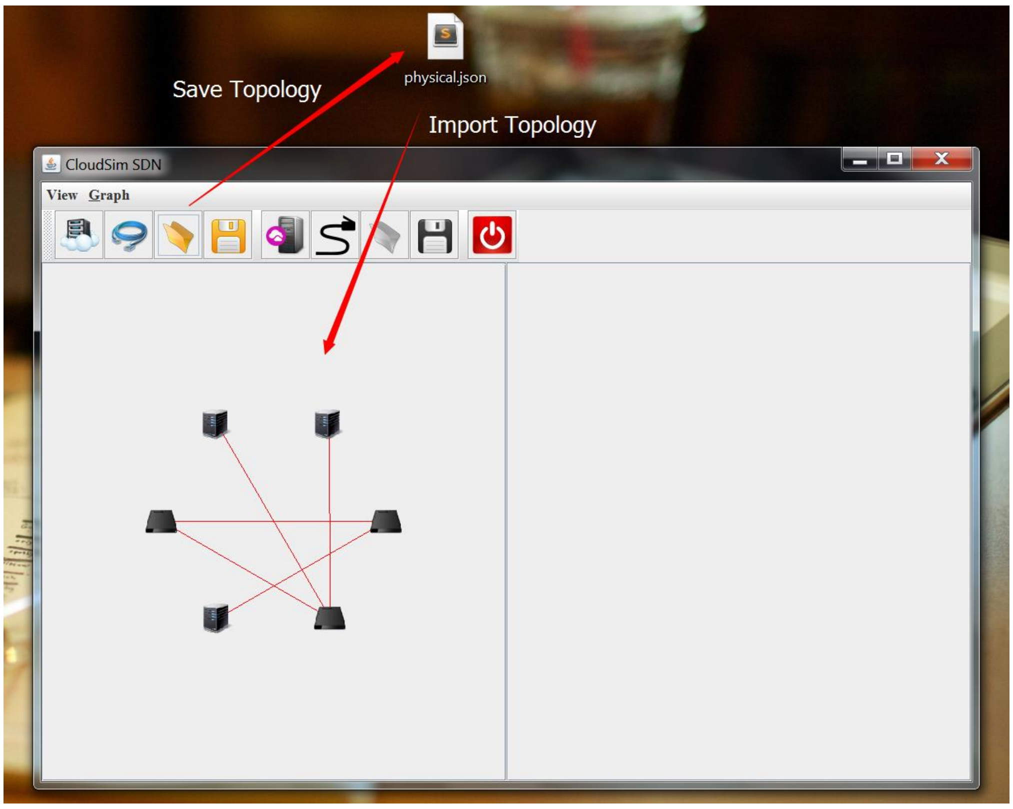


Figure 10. Saving and loading network topology.

3.2.4 Execution Mode

Execution mode is developed to visually execute SDN simulation. As SDN simulation is based on four configuration files, which are physical network topology, virtual network topology and two workload files. They are imported into GUI by Java chooser, which is shown in Figure 11. With Java chooser, users can choose configuration files dynamically instead of putting the files at fixed directory or changing the source code when the files are changed.

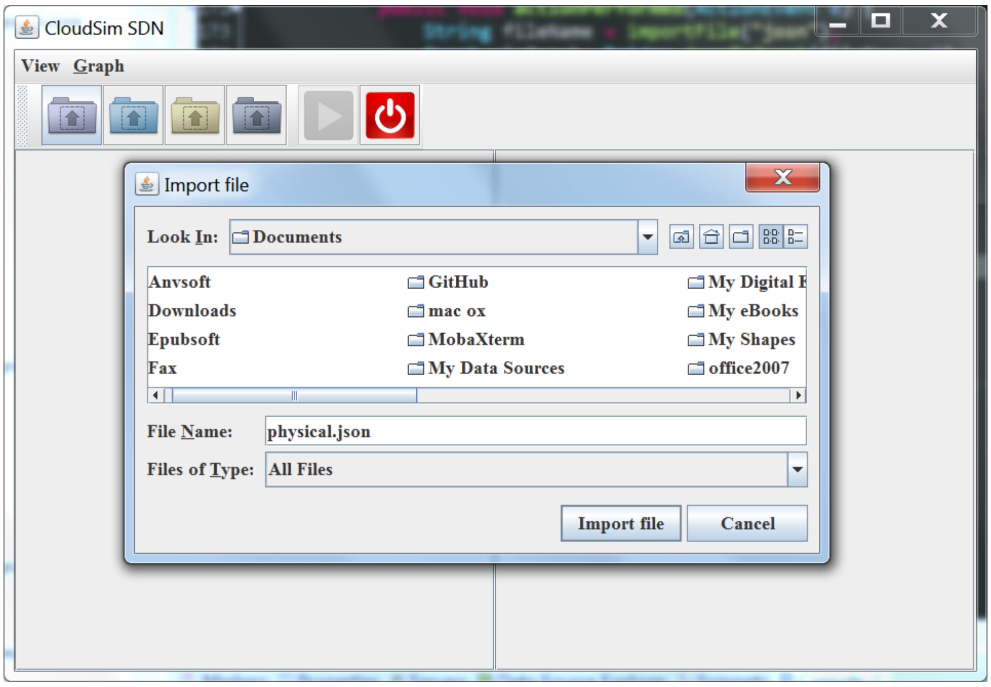


Figure 11. Configuration file selection.

If the configuration files are chosen correctly, the play button will be activated. If not, it will keep inactive to protect simulator from unexpected crash. The play button is used to start up SDN simulation by opening the 'Run Simulation' dialog, as shown in Figure 12. As the simulation may consume for a long time, a progress bar is applied to show the running process. Finally, the simulation result will be displayed in a text field, by which users can review the running details visually and conveniently, and do not need to check it in a console window.

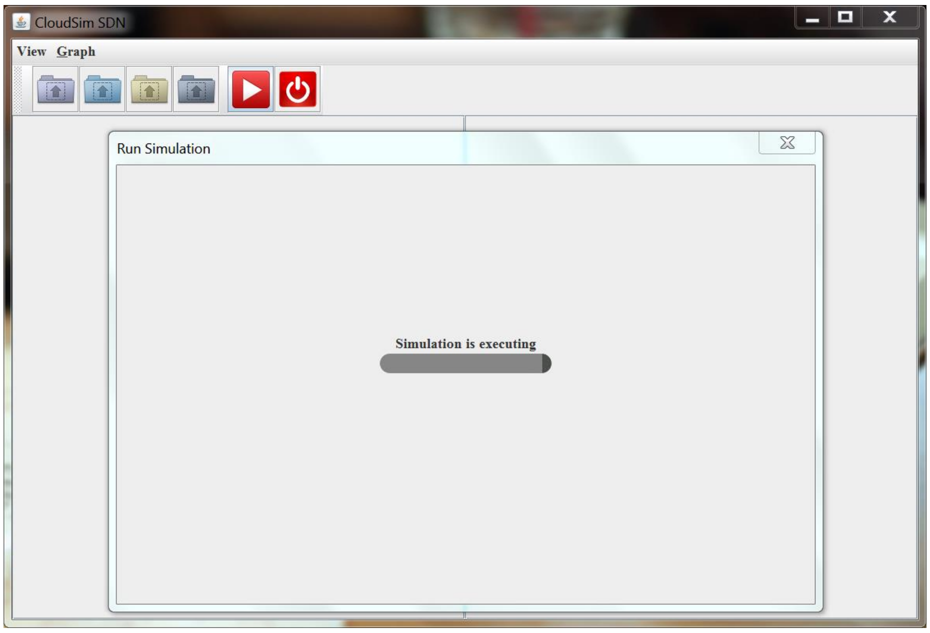


Figure 12. SDN simulation process.

In next section, a case study with real data will be carried out based on this GUI to check its availability and validity.

4 PERFORMANCE EVALUATION

In order to test the capability of the GUI developed for SDN simulation, an evaluation is designed with two case studies. The first case study will build network topological graphs, including physical network topology and virtual network topology by using the GUI. The results will be saved as independent JSON files. The second case will execute SDN simulation by using the network topologies that created in the first case.

4.1 Case study 1 - creating network topology

As SDN simulation is conducted based on network topology, the case 1 will first create a pair of executable physical and virtual network topologies. For physical network topology, three host nodes and three switch nodes are defined, and their attributes are shown in Table 1. For the virtual network topology, three virtual machines are defined, and their attributes are shown in Table 2.

Table 1. Attributes of physical network topology.

	NAME	TYPE	IOPS	UPPORTS	DOWNPORTS	BANDWIDTH
	core	core	1000000000	0	2	1000000000

Nodes	edge1	edge	1000000000		1	4	1000000000
	edge2	edge	1000000000		1	4	1000000000
	NAME	**TYPE**	**PES**	**MIPS**	**RAM**	**STORAGE**	**BANDWIDTH**
	host01	host	1	30000000	10240	10000000	200000000
	host02	host	1	30000000	10240	10000000	200000000
	host03	host	1	30000000	10240	10000000	200000000
Links	**SOURCE**			**DESTINATION**			**LATENCY**
	core			edge1			0.5
	core			edge2			0.5
	edge1			host01			0.5
	edge1			host02			0.5
	edge2			host03			0.5

Table 2. Attributes of virtual network topology.

Nodes	**NAME**	**TYPE**	**SIZE**	**PES**	**MIPS**	**RAM**
	vm01	vm	1000	1	30000000	512
	vm02	vm	1000	1	30000000	512
	vm03	vm	1000	1	30000000	512
Links	**NAME**	**SOURCE**		**DESTINATION**		**BANDWIDTH**
	132	vm03		vm02		66000000
	121	vm02		vm01		66000000
	default	vm01		vm02		
	default	vm02		vm01		
	default	vm02		vm03		
	default	vm03		vm02		

Based on Tables 2 and 3, the physical network topology (seen as the left part of Figure 13), and virtual network topology (seen as the right part of Figure 13) are created by using the functions of GUI. Finally, the two topologies are saved as two JSON files, as shown in Figures 14 and 15.

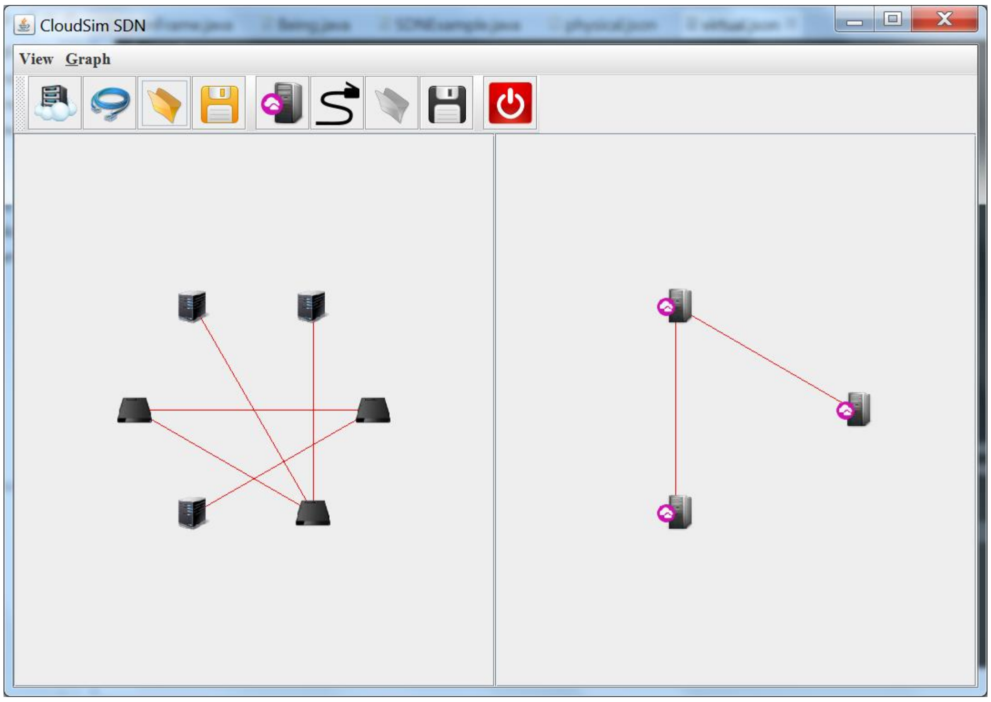
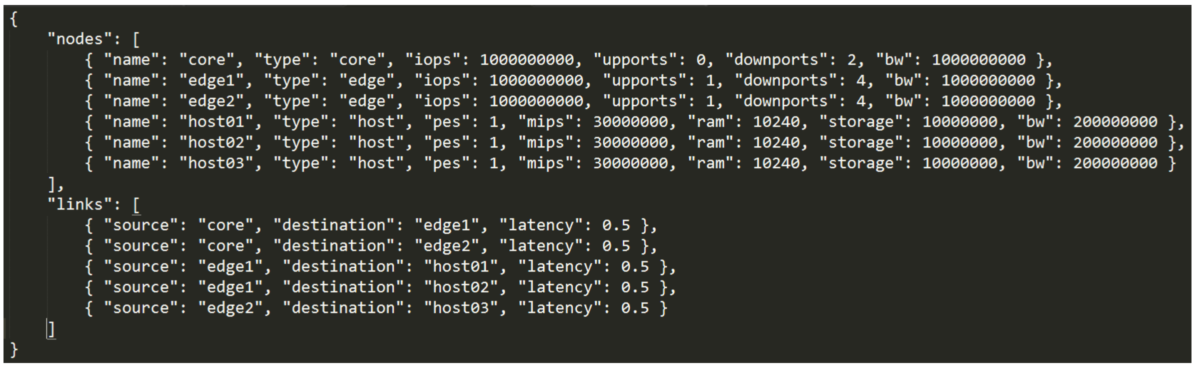
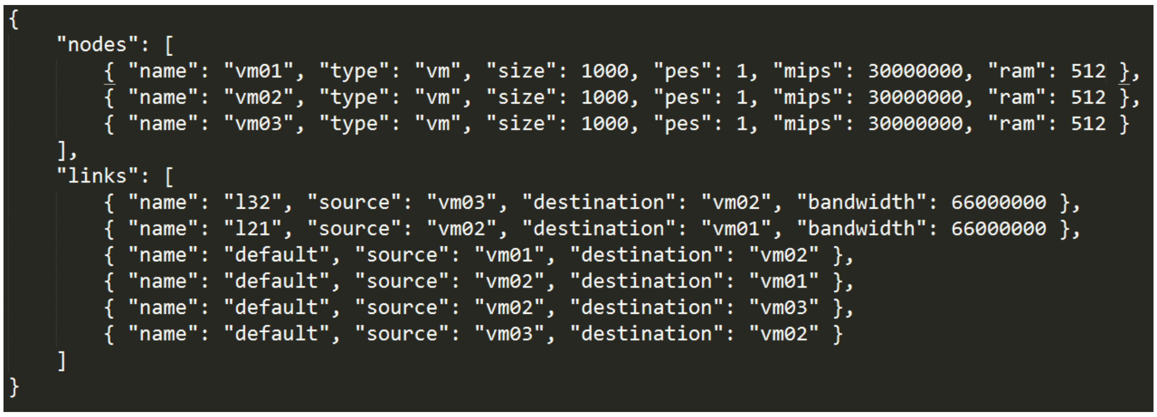


Figure 13. Creating network topologies.



```
{
    "nodes": [
        { "name": "core", "type": "core", "iops": 1000000000, "upports": 0, "downports": 2, "bw": 1000000000 },
        { "name": "edge1", "type": "edge", "iops": 1000000000, "upports": 1, "downports": 4, "bw": 1000000000 },
        { "name": "edge2", "type": "edge", "iops": 1000000000, "upports": 1, "downports": 4, "bw": 1000000000 },
        { "name": "host01", "type": "host", "pes": 1, "mips": 30000000, "ram": 10240, "storage": 10000000, "bw": 200000000 },
        { "name": "host02", "type": "host", "pes": 1, "mips": 30000000, "ram": 10240, "storage": 10000000, "bw": 200000000 },
        { "name": "host03", "type": "host", "pes": 1, "mips": 30000000, "ram": 10240, "storage": 10000000, "bw": 200000000 }
    ],
    "links": [
        { "source": "core", "destination": "edge1", "latency": 0.5 },
        { "source": "core", "destination": "edge2", "latency": 0.5 },
        { "source": "edge1", "destination": "host01", "latency": 0.5 },
        { "source": "edge1", "destination": "host02", "latency": 0.5 },
        { "source": "edge2", "destination": "host03", "latency": 0.5 }
    ]
}
```

Figure 14. Physical network topology file.



```
{
    "nodes": [
        { "name": "vm01", "type": "vm", "size": 1000, "pes": 1, "mips": 30000000, "ram": 512 },
        { "name": "vm02", "type": "vm", "size": 1000, "pes": 1, "mips": 30000000, "ram": 512 },
        { "name": "vm03", "type": "vm", "size": 1000, "pes": 1, "mips": 30000000, "ram": 512 }
    ],
    "links": [
        { "name": "l32", "source": "vm03", "destination": "vm02", "bandwidth": 66000000 },
        { "name": "l21", "source": "vm02", "destination": "vm01", "bandwidth": 66000000 },
        { "name": "default", "source": "vm01", "destination": "vm02" },
        { "name": "default", "source": "vm02", "destination": "vm01" },
        { "name": "default", "source": "vm02", "destination": "vm03" },
        { "name": "default", "source": "vm03", "destination": "vm02" }
    ]
}
```

Figure 15. Virtual network topology file.

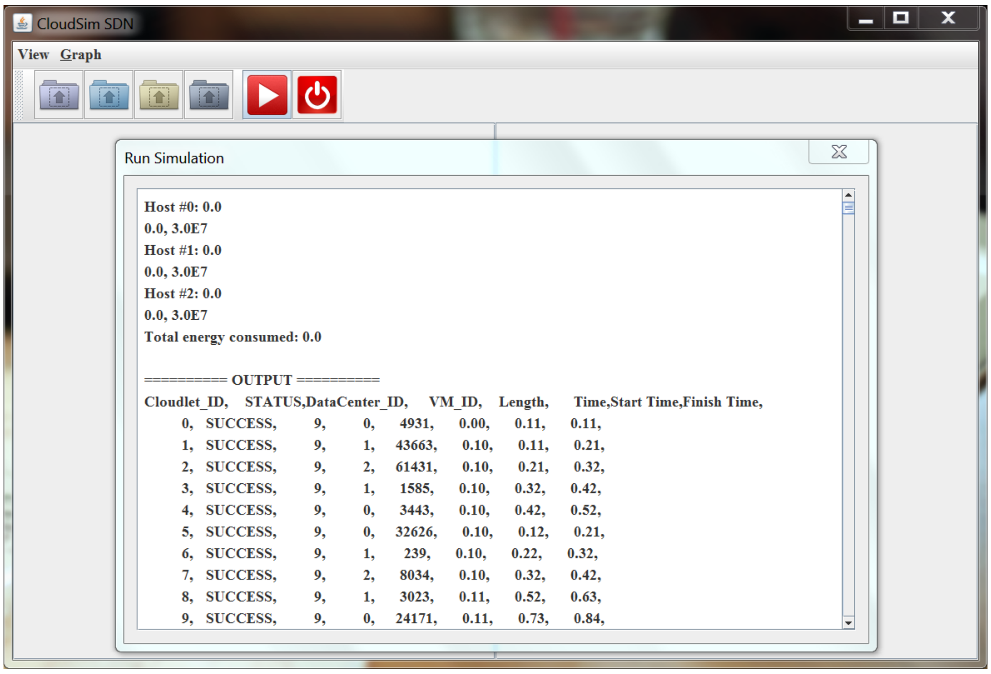
4.2 Case study 2 - Executing SDN Simulation

To start up SDN simulation, four configuration files are loaded as shown in Table 3. The first two JSON files are defined by the first case. The two CVS files are given by default, which represent the workloads of this case.

Table 3. Configuration files.

File Name	Description	Format
physical.json	Physical network topology file	JSON
virtual.json	Deployment file (virtual network topology)	JSON
workload_10sec_100.csv	Workload background file	CVS
workload_10sec_100_default.csv	Workload file	CVS

The play button will be activated after the configuration files are loaded correctly. The running time depends on the complexity of the network topology and workloads. If the simulation completes correctly, the simulation result will be displayed as shown in Figure 16.



```
Host #0: 0.0
0.0, 3.0E7
Host #1: 0.0
0.0, 3.0E7
Host #2: 0.0
0.0, 3.0E7
Total energy consumed: 0.0

========== OUTPUT ==========
Cloudlet_ID,   STATUS,DataCenter_ID,   VM_ID,   Length,    Time,Start Time,Finish Time,
       0,  SUCCESS,      9,      0,    4931,   0.00,   0.11,   0.11,
       1,  SUCCESS,      9,      1,   43663,   0.10,   0.11,   0.21,
       2,  SUCCESS,      9,      2,   61431,   0.10,   0.21,   0.32,
       3,  SUCCESS,      9,      1,    1585,   0.10,   0.32,   0.42,
       4,  SUCCESS,      9,      0,    3443,   0.10,   0.42,   0.52,
       5,  SUCCESS,      9,      0,   32626,   0.10,   0.12,   0.21,
       6,  SUCCESS,      9,      1,     239,   0.10,   0.22,   0.32,
       7,  SUCCESS,      9,      2,    8034,   0.10,   0.32,   0.42,
       8,  SUCCESS,      9,      1,    3023,   0.11,   0.52,   0.63,
       9,  SUCCESS,      9,      0,   24171,   0.11,   0.73,   0.84,
```

Figure 16. The simulation result.

5 Conclusion and Future Directions

This project developed a GUI for SDN simulation under cloud environments. The GUI is based on CloudSim framework with SDN features integrated. It is developed by using Java

Swing, and implemented with an SDN-specific graph visualization library. This library provides foundational components for drawing and managing network topological graph, including node, edge, bridge, graph and graphview. The GUI provides two modes for supporting SDN simulation, which are Canvas Mode and Execution Mode. The Canvas Mode is used to manage network topology and the Execution Mode is used to execute SDN simulation.

This project addressed two important aspects: GUI design and implementation. For the GUI design, the high-level structures and style of the GUI is defined as the GUI architecture. The architecture includes three layers, including framework layer, business layer and interface layer, are elaborated by using UML class diagram and sequence diagram. For the GUI implementation, the project presented the main components of GUI, including project IDE, Graph Visualisation Library, Canvas Mode, and Execution Mode. Instead of importing a third-party library, a SDN-specific graph visualisation library is developed, which is extensible for integrating more SDN features. The design and implementation of the GUI under cloud environment that can visualise SDN simulation contributes to the development of the CloudSim framework. It will facilitate the integration of the SDN features with the cloud-based networking management.

For future works, researchers and practitioners may consider address the following unsolved issues. The first issue is the operability of GUI may be improved by implementing a toolbox, such as Microsoft Visual Studio IDE. Such a toolbox will simplify the network topology management significantly by using only the drag and drop functions. Thus the interface complexity of using dialogs will be largely reduced. Another issue is to visualise the whole SDN simulation process. In this way, all the changes and movements of components in CloudSim can be monitored, and more ideally the simulation can also be paused or resumed at specific state.

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