Exploring Network Traffic Generation in a Simulation Environment

by

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B.Tech(IT), Amity University, Rajasthan, 2013

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ABSTRACT

Simulations have become a very effective approach for visualizing how data transfer takes place in a network. But simulating network traffic in iCanCloud is a challenging process for students trying to learn how protocols work. This project proposes an environment combining an implementation of TCP/IP using INET and iCanCloud on top of OMNeT++ to simulate network traffic. Documenting the design of all the created simulations provide rationale as to how network traffic is generated. Furthermore, this project shows how promising the proposed environment is for analyzing network traffic. Evaluating and analyzing the created simulations provides potential ideas for extending the proposed environment as a platform for learning in the future.

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ACKNOWLEDGEMENTS

I would like to thank:

My Family, especially my parents for their unconditional love and support.

Dr. Yvonne Coady, for mentoring, support, encouragement, and patience.

And anybody else, who helped me in this long and unforgetable journey.

Nishant Khanna

DEDICATION

I dedicate this project to my parents who have always supported and encouraged me.

Chapter 1

Introduction

Creating and exploring network traffic generation in any kind of simulation involves several steps, for example:

- Selecting a suitable environment for creating the simulations.
- Understanding what needs to be implemented in that simulation environment to simulate network traffic.
- Evaluating the created simulations.
- Analysis of the traffic generated from the simulation.

This project proposes a simulation environment that can be used to simulate network traffic in OMNeT++ using TCP/IP and iCanCloud and provide sample assignments that can be solved by someone not familiar with the tool using the proposed simulation environment and the project documentation. To explore the network traffic being generated, chapter's 3, 4 and 5 show the design and execution of the simulations created in this project. Based on the scope of simulations that were created, OMNeT++ was chosen as a suitable environment. An explanation of this decision is given in chapter's 2 and 3.

1.1 Structure of the report

This section gives the structure of the entire report, along with a summary of the content of each chapter:

Chapter 2 explains the related work for the technologies used in this project.

Chapter 3 briefly explains the functionality of all the components used in designing the simulations.

Chapter 4 describes the design process of all the simulations.

Chapter 5 describes the working, evaluation and analysis of all the simulations and the limitations of this project. Also some sample assignments to show how this project can be used in different cases.

Chapter 6 identifies possible future work and concludes the project.

Chapter 2

Related Work

This chapter begins with explaining OMNeT++, along with some of the other available simulation frameworks that are available for research and commercial purposes. I identify the advantage of using OMNeT++ over the other frameworks. Next, there is a description of iCanCloud and some of the important components used in iCanCloud while comparing it with some other cloud computing frameworks. Then, there is a description about TCP/IP, why is it preferred over other protocols and how it is implemented in OMNeT++. Finally, a brief description of what is cloud computing, and the importance of having TCP/IP implemented in a cloud computing environment.

2.1 Simulation Platforms

2.1.1 OMNeT++

OMNeT++ is a software used for modeling network based simulations using C++ as its coding language. As mentioned by Varga and Hornig in [24], OMNeT++ has been available since 1997. One of the biggest advantages of the software is that it is open source, so it can be used freely without the requirement of purchasing a license. In [22] Varga has briefly explained the structure of OMNeT++ and the different components used to model and run a simulation like the OMNeT++ model structure, NED language design, Graphical editor used in OMNeT++, design and contents of the simulation library, the internal architecture of OMNeT++.

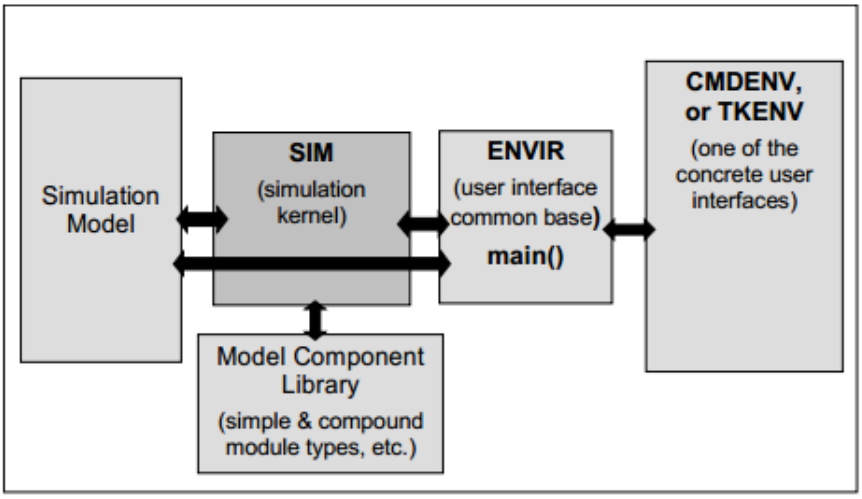


Figure 2.1: Internal Architecture of an OMNeT++ Simulation Program [22].

2.1.2 NS-2

One other framework used widely for both academic and research purposes is the NS-2 as described by Bajaj, Sandeep et. al in [6]. NS-2 is very different in its architecture from OMNeT++ where there is a clear separation between the simulation kernel and the model whereas in NS-2 there is no clear separation and the main goal of the NS-2 framework is to build a network simulator instead of providing a platform for modelling and running simulations as provided by OMNeT++. This is one important reason for choosing OMNeT++ over NS-2 as one of the main goals of this project was to see actual network traffic and to visualize how the packets are being transferred between nodes in iCanCloud using TCP/IP. Both TCP/IP and iCanCloud are explained further in this chapter.

2.1.3 OPNET

Another framework described by OPNET Technologies Inc. in [15], is the OPNET Modeler which is available to universities worldwide if they qualify to use the product and is available freely to be used for academic and research purposes. Even though OPNETs architecture is very similar to that of OMNeT++, there are some features of OPNET that are not user-friendly such as, the topologies of the models provided by OPNET are fixed which means they cannot be modeled or re-designed as

in OMNeT++. Also, because of its protected nature, OPNET does not provide any simulation source code which makes it very difficult to perform any kind of debugging at the simulation level which is not the case in OMNeT++.

2.2 Cloud Simulation Platforms

2.2.1 iCanCloud

iCanCloud is a simulator built on top of OMNeT++, capable of modeling and running cloud computing environments. As mentioned by Nez et. al. in [16] there are some features in iCanCloud that make it a suitable platform for simulating cloud computing infrastructures. One very important feature is a flexible hypervisor module provided with each node component which helps in assigning and linking the four important interfaces: the OS Module, Storage Module, CPU Module and the Network Module. Each of these interfaces is responsible for assigning the essential components for a node and are linked to the network layer through the hypervisor. A further detailed explanation of the hypervisor and these interfaces is given in the next chapter. Another important feature is the way a Virtual Machine (VM) can be customised in different specifications according to the needs of the user i.e. a VM can have just a single core which can be assigned to perform a single process or a single VM can have multiple cores with each core responsible for performing a different task.

2.2.2 CloudSim

Another application which can be used for a purpose similar to that of iCanCloud is CloudSim. As described by Calheiros, Rodrigo N., et al. in [8], CloudSim is a simulation toolkit and application which helps in modeling and simulating cloud computing systems. But, one disadvantage with CloudSim which makes it unsuitable for this project is that, in CloudSim a ready to use environment is not provided and it is not a framework. This means that the cloud scenarios need to be developed manually by the users, whereas in iCanCloud a ready to use environment is provided where the simulations can be modelled according to the users needs.

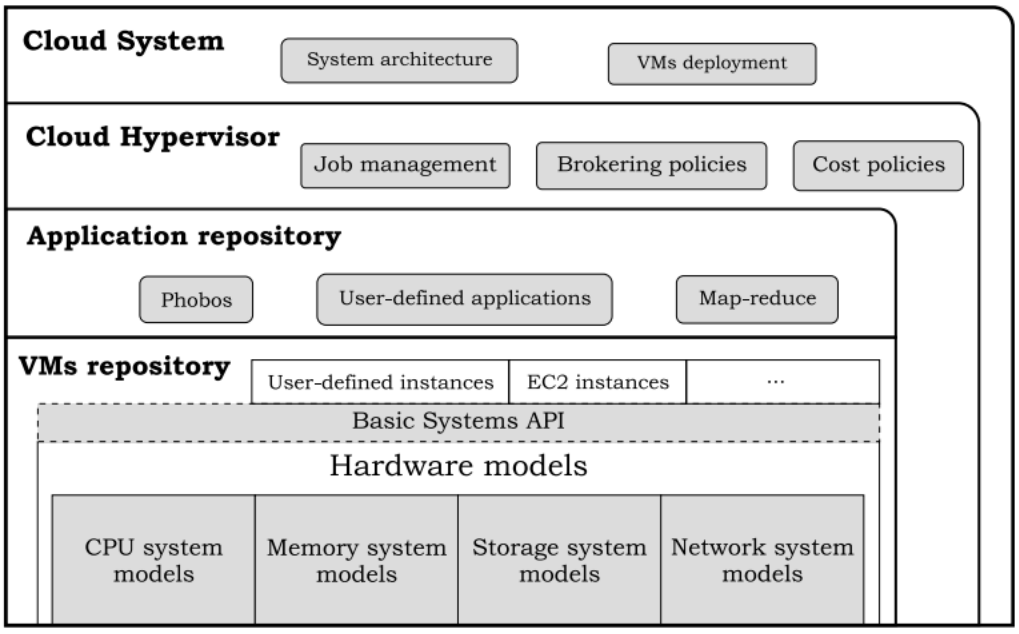


Figure 2.2: Internal structure of iCanCloud [16].

2.2.3 TechCloud

One more application used for the same purpose as iCanCloud but with a more specific focus on educational purposes is TechCloud. As mentioned by Jararweh, Yaser, et al. in [12], TechCloud is build upon CloudSim, with some additional features like allowing the cloud systems to be reconfigured thereby studying the different impact this may have on the performance of the system. But, one limitation in TechCloud is its inability to support TCP/IP which makes TechCloud unsuitable for this project.

2.3 TCP/IP in OMNeT++

TCP/IP short for Transmission Control Protocol / Internet Protocol presently is one of the most widely used network protocols. As described in its first version of the RFC 793 in [18], TCP/IP has some features important for this project like, three-way handshaking in which the sending and the receiving nodes both send a request to establish a connection between them and only after receiving an acknowledgement that a connection has been established will the packet or data transmission between the nodes start there by making TCP a much more reliable means of data transmission as suppose to UDP (User DataGram Protocol) where there is no such feature like

three-way handshaking so data transmission can take place but there will be no acknowledgement either to the sender or the receiver whether the packets are being sent or whether the other node has received the sent packet successfully. Due to this reliable means of data transmission, TCP is a much more reliable and a dependable protocol as compared to UDP.

There are models for simulating TCP and UDP in INET which is build on of OMNeT++ . But, using the TCP protocol will be suitable for this project. As it can be seen from the Figure 2.3 and described in [10], the TCP model included in OMNeT++ has been set up in a way where it contains several modules within one top TCP model. Each of these modules is responsible for performing a specific task which is described in great detail by VARGA, Andras in [23].

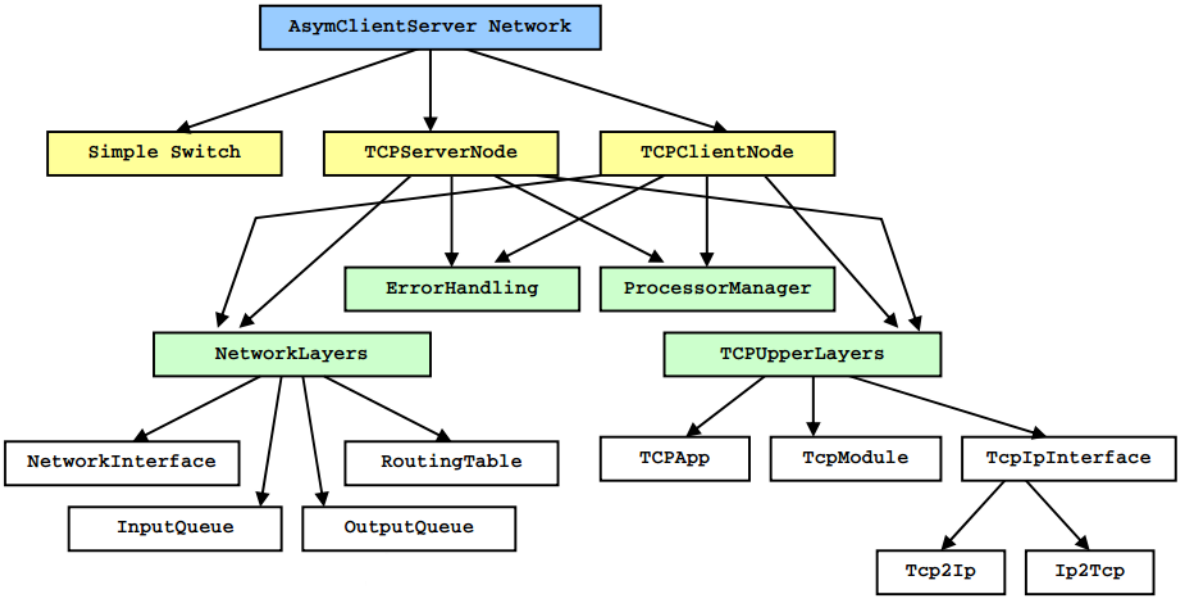


Figure 2.3: TCP model in OMNeT++ [10].

Some of the modules mentioned in Figure 2.3 like Network Layers and its components (NetworkInterface, InputQueue, OutputQueue and RoutingTable) and the TCPApp are important for this project are described in detail in the next chapter. TCP is part of the INET framework which is a part of OMNeT++, just like how iCanCloud is also a framework part of OMNeT++.

2.4 Cloud Computing

Cloud Computing, is one of the hottest topics in the industry. As mentioned in [9], cloud computing became a reality in October 2007 when Google and IBM decided to collaborate in this technology. There are a number of key characteristics of cloud computing like device and location independence, high reliability, high scalability, sustainability, and security.

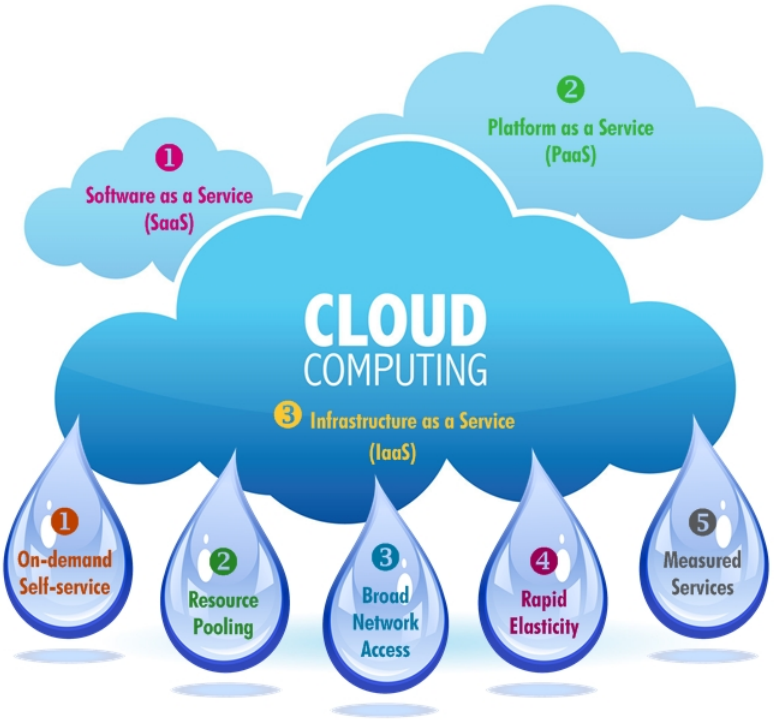


Figure 2.4: Cloud computing architecture [1].

As seen in Figure 2.4, with so many devices that can be connected with each other in a cloud computing environment, so having security is of utmost importance thereby having a reliable connection with all the connected devices is important, this is one of the biggest reasons for having TCP/IP implemented in a cloud computing environment is important, which is what is described in this project in the later chapters.

2.5 Summary

This chapter gave a brief description of the technologies used for this project along with giving some advantages of using these technologies over others and provides rationale as to why they were used. The next chapter will give a brief description of all the components used in the simulations designed in this project.

Chapter 3

Simulation Components

This chapter describes all the components that were used in designing the simulations in this project. This chapter is divided into three different sections. First, a description of all the components in the main simulation using iCanCloud created in the project is given. Then, a description of the components within a NodeVL is given. Finally, the components within a router are described.

3.1 Components of the iCanCloud simulation

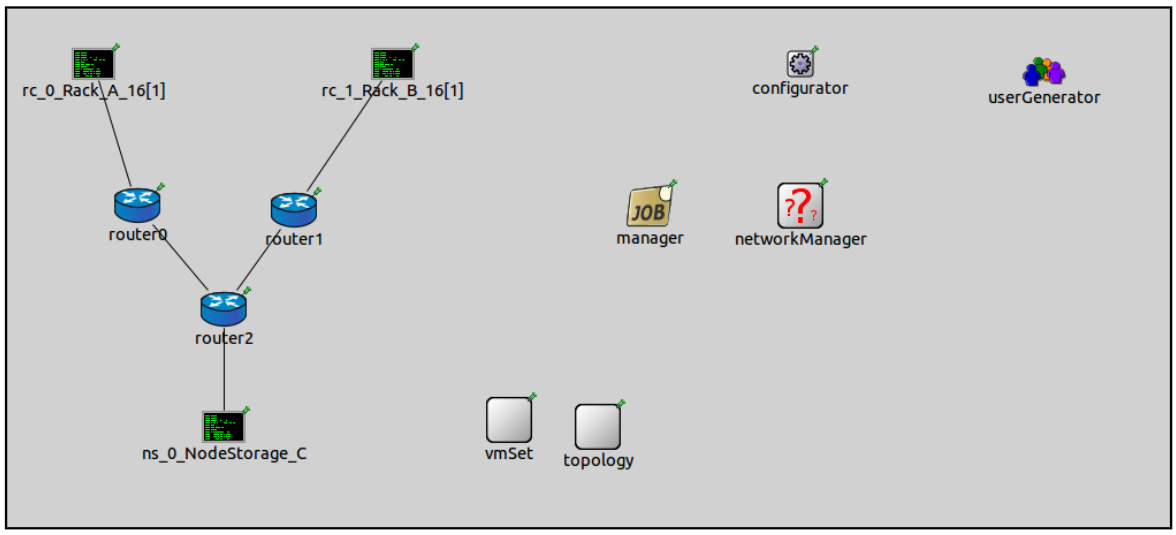
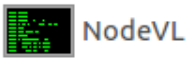
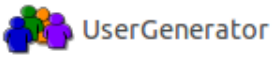


Figure 3.1: iCanCloud simulation.



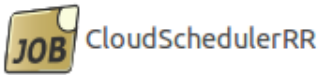
Is used for communication within the network in iCanCloud. It is different from the typical Standard host node used in the INeT framework, i.e. A Standard Host has an architecture very similar to that of a router which is explained in section 3.3, whereas in the NodeVL all the components like the Memory, Storage, Operating System and the CPU are all embedded within the node itself. All these components are linked to the hypervisor responsible for linking the four components of the NodeVL with the network layer.

As described in [23] the Router used in the simulations is the IPv4 router which supports wireless, Ethernet, PPP(Point-to-point Protocol) and external interfaces. It can be connected to other nodes using the pppg or the eth gate. For it to support a different routing protocol like OSPF(Open Shortest Path First Protocol), RIP(Routing Information Protocol) or BGP(Border Gateway Protocol) the hasOSPF/hasRIP/hasBGP parameters can be set to add any of these protocols to the router.



By the name, it suggests that this node should be responsible for generating users, in a way it does generate users but in a different way. It defines a cell which consists of four groups which together constitute a single user, i.e.

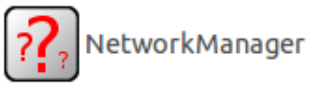
- Number of virtual machines that a user requires is given by the VmDefinition parameter.
- Type of distribution that has to be defined by the user is given by the DistributionDefinition parameter.
- Definition of the set of applications that a user will launch is given by the AppDefinition parameter.
- Module interface used to create the users is given by the IUserGenarator parameter.



Responsible for managing the different jobs created to be handled using the scheduling technique defined in the initialization file. By default, there are three types of scheduling techniques defined in iCanCloud i.e.

- First-Come-First-Serve scheduling (FCFS).
- Priority scheduling.
- Round Robin scheduling.

For the simulation in Figure 3.1 the FCFS (First-Come-First-Serve) type of scheduling was chosen to manage different jobs by the Job Manager.



As described in [23] the Network Manager is responsible for managing the network as its name suggests. It manages all the Physical IPs allocated to all the nodes in the network. It also assigns Virtual IPs to all the Virtual Machines (VMs) assigned to each physical node in the given network.

Consists of two submodules, each containing one parameter,

- The first submodule consists the number of computing nodes in the network.
- The other submodule consists the number of storage nodes in the network.

Is a vector that points to the VmImage node in the simulation. The Virtual Machine Image (VMImage) is defined in iCanCloud as a Virtual Machine i.e. a machine without any physical resources. The physical resources for this machine are managed by the hypervisor and the virtual machine is linked to the hypervisor for performing tasking using the physical resources. There are four main parameters that define a virtual machine in the simulation:

- Identification: Represents a string which gives each virtual machine a unique id thereby giving a way to uniquely identify the virtual machine.
- NumCores: Defines the total number of cores that will be assigned to the specific virtual machine.
- MemorySizeMB: Defines the memory size in Megabytes (MB) to a particular virtual machine will be assigned.
- StorageSizeGB: Defines the total storage in Gigabytes (GB) to a particular virtual machine will be assigned.


IPv4NetworkConfigurator As described in [23] the Network Configurator is responsible for assigning IP addresses and setting up a static routing type interface for an IPv4 network. It assigns each interface in the network with a unique IP address, but at the same time, it takes into account the subnet of each of the interfaces to which an IP address is being assigned. The configurator also has the capacity to optimize the routing tables generated for the network by merging specific routing entries in the routing table. The Configurator is capable of assigning addresses in a network both manually or automatically, i.e. The user can provide the address and the netmask templates with some parts that are unspecified and the configurator will automatically complete them by putting the nodes on the same LAN belonging to the same subnet. Another feature of the configurator is that it supports both manual and automatic routes for the nodes in a way that the assigned route will be designed to follow the shortest path possible. For the configurator to recognize a network node i.e. a host, bus, switch, router, etc., each of them needs to have the *@node* property which allows the configurator to recognize the nodes in the network.

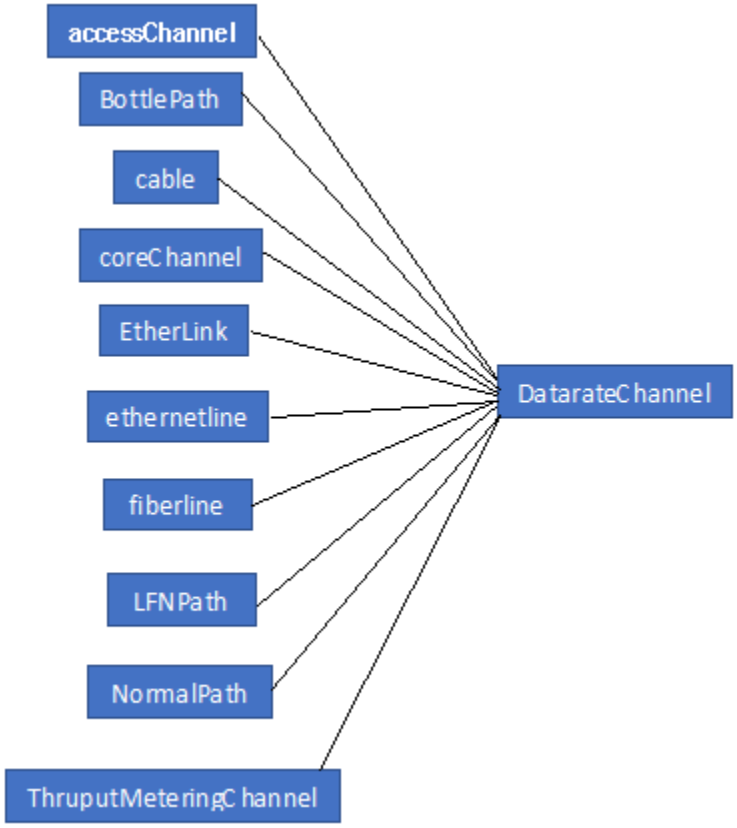


Figure 3.2: Data Rate Channel Architecture [23].

Data Rate Channel: A channel in iCanCloud is used to add certain metrics that can be calculated and be recorded in the results section of the simulation. Like by using the Data rate channel as given in [23] metrics like, throughput of the network, utilization of the channel between the nodes, how busy each channel is when the simulation is running, how many packets are discarded by the channel when the simulation is running, the amount of memory in bytes of the packets that are being forwarded through the channel and the total number of packets being transferred over the channel in the entire simulation.

3.2 Components within a NodeVL

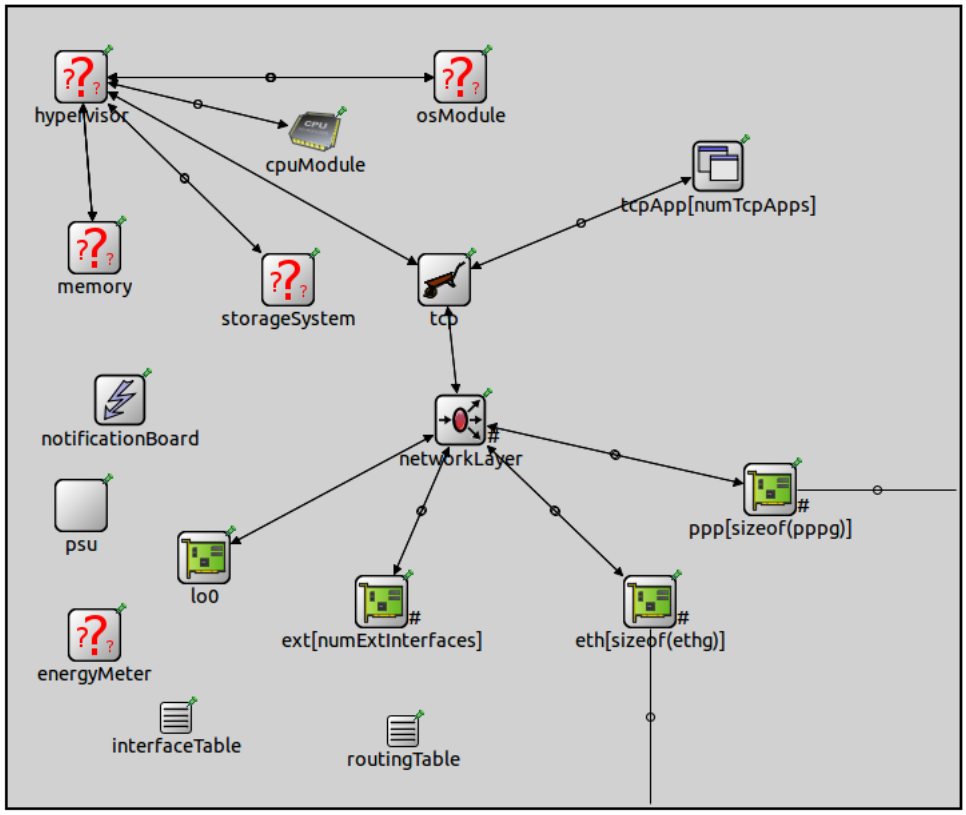


Figure 3.3: Design of the architecture inside a NodeVL.

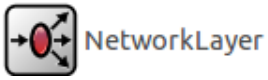
Used as an interface to implement the TCP protocol. This is the central node which is responsible for setting up the connections and linking the hypervisor, the network layer, and the tcpApp.

Responsible for linking each virtual machine to an instance of the physical resource like, CPU, Memory, Network, and Storage. All these resources are linked to the hypervisor with the help of controllers for each resource. There are a number of metrics that need to be specified in the hypervisor module:

- numStorageServers: Number of physical storage servers that will be needed by the virtual machines based on their storage needs.

- numCPUs: Number of physical CPUs that will be needed by the virtual machines for their computing needs.
- memorySizeMB: Amount of physical memory needed in Megabytes (MB), which will be based on the type of data or amount of data which will be processed by the virtual machines.
- blockSizeKB: Size of the physical blocks in Kilobytes (KB) which denotes the size of each block that will be processed by the virtual machine.
- storageSizeGB: Amount of physical storage space in Gigabytes (GB) that the virtual machines need for storing any kind of data.
- numNetworkInterfaces: Number of physical network interfaces that the hypervisor might be linked to based on the needs of the virtual machine.
- IP: Defines the IP address of the physical node.
- storageAppModuleIndex: Index of the storage module that is linked to the hypervisor.
- connectionTimeOut: Time limit from when a message has been sent by the hypervisor until the time when the hypervisor gets back the response.
- networkServiceType: Type of network service that is being used by the hypervisor. In our case the network service being used is TCP.

Acts as a template for the TCP application that will be used by the network. It displays the type of gates that will be needed by the TCP application so that TCP can be used in the network for communication between the various nodes. In our case, the type of applications used is the TCPSessionApp and the TCPEchoApp, for which only the tcpIn and the tcpOut gates are needed by the application. The SessionApp is used for creating a connection(session) between the nodes, where after the connection is open the application sends the given number of bytes and then closes the connection. The EchoApp is used to receive the data packets that arrive through a TCP connection. Other applications available are the TCPGenericsSrvApp and the TCPBasicClientApp.



Links different interfaces based on the link layer that can be utilized by the node in the simulation. There are four different interfaces that can be applied in our simulation, i.e.:

- lo0 (Loopback Interface) [3]: Can be utilized to identify the device in the network, i.e. the loopback address can be used to check whether a particular device is online on the network as the loopback address remains constant and does not change.

- ext (External Interface) [13]: Relates to a real interface on the host node that is running the simulation. This type of interface is very useful for hardware-in-the-loop simulations. Hardware-in-the-loop simulations is a technique that is used in the development and in the testing purpose for real-time embedded systems.

- eth (Ethernet Interface) [4]: Node that acts as a prototype for the link layer protocol dealing with the ethernet interface. This is the type of interface that allows a physical device like a computer or a mobile device or in our case a node in the simulation with the other nodes in the network using ethernet as the transmission medium. In iCanCloud an ethernet interface is used with the notation(ethg) and is used to connect different nodes with each other through a channel.

- ppp (Point-to-point Interface) [20]: Implements the point-to-point protocol in the network. PPP is the type of protocol that gives strong emphasis on the configuration of the links in the network and their maintenance. In the routers, this model relies on the queue model to request for packets from the queue and forward them one-by-one. Similarly, in the nodes, there is no such queue present so the ppp model creates its own queue(txQueue) and aligns the packets in this queue where the packets will be waiting for transmission. In iCanCloud a point-to-point interface is used with the notation(pppg) and is used to connect different nodes with each other through a channel.

In the simulation, either the ethg(Ethernet Interface) or the pppg(point-to-point Interface) can be used to connect different nodes with each other.

Stores the routing table of the network. The routing table basically consists information regarding the routes to specific network destinations. The routing table also consists information regarding the topology of the network present around it, like in the given simulation the routing table consists information like,

- routerID: Is left empty if the node is a computing or a storage node. If the node is a router then the router ID will already be set.
- IPForward: Is used to set IPforwarding feature for a node which determines the route that will be taken to send a packet to another node in the network. By default, this parameter is set to true.
- forwardMulticast: Is used to set multicast forwarding feature for a node which determines whether a packet will be sent to multiple destinations in a single transaction. By default, this parameter is set to false.
- routingFile: Consists the name of the file that contains the routing table for a particular node. By default this parameter is empty.

Is responsible for containing information regarding the network interfaces that have been registered for a particular node in the network. This table only contains protocol-independent properties of interfaces, i.e. routing capabilities and features that are not specific to a particular routing protocol, like a static route can be defined using a protocol-independent property and then this static route can be redistributed in the network using a routing protocol. This node has only one parameter used in the simulation i.e.:

- displayAddress: This parameter is used to ask the user whether the IP addresses should be displayed on the links in the network. By default, this parameter is set to true.

Notifies all the other nodes in the network regarding any changes like,

- Changes or updates made in the routing table of one node.
- Interface status changes in the interface table.
- Changes made in the state of the wireless channel.
- Wireless handovers being made in the network.
- The position change of a mobile node.

These are the changes that can take place in a network over time, and so to keep track of all these changes and notifying other nodes of these changes the notificationBoard is used in all the computing or the storage nodes present in the network.

Consists of parameters for all the controllers that are linked to the hypervisor for measuring the energy being utilized by each of those controllers in the simulation. The parameters defined in the node are:

- cpuMeterType: Representing the cpuModule controller.
- memoryMeterType: Representing the memory controller.
- storageMeterType: Representing the storageSystem controller.
- networkMeterType: Representing the osModule controller.

Is the power supply unit used by a specific node while running in the simulation. It has two parameters,

- Wattage: This is the power output in watts for the node.
- Scale: This is the time it takes to recalculate the energy lost by the power supply unit (psu) after the simulation is complete.

3.3 Components within a router

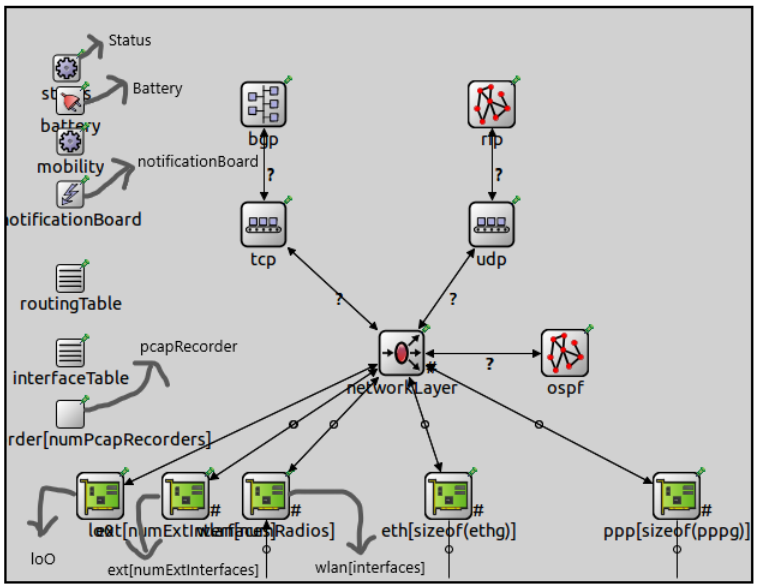


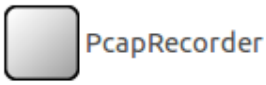
Figure 3.4: Internal Architecture within a router.

There are a number of important components present in the router which are similar to the components present within a NodeVL, like:

- A router has a routing table, interface table, and a notification board node. All these nodes perform the same functions inside a router as they do for a NodeVL.
- There is also a network layer present in the router which performs all the functions similar to the network layer present in the NodeVL, but along with those features the network layer has some additional features that it performs only in the router and not in the NodeVL, i.e.:
  - Along with the four interfaces present in the network layer of the NodeVL i.e., lo0 (loopback Interface), ext (external Interface), eth (ethernet Interface) and the ppp (point-to-point Interface), there is a fifth interface that can be used by the router which is the WLAN (wireless Interface) which can be used for using the router to connect to different devices in a wireless computer network rather than a wired network.
  - The network layer in the router also has an option to implement different protocols in the simulation, like:

* TCP (Transmission Control Protocol) [18]: Is the most popular protocol among the internet protocol suite. TCP is responsible for providing a reliable, ordered and an error-checked system for delivering packets among nodes communicating with each other over an IP network.
* UDP (User Datagram Protocol) [17]: Is one of the core members of the internet protocol suite. In this protocol communication between nodes over a network takes place in a way similar to the TCP protocol, but the only difference in UDP is that there needs to be no prior communication between the nodes before packets are sent between them which is why UDP is not considered a secure means to communicate over a network as compared to TCP.
* BGP (Border Gateway Protocol) [19]: Is used to make routing decisions based on the paths and the network policies that have been configured by the network administrator. As a result of the functions that this protocol is responsible for it is sometimes called as the path vector protocol and sometimes it is called as a distance-vector routing protocol.
* RIP (Routing Information Protocol) [7]: Is one of the oldest distance-vector routing protocols making use of the hop count strategy for applying any kind of routing in the network. The maximum allowed hop counts in this protocol are 15 which is one of the reasons why this protocol is not very popular now as it limits the size of a network that the protocol can support.
* OSPF (Open Shortest Path First) [14]: Is an interior gateway protocol responsible for transmitting packets within a single routing domain. It detects changes in the topology, links failures and constructs a new routing structure within seconds. This protocol does not use TCP or UDP for transmitting packets, so it is not a very secure means of communication in a network.

Based on the requirement of the simulation any of these five protocols can be used and implemented. In our case TCP protocol has been implemented in the simulation.



As mentioned in [11] the Pcap recorder is responsible for

capturing the pcap (packet capturing) traces for the frames of packets that have been sent or received by the other modules or components present in the same node, i.e. a NodeVL or a Router. This node also has the capability to print a tcpdump like information in the form of a log file. Tcpdump is basically a file containing the TCP/IP information regarding the packets being sent or received within the network.

Is used for as the name suggests mobility model as explained in [21], i.e. models that represent the movement of mobile users and their location, velocity or acceleration can change over a certain time frame. This node consists of a single parameter:

- mobilityStateChanged: This is a signal that will indicate to the router whether the state of a node or any other component in the network has changed from its previous position.

Is for the usage of battery models, i.e. in simulations where the main aim of the simulation is to conserve energy or to conserve less battery life that is where the battery models come in the picture. This node has no parameter it is just used as an interface to link the battery module interface in the inet.battery package that is provided in the OMNeT++ framework.

Is responsible for keeping track of the status of a node in a particular network i.e. whether the node is up, down, idle, not connected or any other status that a node can have depended on the type of node in the network. This node consists of two parameters, i.e.:

- initialStatus: Gives the initial status of a node in the network which in our case if the node is a router then the default status is up.
- nodeStatusChanged: Is a signal that indicates to the other nodes in the network whether the status of a node has changed from its previous state.

3.4 Summary

Important Components	Description
NodeVL	Used as the main node in the simulation.
Router	Used to transfer information.
Data Rate Channel	Used to connect all the nodes with the routers.
Configurator	Used to assign IP address.
userGenerator	Used to generate users.
manager	Used to manage jobs.
networkManager	Used to manage the network.
vmSet	Vector pointing to the vitual machine.
topology	Defines the computing and storage node quantities.

Table 3.1: Important components used in the iCanCloud simulation.

This chapter gave a brief overview of all the components used in the simulations created. The next chapter will describe the process of designing those simulations.

Chapter 4

Simulation Designs

This chapter begins with explaining how TCP/IP is implemented in OMNeT++ and based on that two simulations were designed to explain the working of TCP/IP. Finally, the process of designing the simulation using iCanCloud is explained.

4.1 Understanding TCP/IP in OMNeT++

In order to understand and implement a working simulation with a working model of TCP/IP implemented successfully in OMNeT++ using iCanCloud, it is important to understand which package is used in OMNeT++ for implementing TCP/IP. This was the first task in the design process of the simulations used in the project, and the answer to this question was INET which is another package included along with OMNeT++ which is responsible for implementing TCP/IP in OMNeT++. A detailed explanation along with the working of various components in the INET framework are explained in [23]. There are multiple types of TCP applications provided in the INET framework like,

- TCPSessionApp
- TCPEchoApp
- TCPBasicClientApp
- TCPGenericsSrvApp

For designing a simulation in OMNeT++, there are two basic components that are important and that have to be present in each and every simulation i.e. the **ini** file

that is used to initialize all the parameters that will be required to run the simulation and the **NED** file in which all the components that will be used in the simulation will be setup and connected in the design view in the OMNeT++ editor.

4.2 Simulation design for one client and server using TCP/IP

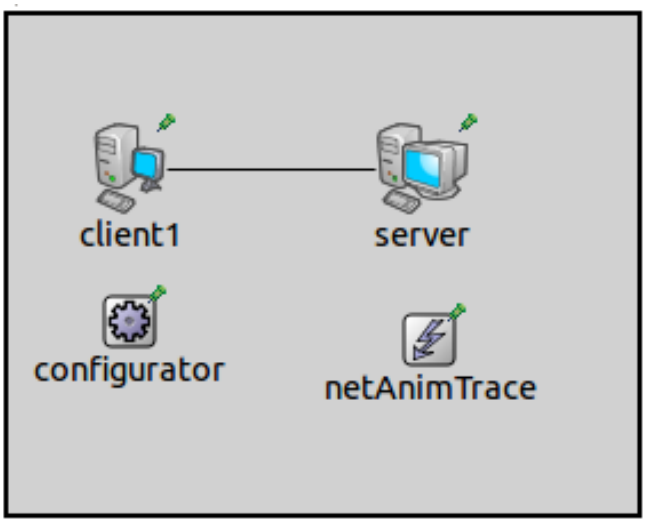


Figure 4.1: Simulation between a single client and server.

Figure 4.1 shows the design view of the NED file. In this view, all the components that will be used to carry out the client-server simulation can be visualized. There is another view for the NED file which is the source view which shows all the components that were added in the design view along with their exact position in the design view. Also, the source view shows the number and type of channels that were used in the simulation and which components were connected using the channels in the simulation.

```
network ClientServer
{
    parameters:
        double per = default(0);
        @display("bgb=232,193");
    types:
        channel C extends DatarateChannel
        {
            datarate = 10Mbps;
            delay = 0.1us;
            per = per;
        }
    submodules:
        client1: StandardHost {
            parameters:
                @display("p=53,67;i=device/pc3");
        }
        server: StandardHost {
            parameters:
                @display("p=181,67;i=device/pc2");
        }
        configurator: IPv4NetworkConfigurator {
            parameters:
                @display("p=53,134");
        }
        netAnimTrace: NetAnimTrace {
            @display("p=184,142");
        }
    connections:
        client1.pppg++ <--> C <--> server.pppg++;
}
```

Figure 4.2: NED File source view for the client-server simulation.

Figure 4.2 shows the source view of the NED file for the client-server simulation shown in Figure 4.1. Figure 4.2 shows, that there is one channel used in the simulation. The submodules are basically all the components that have been used in the simulation and the connections section shows the components that are connected to each other which in this case is the client and server.

Now after the NED file comes the ini file that is used to initialize all the parameters that are required to run the simulation.

```
**.numTcpApps = 1
**.client*.tcpApp[*].typename = "TCPSessionApp"
**.client*.tcpApp[0].active = true
**.client*.tcpApp[0].localPort = -1
**.client*.tcpApp[0].connectAddress = "server"
**.client*.tcpApp[0].connectPort = 1000
**.client*.tcpApp[0].tOpen = 0.2s
**.client*.tcpApp[0].tSend = 0.4s
**.client*.tcpApp[0].sendBytes = 1000000B
**.client*.tcpApp[0].sendScript = ""
**.client*.tcpApp[0].tClose = 25s
```

Figure 4.3: TCPSessionApp configuration for client-server simulation.

Figure 4.3 shows the ini file for the TCPSessionApp used for the client-server simulation described in this section. The TCPSessionApp simply is a single connection application, which means it opens a connection, then sends the total number of bytes through that connection and then closes the connection. A more detailed explanation of the TCPSessionApp and each of the parameters initialized in the ini file is given in [23].

```
**.server*.tcpApp[*].typename = "TCPEchoApp"
**.server*.tcpApp[0].localPort = 1000
**.server*.tcpApp[0].echoFactor = 2.0
**.server*.tcpApp[0].echoDelay = 0
```

Figure 4.4: TCPEchoApp configuration for client-server simulation.

Figure 4.4 shows the ini file for the TCPEchoApp, the other TCP application used for the client-server simulation along with the TCPSessionApp. The TCPEchoApp has a functionality of receiving data packets that are being sent by one node(in this case client) to the other node(in this case server) through TCP. A further explanation of the TCPEchoApp is given in [23].

4.3 Simulation design for multiple clients and servers using TCP/IP

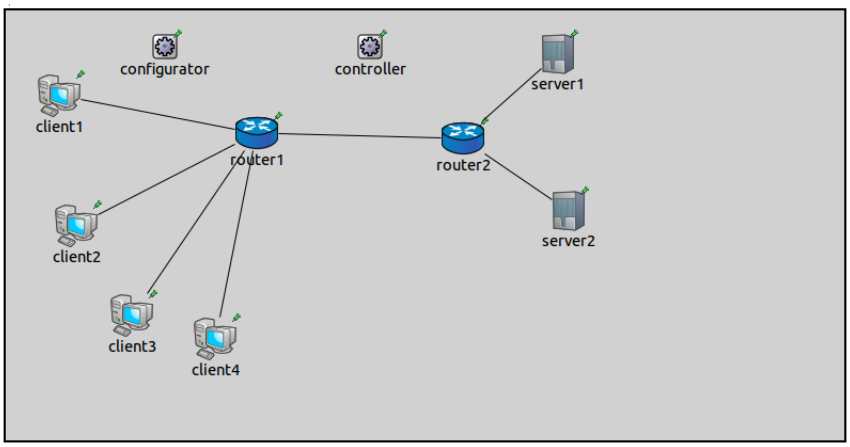


Figure 4.5: Simulation between multiple clients and servers.

Figure 4.5 shows the design view of the NED file of the simulation between multiple clients and servers. This simulation is a little different from the one described in section 4.2 where there only a single server and client that were directly connected with each other without having any routers in between them, whereas in this section the simulation has four clients and two servers that connected with each other through routers. Also in this simulation, there are three channels defined to connect the nodes with each other.

```
connections:
    client1.pppg++ <--> C1 <--> router1.pppg++;
    client2.pppg++ <--> C1 <--> router1.pppg++;
    client3.pppg++ <--> C1 <--> router1.pppg++;
    client4.pppg++ <--> C1 <--> router1.pppg++;
    router1.pppg++ <--> C2 <--> router2.pppg++;
    router2.pppg++ <--> C3 <--> server1.pppg++;
    router2.pppg++ <--> C3 <--> server2.pppg++;
```

Figure 4.6: NED file showing the connections between multiple clients and servers.

Figure 4.6 shows all the connections that have been made in this simulation, like

- C1 is the channel used to connect all the client nodes to the first router namely router1.

- C2 is the channel used to connect the different routers with each other.
- C3 is the channel used to connect both the servers with second router namely router2.

```
**.client2.tcpApp[*].typename = "TCPBasicClientApp"
**.client2.tcpApp[*].video_duration = 600
**.client2.tcpApp[*].requestLength = 100B
**.client*.tcpApp[*].replyLength = 500B
**.client*.tcpApp[*].thinkTime = 1s
**.client*.tcpApp[*].idleInterval = 1s
**.client2.tcpApp[*].localPort = 10020
**.client2.tcpApp[*].connectAddress = "server2"
**.client2.tcpApp[*].connectPort = 10021
**.client2.tcpApp[*].dataTransferMode = "object"
**.client2.tcpApp[*].localAddress = "client2"
```

Figure 4.7: TCPBasicClientApp configuration for multiple clients-servers simulation.

Next, comes the ini files used in this simulation. Similar to the simulation described in the previous section, this simulation also uses two different TCP Applications i.e, the TCPBasicClientApp and the TCPGenericsSrvApp. Figure 4.7 shows the code snippet used to initialize the TCPBasicClientApp in this simulation. The TCPBasicClientApp has a functionality fairly similar to the TCPSessionApp where a single TCP connection is opened by the client, then it sends through the connection and then closes the connection. There is some other functionality and features related to the TCPBasicClientApp which can be found in [23].

```
**.server1.tcpApp[*].typename = "TCPGenericSrvApp"
**.server1.tcpApp[*].localPort = 10021
```

Figure 4.8: TCPGenericSrvApp configuration for multiple clients-servers simulation.

Figure 4.8 shows the code snippet of the TCPGenericSrvApp used in this simulation. Similar to the TCPEchoApp described in section 4.2, the TCPGenericSrvApp has a functionality of receiving any number of TCP packets. The only difference in the TCPGenericSrvApp is that it can only receive packets with GenericAppMsg class on them which is the reason for pairing the TCPGenericSrvApp with the TCPBasicClientApp because this app sends packets, but with the GenericSrvApp class on them. All the other parameters that can be initialized along with TCPGenericSrvApp are explained in [23].

4.4 Design of iCanCloud simulation using TCP/IP

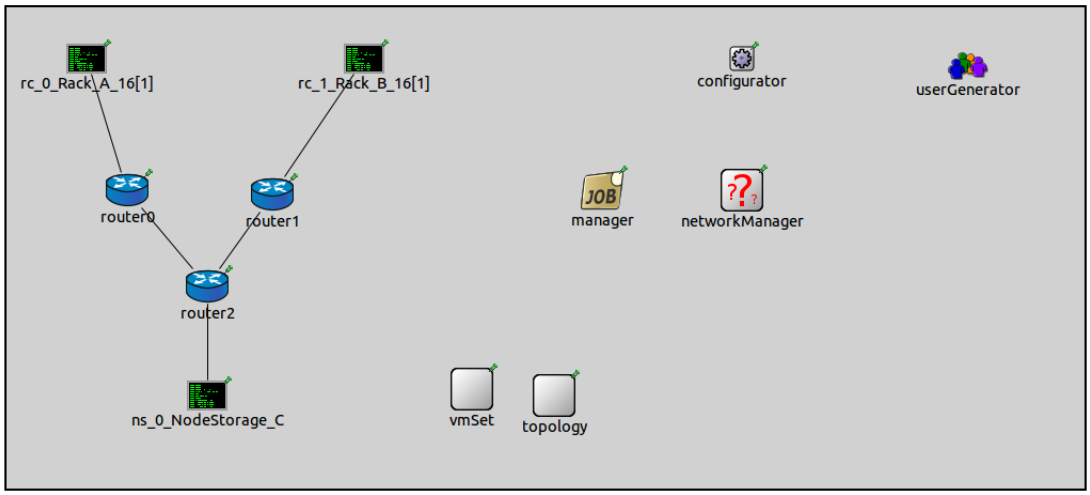


Figure 4.9: iCanCloud simulation.

Figure 4.9, shows the design view of the NED file for the iCanCloud simulation created in this project. On comparing the two simulations described in section 4.2 and 4.3, this simulation has some similar components. But there are some important components used in this simulation which is different from the previous two simulations, instead of a client and a server, in iCanCloud a nodeVL is used. Other dissimilarities include the vmSet, topology, networkManager, JobSceduler and userGenerator. All these components have been described in section 3.1 of the previous chapter.

```
channel Channel_0_TCP_NodeVL extends DatarateChannel
{
    delay = 1.25E-2us;
    datarate = 10Mbps;
    ber = 0.0;
    per = 0.0;
}

channel Channel_1_TCP_NodeVL extends DatarateChannel
{
    delay = 1.25E-2us;
    datarate = 10Mbps;
    ber = 0.0;
    per = 0.0;
}

channel RackChannel_0_TCP_NodeVL extends DatarateChannel
{
    delay = 1.25E-2us;
    datarate = 10Mbps;// RackChannelBandwidth
    ber = 0.0;
    per = 0.0;
}
```

Figure 4.10: Bandwidth of the channels used in iCanCloud simulation.

Figure 4.10 shows the bandwidth of all the channels that been used to in the connections made in the iCanCloud simulation.

```
rc_0_Rack_A_16[0].pppg++ <--> RackChannel_0_TCP_NodeVL <--> router.pppg++;
rc_1_Rack_B_16[0].pppg++ <--> RackChannel_0_TCP_NodeVL <--> router1.pppg++;

router.pppg++ <--> Channel_0_TCP_NodeVL <--> router2.pppg++;
router2.pppg++ <--> Channel_0_TCP_NodeVL <--> ns_0_NodeStorage_C.pppg++;

router1.pppg++ <--> Channel_1_TCP_NodeVL <--> router2.pppg++;
router2.pppg++ <--> Channel_1_TCP_NodeVL <--> ns_0_NodeStorage_C.pppg++;
```

Figure 4.11: Connections made in the iCanCloud simulation.

Figure 4.11 shows the connections that have been made in the iCanCloud simulation. Similar to the simulation with multiple clients and servers in the previous section, there are three channels in this simulation also but the way these connections are made is different.

- The first channel(`RackChannel_0_TCP_NodeVL`) is used to connect the first node (`rc_0_Rack_A_16[0]`) to the first router(router0) and the same channel is also used to connect the second node(`rc_0_Rack_B_16[0]`) to the second router(router1).

- The second channel(`Channel_0_TCP_NodeVL`) is used to connect the first router(router0) to the third router(router2) and the same channel is also used to connect the third router(router2) to the last node(`ns_0_NodeStorage_C`).

- The third channel(`Channel_1_TCP_NodelVL`) is used to connect the second router(router1) to the third router(router2) and the same channel is also used to connect the third router(router2) to the last node(`ns_0_NodeStorage_C`).

Similar, to the previous two simulations two TCP applications are used to set up the TCP connections between two nodes in this simulation. The only question is that which two TCP applications have been used and what was the reason for choosing these applications?

- Firstly, as seen from the previous two simulations the TCPBasicClientApp is more useful when used in the case of multiple clients and multiple servers, which is the case for the simulation in section 4.3, while in the case of a single client and a server the TCPSessionApp is better.

- Another reason is that along with the TCPBasicClientApp there is another condition, i.e. it needs to be paired with the TCPGenericSrvApp as the messages that are sent from this application have the GenericSrvApp class on them which cannot be read by the TCPEchoApp.

```
**.numTcpApps = 1
**.rc_0_Rack_A_16*.tcpApp[*].typename = "TCPSessionApp"
**.rc_0_Rack_A_16*.tcpApp[0].active = true
**.rc_0_Rack_A_16*.tcpApp[0].localPort = -1
**.rc_0_Rack_A_16*.tcpApp[0].connectAddress = "rc_1_Rack_B_16[0]"
**.rc_0_Rack_A_16*.tcpApp[0].connectPort = 1000
**.rc_0_Rack_A_16*.tcpApp[0].tOpen = 0.2s
**.rc_0_Rack_A_16*.tcpApp[0].tSend = 0.4s
**.rc_0_Rack_A_16*.tcpApp[0].sendBytes = 1000000B
**.rc_0_Rack_A_16*.tcpApp[0].sendScript = ""
**.rc_0_Rack_A_16*.tcpApp[0].tClose = 25s

**.rc_0_Rack_A_16[*].tcpApp[*].dataTransferMode = "object"
```

Figure 4.12: TCPSessionApp configuration used in iCanCloud simulation.

Figure 4.12 shows the TCPSessionApp configurations that have been used in the iCanCloud simulation.

```
**.rc_1_Rack_B_16*.tcpApp[*].typename = "TCPEchoApp"
**.rc_1_Rack_B_16*.tcpApp[0].localPort = 1000
**.rc_1_Rack_B_16*.tcpApp[0].echoFactor = 2.0
**.rc_1_Rack_B_16*.tcpApp[0].echoDelay = 0
**.rc_1_Rack_B_16[*].tcpApp[*].dataTransferMode = "object"
```

Figure 4.13: TCPEchoApp configuration used in iCanCloud simulation.

Figure 4.13 shows the TCPEchoApp configurations that have been used in the iCanCloud simulation.

Along with the TCP applications, there are other parameters that have been initialized in this simulation. Figure 4.14 shows the snippet of the ini file where the main parameters that have been used in the iCanCloud simulation are initialized. Some of the terminology used to define the parameters in this section is different from the previous two simulations, like

- The client and server node are called as the **compute nodes** in iCanCloud. In the given simulation there are two compute nodes, i.e. computeNode0 (`rc_0_Rack_A_16`) and computeNode1 (`rc_0_Rack_B_16`).

```
################################################################
### Main parameters
################################################################

    TCP_NodeVL.manager.timeBetweenLogResults_s = 30
    TCP_NodeVL.manager.numberOfVMperNode = 4
    TCP_NodeVL.topology.computeNodeQuantity = 2
    TCP_NodeVL.topology.computeNode[0].id = "rc_0_Rack_A_16"
    TCP_NodeVL.topology.computeNode[1].id = "rc_1_Rack_B_16"

    TCP_NodeVL.topology.computeNode[0].quantity = 1
    TCP_NodeVL.topology.computeNode[1].quantity = 1

    TCP_NodeVL.topology.storageNodeQuantity = 1
    TCP_NodeVL.topology.storageNode[0].id = "ns_0_NodeStorage_C"
    TCP_NodeVL.topology.storageNode[0].quantity = 1
```

Figure 4.14: Main parameters in the iCanCloud simulation.

- There is a third node in the iCanCloud simulation called as the **storage node** whose structure is similar to the compute nodes and is also defined as a TCPEchoApp which is the second server in the simulation. In the given simulation this node is named as(`ns_0_NodeStorage_C`). The main purpose of using this node is that, in case there is any failure in the first server or the link between the router and the first server fails this node can act as the server node in the iCanCloud simulation.

After all, the main parameters are initialized then each component inside a NodeVL needs to be initialized. There are four main components inside each NodeVL i.e., cpuModule, storageSystem, memory and the osModule. Apart from these four, there are two other things that are part of the operating system module of a NodeVL that are also initialized is the vmModule(initializing the Volume Manager) and the fsModule(initializing the File System).

Figure 4.15 shows the snippet of the ini file for the node storage (`ns_0_NodeStorage_C`), where all the above mentioned six components have been initialized for the iCanCloud simulation.

- The first set of parameters to be initialized belong to the CPU System like cpu core type, speed of the core and the ticks per second of the core while it is running.

```
####################
##### Node internals
####################

### CPU system
TCP_NodeVL.ns_0_NodeStorage_C.cpuModule.cpuCoreType = "CPUcore"
TCP_NodeVL.ns_0_NodeStorage_C.cpuModule.CPUcore[*].speed = 97125
TCP_NodeVL.ns_0_NodeStorage_C.cpuModule.CPUcore[*].tick_s = 0.1
### Storage system
TCP_NodeVL.ns_0_NodeStorage_C.storageSystem.device[*].deviceType = "SimpleDisk"
TCP_NodeVL.ns_0_NodeStorage_C.storageSystem.device[*].cacheType = "NullCache"
TCP_NodeVL.ns_0_NodeStorage_C.storageSystem.device[*].device.readBandwidth = 146.0
TCP_NodeVL.ns_0_NodeStorage_C.storageSystem.device[*].device.writeBandwidth = 112.0

### Memory system
TCP_NodeVL.ns_0_NodeStorage_C.memory.readLatencyTime_s = 6.9E-6
TCP_NodeVL.ns_0_NodeStorage_C.memory.writeLatencyTime_s = 6.9E-6
TCP_NodeVL.ns_0_NodeStorage_C.memory.searchLatencyTime_s = 6.9E-6
TCP_NodeVL.ns_0_NodeStorage_C.memory.numDRAMChips = 8
TCP_NodeVL.ns_0_NodeStorage_C.memory.numModules = 1

### Operating system
TCP_NodeVL.ns_0_NodeStorage_C.osModule.cpuSchedulerType = "CPU_Scheduler_FIFO"

### Volume manager
TCP_NodeVL.ns_0_NodeStorage_C.osModule.vmModule.storageManagerType = "NullStorageManager"
TCP_NodeVL.ns_0_NodeStorage_C.osModule.vmModule.schedulerType = "NullStorageScheduler"
TCP_NodeVL.ns_0_NodeStorage_C.osModule.vmModule.cacheType = "NullCache"

### File system
TCP_NodeVL.ns_0_NodeStorage_C.osModule.fsModule[0].fsType = "Node_FileSystem"
```

Figure 4.15: Components inside a NodeVL in iCanCloud.

- The second set of parameters represent the Storage System like device type, type of the cache, read and write bandwidth of the device.
- Next, comes the Memory system parameters like the latency time (for reading, writing and searching in seconds), number of RAM chips and number of modules in the system.
- Next are the Operating system and the type of scheduler that has been used in the system.
- Next is the Volume manager parameters like storage manager type, schedule type and the cache type used in the operating system module.
- Finally, there is the File system and the file system type that is used by the operating system module.

4.5 Summary

This chapter gave an overview of how TCP/IP is implemented in OMNeT++ and what kind of applications can be used to implement TCP/IP. Based on these applications three simulations were designed to show how TCP/IP can be used in OMNeT++. The next chapter will describe the working of the three simulations described in this chapter, along with an evaluation of the simulations and an analysis of the proposed environment, with some limitations of this project and ends with some sample assignments.

Chapter 5

Working, Evaluation, Analysis of Simulations, Challenges and Sample Assignments

This chapter begins with an explanation of how to run and then start a simulation in OMNeT++. Then the three simulations described in the previous chapter, are explained. Then an evaluation of all the simulations in this project is given. Then an analysis of the proposed simulation environment is done along with some strengths and weaknesses of the proposed environment. Then some limitations of this project are given. Finally some sample assignments are given, that show how the project can be used to create different types of simulations by someone unfamiliar with the tool.

5.1 Running and starting a simulation in OMNeT++

Now, before running a simulation in OMNeT++ the NED file and ini file, which define and initialize all the components needed to run the simulation are required. From the previous chapter, both these files have been included for all the simulations designed.

Next step is running the simulation. For this purpose, there are two ways of doing this,

- The first way is to right-click on the ini file in the project explorer in OMNeT++, which will give an option to run the simulation as an OMNeT++ simulation.

- The other way is to click on the play button marked with the circle in the Figure 5.1 to run the simulation.

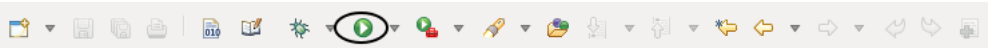


Figure 5.1: Play button to run the simulation.

After running a simulation using any of the above mentioned two steps another window comes up, where the actual simulation environment the way it was designed in the NED file can be seen. In this window, there is a run button marked with the black circle in Figure 5.2.

Figure 5.2: Run button to start the simulation.

On clicking the run button in the Figure 5.2 the simulation starts by first initializing all the components of the simulation as mentioned in the ini file and then the actual packet transfer can be seen between the nodes defined in the simulation.

5.2 Working of simulation with one client and server using TCP/IP

```
** Initializing network
Initializing channel ClientServer.client1.pppg$o[0].channel, stage 0
Initializing channel ClientServer.server.pppg$o[0].channel, stage 0
Initializing channel ClientServer.client1.ppp[0].phys$o.channel, stage 0
Initializing channel ClientServer.client1.pppg$i[0].channel, stage 0
Initializing channel ClientServer.client1.networkLayer.ip.transportOut[0].channel, stage 0
Initializing channel ClientServer.client1.networkLayer.ip.queueOut[0].channel, stage 0
Initializing channel ClientServer.client1.networkLayer.ip.queueOut[1].channel, stage 0
Initializing channel ClientServer.client1.networkLayer.ifIn[0].channel, stage 0
Initializing channel ClientServer.client1.networkLayer.ifIn[1].channel, stage 0
Initializing channel ClientServer.client1.networkLayer.transportIn[0].channel, stage 0
Initializing channel ClientServer.client1.lo0.lo.netwOut.channel, stage 0
Initializing channel ClientServer.client1.lo0.upperLayerIn.channel, stage 0
Initializing channel ClientServer.client1.ppp[0].ppp.netwOut.channel, stage 0
Initializing channel ClientServer.client1.ppp[0].ppp.phys$o.channel, stage 0
Initializing channel ClientServer.client1.ppp[0].upperLayerIn.channel, stage 0
Initializing channel ClientServer.client1.ppp[0].phys$i.channel, stage 0
Initializing channel ClientServer.server.ppp[0].phys$o.channel, stage 0
Initializing channel ClientServer.server.pppg$i[0].channel, stage 0
Initializing channel ClientServer.server.networkLayer.ip.transportOut[0].channel, stage 0
Initializing channel ClientServer.server.networkLayer.ip.queueOut[0].channel, stage 0
Initializing channel ClientServer.server.networkLayer.ip.queueOut[1].channel, stage 0
Initializing channel ClientServer.server.networkLayer.ifIn[0].channel, stage 0
Initializing channel ClientServer.server.networkLayer.ifIn[1].channel, stage 0
Initializing channel ClientServer.server.networkLayer.transportIn[0].channel, stage 0
Initializing channel ClientServer.server.lo0.lo.netwOut.channel, stage 0
Initializing channel ClientServer.server.lo0.upperLayerIn.channel, stage 0
Initializing channel ClientServer.server.ppp[0].ppp.netwOut.channel, stage 0
Initializing channel ClientServer.server.ppp[0].ppp.phys$o.channel, stage 0
Initializing channel ClientServer.server.ppp[0].upperLayerIn.channel, stage 0
Initializing channel ClientServer.server.ppp[0].phys$i.channel, stage 0
```

Figure 5.3: Initializing components of the simulation network.

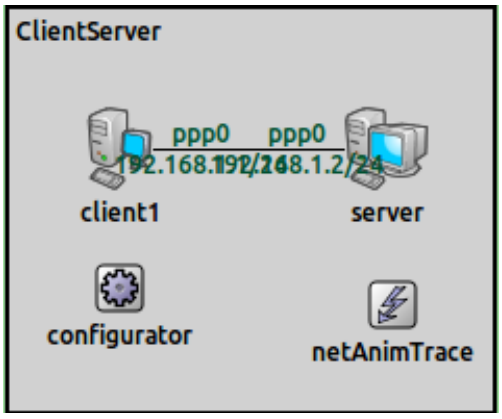


Figure 5.4: Run window for simulation with one client and server.

For the simulation with one client and server, on clicking the play button in Figure 5.1 the run window Figure 5.4 comes up. In this window, after each of the components in the ini file are initialized properly in Figure 5.3 each node that is connected through a channel is assigned an IP address as seen in Figure 5.4.

After the run window comes up in Figure 5.4, the next step is to run the simulation by clicking the run button in Figure 5.2. Before the packet transfer can take place using TCP, first a reliable connection needs to be established between the two nodes which in this case are the client and the server nodes. The process of establishing this connection is called as three-way handshaking, in which

- First, a SYN(Synchronize) packet is sent from the client to the server in Figure 5.5.
- Next, the server sends a SYN+ACK(Synchronize and Acknowledgement) packet to the client thereby acknowledging that the server has received the SYN packet from the client.
- Then finally the client sends an ACK packet to the server acknowledging that the client has received the SYN packet from the server.
- Once this three-step procedure is completed successfully, a reliable connection between the client and the server is established.

After the three-way handshaking between the client and the server is complete the packet transfer between the client and the server begins.

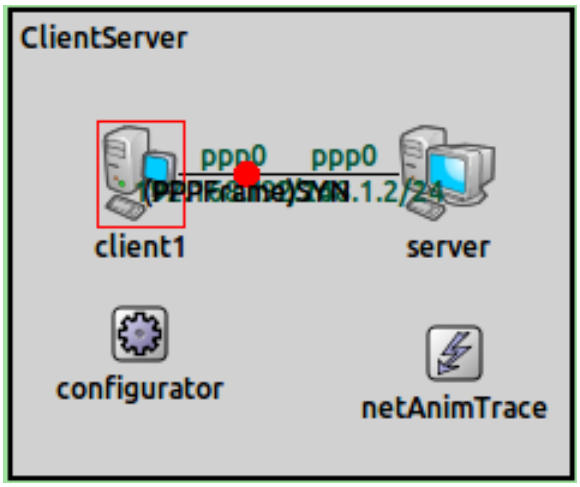


Figure 5.5: SYN packet being sent to the server.

In Figure 5.5, a SYN packet is being sent from the client to the server. In the same way all the other packets for the three-way handshaking are sent.

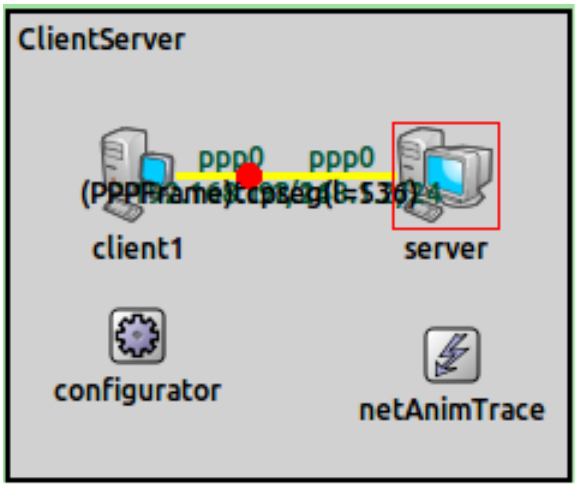


Figure 5.6: TCP packet transfer.

Figure 5.6 shows the TCP packet begin sent from client to server. Once this packet transfer begins, on each step i.e., if the client is sending something to the server or if the client is receiving something from the server at every step an additional ACK(acknowledgment) packet is also sent to the sender of the packet acknowledging that they have received the packet. This way once both the client and server has sent the packets the TCP connection established between the nodes is closed.

5.3 Working of the simulation with Multiple clients and servers using TCP/IP

```
Initializing channel TCP_t.client1.pppg$o[0].channel, stage 0
Initializing channel TCP_t.client2.pppg$o[0].channel, stage 0
Initializing channel TCP_t.client3.pppg$o[0].channel, stage 0
Initializing channel TCP_t.client4.pppg$o[0].channel, stage 0
Initializing channel TCP_t.server1.pppg$o[0].channel, stage 0
Initializing channel TCP_t.server2.pppg$o[0].channel, stage 0
Initializing channel TCP_t.router1.pppg$o[0].channel, stage 0
Initializing channel TCP_t.router1.pppg$o[1].channel, stage 0
Initializing channel TCP_t.router1.pppg$o[2].channel, stage 0
Initializing channel TCP_t.router1.pppg$o[3].channel, stage 0
Initializing channel TCP_t.router1.pppg$o[4].channel, stage 0
Initializing channel TCP_t.router2.pppg$o[0].channel, stage 0
Initializing channel TCP_t.router2.pppg$o[1].channel, stage 0
Initializing channel TCP_t.router2.pppg$o[2].channel, stage 0
Initializing channel TCP_t.client1.ppp[0].phys$o.channel, stage 0
Initializing channel TCP_t.client1.pppg$i[0].channel, stage 0
Initializing channel TCP_t.client1.networkLayer.ip.transportOut[0].channel, stage 0
Initializing channel TCP_t.client1.networkLayer.ip.queueOut[0].channel, stage 0
Initializing channel TCP_t.client1.networkLayer.ip.queueOut[1].channel, stage 0
Initializing channel TCP_t.client1.networkLayer.ifIn[0].channel, stage 0
Initializing channel TCP_t.client1.networkLayer.ifIn[1].channel, stage 0
Initializing channel TCP_t.client1.networkLayer.transportIn[0].channel, stage 0
Initializing channel TCP_t.client1.lo0.lo.netwOut.channel, stage 0
Initializing channel TCP_t.client1.lo0.upperLayerIn.channel, stage 0
Initializing channel TCP_t.client1.ppp[0].ppp.netwOut.channel, stage 0
Initializing channel TCP_t.client1.ppp[0].ppp.phys$o.channel, stage 0
Initializing channel TCP_t.client1.ppp[0].upperLayerIn.channel, stage 0
Initializing channel TCP_t.client1.ppp[0].phys$i.channel, stage 0
Initializing channel TCP_t.client2.ppp[0].phys$o.channel, stage 0
Initializing channel TCP_t.client2.pppg$i[0].channel, stage 0
Initializing channel TCP_t.client2.networkLayer.ip.transportOut[0].channel, stage 0
Initializing channel TCP_t.client2.networkLayer.ip.queueOut[0].channel, stage 0
Initializing channel TCP_t.client2.networkLayer.ip.queueOut[1].channel, stage 0
Initializing channel TCP_t.client2.networkLayer.ifIn[0].channel, stage 0
Initializing channel TCP_t.client2.networkLayer.ifIn[1].channel, stage 0
Initializing channel TCP_t.client2.networkLayer.transportIn[0].channel, stage 0
Initializing channel TCP_t.client2.lo0.lo.netwOut.channel, stage 0
Initializing channel TCP_t.client2.lo0.upperLayerIn.channel, stage 0
Initializing channel TCP_t.client2.ppp[0].ppp.netwOut.channel, stage 0
Initializing channel TCP_t.client2.ppp[0].ppp.phys$o.channel, stage 0
Initializing channel TCP_t.client2.ppp[0].upperLayerIn.channel, stage 0
Initializing channel TCP_t.client2.ppp[0].phys$i.channel, stage 0
Initializing channel TCP_t.client3.ppp[0].phys$o.channel, stage 0
Initializing channel TCP_t.client3.pppg$i[0].channel, stage 0
Initializing channel TCP_t.client3.networkLayer.ip.transportOut[0].channel, stage 0
Initializing channel TCP_t.client3.networkLayer.ip.queueOut[0].channel, stage 0
Initializing channel TCP_t.client3.networkLayer.ip.queueOut[1].channel, stage 0
Initializing channel TCP_t.client3.networkLayer.ifIn[0].channel, stage 0
Initializing channel TCP_t.client3.networkLayer.ifIn[1].channel, stage 0
Initializing channel TCP_t.client3.networkLayer.transportIn[0].channel, stage 0
Initializing channel TCP_t.client3.lo0.lo.netwOut.channel, stage 0
Initializing channel TCP_t.client3.lo0.upperLayerIn.channel, stage 0
Initializing channel TCP_t.client3.ppp[0].ppp.netwOut.channel, stage 0
Initializing channel TCP_t.client3.ppp[0].ppp.phys$o.channel, stage 0
Initializing channel TCP_t.client3.ppp[0].upperLayerIn.channel, stage 0
Initializing channel TCP_t.client3.ppp[0].phys$i.channel, stage 0
Initializing channel TCP_t.client4.ppp[0].phys$o.channel, stage 0
Initializing channel TCP_t.client4.pppg$i[0].channel, stage 0
Initializing channel TCP_t.client4.networkLayer.ip.transportOut[0].channel, stage 0
Initializing channel TCP_t.client4.networkLayer.ip.queueOut[0].channel, stage 0
Initializing channel TCP_t.client4.networkLayer.ip.queueOut[1].channel, stage 0
Initializing channel TCP_t.client4.networkLayer.ifIn[0].channel, stage 0
Initializing channel TCP_t.client4.networkLayer.ifIn[1].channel, stage 0
Initializing channel TCP_t.client4.networkLayer.transportIn[0].channel, stage 0
Initializing channel TCP_t.client4.lo0.lo.netwOut.channel, stage 0
Initializing channel TCP_t.client4.lo0.upperLayerIn.channel, stage 0
Initializing channel TCP_t.client4.ppp[0].ppp.netwOut.channel, stage 0
```

Figure 5.7: Initializing components for multiple clients and servers simulation.

In Figure 5.7, similar to the simulation in the previous section on clicking the play button as in Figure 5.1 the components of the simulation with multiple clients and servers are initialized if both the ini and NED files are included and defined properly for the components included in the simulation.

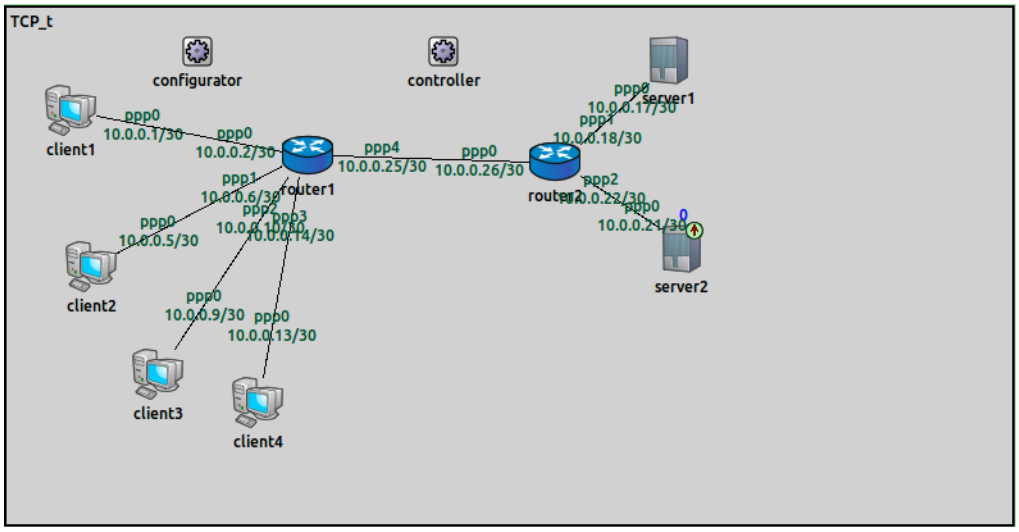


Figure 5.8: Run Window for simulation with multiple clients and servers.

Also on clicking the play button another part that comes up is the run window in Figure 5.8. The way each node is assigned an IP address in the run window in Figure 5.4, the same way each node in the run window in Figure 5.8 is also assigned an IP address. But, in this simulation along with multiple clients and servers there are routers as well and in a router with every link that is coming in the router is assigned an IP address. Every link going out from the router will also have an IP address assigned to it, which in this case is,

- For the first router(router1), it has four links coming in from each of the four client nodes and the link going out of the router1 connects to the other router(router2). So in total, the first router has 5 IP addresses assigned to it.
- For the second router(router2), it has one link coming in from the first router and two links that are going out to the two server nodes. So in total, the second router has 3 IP addresses assigned to it.

After all the components are initialized properly, the simulation can be started by clicking the run button in Figure 5.2. On clicking this button first the three-way handshaking will take place between the client and the server nodes the same way it was done in the previous simulation between one client and server.

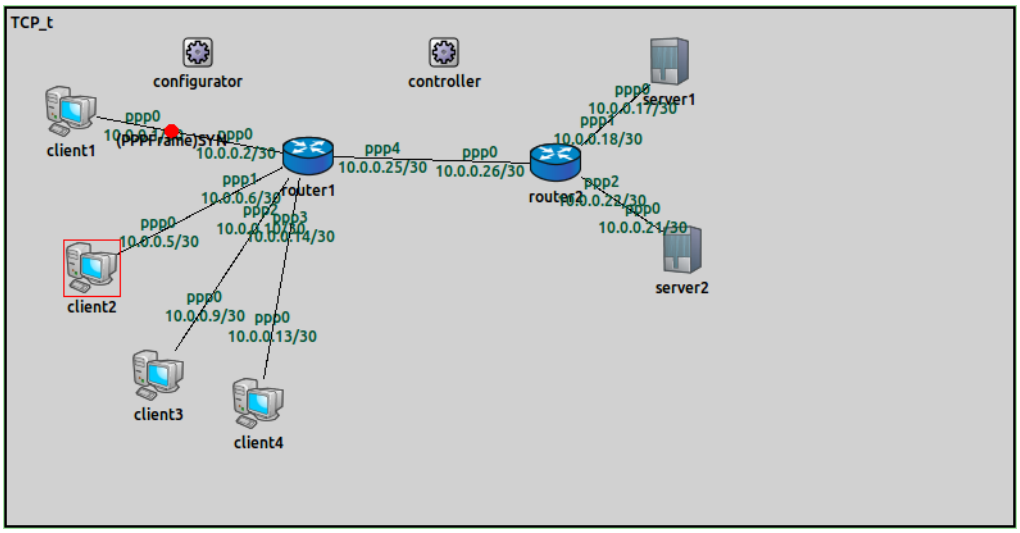


Figure 5.9: SYN Packet being sent from client1 to the server1.

In Figure 5.9, a SYN packet is being sent from client1 to router1. The router1 will then send the SYN packet to the router2 and finally, router2 will send it to the destination node for the packet i.e. server1. The same process will be repeated by client 2 which will send a SYN packet to be received by server2. This completes the first step of three-way handshaking.

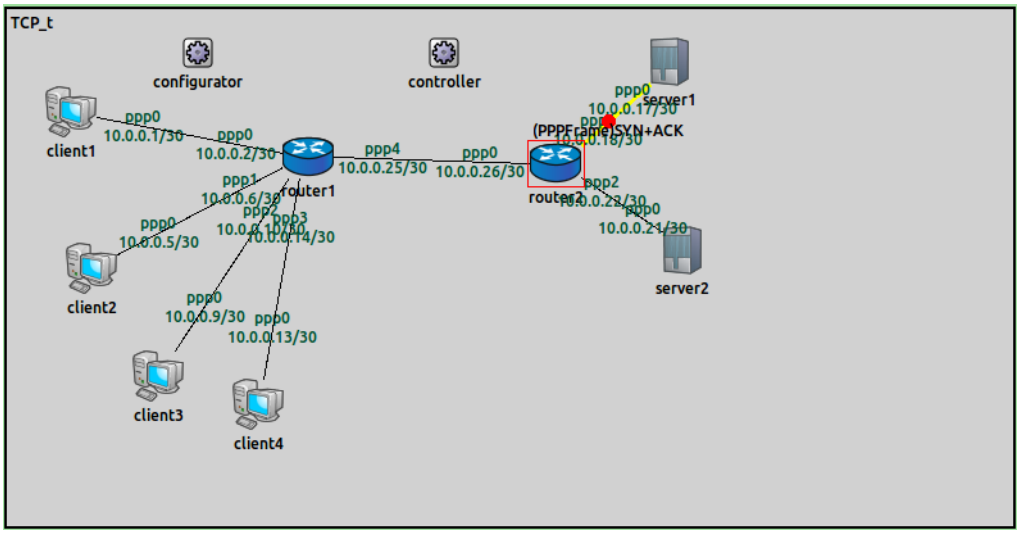


Figure 5.10: SYN+ACK packet sent from server1 to client1.

After both the servers have received the SYN packet from the clients, then the server will send the SYN+ACK packet to the client acknowledging that they have received the earlier sent SYN packet from the client. Figure 5.10 shows the server1

sending the SYN+ACK packet to the router2. Then router2 sends this packet to router1, which is finally received by client1. The same process is done by server2, which sends the SYN+ACK packet to client2. This completes the second step of three-way handshaking.

For the final step, both the client nodes send an ACK packet to the server nodes acknowledging that they received the SYN+ACK packet sent from the server and are ready to establish a TCP connection. After both the servers receive the respective ACK packets sent from the clients the connection is established. Now the data transfer begins.

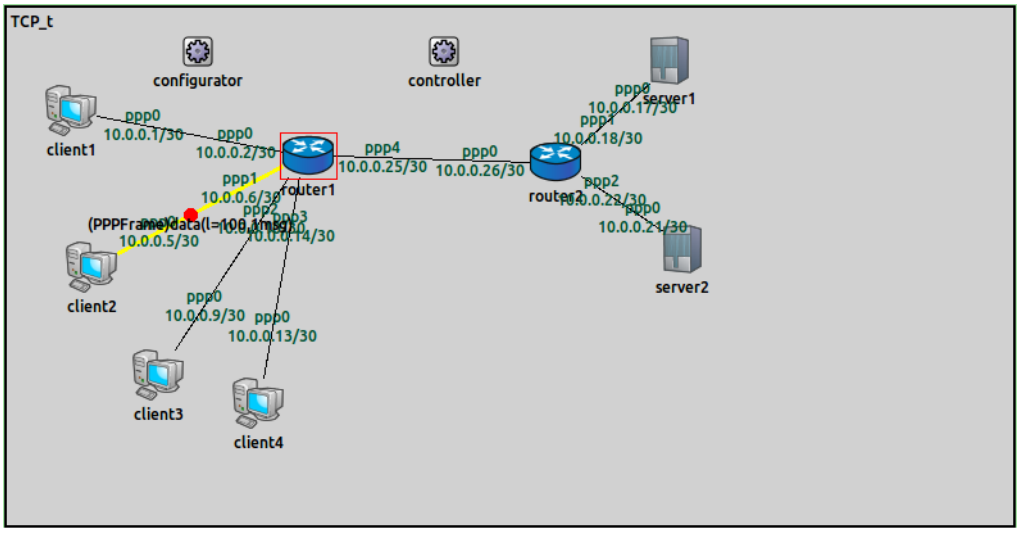


Figure 5.11: TCP packet transfer.

Figure 5.11 shows data being transferred from client2 to router1, which will be finally received by server2 via router2. The steps are as follows:

- After the server receives the TCP packet it sends an ACK packet to the client acknowledging that it has received the TCP packet.
- Then the server sends a TCP packet to the client.
- Now the client will send an ACK packet to server acknowledging that it has received the packet from the server.
- Along with the ACK packet, the client also sends the FIN packet to the server, indicating that the packet transfer between the client and the server has completed.

- On receiving this FIN packet, the server then sends an ACK packet to the client acknowledging that it has received the FIN packet from the client.
- Finally, the server sends a FIN packet to the client indicating that it has finished the packet transfer as well.
- On receiving this FIN packet the client, sends a final ACK packet to the server and then the connection is closed.
- Now, after the connection is closed to send further packets the entire process explained in this section about three-way handshaking for TCP takes place again and then the packet transfer begins again.

5.4 Working of iCanCloud simulation using TCP/IP

Figure 5.12: Initializing network for iCanCloud simulation.

Figure 5.12, shows the network initialization that takes place similar to the simulations in the previous two sections. This initialization for the iCanCloud simulation begins on clicking the play button in Figure 5.1. The initialization completes properly only if all the parameters of simulation components are initialized in the ini file and configured in the NED file.

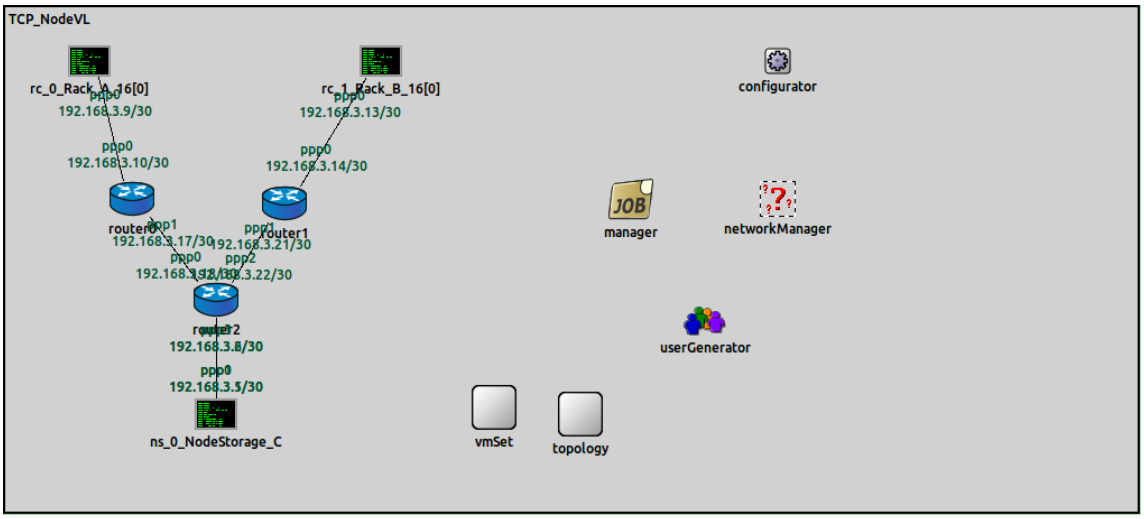


Figure 5.13: Run Window for iCanCloud simulation.

Figure 5.13 shows the run window which also comes up along with the initialize window in Figure 5.12 on clicking the play button. The way IP addresses are assigned to the nodes for the simulations in the previous two sections, the same way in this simulation also each node connected with a channel is assigned an IP address. As in this simulation, there are routers as well, so each router will be assigned two IP addresses the same way it was done for the simulation with the multiple clients and servers.

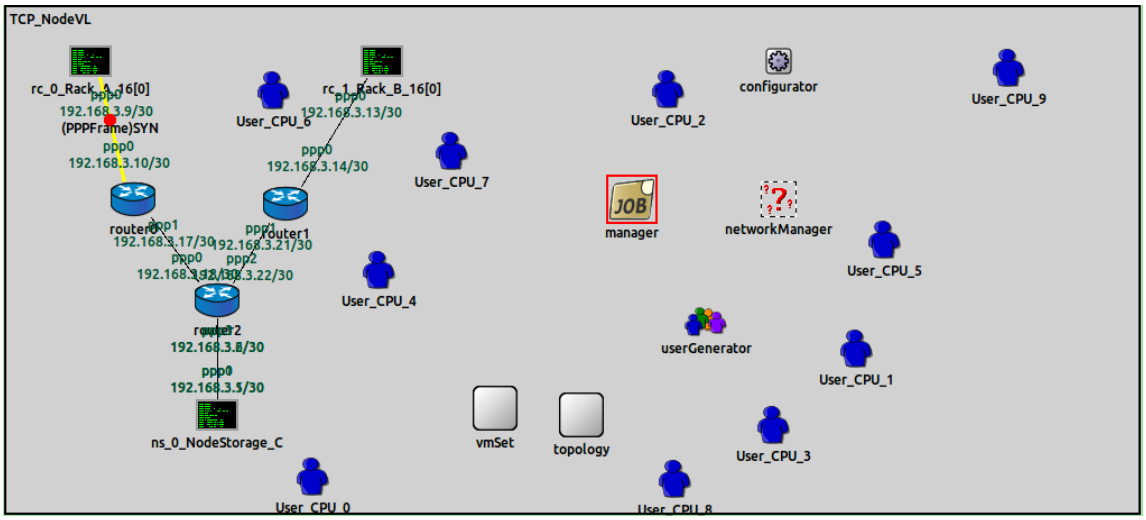


Figure 5.14: SYN packet being sent from `rc_0_Rack_A_16[0]` to router1.

On clicking the run button in Figure 5.2, the three-way handshaking process begins where, in the first step the SYN packet is sent from the `rc_0_Rack_A_16[0]` node to

the first router(named router0) shown in Figure 5.14. Then from router0, this SYN packet travels via router2 to get to router1 and finally to arrive at the destination node i.e. `rc_1_Rack_B_16[0]`.

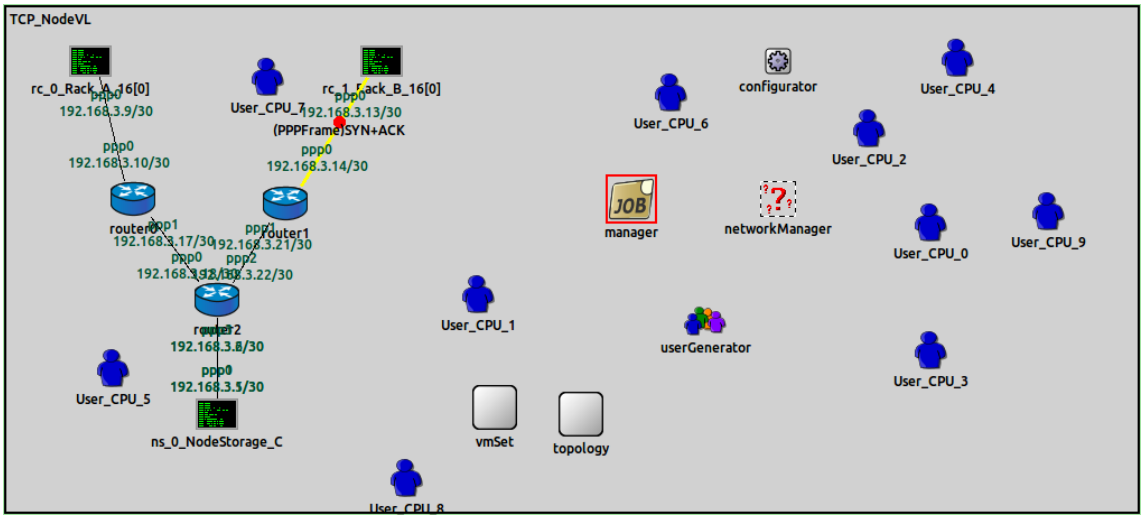


Figure 5.15: SYN+ACK packet sent from `rc_1_Rack_B_16[0]` to router1.

After the first step for the three-way handshaking is complete, then in the next step, the `rc_1_Rack_B_16[0]` node sends the SYN+ACK packet to the router1, which will finally reach its destination which is `rc_0_Rack_A_16[0]` node traveling via router2 and router0.

For the final step, the `rc_0_Rack_A_16[0]` node will send an ACK packet to the `rc_1_Rack_B_16[0]` node, there by finishing the three-way handshaking and successfully establishing a reliable TCP connection between the two nodes.

After the three-way handshaking process is complete, the TCP packet transfer process begins.

- Figure 5.16 shows the TCP packet being sent from `rc_0_Rack_A_16[0]` node to the router0. This packet is finally received by the destination node `rc_1_Rack_B_16[0]`, traveling via the router2 to router1.

- On receiving the packet the `rc_1_Rack_B_16[0]` node sends the ACK packet to the `rc_0_Rack_A_16[0]` node acknowledging the earlier packet sent was received.

- Then the `rc_1_Rack_B_16[0]` sends a TCP packet to the `rc_0_Rack_A_16[0]` node.

- On receiving this packet the `rc_0_Rack_A_16[0]` node sends an ACK packet to the `rc_1_Rack_B_16[0]` node thereby completing the packet transfer process between the two nodes.

Finally, the TCP connection established between the two nodes is closed after the packet transfer process is completed.

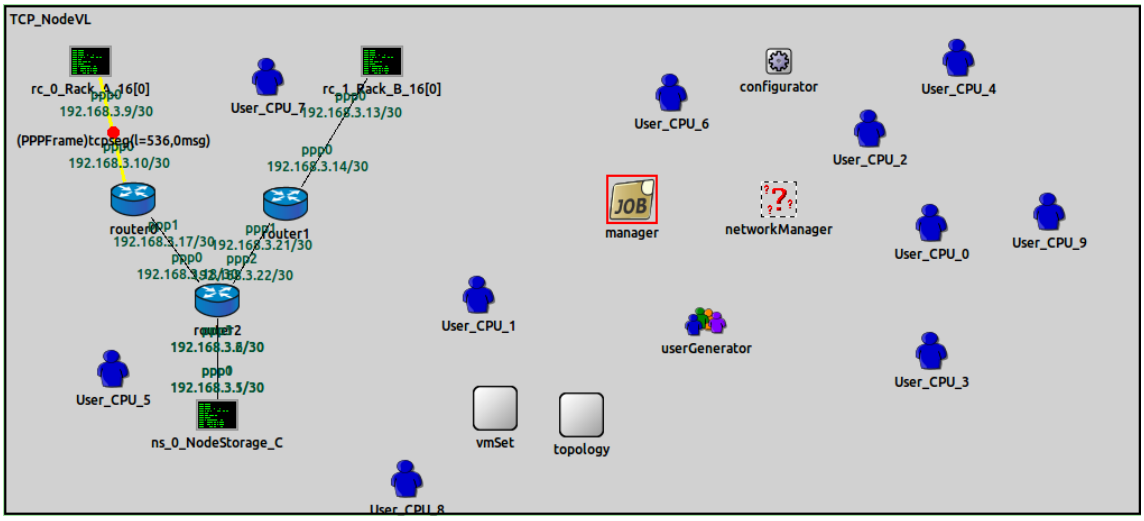


Figure 5.16: TCP packet transfer in iCanCloud simulation.

5.5 Evaluation

The simulation with TCP/IP implemented in iCanCloud shown in Figure 5.13 is the main simulation created to achieve the goal of this project. Evaluating this simulation depends on,

- Evaluating the design and working of the first two simulations created for this project.
- Comparing all the components used for all the three simulations.
- The TCP applications used in all the simulations.
- The type TCP support available for all the three simulations.

So just for the purpose of evaluation of all the three simulations, let's call,

- The first simulation with one client and server as **Simulation 1**.
- The second simulation with multiple clients and servers as **Simulation 2**.
- The last simulation using iCanCloud as **Simulation 3**.

Parameter	**Simulation 1**	**Simulation 2**	**Simulation 3**
Components Used	One Client, One Server, configurator, and netAnimTrace	Four Clients, Two servers, Two routers, configurator and controller	One Client, Two Server Three routers, configurator networkManager jobManager, userGenerator vmSet and topology.
TCP Application Used	TCP Session App TCP Echo App	TCPBasicClientApp TCPGenericsSrvApp	TCP Session App TCP Echo App
TCP Support	Full Support	Full Support	No Support

Table 5.1: Comparing the three simulations.

From the Table 5.1, there are some similarities and some differences present in Simulation 1, Simulation 2 and Simulation 3 which can also be seen in Figure 5.4 for Simulation 1, Figure 5.8 for Simulation 2 and Figure 5.13 for Simulation 3. The reason for that is,

- First, the Simulation 1 and 2 are based on the INET framework present in OMNeT++ and Simulation 3 is based on the iCanCloud Framework for OMNeT++ in which INET framework is used for implementing TCP.
- Second, Simulation 1 and 2 were designed for the purpose of understanding how TCP is implemented in OMNeT++ using INET, but Simulation 3 was designed to see how using iCanCloud in OMNeT++ TCP can be implemented or not.
- Third, in case of the TCP support section as mentioned in Table 6.1 Simulation 1 and 2 are based on INET, which means that as mentioned in [23] there are a bunch of predefined packages implemented in INET for implementing TCP. But in iCanCloud used for Simulation 3, there is no TCP support so TCP applications from INET had to be used along with using iCanCloud to implement TCP for Simulation 3.

- Fourth, for the type of TCP Applications that were used for all the three simulations are used in pair's, because the design of TCP in INET is such that there is one application that is used for the client-side implementation of TCP and the other application is used for the server-side implementation of TCP.

- Finally, in the case, where there is one client and one or multiple servers then the client-side application is always the TCPSessionApp and the server-side application is always TCPEchoApp , and when there are multiple clients and multiple servers involved in the simulation then the client-side application is TCPBasicClientApp and the server side application is TCPGenericsSrvApp, the reasons for this are:

  – With TCPSessionApp the packet sent does not have the GenericsSrvApp class set which is required by the TCPGenericsSrvApp to receive the packet sent. So the TCPSessionApp is paired with the TCPEchoApp.

  – The packet sent using the TCPBasicClientApp has the GenericsSrvApp class set which can be received by the TCPGenericsSrvApp, so the TCP-BasicClientApp is paired with the TCPGenericsSrvApp.

For all the components compared in Table 5.1, a detailed explanation of each of these components is given in chapter 3.

Apart, from the comparisons in Table 5.1 there are also some differences in the design of all the simulations seen in the various Figures shown in chapter 4, i.e.

File Type	**Simulation 1**	**Simulation 2**	**Simulation 3**
NED File	Figure 4.2	Figure 4.6	Figure 4.10
ini File	Figure 4.3 Figure 4.4	Figure 4.7 Figure 4.8	Figure 4.11 Figure 4.12

Table 5.2: NED Files and ini files used for the three simulations.

From Table 5.2, all the Figures for the NED files and the ini files for all the three simulations are mentioned.

- For the NED files, all the three are similar the only difference will be that as the number of components in the simulations increase

  – The types section of the NED file where the channels connecting the nodes are defined will have more definitions for multiple channels.

  - The submodules sections where what component included in the simulation is defined will also increase.
  - The connections sections where all the connections made in the simulation is defined will also increase.
  - A sample of the NED file can be seen in Figure 4.2.

- For the ini Files, Simulation 1 and 2 are similar but Simulation 3 has many differences from the previous two simulations.
  - As seen in the Figures for the ini files, in Simulation 1 and 2 basically all the parameters that need to be initialized for the TCP application being used for that simulation is given in the file.
  - In Simulation 3 along with the TCP applications all the other components within a client NodeVL (`rc_0_Rack_A_16[0]`) given in Figure 3.3 also need to be initialized.
  - Same components will be initialized for the first server NodeVL (`rc_1_Rack_B_16[1]`) and the second server NodeVL (`ns_0_NodeStorage_C`).
  - A small sample of the ini file for Simulation 3 is Figure 4.12 defining components within the `ns_0_NodeStorage_C` NodeVL.

5.6 Analysis

Based on the network traffic analysis and the performance analysis, the strengths and weakness of the proposed simulation environment are described in this section.

5.6.1 Network traffic analysis

- From the table 5.3, at every stage before a packet transfer can begin between the nodes in the network the first three packets need to be sent between the client and server nodes, in the order they have been given in the table.
- After the first three packets have been sent and a connection is established then the packet transfer process begins.

Type of Packet	Sequence number for sending the packet
SYN	1
SYN+ACK	2
ACK	3
Packet	4
FIN	5

Table 5.3: Types of packets sent in all the simulations.

- The total number of bytes of the information that is being transferred is set in the ini file.
- Maximum size of each packet sent for transferring that information can be any number of bytes that can be set in the ini file.
- So based on the total number of bytes set to be transferred, the number of packets needed to transfer can vary.
- Finally after all the packets have been transferred then the last packet in table 5.3, FIN is sent indicating that the TCP connection between the nodes can be closed.

So, this was just a basic theoretical analysis of the simulation environment. On running the simulation, real simulated data is generated and can be analyzed using Wireshark [5] a packet capturing tool.

1	0.000000	192.168.1.1	192.168.1.2	TCP	48	1025 → 1000 [SYN] Seq=0 Win=7504 Len=0 MSS=536
2	0.000082	192.168.1.2	192.168.1.1	TCP	48	1000 → 1025 [SYN, ACK] Seq=0 Ack=1 Win=7504 Len=0 MSS=536
3	0.000082	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [ACK] Seq=1 Ack=1 Win=7504 Len=0
4	0.200000	192.168.1.1	192.168.1.2	TCP	580	1025 → 1000 [ACK] Seq=1 Ack=1 Win=7504 Len=536
5	0.200505	192.168.1.2	192.168.1.1	TCP	44	1000 → 1025 [ACK] Seq=1 Ack=537 Win=7504 Len=0
6	0.200505	192.168.1.1	192.168.1.2	TCP	508	1025 → 1000 [ACK] Seq=537 Ack=1 Win=7504 Len=464
7	0.200971	192.168.1.2	192.168.1.1	TCP	580	1000 → 1025 [ACK] Seq=1 Ack=537 Win=7504 Len=536
8	0.200971	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [ACK] Seq=1001 Ack=537 Win=7504 Len=0
9	0.201009	192.168.1.2	192.168.1.1	TCP	44	1000 → 1025 [ACK] Seq=537 Ack=1001 Win=7504 Len=0
10	0.201475	192.168.1.2	192.168.1.1	TCP	580	1000 → 1025 [ACK] Seq=537 Ack=1001 Win=7504 Len=536
11	0.201475	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [ACK] Seq=1001 Ack=1073 Win=7504 Len=0
12	0.201942	192.168.1.2	192.168.1.1	TCP	580	1000 → 1025 [ACK] Seq=1073 Ack=1001 Win=7504 Len=536
13	0.201942	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [ACK] Seq=1001 Ack=1609 Win=7504 Len=0
14	0.202293	192.168.1.2	192.168.1.1	TCP	436	1000 → 1025 [ACK] Seq=1609 Ack=1001 Win=7504 Len=392
15	0.202293	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [ACK] Seq=1001 Ack=2001 Win=7504 Len=0
16	24.800001	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [FIN, ACK] Seq=1001 Ack=2001 Win=7504 Len=0
17	24.800076	192.168.1.2	192.168.1.1	TCP	44	1000 → 1025 [ACK] Seq=2001 Ack=1002 Win=7504 Len=0
18	24.800113	192.168.1.2	192.168.1.1	TCP	44	1000 → 1025 [FIN, ACK] Seq=2001 Ack=1002 Win=7504 Len=0
19	24.800113	192.168.1.1	192.168.1.2	TCP	44	1025 → 1000 [ACK] Seq=1002 Ack=2002 Win=7504 Len=0

Figure 5.17: Basic Layout of a wireshark packet capture.

Figure 5.17 gives an overview of the layout of how a packet capture window looks like in wireshark. Each line in the figure is a frame giving information of what was captured in the entire packet transfer process.

For the proposed environment the data is captured by running the simulation with different number of bytes being sent in the network.

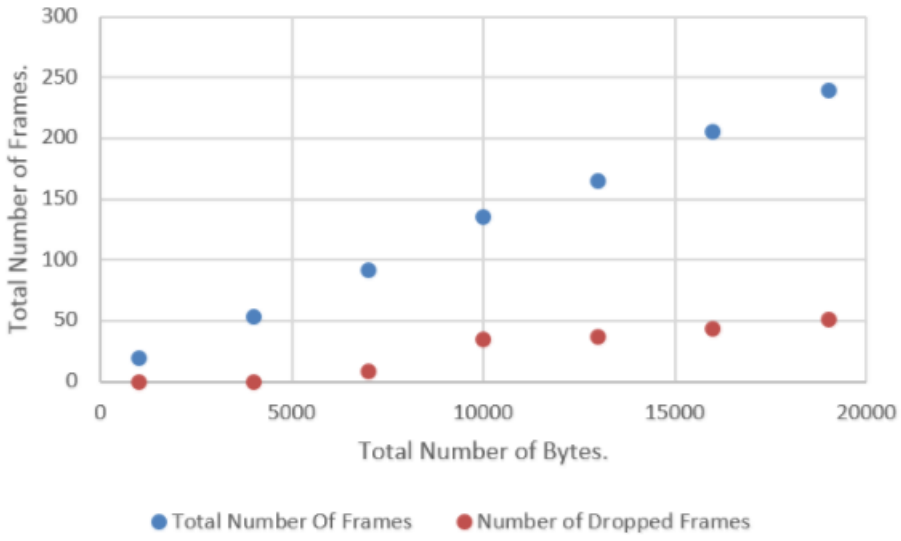


Figure 5.18: Different Frames captured using wireshark.

Figure 5.18 gives an analysis after running the proposed environment with seven different configurations. As shown in the figure there are two kind of frames captured i.e., the total number of frames shown with the blue circles and the number of dropped frames shown with the red circles. The dropped frames are basically those frames that were sent but for some reason were re-transmitted. The reason for this re-transmission can be:

- The previous packet sent was not processed by the destination node, and before that the new packet was sent, OR
- The destination queue queue might be full, and could not receive the new packet right away.

This re-transmission of the packet is one advantage of using TCP in the network as it does not discard that packet. Also from the figure it can be seen that the packet re-transmission takes place only when the bytes being sent are 7000 or more.

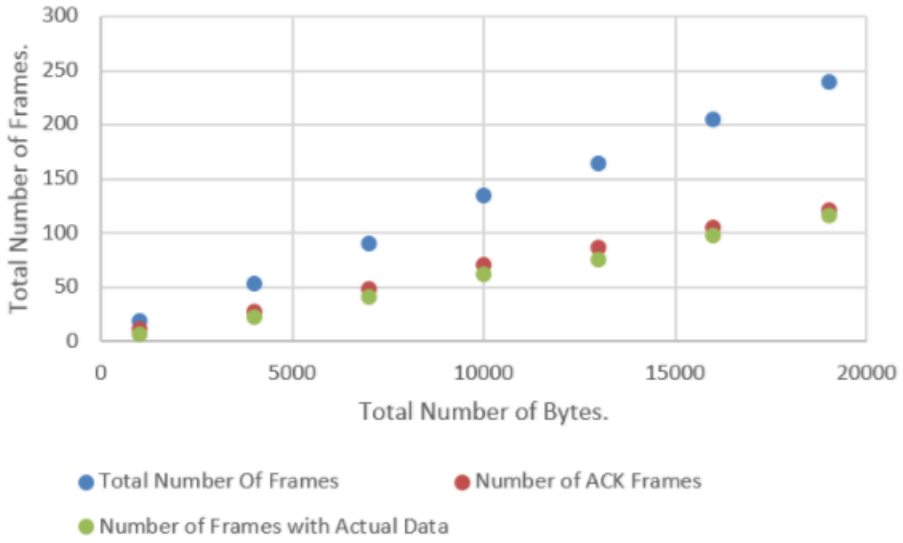


Figure 5.19: ACK and Data Frames captured using wireshark.

Figure 5.19 gives an analysis of the number of ACK frames shown with the red circles and the frames consisting of actual data shown with the green circles. Analyzing this data shows that with using TCP, the amount ACK packets and the packets containing data in them is almost the same, which means every ACK packet sent:

- Will be for acknowledging that the previous packet sent by the other node has been received by the current node successfully, OR
- The current node has processed the previous sent packet and is ready receive more data.

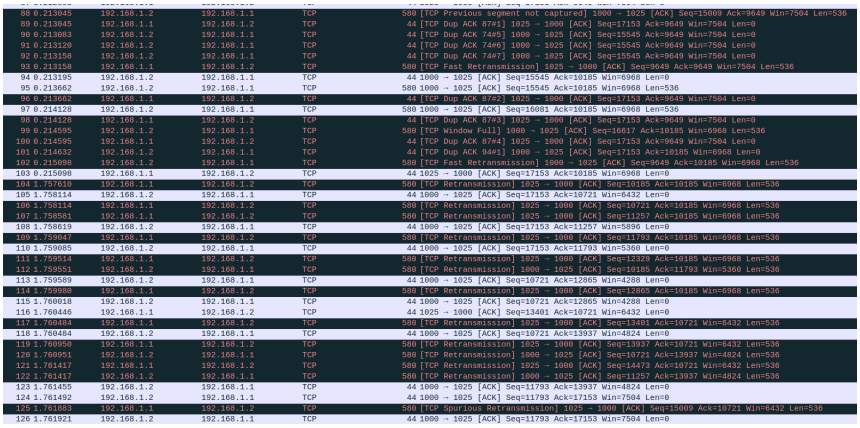


Figure 5.20: Different re-transmission frames captured in wireshark.

Figure 5.20 shows all the different re-transmission frames captured using wireshark. These frames are:

- Previous segment not captured.
- Duplicate acknowledgement.
- Fast re-transmission.
- Window Full.
- Re-transmission.
- Spurious re-transmission.

All of these frames are ultimately re-transmitted back in the network thereby restoring the normal functioning of the network.

5.6.2 Performance Analysis

This section will give some performance analysis based on the throughput and utilization of the simulation in Figure 5.13, simulation in Figure 5.23 with a bottleneck link, simulation for assignment 1 and a simulation for assignment 1 with a bottleneck link. Then there is a comparison between DropTailQueue and RED and finally an analysis of the simulation in Figure 5.13 is done, using some bad configurations.

5.6.2.1 Simple iCanCloud simulation

This section shows the throughput and utilization of the simulation created in Figure 5.13.

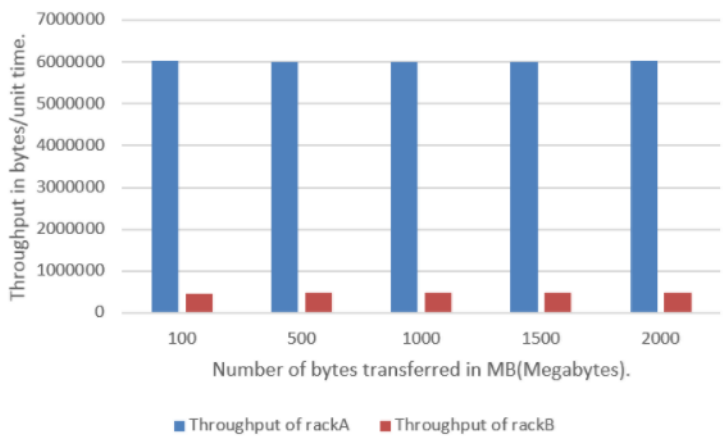


Figure 5.21: Throughput of rackA and rackB in the iCanCloud simulation.

Figure 5.21 shows the throughput for both the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation shown in Figure 5.13.

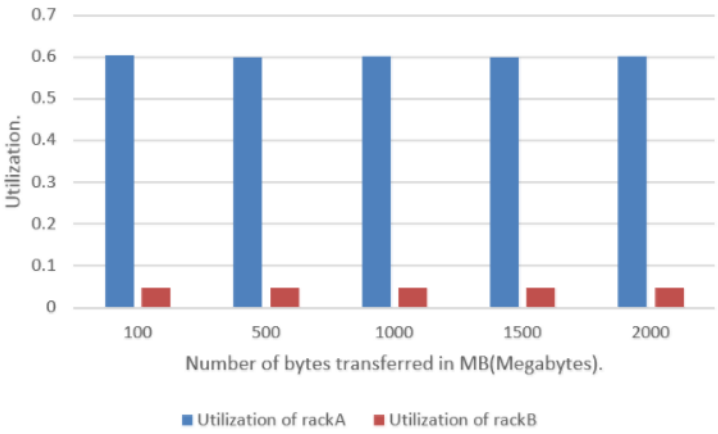


Figure 5.22: Utilization of rackA and rackB in the iCanCloud simulation.

Figure 5.22 shows the utilization for both the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation shown in Figure 5.13.

The bandwidth used for all the channels in this simulation is 10Mbps.

5.6.2.2 Simple iCanCloud simulation with bottleneck link

This section shows the throughput and utilization of the simulation created in Figure 5.23.

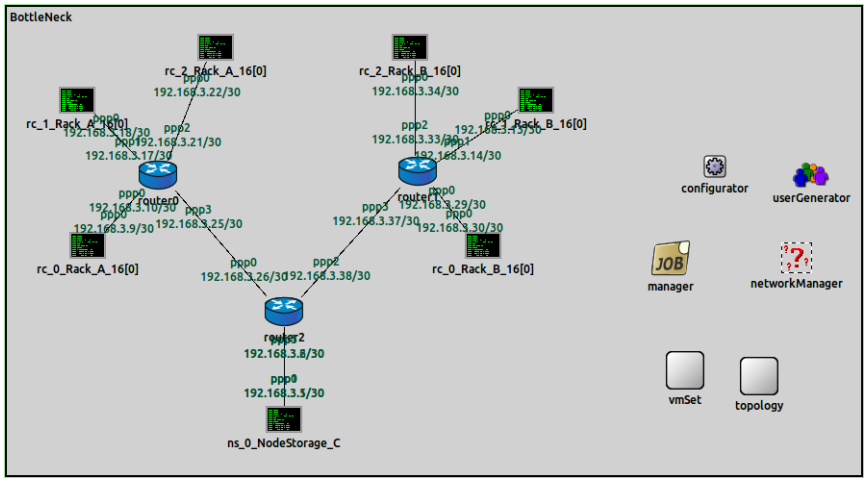


Figure 5.23: iCanCloud simulation with bottleneck link.

Figure 5.23 shows the iCanCloud simulation with multiple clients connected to the router0 and multiple servers connected to router1. This will create a bottleneck link between the routers doing the packet transfer between the clients and servers, i.e. the link between router0 and router2, and the link between router2 and router1.

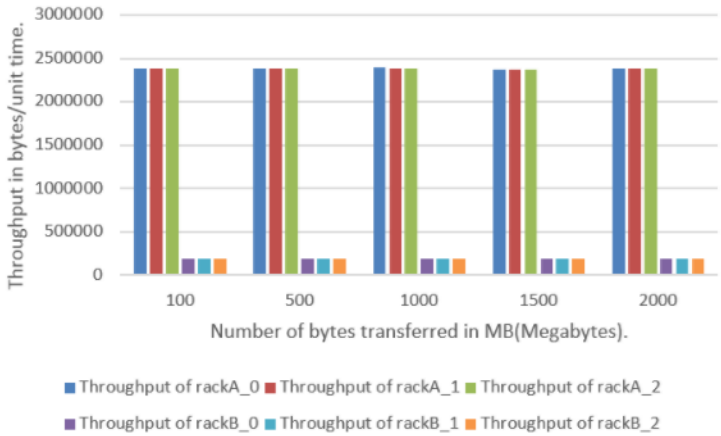


Figure 5.24: Throughput of each node in the iCanCloud simulation with bottleneck link.

Figure 5.24 shows the throughput for all the nodes in the iCanCloud simulation with the bottleneck link in Figure 5.23.

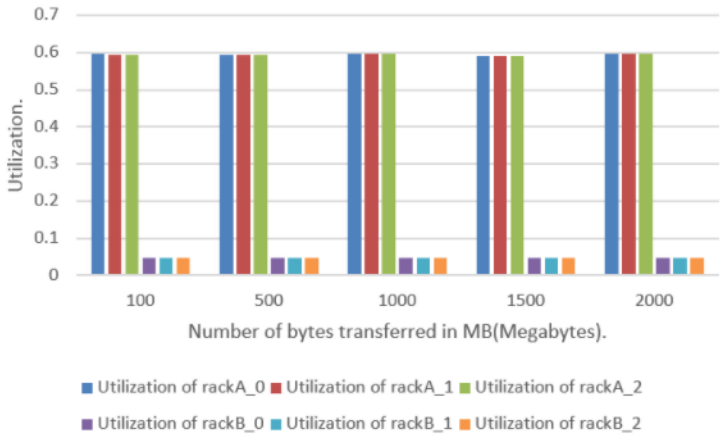


Figure 5.25: Utilization of each node in the iCanCloud simulation with bottleneck link.

Figure 5.25 shows the utilization for all the nodes in the iCanCloud simulation with the bottleneck link in Figure 5.23.

The bandwidth for each of the three client nodes(`rackA_0`, `rackA_1`, `rackA_2`) connected to router0 and the the server nodes(`rackB_0`, `rackB_1`, `rackB_2`) connected to router1 is 4Mbps. The bandwidth between (router0 and router2, and router2 and router1) which is the bottleneck link in the simulation is 12Mbps. The difference in the bandwidth in the simulation is one of the reasons why the throughput of each node in Figure 5.23 is 1/3 of the total throughput a single node would have in the normal iCanCloud simulation in Figure 5.13.

5.6.2.3 Simulation for Assignment 1

This section gives an analysis of the throughput and utilization of the iCanCloud simulation shown in assignment 1 in section 5.8.1.

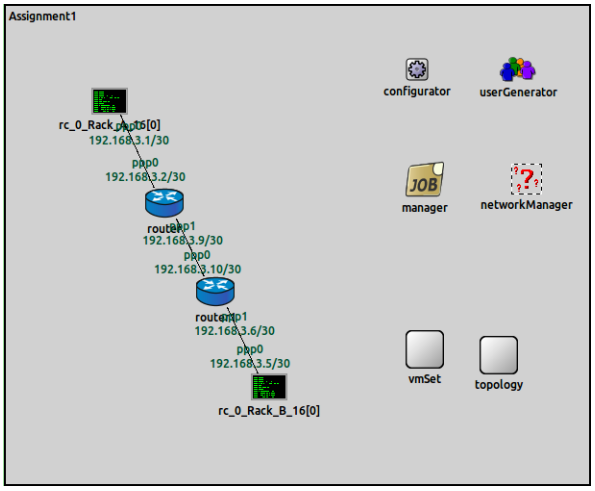


Figure 5.26: Run window for assignment 1 simulation.

Figure 5.26 shows the run window for the iCanCloud simulation created for assignment 1.

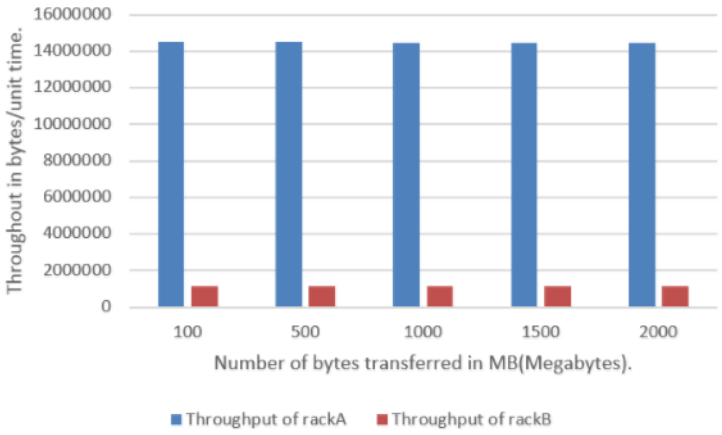


Figure 5.27: Throughput of assignment 1 simulation.

Figure 5.27 shows the throughput of the iCanCloud simulation created for assignment 1.

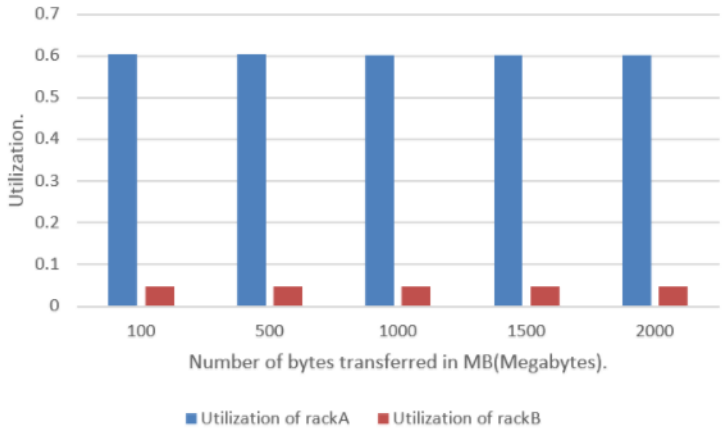


Figure 5.28: Utilization of assignment 1 simulation.

Figure 5.28 shows the utilization of the iCanCloud simulation created for assignment 1.

In this section the bandwidth used of all the channels used in the simulation shown in Figure 5.26 was 24Mbps.

5.6.2.4 Simulation for assignment 1 with bottleneck

This section gives an analysis of the throughput and utilization of a simulation similar to the one created for assignment 1 is used, but with a bottleneck link.

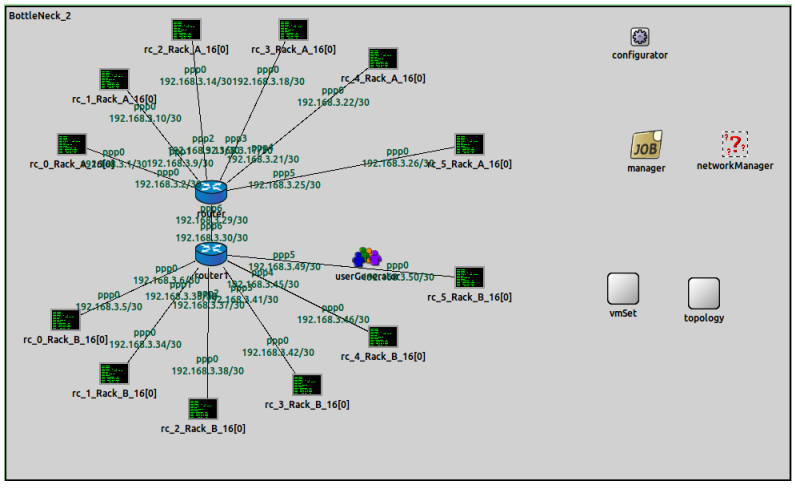


Figure 5.29: Run window for assignment 1 simulation with bottleneck link.

Figure 5.29 shows the run window for the assignment 1 simulation created with a bottleneck link. The bottleneck link in this simulation will be the connection between

the two routers as that is the only way a packet can be transferred from the client nodes to the server nodes.

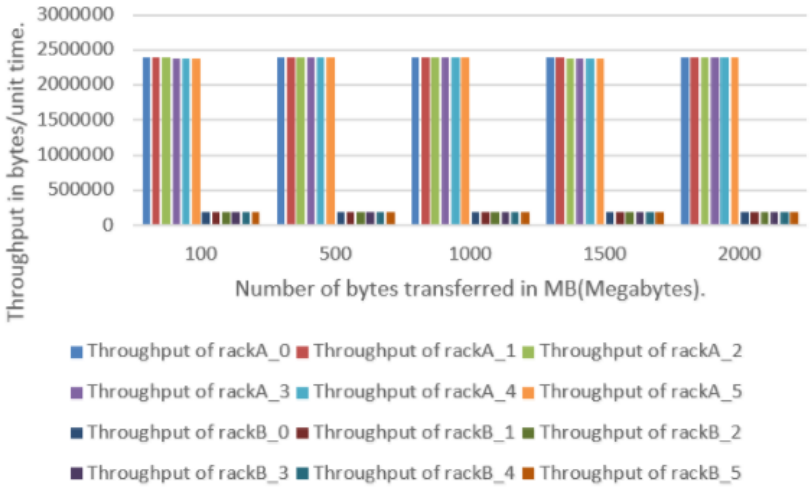


Figure 5.30: Throughput of assignment 1 simulation with bottleneck.

Figure 5.30 shows the throughput of the assignment 1 simulation with a bottleneck link.

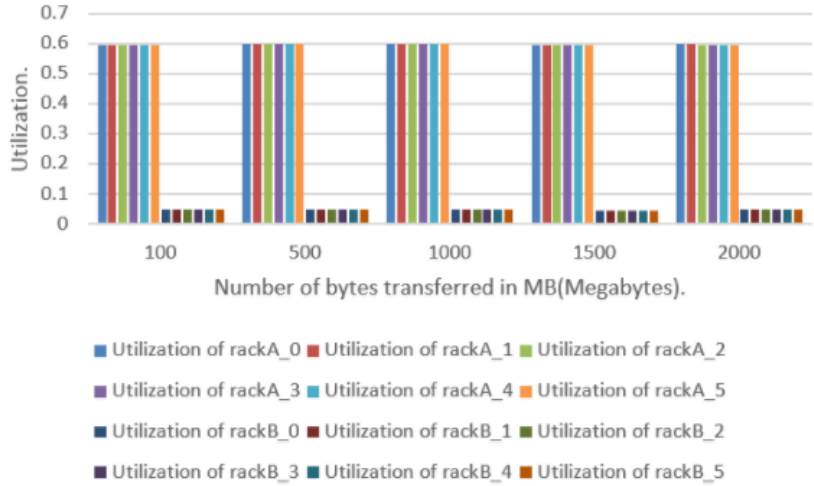


Figure 5.31: Utilization of assignment 1 simulation with bottleneck.

Figure 5.31 shows the utilization of the assignment 1 simulation with a bottleneck link.

In this section the bandwidth of the channel used for the bottleneck link between the two routers was 24Mbps and the bandwidth used for all the other channels used

to connect the client nodes to the first router(router0) and the server nodes used to connect to the second router(router1) was 4Mbps each.

The variation in the bandwidth for the channels used in the simulation is one of the reasons why the throughput for all the client nodes(`rackA_0`, `rackA_1`, `rackA_2`, `rackA_3`, `rackA_4` and `rackA_5`) and the server nodes(`rackB_0`, `rackB_1`, `rackB_2`, `rackB_3`, `rackB_4` and `rackB_5`) is so different. Also on comparing the results in this section with section 5.6.2.3 it can be seen that the throughput of all the nodes in this section is 1/6 the value of the throughput of the simulation used in the previous section.

5.6.2.5 DropTailQueue vs RED

In the analysis done in all the previous four sections, it was observed that there was a lot of difference in the throughput and utilization between all the client nodes and the server nodes. The reason for this is that in a router by default the queue implemented is the DropTailQueue.

```
**.ppp[*].queueType = "DropTailQueue" # in routers
**.ppp[*].queue.frameCapacity = 100  # in routers
```

Figure 5.32: DropTailQueue configuration.

Figure 5.32 shows the default configuration of a DropTailQueue in a router. The disadvantage of using DropTailQueue [2] is that it does not differentiate the network traffic from different sources, this simply means that if the queue in a router is full then the packets that are sent after will be dropped. This is the reason why the throughput and the utilization in the network is affected significantly for the all simulations.

To solve this problem the Random Early Detection (RED) [2] algorithm can be implemented in the router. The advantage of using RED is that it monitors the size of the queue in the router and based on that it takes action on the different packets i.e., either mark the packet or drop it. As RED helps in monitoring the queue size, it alters the queue size based on the congestion in the network and thereby avoids dropping packets that would affect the throughput or utilization of the network.

5.6.2.6 Simulation run with bad configurations

This section gives the throughput and utilization for the simulation in Figure 5.13 but with some bad configurations.

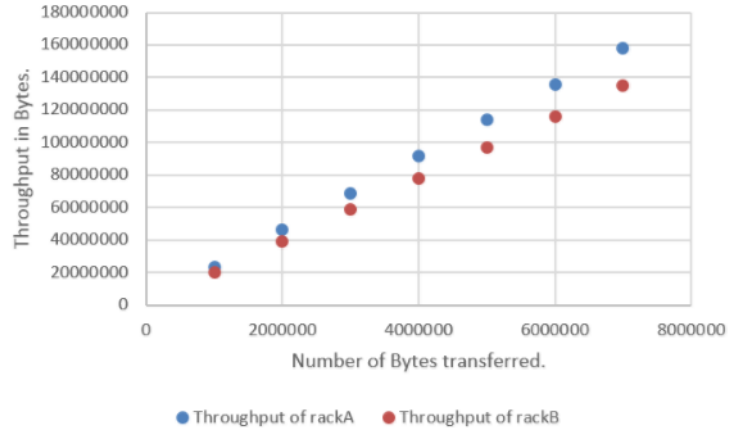


Figure 5.33: Throughput of rackA and rackB in the iCanCloud simulation in the first bad run.

Figure 5.33 shows the throughput for both the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation shown in Figure 5.13.

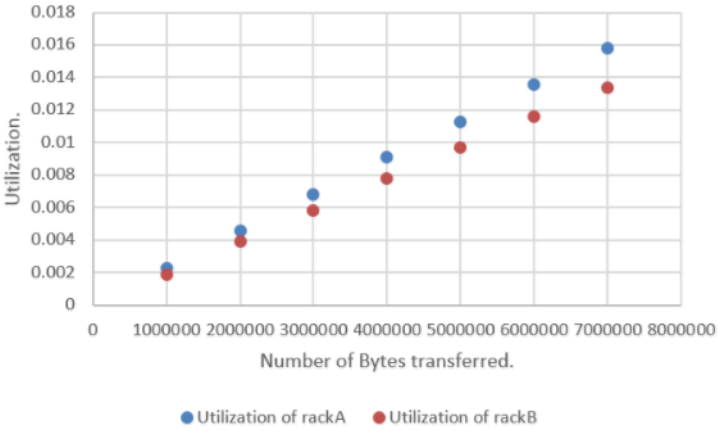


Figure 5.34: Utilization of rackA and rackB in the iCanCloud simulation in the first bad run.

Figure 5.34 shows the utilization for both the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation shown in Figure 5.13.

One thing that can be noted is that both the throughput and the utilization for the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) is increasing as the number of bytes being transferred in the simulation is increasing. The reason for this is that, each run of the simulation had an increase in the number of events that it was run for, i.e. the first simulation run had 150000 events in it and the last simulation had 1050000 events in it and all the others had an increase in 150000 events each time the simulation was run.

Now let us consider what happens to the throughput and utilization of rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) when the bandwidth in the simulation remains the same and each run in the simulation has similar number of events.

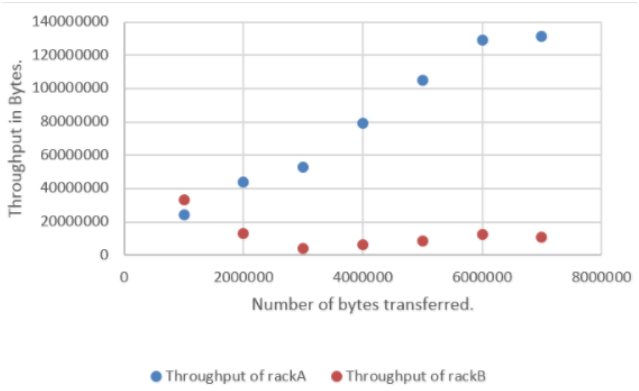


Figure 5.35: Throughput of rackA and rackB in the iCanCloud simulation in the second bad run.

Figure 5.35 shows the throughput for both the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation shown in Figure 5.13.

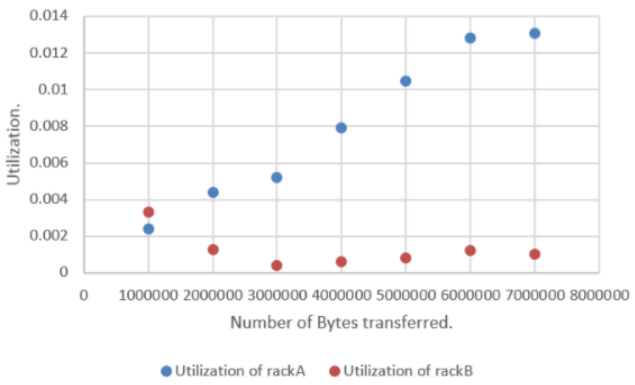


Figure 5.36: Utilization of rackA and rackB in the iCanCloud simulation in the second bad run.

Figure 5.36 shows the utilization for both the rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation shown in Figure 5.13.

From Figure 5.35 and 5.36 it can be seen that when the simulation is run with similar configurations there can be a lot difference in the throughput and utilization for both rackA(`rc_0_Rack_A_16[0]`) and rackB(`rc_1_Rack_B_16[1]`) in the iCanCloud simulation.

The bandwidth used for the simulation in this section is 10Gbps. The reason for seeing so much difference in the throughput and utilization for the analysis done in this section is:

- The simulation was not run completely i.e., each time the simulation was run for different amount of time.
- Also the bandwidth was so high and the number of bytes being transferred is so low that the utilization of the node will never increase, so the throughput of all the nodes will not be correct.

This section gives an example of what is obtained if the simulation is not configured properly and also if the simulation is not run completely each time.

5.6.3 Strengths

- Using TCP/IP ensures that, only after the three-way handshaking process is complete and a reliable connection is established between the nodes the packet

transfer process will begin.

- Because of using TCP/IP, the connection established will be reliable which might not be in the case if UDP was used.
- Once a connection is established, the connection closes only after the packet transfer process is complete.
- Once a packet transfer process begins, the packet will not be lost in the network which might happen in the case of a wireless network.

5.6.4 Weakness

- Because of the wired connections the size of the network is limited.
- If a link fails no packet transfer can take place.
- If the three-way handshaking process does not complete properly no packet transfer takes place.
- The simulation environment does not have support for having a wireless connection between the nodes.
- Only a single packet transfer process can take place at a time.
- There is no support for having multiple TCP/IP connections between nodes in the network for the proposed environment.

Based on the analysis, even tough the proposed environment has a simple topology, it has potential for being scaled up to large networks where each node might represent a rack consisting of multiple NodeVLs similar to the nodes used in the proposed environment, will give the same performance and will have similar results achieved from the analysis of the proposed environment. The main drawback to the analysis of the proposed environment is that there is no comparison of the simulated data with actual data captured through an actual network.

5.7 Challenges

A number of challenges were encountered in this project, including:

- It was difficult to figure out the simulation environment to use which was freely available for academic purposes.
- Understanding the designing and working of simulations in OMNeT++ was a bit challenging.
- It was important to understand the way TCP/IP was implemented in the INET framework included with OMNeT++.
- One of the most challenging parts of the project was to understand the working of iCanCloud due to the limited documentation available.
- As the proposed environment has a small network, it was difficult to analyze the efficiency of a larger network. This however can be dealt by extending the network in the future.

5.8 Sample Assignments

This section shows some sample assignments and how they can be solved using the project by someone new to the tool.

5.8.1 Assignment 1

This assignment will show how to create a simulation implementing TCP/IP in OMNeT++ using iCanCloud, with one client and server.

5.8.1.1 Creating a new simulation

- First to create a new simulation in OMNeT++ using iCanCloud, right clicking the simulations section in the object explorer of OMNeT++ the window shown in Figure 5.37 comes up. Here after entering the name for the new simulation click the next button.

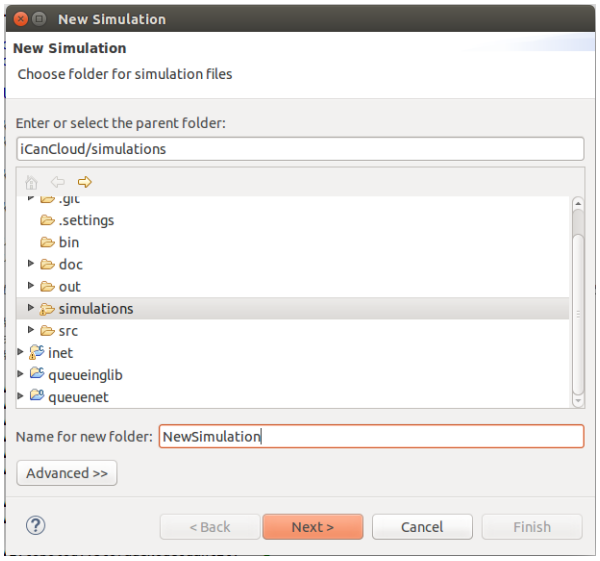


Figure 5.37: New Simulation Creation Window.

- On clicking the next button in Figure 5.37, Figure 5.38 comes up showing the files that will be present in the simulation. Clicking the finish button in Figure 5.38 will finish the creation of a new empty simulation.

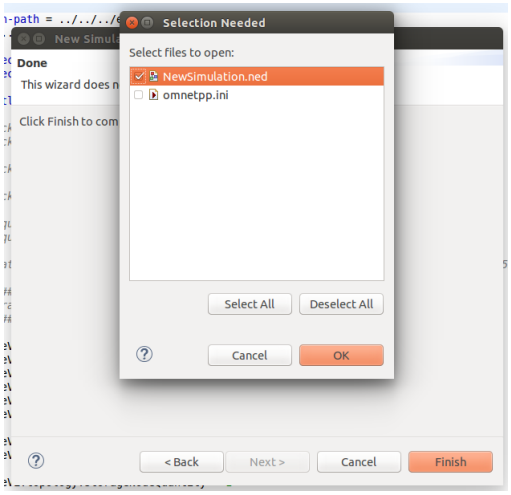


Figure 5.38: Finish Simulation Creation Window.

- The two files in the new simulation will be the NED file where all the components needed in the simulation will be included and an ini file where all parameters for the components needed in the simulation will be initialized.

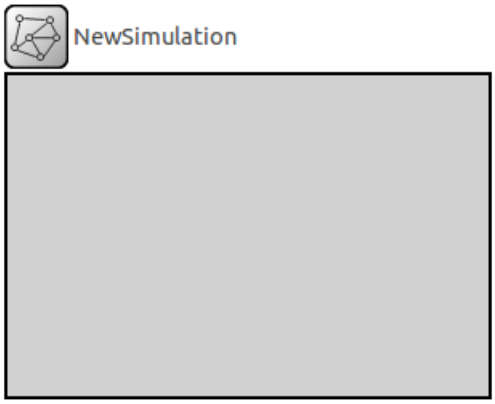


Figure 5.39: Empty NED file design view.

- A NED file has a design view and a source view. Figure 5.39 shows how the design view of an empty NED file looks like. Here all the components needed to design the network of the simulation will be placed and connected.

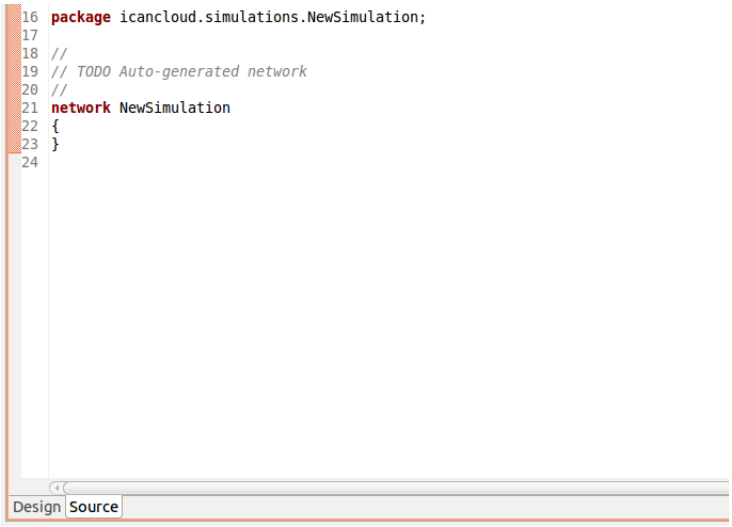


Figure 5.40: Empty NED file source view.

- Figure 5.40 shows an empty source view of a NED file. Here all the channels and connections for the components placed in the design view will be connected. At the bottom of this page a user can toggle between the design and source views.

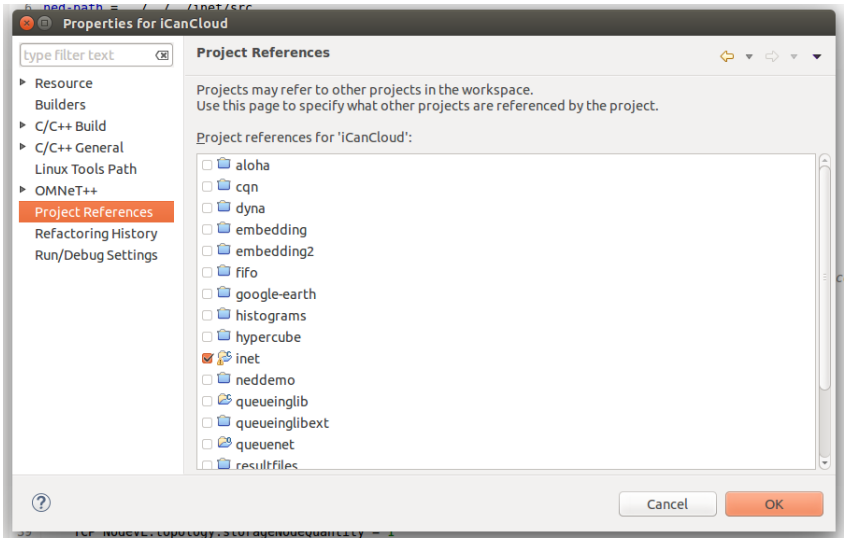


Figure 5.41: Setting the project preferences in OMNeT++ for iCanCloud.

- Now after the new simulation has been created, for implementing TCP/IP in iCanCloud, the INET package in OMNeT++ needs to be referenced.

- For referencing INET, on right clicking the iCanCloud folder in the object explorer in OMNeT++, the Figure 5.41 comes up. In this window the INET package needs to be checked for allowing iCanCloud simulations to use all applications present in INET.

5.8.1.2 TCP examples in INET

Now after the new simulation has been created, the next step will be to understand how TCP/IP is implemented in OMNeT++ using INET. For this purpose there are sample simulations available in INET.

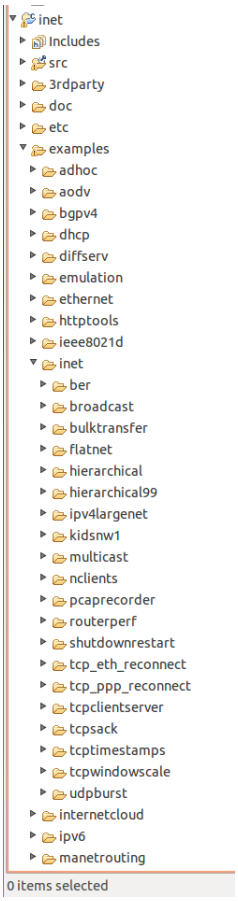


Figure 5.42: INET tcp examples.

Figure 5.42 shows the place in INET where the TCP examples can be found. For this assignment there are two tcp applications that will be used, TCPSessionApp and the TCPEchoApp.

5.8.1.3 Sample solution

This section provides all the components that will be used to complete this assignment.

- First for designing the simulation, use section 4.4 in chapter 4 to understand all the components that will be used in the simulation for this assignment.
- To understand the functionality of each component used in the simulation, use chapter 3.
- Next to understand the working of the simulation, use section 5.4 of chapter 5.
- For evaluating the simulation, use section 5.5 of chapter 5.
- For analyzing the packets transfer in the simulation, use section 5.6 of chapter 5.
- To capture the packets wireshark a packet capturing tool can be used.

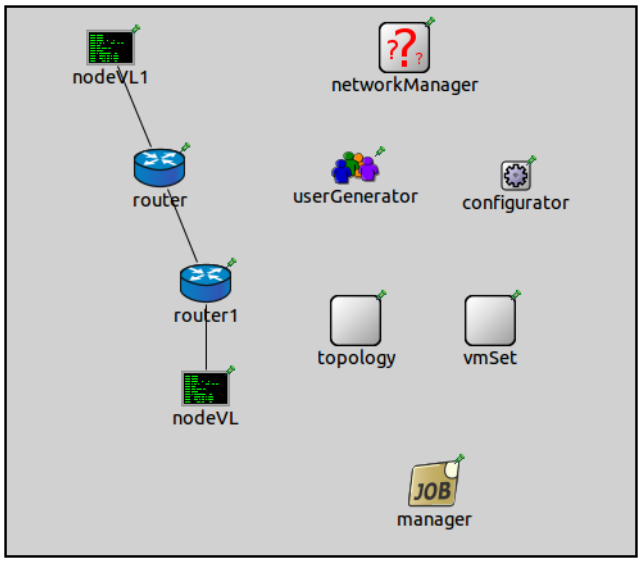


Figure 5.43: Assignment 1 simulation.

Figure 5.43 shows the simulation that will be created in this assignment.

5.8.1.4 Configuration for the simulation

In this assignment as there only a single client and server node, then a simple one-to-one scenario can be configured where,

- The client node(nodeVL1) in the simulation can be configured using the TCPSessionApp. This configuration can be found in Figure 4.13 of chapter 4 where the `rc_0_Rack_A_16*` needs to be replaced by nodeVL1 for this simulation.
- The server node(nodeVL) in the simulation can be configures using the TCPEchoApp. This configuration can be found in Figure 4.14 of chapter 4 where the `rc_1_Rack_B_16*` needs to be replaced by nodeVL for this simulation.

5.8.1.5 Roadblocks while solving assignment 1

There might be a few roadblocks that might be encountered while achieving the goal of the assignment like:

- Understanding how TCP/IP works and how is it implemented in OMNeT++. For this run and evaluate all the TCP related examples using the TCPSessionApp and the TCPEchoApp present in INET and also refer to chapter 4 to see how TCP/IP is designed in iCanCloud.
- How to design the network for this assignment simulation. For this refer to chapter 4.
- How to run the simulation. For this refer to section 5.1 of chapter 5.
- How to analyze the simulation. For this refer to section 5.6 of chapter 5.

5.8.1.6 What was achieved in this assignment and what is next!

On finishing this assignment, you will have learned how TCP/IP is implemented in OMNeT++ using INET and how to simulate TCP/IP in iCanCloud. The next assignment will show you how to enhance the simulation created in this assignment by implementing TCP/IP in a simulation using iCanCloud having multiple clients and servers in OMNeT++.

5.8.2 Assignment 2

This assignment shows how to create a simulation implementing TCP/IP in OMNeT++ using iCanCloud with six clients and four servers.

5.8.2.1 Creating the simulation

For creating the simulation in OMNeT++, use section 5.8.1.1 of assignment 1.

5.8.2.2 TCP application used

For the type of TCP application that can be used section 5.8.1.2 of assignment can be used to study the TCP applications present in INET. **As a hint**, in the case where multiple clients and servers are involved in the simulation, the TCPBasicClientApp and the TCPGenericSrvApp can also be used. To understand how these two applications work and how they are implemented section 4.3 of chapter 4 can be referred.

5.8.2.3 Sample solution

- First for designing the simulation, use section 4.4 in chapter 4 as a basis to understand all the components that will be used in the simulation for this assignment.
- To understand the functionality of each component used in the simulation, use chapter 3.
- Next to understand the working of the simulation, use section 5.4 of chapter 5.
- For evaluating the simulation, use sections 5.5 of chapter 5.
- For analyzing the packets transfer in the simulation, use section 5.6 of chapter 5.
- To capture the packets wireshark a packet capturing tool can be used.

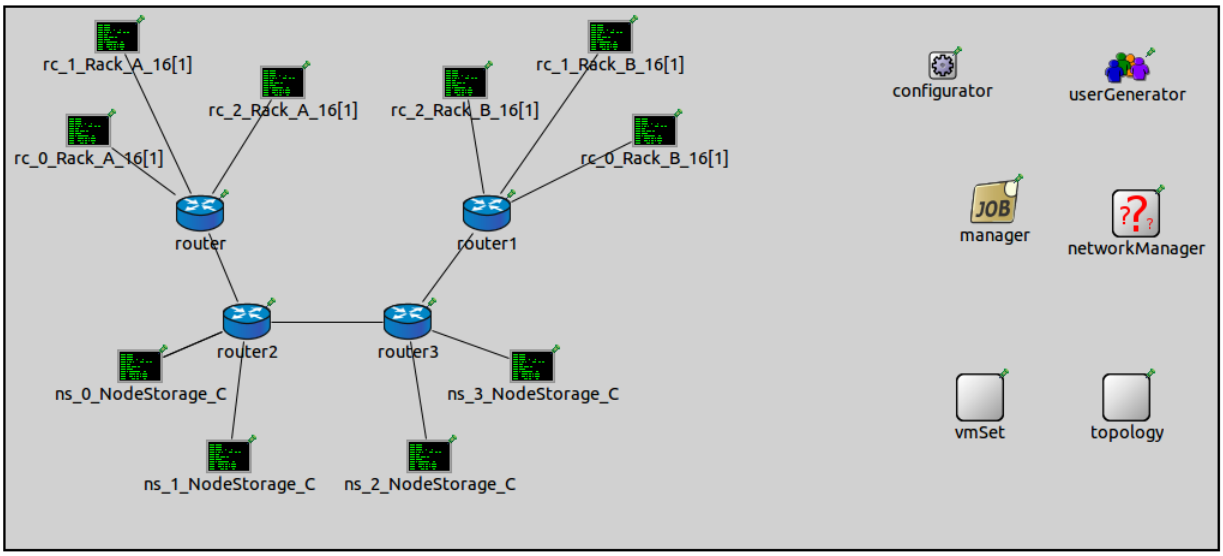


Figure 5.44: Assignment 2 simulation.

Figure 5.44 shows the simulation created in this assignment.

5.8.2.4 Configuration for the simulation

In this assignment as there are multiple clients and servers involved so there can be two scenarios that can be used to configure the simulation.

- If the scenario for configuring is one-to-one,
  - Then all client nodes named as different racks can be configured using the TCPSessionApp. This configuration can be found in Figure 5.46 in this chapter.
  - The server nodes named as different NodeStorage nodes can be configured using the TCPEchoApp. This configuration can be found in Figure 5.47 in this chapter.

```
connections allowunconnected:

    rc_0_Rack_A_16[0].pppg++ <--> Channel_0 <--> router.pppg++;
    rc_2_Rack_B_16[0].pppg++ <--> Channel_0 <--> router1.pppg++;

    rc_1_Rack_A_16[0].pppg++ <--> Channel_1 <--> router.pppg++;
    rc_1_Rack_B_16[0].pppg++ <--> Channel_1 <--> router1.pppg++;

    rc_2_Rack_A_16[0].pppg++ <--> Channel_2 <--> router.pppg++;
    rc_0_Rack_B_16[0].pppg++ <--> Channel_2 <--> router1.pppg++;

    router.pppg++ <--> Channel_3 <--> router2.pppg++;

    router2.pppg++ <--> Channel_4 <--> ns_0_NodeStorage_C.pppg++;
    router2.pppg++ <--> Channel_4 <--> ns_1_NodeStorage_C.pppg++;

    router2.pppg++ <--> Channel_5 <--> router3.pppg++;
    router3.pppg++ <--> Channel_5 <--> router1.pppg++;

    router3.pppg++ <--> Channel_6 <--> ns_2_NodeStorage_C.pppg++;
    router3.pppg++ <--> Channel_6 <--> ns_3_NodeStorage_C.pppg++;
```

Figure 5.45: Connections made for simulation in assignment 2.

Figure 5.45 shows the connections that were made in the NED file for this assignment.

```
**.numTcpApps = 1
**.rc_0_Rack_A_16*.tcpApp[*].typename = "TCPSessionApp"
**.rc_0_Rack_A_16*.tcpApp[0].active = true
**.rc_0_Rack_A_16*.tcpApp[0].localPort = -1
**.rc_0_Rack_A_16*.tcpApp[0].connectAddress = "ns_0_NodeStorage_C"
**.rc_0_Rack_A_16*.tcpApp[0].connectPort = 1000
**.rc_0_Rack_A_16*.tcpApp[0].tOpen = 0.2s
**.rc_0_Rack_A_16*.tcpApp[0].tSend = 0.4s
**.rc_0_Rack_A_16*.tcpApp[0].sendBytes = 7000000B
**.rc_0_Rack_A_16*.tcpApp[0].sendScript = ""
**.rc_0_Rack_A_16*.tcpApp[0].tClose = 25s
**.rc_0_Rack_A_16[*].tcpApp[*].dataTransferMode = "object"

**.rc_1_Rack_A_16*.tcpApp[*].typename = "TCPSessionApp"
**.rc_1_Rack_A_16*.tcpApp[0].active = true
**.rc_1_Rack_A_16*.tcpApp[0].localPort = -1
**.rc_1_Rack_A_16*.tcpApp[0].connectAddress = "ns_1_NodeStorage_C"
**.rc_1_Rack_A_16*.tcpApp[0].connectPort = 1000
**.rc_1_Rack_A_16*.tcpApp[0].tOpen = 0.2s
**.rc_1_Rack_A_16*.tcpApp[0].tSend = 0.4s
**.rc_1_Rack_A_16*.tcpApp[0].sendBytes = 7000000B
**.rc_1_Rack_A_16*.tcpApp[0].sendScript = ""
**.rc_1_Rack_A_16*.tcpApp[0].tClose = 25s
**.rc_1_Rack_A_16[*].tcpApp[*].dataTransferMode = "object"

**.rc_2_Rack_A_16*.tcpApp[*].typename = "TCPSessionApp"
**.rc_2_Rack_A_16*.tcpApp[0].active = true
**.rc_2_Rack_A_16*.tcpApp[0].localPort = -1
**.rc_2_Rack_A_16*.tcpApp[0].connectAddress = "ns_0_NodeStorage_C"
**.rc_2_Rack_A_16*.tcpApp[0].connectPort = 1000
**.rc_2_Rack_A_16*.tcpApp[0].tOpen = 0.2s
**.rc_2_Rack_A_16*.tcpApp[0].tSend = 0.4s
**.rc_2_Rack_A_16*.tcpApp[0].sendBytes = 7000000B
**.rc_2_Rack_A_16*.tcpApp[0].sendScript = ""
**.rc_2_Rack_A_16*.tcpApp[0].tClose = 25s
**.rc_2_Rack_A_16[*].tcpApp[*].dataTransferMode = "object"
```

Figure 5.46: TCPSessionApp configurations for the assignment 2.

Figure 5.46 shows the TCPSessionApp configurations for all the client nodes that are connected to first router(router) shown in Figure 5.44. The same is done for the nodes that are connected to the second router(router1).

Figure 5.47 shows the TCPEchoApp configurations for all the server nodes in the simulation made in this assignment.

- If the scenario for configuring is Many-to-Many,
  - Then all client nodes named as different racks can be configured using the TCPBasicClientApp. This configuration can be found in Figure 4.7 of

```
**.ns_0_NodeStorage_C.tcpApp[*].typename = "TCPEchoApp"
**.ns_0_NodeStorage_C.tcpApp[0].localPort = 1000
**.ns_0_NodeStorage_C.tcpApp[0].echoFactor = 2.0
**.ns_0_NodeStorage_C.tcpApp[0].echoDelay = 0
**.ns_0_NodeStorage_C.tcpApp[*].dataTransferMode = "object"

**.ns_1_NodeStorage_C.tcpApp[*].typename = "TCPEchoApp"
**.ns_1_NodeStorage_C.tcpApp[0].localPort = 1000
**.ns_1_NodeStorage_C.tcpApp[0].echoFactor = 2.0
**.ns_1_NodeStorage_C.tcpApp[0].echoDelay = 0
**.ns_1_NodeStorage_C.tcpApp[*].dataTransferMode = "object"

**.ns_2_NodeStorage_C.tcpApp[*].typename = "TCPEchoApp"
**.ns_2_NodeStorage_C.tcpApp[0].localPort = 1000
**.ns_2_NodeStorage_C.tcpApp[0].echoFactor = 2.0
**.ns_2_NodeStorage_C.tcpApp[0].echoDelay = 0
**.ns_2_NodeStorage_C.tcpApp[*].dataTransferMode = "object"

**.ns_3_NodeStorage_C.tcpApp[*].typename = "TCPEchoApp"
**.ns_3_NodeStorage_C.tcpApp[0].localPort = 1000
**.ns_3_NodeStorage_C.tcpApp[0].echoFactor = 2.0
**.ns_3_NodeStorage_C.tcpApp[0].echoDelay = 0
**.ns_3_NodeStorage_C.tcpApp[*].dataTransferMode = "object"
```

Figure 5.47: TCPEchoApp configurations for the assignment 2.

chapter 4 where the (client) needs to be replaced by the rack names for this simulation.

– The server nodes named as different NodeStorage nodes can be configured using the TCPGenericSrvApp. This configuration can be found in Figure 4.14 of chapter 4 where the (server) needs to be replaced by NodeStorage nodes for this simulation.

5.8.2.5 Roadblocks while solving assignment 2

There might be a few roadblocks that might be encountered while achieving the goal of the assignment like:

- Understanding how TCP/IP works and how is it implemented in OMNeT++. For this run and evaluate all the tcp related examples present in INET using the TCPBasicClientApp and the TCPGenericsSrvApp and also refer to chapter 4 to see how TCP/IP is designed in iCanCloud.
- How to design the network for this assignment simulation. For that refer to chapter 4. This will help to see what extra nodes are required to achieve the desired simulation.
- How to run the simulation. For this refer to section 5.1 of chapter 5.
- How to analyze the simulation. For this refer to section 5.6 of chapter 5.

5.8.2.6 What was achieved in this assignment and what is next!

On finishing this assignment, you will have learned how to simulate TCP/IP in OMNeT++ using iCanCloud for a network with six clients and four servers. The next assignment will show how to enhance the simulation created in this assignment by implementing TCP/IP in a simulation using iCanCloud having multiple racks in OMNeT++.

5.8.3 Assignment 3

This assignment shows how to create a simulation implementing TCP/IP in OMNeT++ using iCanCloud with multiple racks.

5.8.3.1 Creating the simulation

For creating the in OMNeT++, use section 5.8.1.1 of assignment 1.

5.8.3.2 TCP application used

For the type of TCP application that can be used section 5.8.1.2 of assignment can be used to study the TCP applications present in INET. **As a hint**, in the case where multiple racks are involved in the simulation, the TCPBasicClientApp and the TCPGenericSrvApp can be used. To understand how these two applications work and how they are implemented section 4.3 of chapter 4 can be referred.

5.8.3.3 Sample solution

- First for designing the simulation, use section 4.4 in chapter 4 as a basis to understand all the components that will be used in the simulation for this assignment.
- To understand the functionality of each component used in the simulation, use chapter 3.
- Next to understand the working of the simulation, use section 5.4 of chapter 5.
- For evaluating the simulation, use sections 5.5 of chapter 5.
- For analyzing the packets transfer in the simulation, use section 5.6 of chapter 5.

- To capture the packets wireshark a packet capturing tool can be used.

This solution is similar to previous two assignments, there will be some more work involved in this assignment with the designing of the simulation as there are racks involved, but each rack it comprised of multiple nodes, which are the same nodes used in the first two assignments.

For evaluating the simulation, the efficiency of the racks can be checked in cases where a large number of packets are being transferred. Also the throughput of each rack can be analyzed when different number of packets are being transferred in the network.

Also, for the analysis of the simulation, there will a large number of packets involved. So for the analysis, each rack can be responsible for different tasks in the simulation, like:

- Some racks can be used as the clients.
- Some racks can be used as servers.
- One rack can be responsible for storing the excess packets in the network, or for storing the extra requests for packets that have not been accepted by any other client or server racks.
- One rack can be used as a backup, if in any situation any of the client or the server racks goes down.

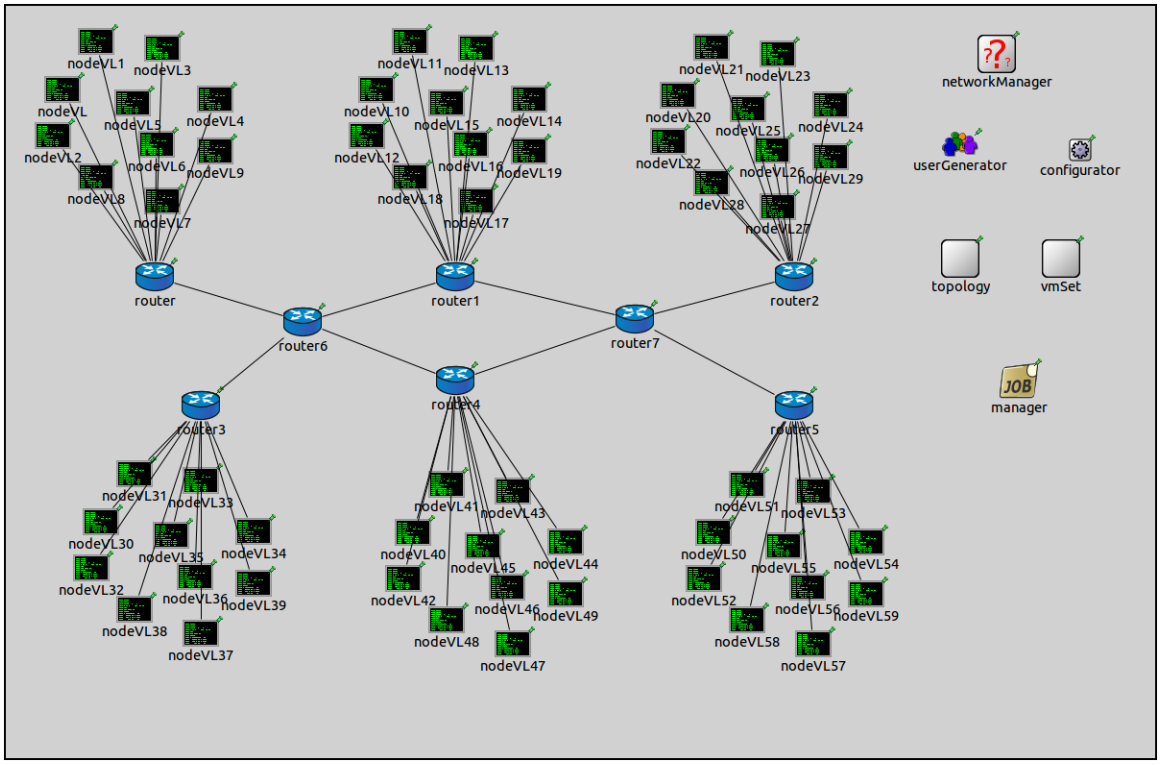


Figure 5.48: Assignment 3 simulation.

Figure 5.48 shows the simulation that will be created in this assignment. In the simulation, all the nodes connected to one single router comprise of a rack.

5.8.3.4 Configurations of the simulation

Even though the scope of this assignment is for the future, there are some parts of the project that can be used as a basis for configuring the simulation in this assignment.

- If the one-to-one scenario is selected,
  - Then all client nodes named as different racks can be configured using the TCPSessionApp. This configuration can be found in Figure 5.46 in this chapter.
  - The server nodes named as different racks can be configured using the TCPEchoApp. This configuration can be found in Figure 5.47 in this chapter.
- If the Many-to-Many scenario is selected,

- Then all client nodes named as different racks can be configured using the TCPBasicClientApp. This configuration can be found in Figure 4.7 of chapter 4 where the (client) needs to be replaced by the rack names for this simulation.
- The server nodes named as different racks can be configured using the TCPGenericSrvApp. This configuration can be found in Figure 4.14 of chapter 4 where the (server needs to be replaced by rack names for this simulation.

In both the scenarios a decision needs to be made as to how many client nodes will be present and how many server nodes will be present in the simulation.

5.8.3.5 Roadblocks while solving assignment 3

There might be a few roadblocks that might be encountered while achieving the goal of the assignment like:

- Understanding how TCP/IP works and how is it implemented in OMNeT++. For this run and evaluate all the tcp related examples present in INET using the TCPBasicClientApp and the TCPGenericsSrvApp and also refer to chapter 4 to see how TCP/IP is designed in iCanCloud.
- How to design the network for this assignment simulation. For that refer to chapter 4. This will help to see what extra nodes are required to achieve the desired simulation. Also refer to the sample solution to see how each rack will be designed in the simulation.
- How to run the simulation. For this refer to section 5.1 of chapter 5.
- How to analyze the simulation. For this refer to section 5.6 of chapter 5. Also refer to the sample solution for some ideas that can be used for analyzing the simulation.

5.8.3.6 What was achieved in this assignment and whats next!

On finishing this assignment, you will have learned how to simulate TCP/IP in OMNeT++ using iCanCloud for a network with multiple racks. Next assignment will show how to enhance the simulations created in the previous 3 assignments by incorporating a simple queue in the network.

5.8.4 Assignment 4

This assignment will show how to create a simulation implementing TCP/IP using a queue in OMNeT++ using iCanCloud.

5.8.4.1 Creating the simulation

For creating the in OMNeT++, use section 5.8.1.1 of assignment 1. For using a queue in the simulation, there is package quenet in OMNeT++ for that purpose. For using queuenet in the simulation another reference along with inet will be added to the simulation which is the queueinglib reference in the project reference section shown in Figure 5.41.

5.8.4.2 Queue implementation

For implementing a queue, there are some examples in OMNeT++ that can be referred to see how queues are implemented in the simulation.

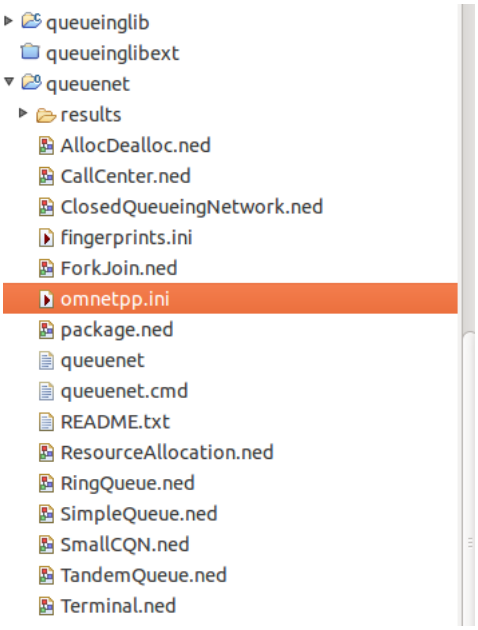


Figure 5.49: Quenet examples

Figure 5.49 shows the section in the project explorer in OMNeT++ where examples of how queues are implemented in a simulation can be found.

5.8.4.3 Scope of the assignment

Based on the understanding of the simulations created in the first three assignments, this assignment has a lot of scope for extending the proposed simulation environment in the future.

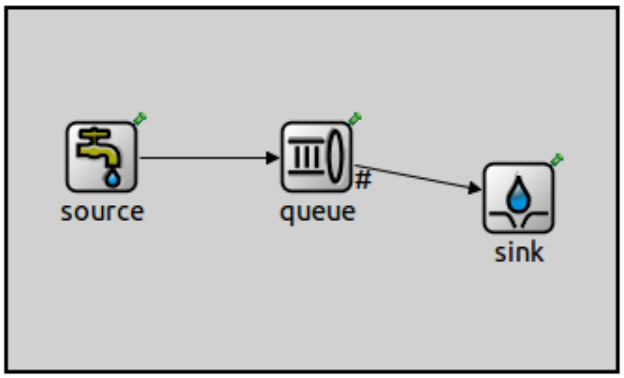


Figure 5.50: Simple Queue simulation.

Figure 5.50 shows a sample simulation of a simple queue in OMNeT++.

5.8.4.4 What was achieved in this assignment and what is next!

This assignment gave a breif overview of how a queue is simulated in OMNeT++. On implementing a queue in simulation with an implementation of TCP/IP in OMNeT++ using iCanCloud, this assignment can have a lot of scope in future where a queue can be implemented in a simulation with multiple racks.

5.9 Debugging

One very important task in creating simulations, is the ability to be able to debug the simulation. Fortunately, there are some inbuilt tools in OMNeT++ that help with this task, like:

- First for running the simulation, in the project explorer on right clicking the ini file before the simulation starts there is an option where the simulation can run in the debug mode instead of the normal run mode.
- Before starting the simulation and running in the debug mode, some configurations for debugging the simulation can be altered in the debug configuration window.

- Figure 5.51 shows the debug configurations window. Here some settings can be altered to debug the simulation, like:
  - Which run number of the simulation should the debugging start from.
  - Which ini file should be included for the debug process.

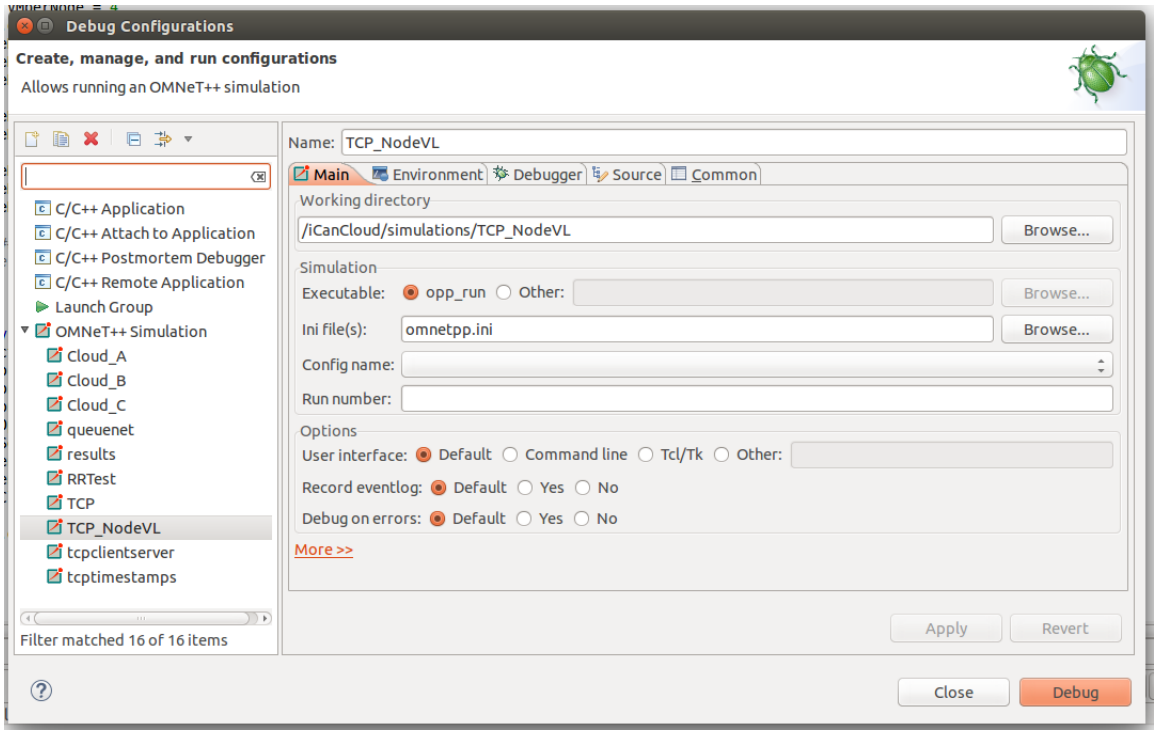


Figure 5.51: Debug configurations window.

- Another method that is a little more time consuming but can be very useful for debugging the simulation is by using the step button in the simulation window to step through the simulation by analyzing each event taking place while running the simulation.

Figure 5.52: Step button in simulation run window.

- Figure 5.52 shows the step button in the simulation run window.

- The advantage of using this method for debugging, is that while stepping through the simulation if there is any error, then it can be analyzed as to where in the simulation the error came from and what was the reason for that error.

5.10 Summary

Simulation Number	Description
Simulation 1	Simulation with one client and server.
Simulation 2	Simulation with multiple clients and servers.
Simulation 3	iCanCloud simulation with one client and two servers.

Table 5.4: All simulations created in this project.

This chapter gave an overview of the working of the three simulations used in this project along with an evaluation of all the simulations. Then an analysis of the traffic generated in the simulations along with some strengths and weaknesses of the simulations, and some limitations of the project. Finally some sample assignments were given. Next chapter will describe some future work to extend this project further and conclude this project.

Chapter 6

Future Work and Conclusion

6.1 Future Work

There are many things that can done in this project in the future, similar to the iCanCloud simulation in Figure 5.13, where there were only one client and two servers, there can be multiple clients and servers in the simulation.

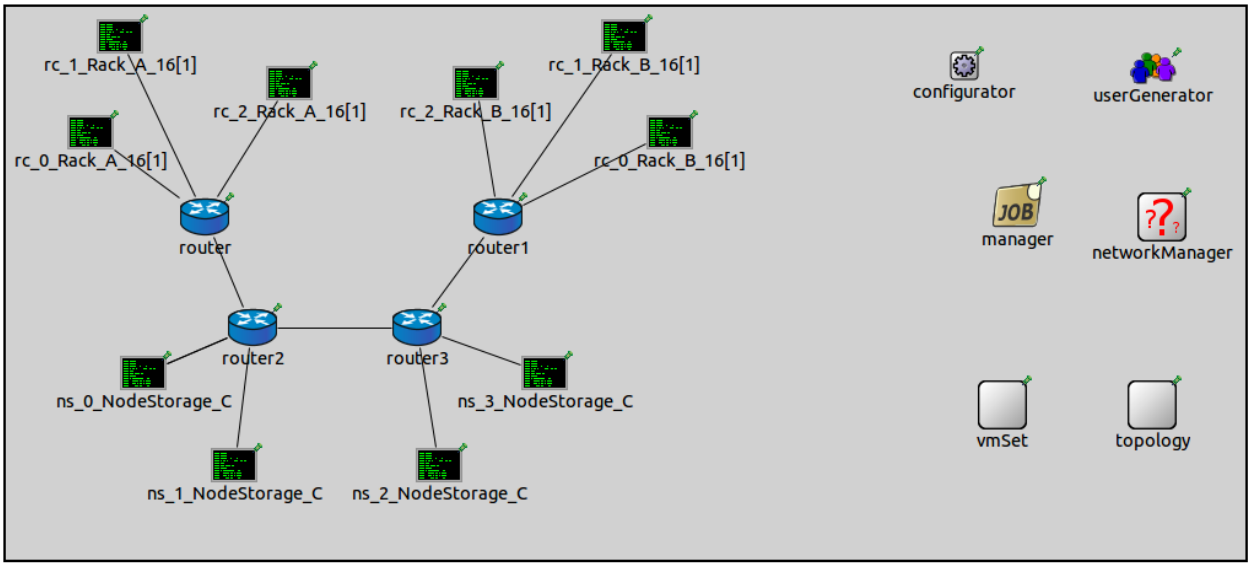


Figure 6.1: Simulation with multiple clients and servers in iCanCloud.

Once the simulation in Figure 6.1 works successfully with TCP, then the next thing can be to actually have a queue model based simulation to simulate TCP in iCanCloud.

Figure 6.2 shows a simple queue-based simulation in OMNeT++. This simulation

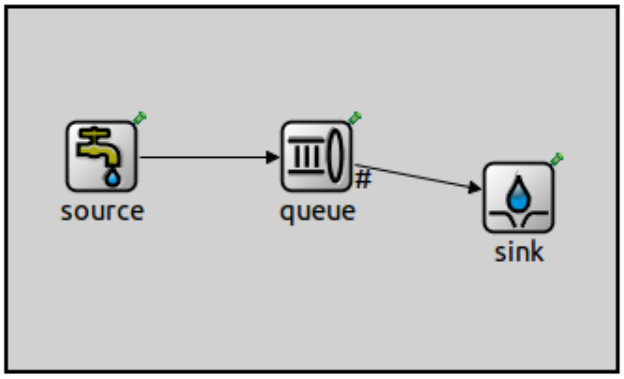


Figure 6.2: Simple Queue simulation in OMNeT++.

helps in visualizing how a queue based simulation for iCanCloud consisting of multiple clients and servers might look like. The advantage of having a queue implemented along with TCP in a cloud environment is:

- The system will be such that no request for data transfer will be left unhandled, i.e. if one node sends a request for data transfer that request will be stored in a queue and when the queue reads that request it will be handled.
- No node will be left idle in the network if there is data in the queue that needs to be transferred it will be sent to the idle node.
- If a queue is full and cannot accept any request further, any additional request will be stored in a waiting queue without discarding the request from the network.
- If a node is already processing data, then any further data that needs to be transferred is stored in a queue until that node can accept any data further.

Another possible approach to this project in the future, could be incorporating Virtual Reality to observe and analyze the simulations. By using Virtual Reality, a person would be able to visualize the network simulating traffic and thereby analyze exactly how the packets are being transferred in a large network.

The advantage of using Virtual Reality would be in a case where there is any network failure or loss of packets then it would be possible to locate the cause of the defect in the network by visualizing it in three-dimensional space. Using Virtual

Reality would help in identifying the exact cause of the defect, which would be helpful to rectify the error quickly without having to debug the entire network manually.

If the size of the network was to be increased, then with Virtual Reality additional racks could be added in the network and their behaviour could be visualized before actually modifying the simulation.

6.2 Conclusion

The purpose of this project was to build a simulation environment consisting of a network layer and to observe network traffic in iCanCloud. Also to provide sample assignments that can be solved by anyone unfamiliar with the tool using the documentation and implementation of the created simulations in the project. To observe network traffic in OMNeT++, TCP/IP was implemented. For simulating proposed environment iCanCloud was used along with OMNeT++ and INET.

For designing the required environment, first simulations with an implementation of TCP/IP were designed. Then after successfully simulating network traffic for both these situations, the final simulation using iCanCloud with the implementation of TCP/IP was designed.

Using TCP/IP stresses the importance of having a reliable connection between any two nodes before any information can be transferred between them. And using OMNeT++ with a combination of INET and iCanCloud helped in creating visualizations which further addressed the purpose of the project.

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