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**C22020-Lalit Chaudhari**

# Deccan Education Society's Navinchandra Mehta Institute of Technology and Development

## C E R T I F I C A T E

This is to certify that **Mr. Lalit Narayan Chaudhari** of M.C.A. Semester II with Roll No.**C22020** has complete **14** practicals of **MCAL26 – Networking with Linux** under my supervision in this college during the year 2022-2023.

| CO | R1: Journal | R2: Performance during lab session | R3: Implementation using different problem solving techniques | R4: Mock Viva | Attendance |
|---|---|---|---|---|---|
| CO1 | | | | | |
| CO2 | | | | | |
| CO3 | | | | | |
| CO4 | | | | | |

Practical-in-charge

Head of Department

MCA Department
(NMITD)

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# Practical 1: Installing NS-3 in Ubuntu

**Network simulator** is a tool used for simulating the real world network on one computer by writing scripts in C++ or Python. Normally if we want to perform experiments, to see how our network works using various parameters. We don't have required number of computers and routers for making different topologies. Even if we have these resources it is very expensive to build such a network for experiment purposes.

So to overcome these drawbacks we used NS3, which is a discrete event network simulator for Internet. NS3 helps to create various virtual nodes (i.e., computers in real life) and with the help of various Helper classes it allows us to install devices, internet stacks, application, etc to our nodes.

Using NS3 we can create PointToPoint, Wireless, CSMA, etc connections between nodes. PointToPoint connection is same as a LAN connected between two computers. Wireless connection is same as WiFi connection between various computers and routers. CSMA connection is same as bus topology between computers. After building connections we try to install NIC to every node to enable network connectivity.

When network cards are enabled in the devices, we add different parameters in the channels (i.e., real world path used to send data) which are data-rate, packet size, etc. Now we use Application to generate traffic and send the packets using these applications.

Steps for installing NS-3 in Ubuntu

**Step 1:** Update the system

$ **sudo apt update**

**Step 2:** Prerequisites for installing NS-3

**$ sudo apt install build-essential autoconf automake libxmu-dev g++ python3 python3-dev pkg-config sqlite3 cmake python3-setuptools git qtbase5-dev qtchooser qt5-qmake qtbase5-dev-tools gir1.2-goocanvas-2.0 python3-gi python3-gi-cairo python3-pygraphviz gir1.2-gtk-3.0 ipython3 openmpi-bin openmpi-common openmpi-doc libopenmpi-dev autoconf cvs bzr unrar gsl-bin libgsl-dev libgslcblas0 wireshark tcpdump sqlite sqlite3 libsqlite3-dev libxml2 libxml2-dev libc6-dev libc6-dev-i386 libclang-dev llvm-dev automake python3-pip libxml2 libxml2-dev libboost-all-dev**

**Step 3 :**Now download the ns3 3.35 from https://nsnam.org

**Step 4 :** Copy the softwares from the Downloads/ folder to the home folder (in my case its /home/ns-3/)
Now extract both the versions using the GUI method.
Just right click and click "Extract Here"
Now we will install ns-3.35

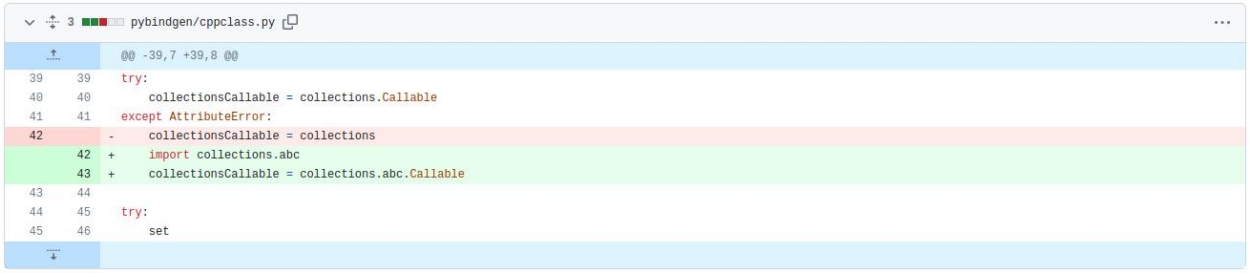
**Step 5 :**

$ cd

$ cd ns-allinone-3.35/

$ ./build.py --enable-examples --enable-tests

In case, if you get the following error pybindgen(ns3 module antenna)
Do this step and repeat the above step




We have installed two version of ns-3.35 successfully in Ubuntu

# Practical 2: Install NetAnim in Ubuntu

NetAnim is an offline network animator tool that now ships along with the ns-allinone-3.xx package.

It can animate the ns-3 network simulation using an XML trace file that is generated as an output during simulation.

So, the necessary steps for creating this XML trace file and setting its related attributes should be done in the ns-3 simulation code itself.

For a beginner who starts learning ns2, the animation that is created by NetAnim will be a more attractive factor in learning and understanding a simulation. Undoubtfully, each and every beginner of ns-3 will be very happy while seeing the first animator output of their simulation on NetAnim for the very first time. So let us enjoy seeing our first network animation on NetAnim.

## Steps to Install NetAnim

You can directly install NetAnim

Otherwise, you have to execute some commands but for this we need NS3 installed or compiled.

**Step1:** sudo apt-get install NetAnim

**Step2:** NetAnim file.xml

**Step3:** Select Xml File

**Step4:** Run the simulation by clicking, NS3 NetAnim successfully.

# Practical 3: Install Wireshark In Ubuntu

Wireshark is an open-source packet analyzer, which is used for education, analysis, software development, communication protocol development, and network troubleshooting.

It is used to track the packets so that each one is filtered to meet our specific needs. It is commonly called as a sniffer, network protocol analyzer, and network analyzer. It is also used by network security engineers to examine security problems.

Wireshark is a free to use application which is used to apprehend the data back and forth. It is often called as a free packet sniffer computer application. It puts the network card into an unselective mode, i.e., to accept all the packets which it receives

## Install WireShark

**Step 1:** Add the stable official PPA. To do this, go to terminal by pressing Ctrl+Alt+T and run:

**sudo add-apt-repository ppa:wireshark-dev/stable**

**Step 2:** Update the repository:

**sudo apt-get update**

**Step 3:** Install wireshark 2.0:

**sudo apt-get install wireshark**

**Step 4:** Run wireshark:

**sudo wireshark**

If you get a error couldn't run /usr/bin/dumpcap in child process: Permission Denied. go to the terminal again and run:

**sudo dpkg-reconfigure wireshark-common**

Say YES to the message box. This adds a wireshark group. Then add user to the group by typing

**sudo adduser $USER wireshark**

## Practical 4: Program to simulate traffic between two nodes

**Code:**

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 */

#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/internet-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/applications-module.h"
//netanimation
#include "ns3/netanim-module.h"
#include "ns3/mobility-module.h"
```

```
// Default Network Topology
//
//       10.1.1.0
// n0 -------------- n1
//    point-to-point
//

using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("FirstScriptExample");

int
main (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);
  cmd.Parse (argc, argv);

  Time::SetResolution (Time::NS);
  LogComponentEnable ("UdpEchoClientApplication", LOG_LEVEL_INFO);
  LogComponentEnable ("UdpEchoServerApplication", LOG_LEVEL_INFO);

  NodeContainer nodes;
  nodes.Create (2);

  PointToPointHelper pointToPoint;
  pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
  pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));
```

```
NetDeviceContainer devices;
devices = pointToPoint.Install (nodes);

InternetStackHelper stack;
stack.Install (nodes);

Ipv4AddressHelper address;
address.SetBase ("10.1.1.0", "255.255.255.0");

Ipv4InterfaceContainer interfaces = address.Assign (devices);

UdpEchoServerHelper echoServer (9);

ApplicationContainer serverApps = echoServer.Install (nodes.Get (1));
serverApps.Start (Seconds (1.0));
serverApps.Stop (Seconds (10.0));

UdpEchoClientHelper echoClient (interfaces.GetAddress (1), 9);
echoClient.SetAttribute ("MaxPackets", UintegerValue (1));
echoClient.SetAttribute ("Interval", TimeValue (Seconds (1.0)));
echoClient.SetAttribute ("PacketSize", UintegerValue (1024));

ApplicationContainer clientApps = echoClient.Install (nodes.Get (0));
clientApps.Start (Seconds (2.0));
clientApps.Stop (Seconds (10.0));
```

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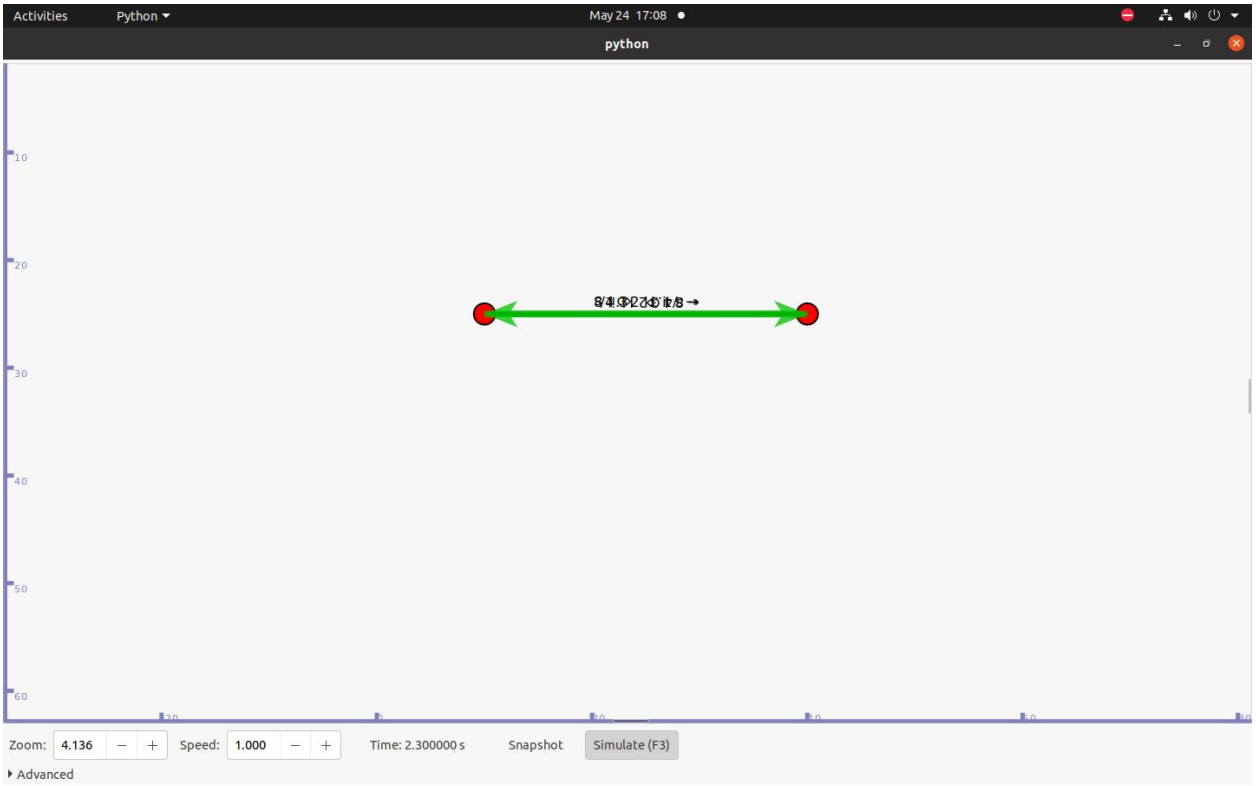
```
MobilityHelper mobility;
mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
mobility.Install(nodes);
AnimationInterface anim("first.xml");
AnimationInterface::SetConstantPosition(nodes.Get(0),10,25);
AnimationInterface::SetConstantPosition(nodes.Get(1),40,25);
anim.EnablePacketMetadata(true);
pointToPoint.EnablePcapAll("first");
Simulator::Run ();
Simulator::Destroy ();
return 0;
}
```

**OutPut:**



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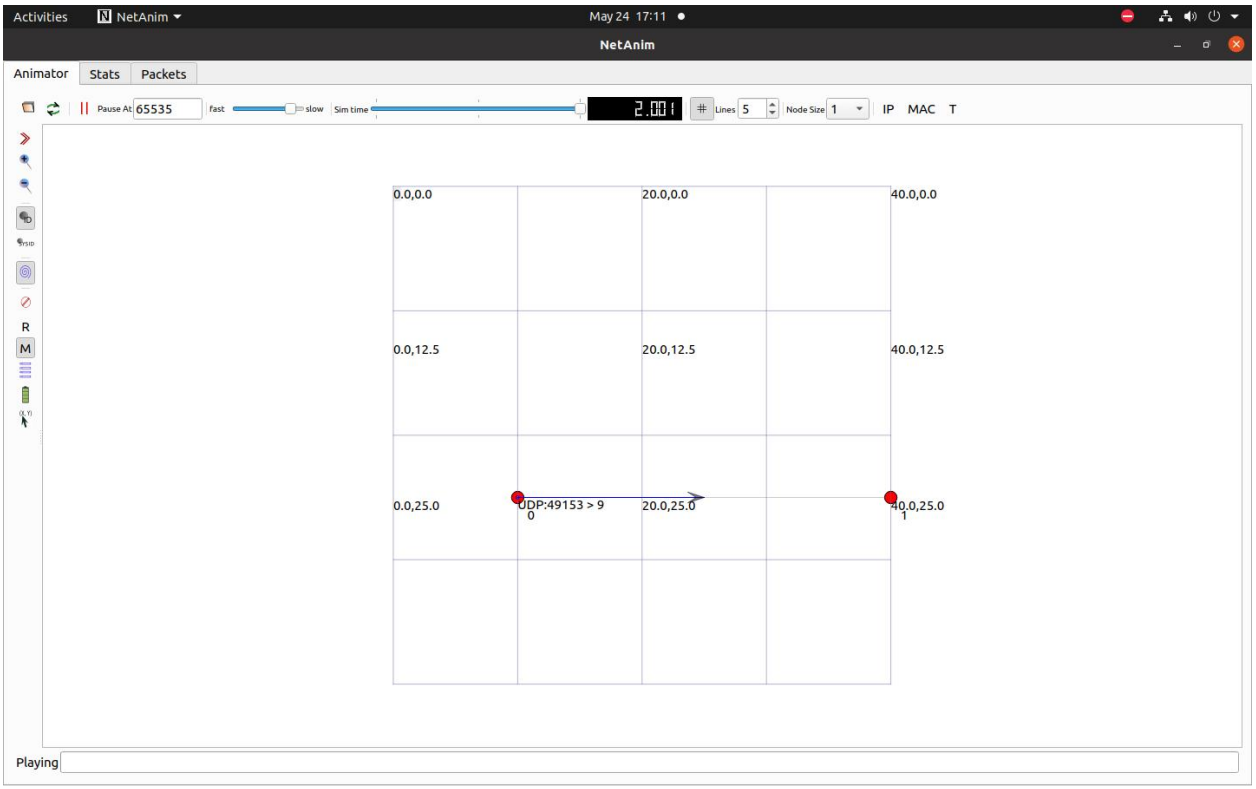
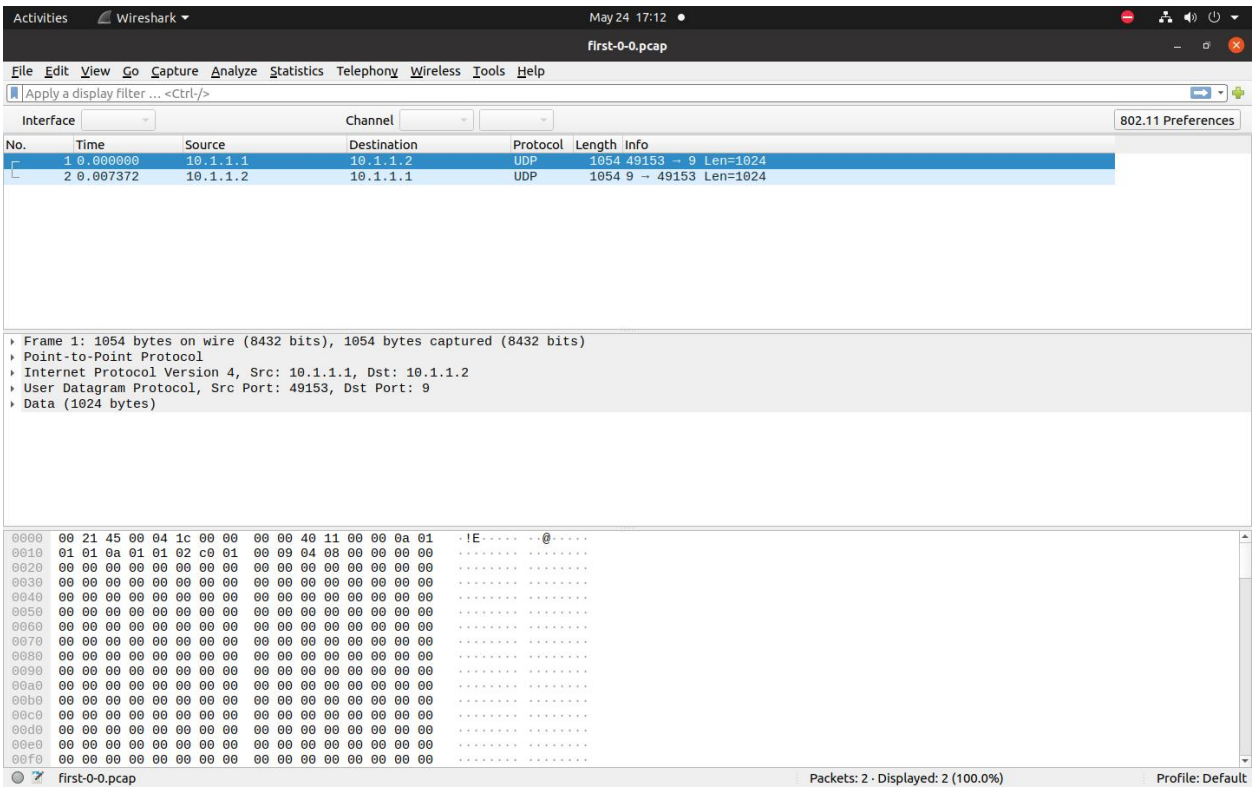
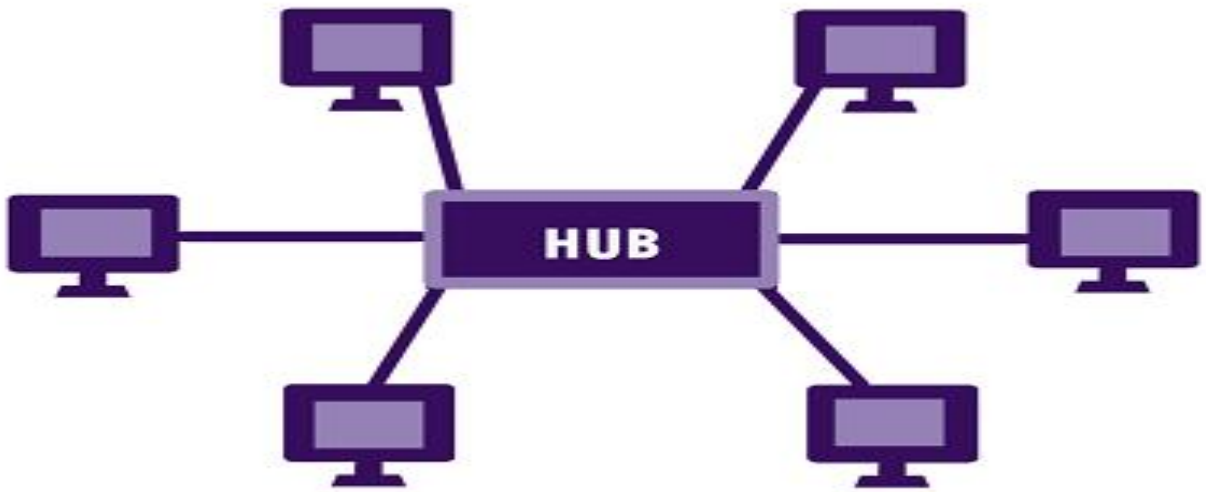


## Practical 5: Program to simulate star topology

A star topology, sometimes known as a star network, is a network topology in which each device is connected to a central hub. It is one of the most prevalent computer network configurations, and it's by far the most popular Network Topology. In this network arrangement, all devices linked to a central network device are displayed as a star.




**Code:**

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
```

```
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 *
 */

#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/netanim-module.h"
#include "ns3/internet-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/applications-module.h"
#include "ns3/point-to-point-layout-module.h"

// Network topology (default)
//
//        n2 n3 n4              .
//         \ | /                .
//          \|/                 .
//     n1--- n0---n5            .
//          /|\                 .
//         / | \                .
//        n8 n7 n6              .
//
```

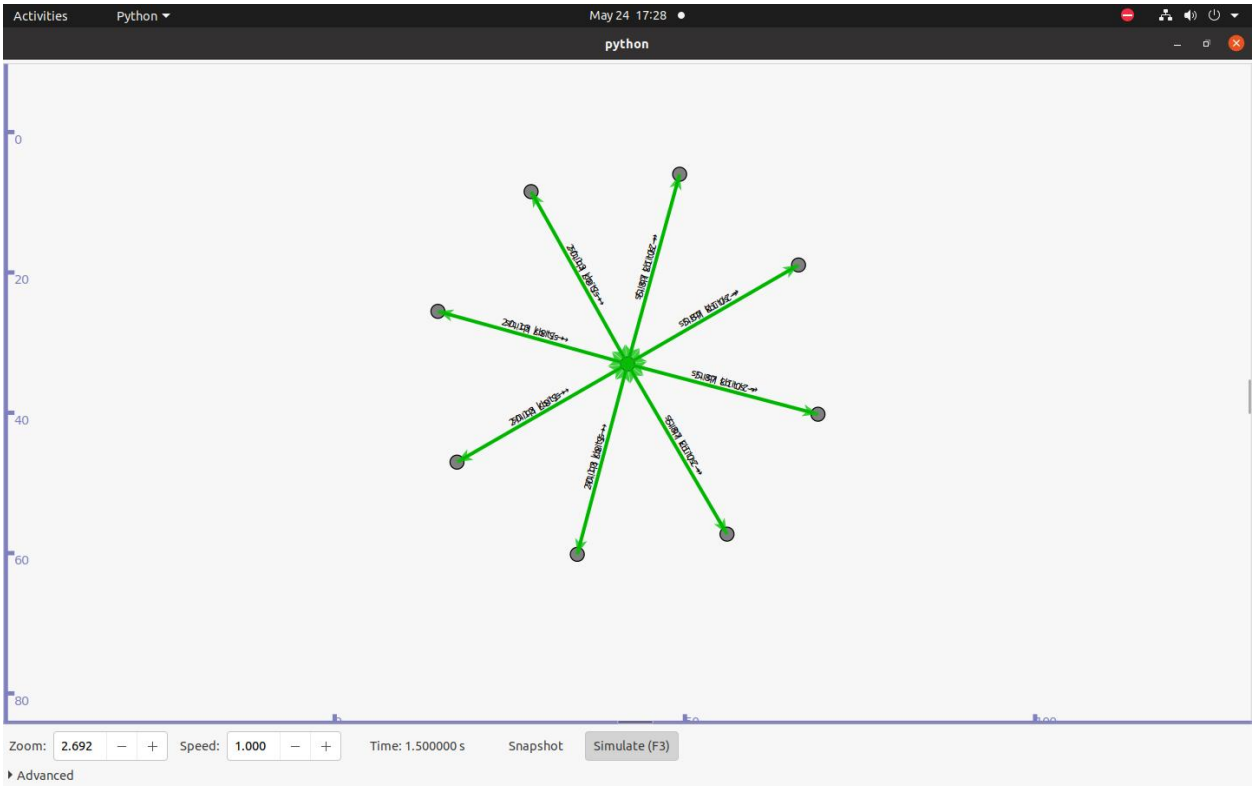
```
using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("Star");

int
main (int argc, char *argv[])
{

 //
 // Set up some default values for the simulation.
 //
 Config::SetDefault ("ns3::OnOffApplication::PacketSize", UintegerValue (137));

 // ??? try and stick 15kb/s into the data rate
 Config::SetDefault ("ns3::OnOffApplication::DataRate", StringValue ("14kb/s"));

 //
 // Default number of nodes in the star.  Overridable by command line argument.
 //
 uint32_t nSpokes = 8;

 CommandLine cmd;
 cmd.AddValue ("nSpokes", "Number of nodes to place in the star", nSpokes);
 cmd.Parse (argc, argv);

 NS_LOG_INFO ("Build star topology.");
 PointToPointHelper pointToPoint;
```

```
pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));
PointToPointStarHelper star (nSpokes, pointToPoint);

NS_LOG_INFO ("Install internet stack on all nodes.");
InternetStackHelper internet;
star.InstallStack (internet);

NS_LOG_INFO ("Assign IP Addresses.");
star.AssignIpv4Addresses (Ipv4AddressHelper ("10.1.1.0", "255.255.255.0"));

NS_LOG_INFO ("Create applications.");
//
// Create a packet sink on the star "hub" to receive packets.
//
uint16_t port = 50000;
Address hubLocalAddress (InetSocketAddress (Ipv4Address::GetAny (), port));
PacketSinkHelper packetSinkHelper ("ns3::TcpSocketFactory", hubLocalAddress);
ApplicationContainer hubApp = packetSinkHelper.Install (star.GetHub ());
hubApp.Start (Seconds (1.0));
hubApp.Stop (Seconds (10.0));

//
// Create OnOff applications to send TCP to the hub, one on each spoke node.
//
OnOffHelper onOffHelper ("ns3::TcpSocketFactory", Address ());
```

```
  onOffHelper.SetAttribute ("OnTime", StringValue
("ns3::ConstantRandomVariable[Constant=1]"));
  onOffHelper.SetAttribute ("OffTime", StringValue
("ns3::ConstantRandomVariable[Constant=0]"));


  ApplicationContainer spokeApps;


  for (uint32_t i = 0; i < star.SpokeCount (); ++i)
    {
      AddressValue remoteAddress (InetSocketAddress (star.GetHubIpv4Address (i),
port));
      onOffHelper.SetAttribute ("Remote", remoteAddress);
      spokeApps.Add (onOffHelper.Install (star.GetSpokeNode (i)));
    }
  spokeApps.Start (Seconds (1.0));
  spokeApps.Stop (Seconds (10.0));


  NS_LOG_INFO ("Enable static global routing.");
  //
  // Turn on global static routing so we can actually be routed across the star.
  //
  Ipv4GlobalRoutingHelper::PopulateRoutingTables ();


  NS_LOG_INFO ("Enable pcap tracing.");
  //
  // Do pcap tracing on all point-to-point devices on all nodes.
  //
  pointToPoint.EnablePcapAll ("star");
```

```
  NS_LOG_INFO ("Run Simulation.");
  Simulator::Run ();
  Simulator::Destroy ();
  NS_LOG_INFO ("Done.");
  return 0;
}
```

**OutPut:**



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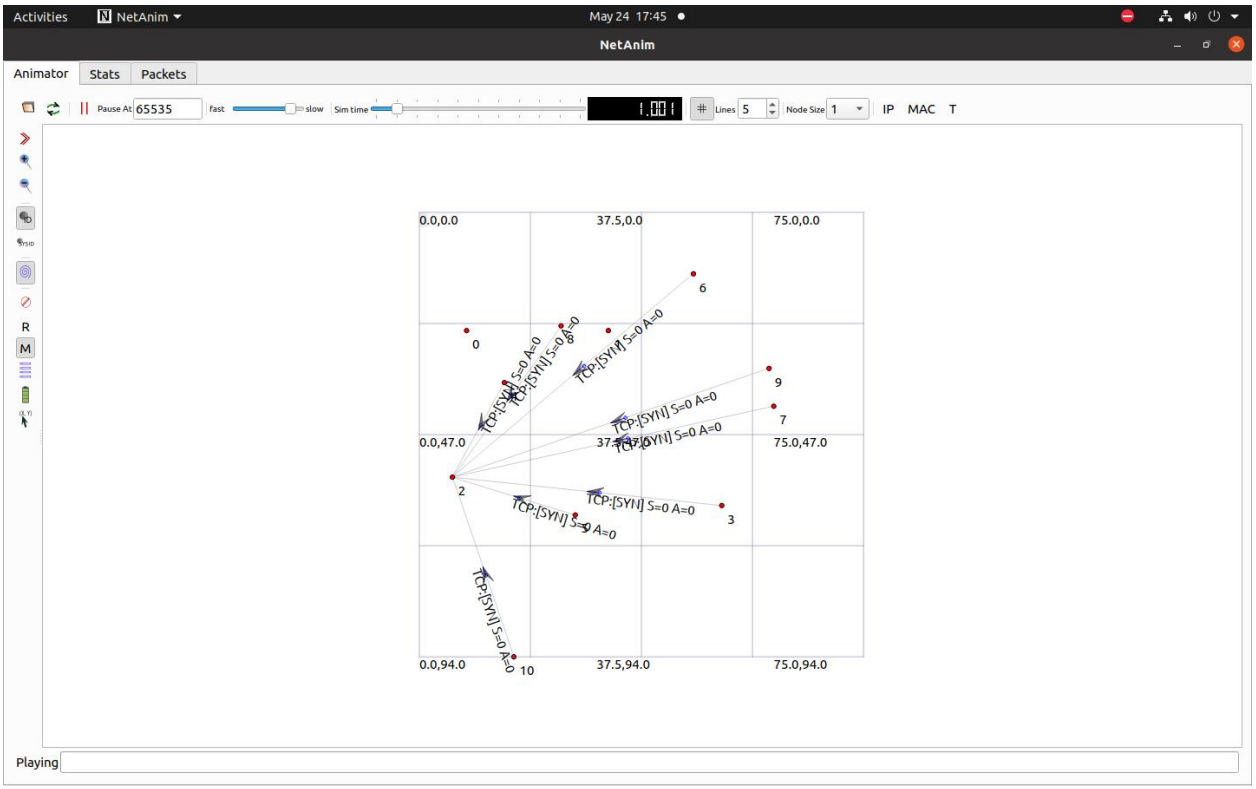
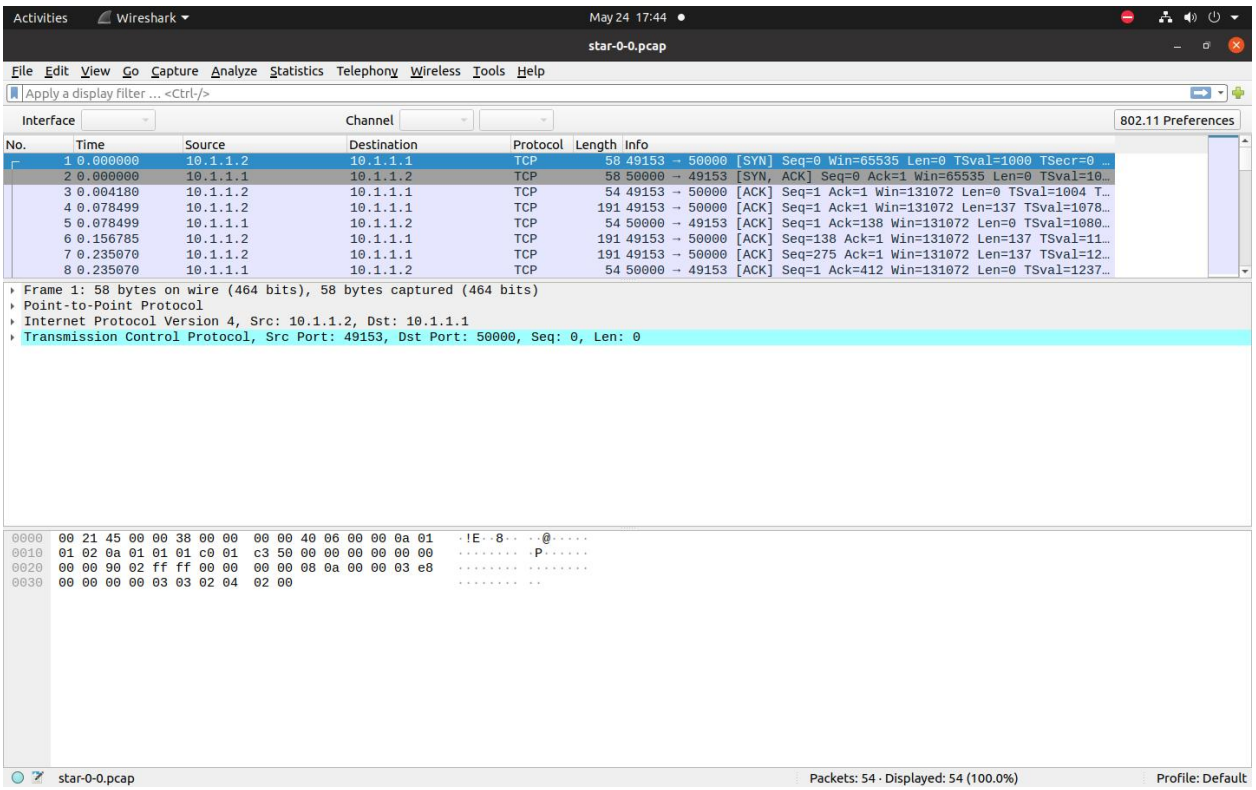
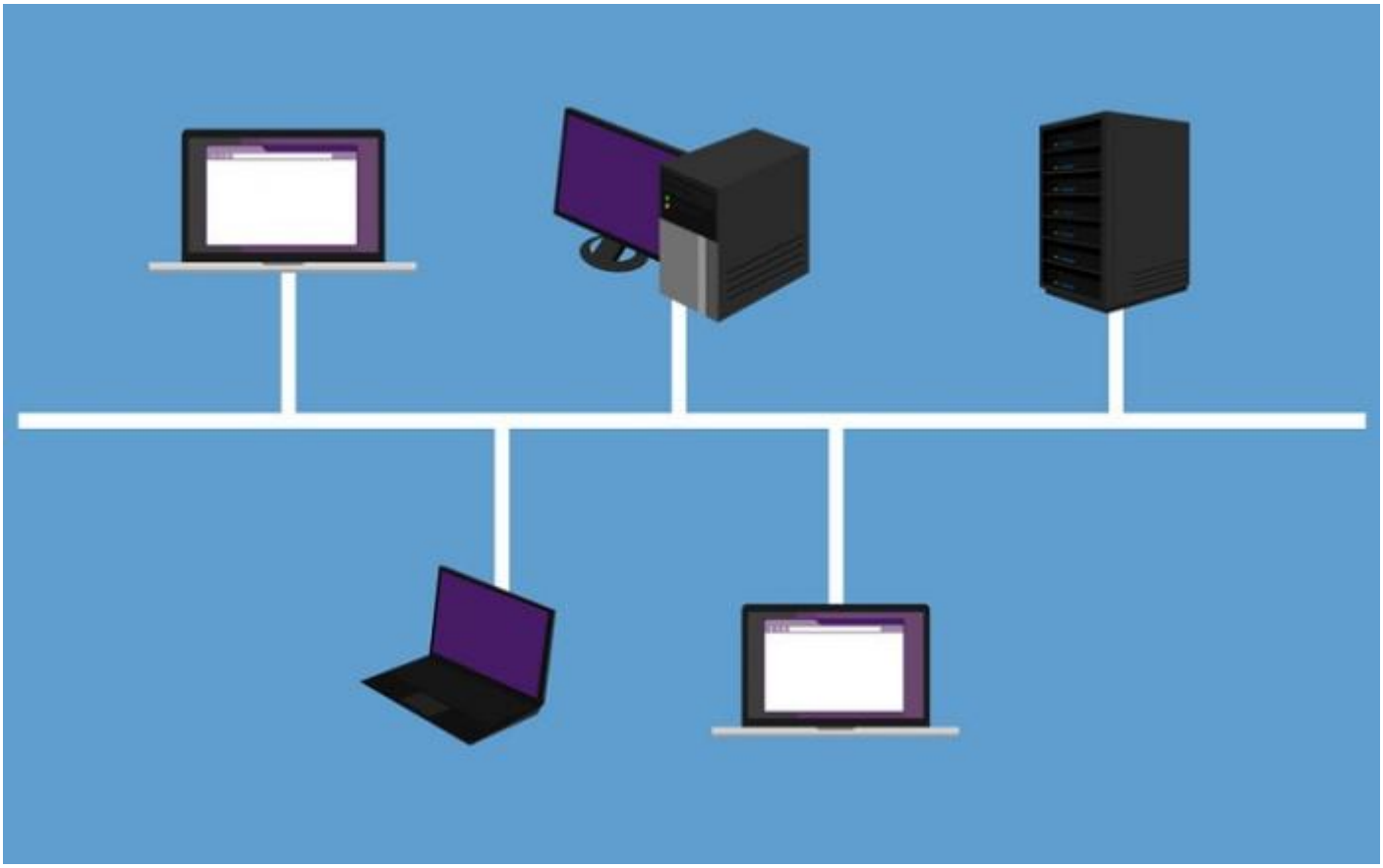


## Practical 6: Program to simulate bus topology

The bus network topology is also referred to as horizontal topology. This topology is very common among local area networks. In this network, every computer is linked to a single connection line or cable through an interface. Thus each computer can directly communicate with other computer or device in the network.

Each work station or node has a particular address, and to access a specific node, a user just needs to know its address. There is no concentration point in the network, and thus the problem of resolution is severe. Traffic flow among various computers in the network is relatively simple because it grants all stations to get each transmission. So a single station can broadcast to multiple stations.



**Code:**

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
```

```
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 */

#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/csma-module.h"
#include "ns3/internet-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/applications-module.h"
#include "ns3/ipv4-global-routing-helper.h"
//netanimation
#include "ns3/netanim-module.h"
#include "ns3/mobility-module.h"

// Default Network Topology
//
//       10.1.1.0
// n0 ---------------- n1   n2   n3   n4
//    point-to-point |    |    |    |
```

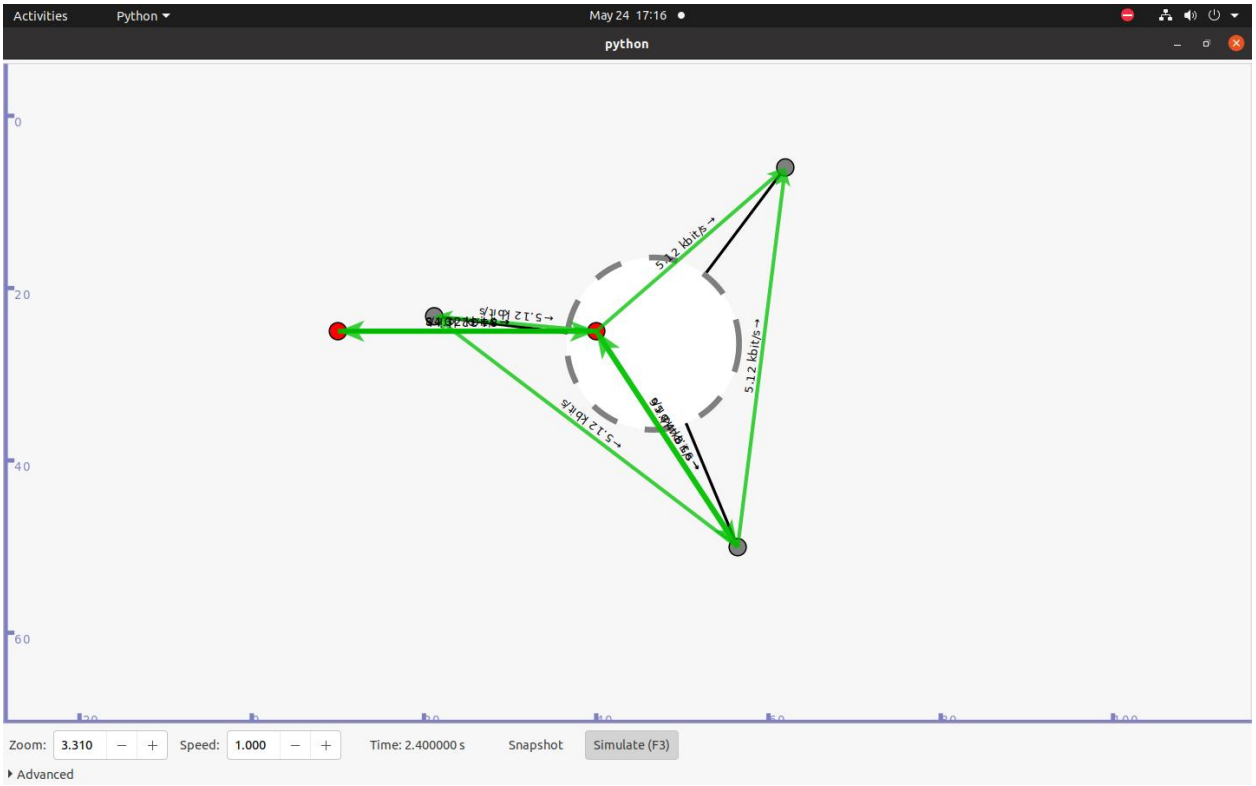
```
//                ================
//                  LAN 10.1.2.0


using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("SecondScriptExample");

int
main (int argc, char *argv[])
{
  bool verbose = true;
  uint32_t nCsma = 3;

  CommandLine cmd (__FILE__);
  cmd.AddValue ("nCsma", "Number of \"extra\" CSMA nodes/devices", nCsma);
  cmd.AddValue ("verbose", "Tell echo applications to log if true", verbose);

  cmd.Parse (argc,argv);

  if (verbose)
    {
      LogComponentEnable ("UdpEchoClientApplication", LOG_LEVEL_INFO);
      LogComponentEnable ("UdpEchoServerApplication", LOG_LEVEL_INFO);
    }

  nCsma = nCsma == 0 ? 1 : nCsma;
```

```
NodeContainer nodes;
nodes.Create (2);

NodeContainer csmaNodes;
csmaNodes.Add (nodes.Get (1));
csmaNodes.Create (nCsma);

PointToPointHelper pointToPoint;
pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));

NetDeviceContainer p2pDevices;
p2pDevices = pointToPoint.Install (nodes);

CsmaHelper csma;
csma.SetChannelAttribute ("DataRate", StringValue ("100Mbps"));
csma.SetChannelAttribute ("Delay", TimeValue (NanoSeconds (6560)));

NetDeviceContainer csmaDevices;
csmaDevices = csma.Install (csmaNodes);

InternetStackHelper stack;
stack.Install (nodes.Get (0));
stack.Install (csmaNodes);

Ipv4AddressHelper address;
```

```
address.SetBase ("10.1.1.0", "255.255.255.0");
Ipv4InterfaceContainer p2pInterfaces;
p2pInterfaces = address.Assign (p2pDevices);

address.SetBase ("10.1.2.0", "255.255.255.0");
Ipv4InterfaceContainer csmaInterfaces;
csmaInterfaces = address.Assign (csmaDevices);

UdpEchoServerHelper echoServer (9);

ApplicationContainer serverApps = echoServer.Install (csmaNodes.Get (nCsma));
serverApps.Start (Seconds (1.0));
serverApps.Stop (Seconds (10.0));

UdpEchoClientHelper echoClient (csmaInterfaces.GetAddress (nCsma), 9);
echoClient.SetAttribute ("MaxPackets", UintegerValue (1));
echoClient.SetAttribute ("Interval", TimeValue (Seconds (1.0)));
echoClient.SetAttribute ("PacketSize", UintegerValue (1024));

ApplicationContainer clientApps = echoClient.Install (nodes.Get (0));
clientApps.Start (Seconds (2.0));
clientApps.Stop (Seconds (10.0));

Ipv4GlobalRoutingHelper::PopulateRoutingTables ();

MobilityHelper mobility;
mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
```

```
mobility.Install(nodes);

AnimationInterface anim("second.xml");
AnimationInterface::SetConstantPosition(nodes.Get(0),10,25);
AnimationInterface::SetConstantPosition(nodes.Get(1),40,25);
anim.EnablePacketMetadata(true);
pointToPoint.EnablePcapAll ("second");
csma.EnablePcap ("second", csmaDevices.Get (1), true);
Simulator::Run ();
Simulator::Destroy ();
return 0;
}
```

**OutPut**



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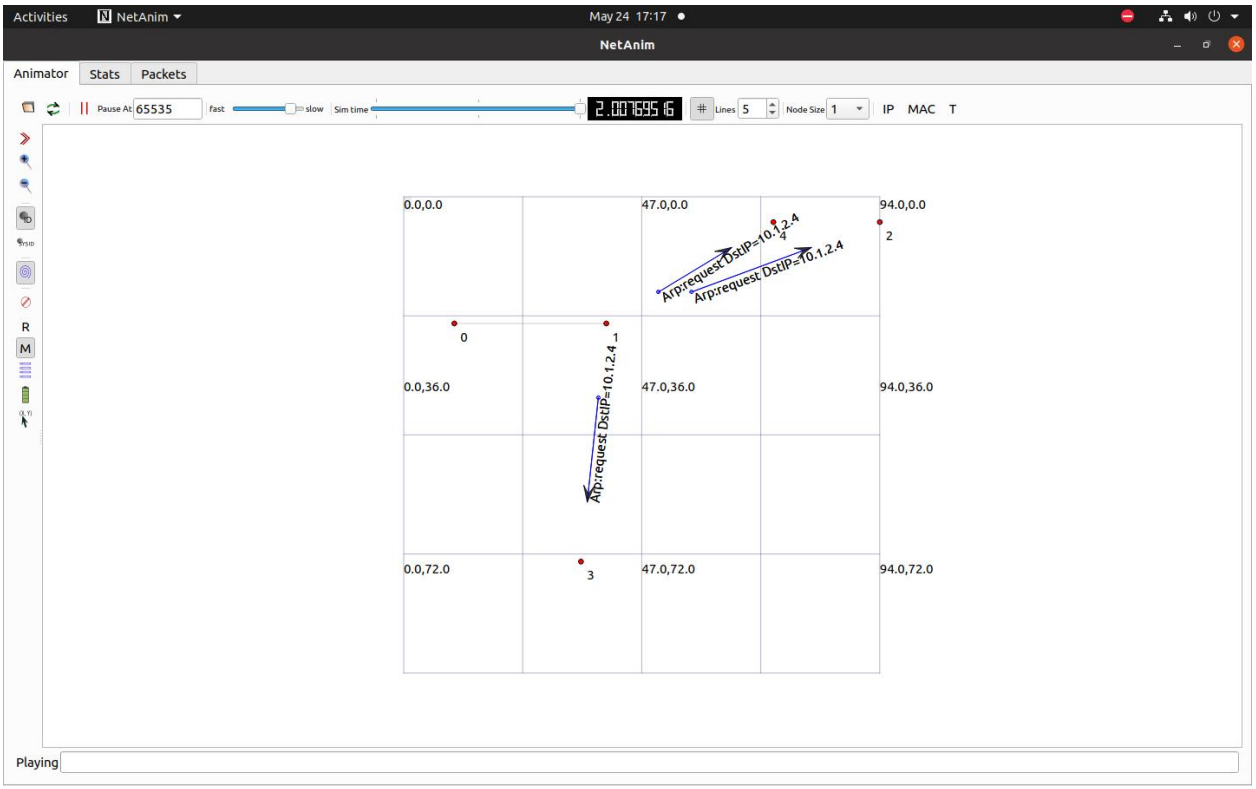
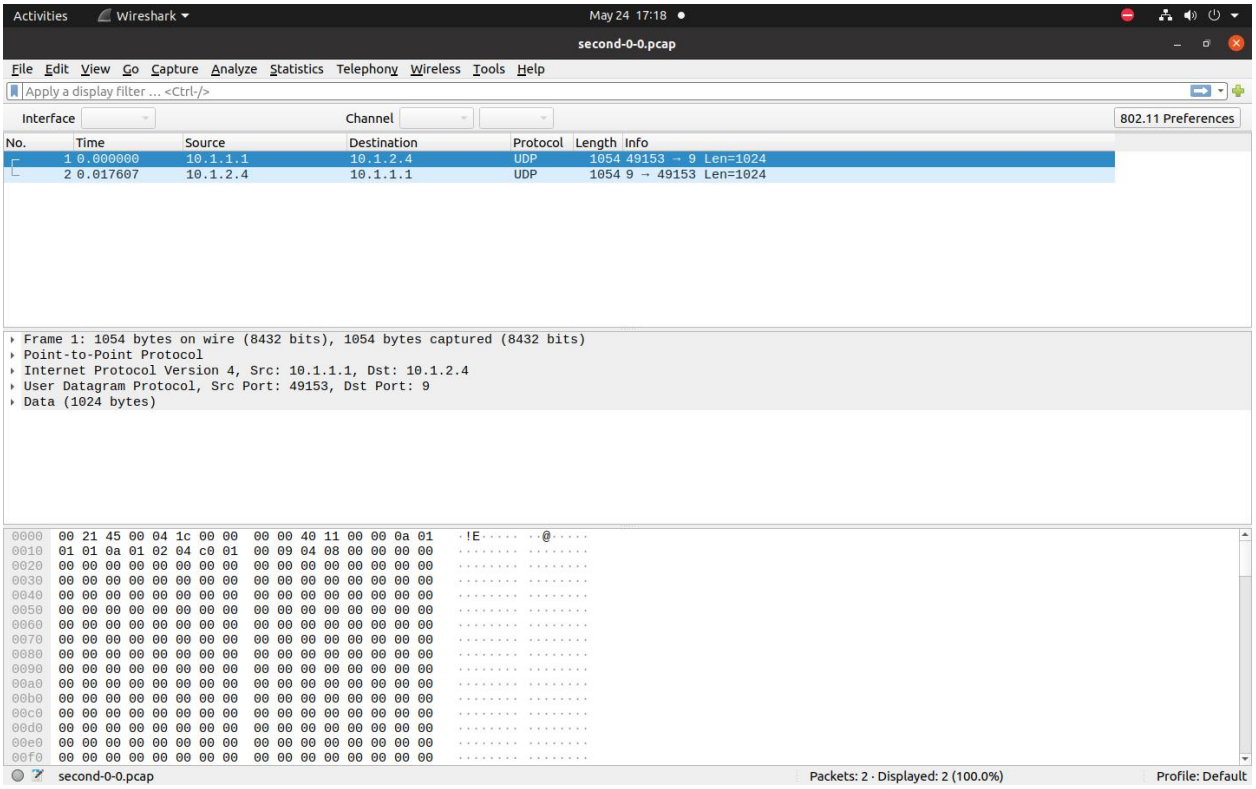
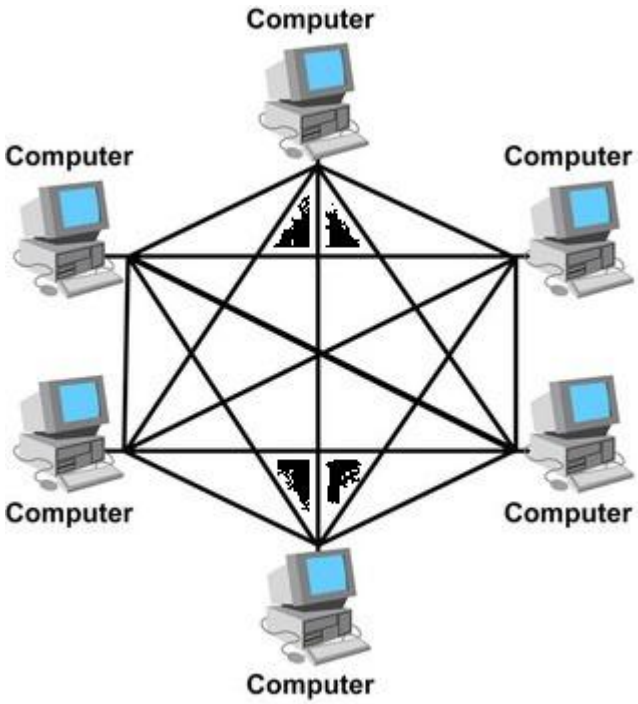


## Practical 7:Program to simulate mesh topology

Mesh topology is a type of networking in which all the computers are inter-connected to each other. In Mesh Topology, the connections between devices take place randomly. The connected nodes can be computers, switches, hubs, or any other devices. In this topology setup, even if one of the connections goes down, it allows other nodes to be distributed. This type of topology is very expensive and does not have any hierarchy, interdependency, and uniform pattern between nodes. The connections of the mesh topology are not easier to establish.

All computers, in a mesh topology, not only responsible for sending their own signals but also relays for other nodes. Usually, it is used for wireless networks, and its connections can be wired or wireless. Also, there is a point-to-point connection between all nodes in the mesh topology setup. The below picture is an instance of a mesh topology network.




**Code:**

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * Copyright (c) 2008,2009 IITP RAS
 *
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
```

```
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 *
 * Author: Kirill Andreev <andreev@iitp.ru>
 *
 *
 * By default this script creates m_xSize * m_ySize square grid topology with
 * IEEE802.11s stack installed at each node with peering management
 * and HWMP protocol.
 * The side of the square cell is defined by m_step parameter.
 * When topology is created, UDP ping is installed to opposite corners
 * by diagonals. packet size of the UDP ping and interval between two
 * successive packets is configurable.
 *
 *  m_xSize * step
 *  |<--------->|
 *   step
 *  |<--->|
 *  * --- * --- * <---Ping sink  _
```

```
 * |\  |  /|          ^
 * |  \|/  |          |
 *  * --- * --- * m_ySize * step |
 * |  /|\  |          |
 * |/  |  \|          |
 *  * --- * --- *          _
 *  ^ Ping source
 *
 *  See also MeshTest::Configure to read more about configurable
 *  parameters.
 */

#include <iostream>
#include <sstream>
#include <fstream>
#include "ns3/core-module.h"
#include "ns3/internet-module.h"
#include "ns3/network-module.h"
#include "ns3/applications-module.h"
#include "ns3/mesh-module.h"
#include "ns3/mobility-module.h"
#include "ns3/mesh-helper.h"
#include "ns3/yans-wifi-helper.h"

using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("TestMeshScript");
```

```
/**
 * \ingroup mesh
 * \brief MeshTest class
 */
class MeshTest
{
public:
  /// Init test
  MeshTest ();
  /**
   * Configure test from command line arguments
   *
   * \param argc command line argument count
   * \param argv command line arguments
   */
  void Configure (int argc, char ** argv);
  /**
   * Run test
   * \returns the test status
   */
  int Run ();
private:
  int       m_xSize; ///< X size
  int       m_ySize; ///< Y size
  double    m_step; ///< step
  double    m_randomStart; ///< random start
```

```
  double    m_totalTime; ///< total time
  double    m_packetInterval; ///< packet interval
  uint16_t  m_packetSize; ///< packet size
  uint32_t  m_nIfaces; ///< number interfaces
  bool      m_chan; ///< channel
  bool      m_pcap; ///< PCAP
  bool      m_ascii; ///< ASCII
  std::string m_stack; ///< stack
  std::string m_root; ///< root
  /// List of network nodes
  NodeContainer nodes;
  /// List of all mesh point devices
  NetDeviceContainer meshDevices;
  /// Addresses of interfaces:
  Ipv4InterfaceContainer interfaces;
  /// MeshHelper. Report is not static methods
  MeshHelper mesh;
private:
  /// Create nodes and setup their mobility
  void CreateNodes ();
  /// Install internet m_stack on nodes
  void InstallInternetStack ();
  /// Install applications
  void InstallApplication ();
  /// Print mesh devices diagnostics
  void Report ();
};
```

```
MeshTest::MeshTest () :
  m_xSize (3),
  m_ySize (3),
  m_step (100.0),
  m_randomStart (0.1),
  m_totalTime (100.0),
  m_packetInterval (0.1),
  m_packetSize (1024),
  m_nIfaces (1),
  m_chan (true),
  m_pcap (false),
  m_ascii (false),
  m_stack ("ns3::Dot11sStack"),
  m_root ("ff:ff:ff:ff:ff:ff")
{
}
void
MeshTest::Configure (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);
  cmd.AddValue ("x-size", "Number of nodes in a row grid", m_xSize);
  cmd.AddValue ("y-size", "Number of rows in a grid", m_ySize);
  cmd.AddValue ("step",   "Size of edge in our grid (meters)", m_step);
  // Avoid starting all mesh nodes at the same time (beacons may collide)
  cmd.AddValue ("start",  "Maximum random start delay for beacon jitter (sec)",
m_randomStart);
  cmd.AddValue ("time",  "Simulation time (sec)", m_totalTime);
```

```
  cmd.AddValue ("packet-interval",  "Interval between packets in UDP ping (sec)",
m_packetInterval);
  cmd.AddValue ("packet-size",  "Size of packets in UDP ping (bytes)", m_packetSize);
  cmd.AddValue ("interfaces", "Number of radio interfaces used by each mesh point",
m_nIfaces);
  cmd.AddValue ("channels",   "Use different frequency channels for different interfaces",
m_chan);
  cmd.AddValue ("pcap",   "Enable PCAP traces on interfaces", m_pcap);
  cmd.AddValue ("ascii",   "Enable Ascii traces on interfaces", m_ascii);
  cmd.AddValue ("stack",  "Type of protocol stack. ns3::Dot11sStack by default",
m_stack);
  cmd.AddValue ("root", "Mac address of root mesh point in HWMP", m_root);


  cmd.Parse (argc, argv);
  NS_LOG_DEBUG ("Grid:" << m_xSize << "*" << m_ySize);
  NS_LOG_DEBUG ("Simulation time: " << m_totalTime << " s");
  if (m_ascii)
    {
      PacketMetadata::Enable ();
    }
}
void
MeshTest::CreateNodes ()
{
  /*
   * Create m_ySize*m_xSize stations to form a grid topology
   */
  nodes.Create (m_ySize*m_xSize);
```

```
// Configure YansWifiChannel
YansWifiPhyHelper wifiPhy;
YansWifiChannelHelper wifiChannel = YansWifiChannelHelper::Default ();
wifiPhy.SetChannel (wifiChannel.Create ());
/*
 * Create mesh helper and set stack installer to it
 * Stack installer creates all needed protocols and install them to
 * mesh point device
 */
mesh = MeshHelper::Default ();
if (!Mac48Address (m_root.c_str ()).IsBroadcast ())
  {
    mesh.SetStackInstaller (m_stack, "Root", Mac48AddressValue (Mac48Address
(m_root.c_str ())));
  }
else
  {
    //If root is not set, we do not use "Root" attribute, because it
    //is specified only for 11s
    mesh.SetStackInstaller (m_stack);
  }
if (m_chan)
  {
    mesh.SetSpreadInterfaceChannels (MeshHelper::SPREAD_CHANNELS);
  }
else
  {
```

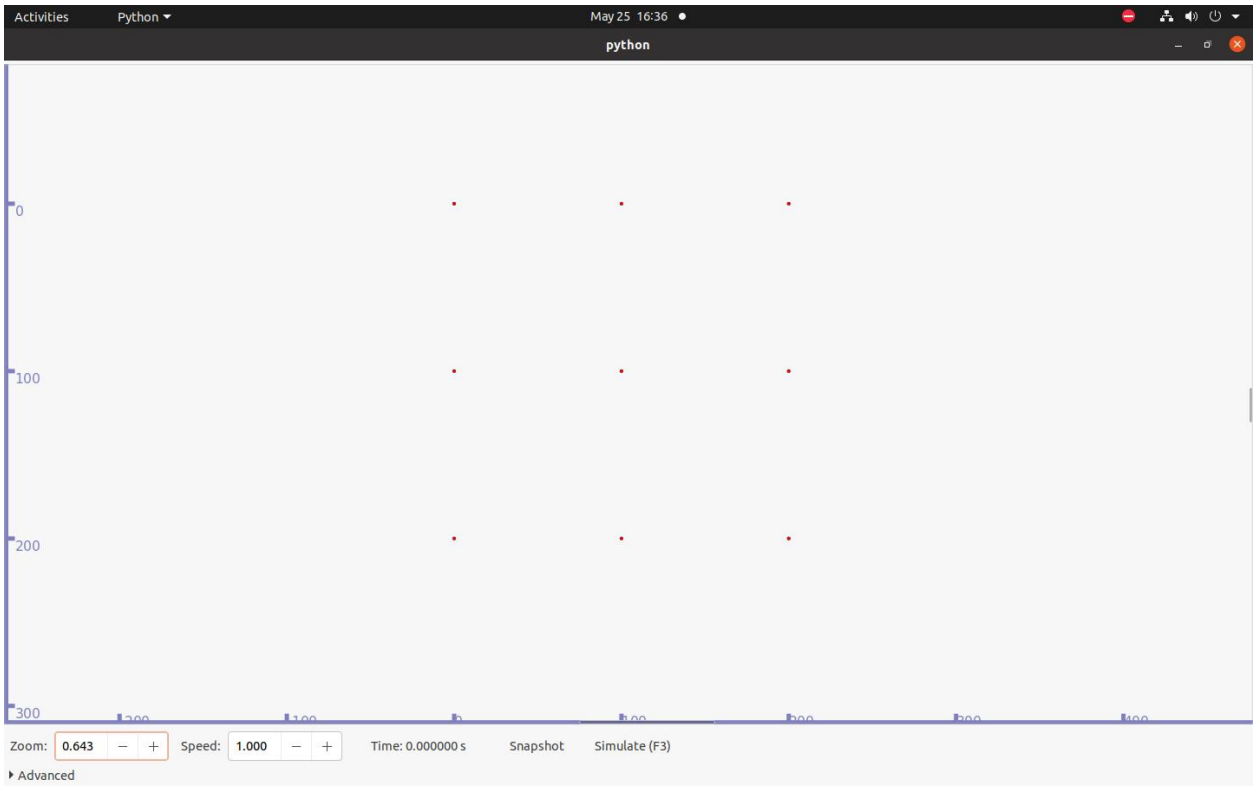
```
    mesh.SetSpreadInterfaceChannels (MeshHelper::ZERO_CHANNEL);
   }
  mesh.SetMacType ("RandomStart", TimeValue (Seconds (m_randomStart)));
  // Set number of interfaces - default is single-interface mesh point
  mesh.SetNumberOfInterfaces (m_nIfaces);
  // Install protocols and return container if MeshPointDevices
  meshDevices = mesh.Install (wifiPhy, nodes);
  // Setup mobility - static grid topology
  MobilityHelper mobility;
  mobility.SetPositionAllocator ("ns3::GridPositionAllocator",
                                 "MinX", DoubleValue (0.0),
                                 "MinY", DoubleValue (0.0),
                                 "DeltaX", DoubleValue (m_step),
                                 "DeltaY", DoubleValue (m_step),
                                 "GridWidth", UintegerValue (m_xSize),
                                 "LayoutType", StringValue ("RowFirst"));
  mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
  mobility.Install (nodes);
  if (m_pcap)
    wifiPhy.EnablePcapAll (std::string ("mp-"));
  if (m_ascii)
    {
      AsciiTraceHelper ascii;
      wifiPhy.EnableAsciiAll (ascii.CreateFileStream ("mesh.tr"));
    }
}
void
```

```
MeshTest::InstallInternetStack ()
{
  InternetStackHelper internetStack;
  internetStack.Install (nodes);
  Ipv4AddressHelper address;
  address.SetBase ("10.1.1.0", "255.255.255.0");
  interfaces = address.Assign (meshDevices);
}
void
MeshTest::InstallApplication ()
{
  UdpEchoServerHelper echoServer (9);
  ApplicationContainer serverApps = echoServer.Install (nodes.Get (0));
  serverApps.Start (Seconds (0.0));
  serverApps.Stop (Seconds (m_totalTime));
  UdpEchoClientHelper echoClient (interfaces.GetAddress (0), 9);
  echoClient.SetAttribute ("MaxPackets", UintegerValue
((uint32_t)(m_totalTime*(1/m_packetInterval))));
  echoClient.SetAttribute ("Interval", TimeValue (Seconds (m_packetInterval)));
  echoClient.SetAttribute ("PacketSize", UintegerValue (m_packetSize));
  ApplicationContainer clientApps = echoClient.Install (nodes.Get (m_xSize*m_ySize-
1));
  clientApps.Start (Seconds (0.0));
  clientApps.Stop (Seconds (m_totalTime));
}
int
MeshTest::Run ()
{
```

```
  CreateNodes ();
  InstallInternetStack ();
  InstallApplication ();
  Simulator::Schedule (Seconds (m_totalTime), &MeshTest::Report, this);
  Simulator::Stop (Seconds (m_totalTime));
  Simulator::Run ();
  Simulator::Destroy ();
  return 0;
}
void
MeshTest::Report ()
{
  unsigned n (0);
  for (NetDeviceContainer::Iterator i = meshDevices.Begin (); i != meshDevices.End ();
++i, ++n)
    {
      std::ostringstream os;
      os << "mp-report-" << n << ".xml";
      std::cerr << "Printing mesh point device #" << n << " diagnostics to " << os.str () <<
"\n";
      std::ofstream of;
      of.open (os.str ().c_str ());
      if (!of.is_open ())
        {
          std::cerr << "Error: Can't open file " << os.str () << "\n";
          return;
        }
      mesh.Report (*i, of);
```

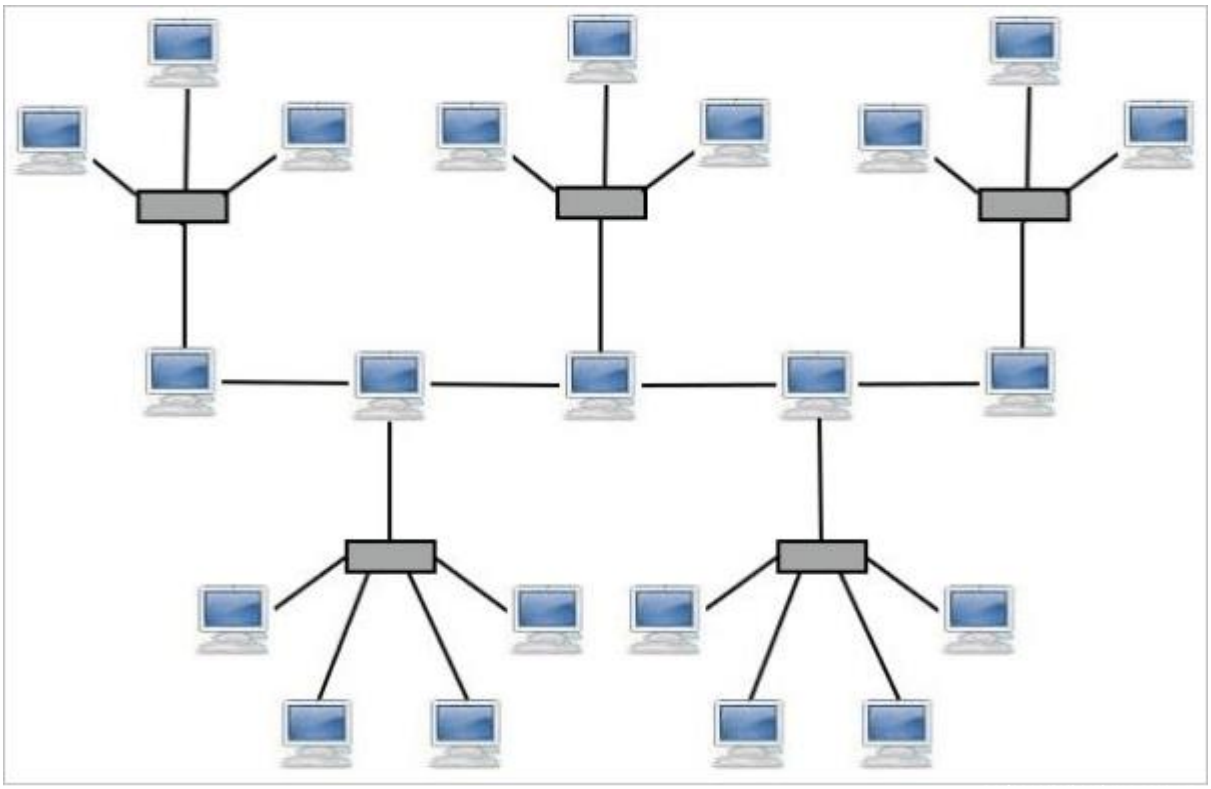
```
    of.close ();
   }
}
int
main (int argc, char *argv[])
{
  MeshTest t;
  t.Configure (argc, argv);
  return t.Run ();
}
```

**OutPut:**



## Practical 8: Program to simulate hybrid topology

A hybrid topology is a kind of network topology that is a combination of two or more network topologies, such as mesh topology, bus topology, and ring topology. Its usage and choice are dependent on its deployments and requirements like the performance of the desired network, and the number of computers, their location.




**Code:**

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
```

```
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 */

#include <fstream>
#include "ns3/core-module.h"
#include "ns3/network-module.h"
#include "ns3/internet-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/applications-module.h"
//netanimation
#include "ns3/netanim-module.h"
#include "ns3/mobility-module.h"

using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("FifthScriptExample");

//
================================================================
============
//
//        node 0                 node 1
//   +----------------+    +----------------+
//   |    ns-3 TCP    |    |    ns-3 TCP    |
```

```
//   +----------------+    +----------------+
//   |    10.1.1.1    |    |    10.1.1.2    |
//   +----------------+    +----------------+
//   | point-to-point |    | point-to-point |
//   +----------------+    +----------------+
//           |                     |
//           +---------------------+
//                5 Mbps, 2 ms
//
//
```

```
// We want to look at changes in the ns-3 TCP congestion window.  We need
// to crank up a flow and hook the CongestionWindow attribute on the socket
// of the sender.  Normally one would use an on-off application to generate a
// flow, but this has a couple of problems.  First, the socket of the on-off
// application is not created until Application Start time, so we wouldn't be
// able to hook the socket (now) at configuration time.  Second, even if we
// could arrange a call after start time, the socket is not public so we
// couldn't get at it.
//
// So, we can cook up a simple version of the on-off application that does what
// we want.  On the plus side we don't need all of the complexity of the on-off
// application.  On the minus side, we don't have a helper, so we have to get
// a little more involved in the details, but this is trivial.
//
// So first, we create a socket and do the trace connect on it; then we pass
// this socket into the constructor of our simple application which we then
// install in the source node.
```

```
//
================================================================================
//
class MyApp : public Application
{
public:

  MyApp ();
  virtual ~MyApp();

  void Setup (Ptr<Socket> socket, Address address, uint32_t packetSize, uint32_t
nPackets, DataRate dataRate);

private:
  virtual void StartApplication (void);
  virtual void StopApplication (void);

  void ScheduleTx (void);
  void SendPacket (void);

  Ptr<Socket>     m_socket;
  Address         m_peer;
  uint32_t        m_packetSize;
  uint32_t        m_nPackets;
  DataRate        m_dataRate;
  EventId         m_sendEvent;
  bool            m_running;
```

```
 uint32_t        m_packetsSent;
};

MyApp::MyApp ()
  : m_socket (0),
    m_peer (),
    m_packetSize (0),
    m_nPackets (0),
    m_dataRate (0),
    m_sendEvent (),
    m_running (false),
    m_packetsSent (0)
{
}

MyApp::~MyApp()
{
  m_socket = 0;
}

void
MyApp::Setup (Ptr<Socket> socket, Address address, uint32_t packetSize, uint32_t
nPackets, DataRate dataRate)
{
  m_socket = socket;
  m_peer = address;
  m_packetSize = packetSize;
```

```
  m_nPackets = nPackets;
  m_dataRate = dataRate;
}

void
MyApp::StartApplication (void)
{
  m_running = true;
  m_packetsSent = 0;
  m_socket->Bind ();
  m_socket->Connect (m_peer);
  SendPacket ();
}

void
MyApp::StopApplication (void)
{
  m_running = false;

  if (m_sendEvent.IsRunning ())
    {
      Simulator::Cancel (m_sendEvent);
    }

  if (m_socket)
    {
      m_socket->Close ();
```

```
    }
}

void
MyApp::SendPacket (void)
{
  Ptr<Packet> packet = Create<Packet> (m_packetSize);
  m_socket->Send (packet);

  if (++m_packetsSent < m_nPackets)
    {
      ScheduleTx ();
    }
}

void
MyApp::ScheduleTx (void)
{
  if (m_running)
    {
      Time tNext (Seconds (m_packetSize * 8 / static_cast<double>
(m_dataRate.GetBitRate ())));
      m_sendEvent = Simulator::Schedule (tNext, &MyApp::SendPacket, this);
    }
}

static void
```

```
CwndChange (uint32_t oldCwnd, uint32_t newCwnd)
{
  NS_LOG_UNCOND (Simulator::Now ().GetSeconds () << "\t" << newCwnd);
}

static void
RxDrop (Ptr<const Packet> p)
{
  NS_LOG_UNCOND ("RxDrop at " << Simulator::Now ().GetSeconds ());
}

int
main (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);
  cmd.Parse (argc, argv);

  NodeContainer nodes;
  nodes.Create (2);

  PointToPointHelper pointToPoint;
  pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
  pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));

  NetDeviceContainer devices;
  devices = pointToPoint.Install (nodes);
```

```
  Ptr<RateErrorModel> em = CreateObject<RateErrorModel> ();
  em->SetAttribute ("ErrorRate", DoubleValue (0.00001));
  devices.Get (1)->SetAttribute ("ReceiveErrorModel", PointerValue (em));

  InternetStackHelper stack;
  stack.Install (nodes);

  Ipv4AddressHelper address;
  address.SetBase ("10.1.1.0", "255.255.255.252");
  Ipv4InterfaceContainer interfaces = address.Assign (devices);

  uint16_t sinkPort = 8080;
  Address sinkAddress (InetSocketAddress (interfaces.GetAddress (1), sinkPort));
  PacketSinkHelper packetSinkHelper ("ns3::TcpSocketFactory", InetSocketAddress
(Ipv4Address::GetAny (), sinkPort));
  ApplicationContainer sinkApps = packetSinkHelper.Install (nodes.Get (1));
  sinkApps.Start (Seconds (0.));
  sinkApps.Stop (Seconds (20.));

  Ptr<Socket> ns3TcpSocket = Socket::CreateSocket (nodes.Get (0),
TcpSocketFactory::GetTypeId ());
  ns3TcpSocket->TraceConnectWithoutContext ("CongestionWindow", MakeCallback
(&CwndChange));

  Ptr<MyApp> app = CreateObject<MyApp> ();
  app->Setup (ns3TcpSocket, sinkAddress, 1040, 1000, DataRate ("1Mbps"));
  nodes.Get (0)->AddApplication (app);
  app->SetStartTime (Seconds (1.));
```

```
  app->SetStopTime (Seconds (20.));

  devices.Get (1)->TraceConnectWithoutContext ("PhyRxDrop", MakeCallback
(&RxDrop));



  MobilityHelper mobility;
  mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
  mobility.Install(nodes);

  AnimationInterface anim("fifth.xml");
  AnimationInterface::SetConstantPosition(nodes.Get(0),10,25);
  AnimationInterface::SetConstantPosition(nodes.Get(1),30,50);
  anim.EnablePacketMetadata(true);

  pointToPoint.EnablePcapAll("fifth");
  Simulator::Stop (Seconds (20));
  Simulator::Run ();
  Simulator::Destroy ();

  return 0;
}
```

**OutPut:**

C

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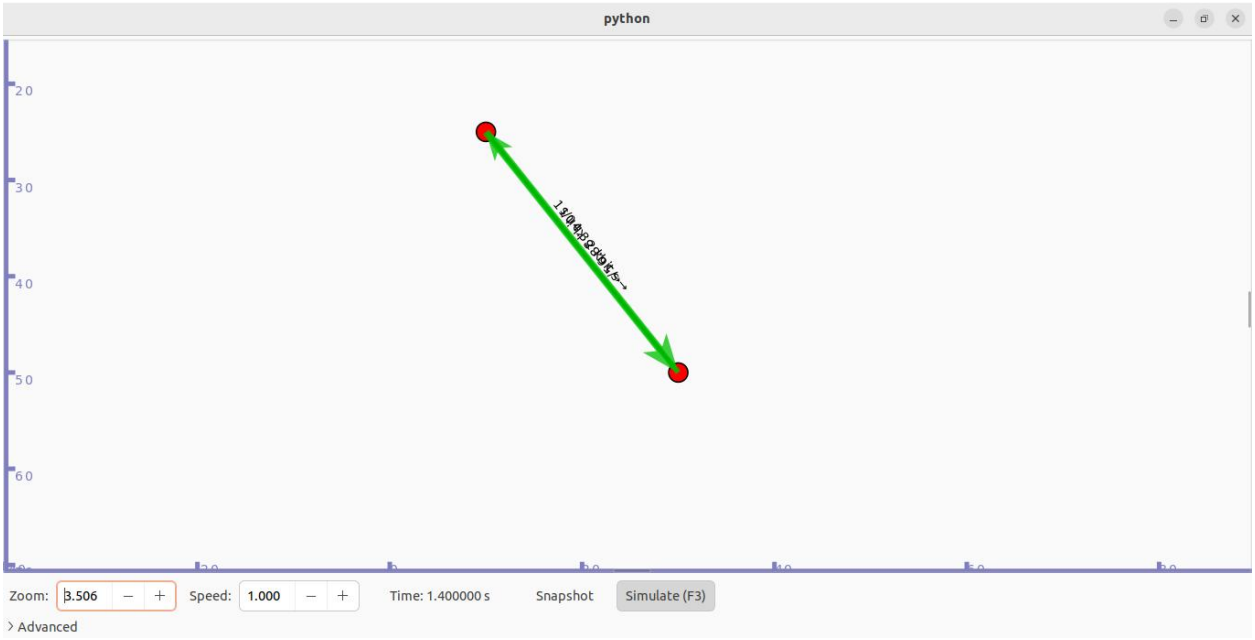


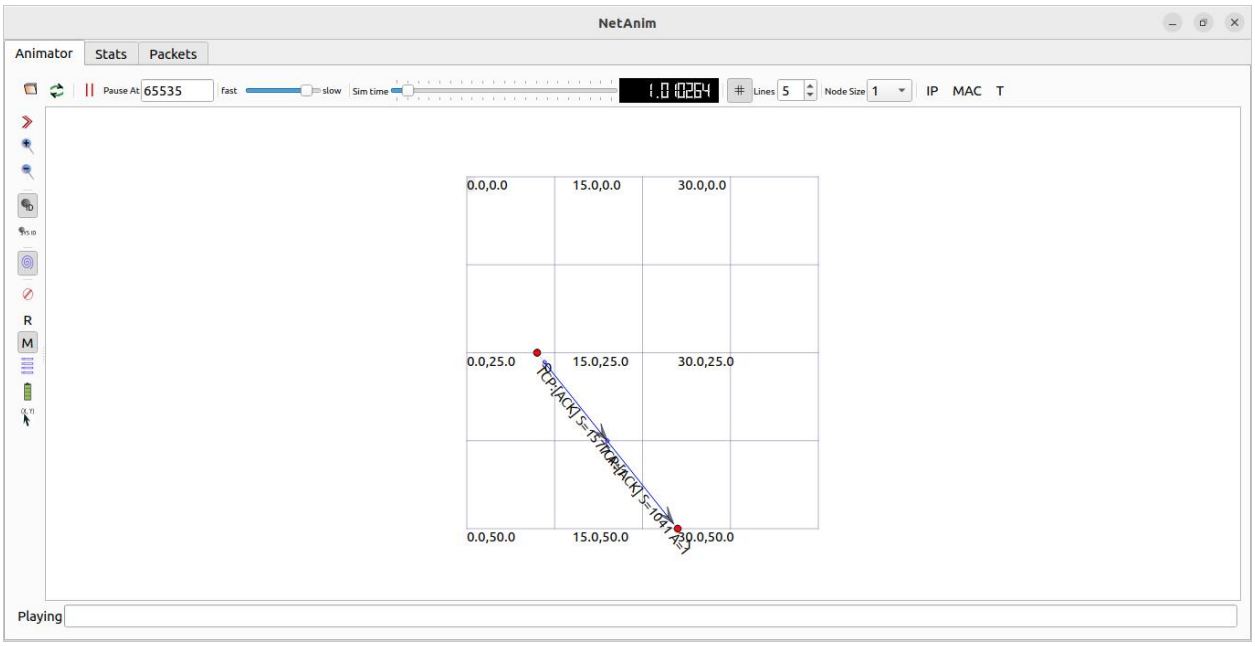

C

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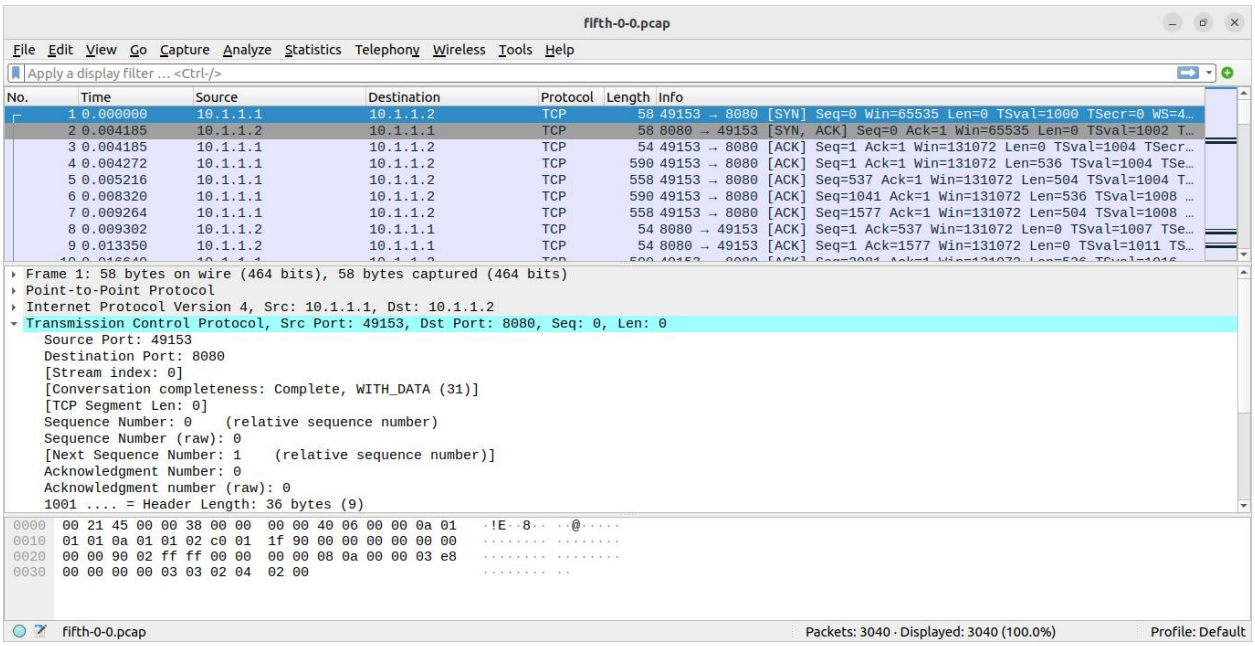

## Practical 9: Program to simulate UDP server

User Datagram Protocol (UDP) is a communications protocol that is primarily used to establish low-latency and loss-tolerating connections between applications on the internet.

UDP speeds up transmissions by enabling the transfer of data before an agreement is provided by the receiving party. As a result, UDP is beneficial in time-sensitive communications, including voice over IP (VoIP), domain name system (DNS) lookup, and video or audio playback.

### Code:

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 */


// Network topology
//
//       n0    n1   n2   n3
//       |    |    |    |
//       =================
```

```
//              LAN
//
// - UDP flows from n0 to n1 and back
// - DropTail queues
// - Tracing of queues and packet receptions to file "udp-echo.tr"

#include <fstream>
#include "ns3/core-module.h"
#include "ns3/csma-module.h"
#include "ns3/applications-module.h"
#include "ns3/internet-module.h"

using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("UdpEchoExample");

int
main (int argc, char *argv[])
{
//
// Users may find it convenient to turn on explicit debugging
// for selected modules; the below lines suggest how to do this
//
#if 0
  LogComponentEnable ("UdpEchoExample", LOG_LEVEL_INFO);
  LogComponentEnable ("UdpEchoClientApplication", LOG_LEVEL_ALL);
  LogComponentEnable ("UdpEchoServerApplication", LOG_LEVEL_ALL);
```

```
#endif
//
// Allow the user to override any of the defaults and the above Bind() at
// run-time, via command-line arguments
//
  bool useV6 = false;
  Address serverAddress;

  CommandLine cmd (__FILE__);
  cmd.AddValue ("useIpv6", "Use Ipv6", useV6);
  cmd.Parse (argc, argv);
//
// Explicitly create the nodes required by the topology (shown above).
//
  NS_LOG_INFO ("Create nodes.");
  NodeContainer n;
  n.Create (4);

  InternetStackHelper internet;
  internet.Install (n);

  NS_LOG_INFO ("Create channels.");
//
// Explicitly create the channels required by the topology (shown above).
//
  CsmaHelper csma;
  csma.SetChannelAttribute ("DataRate", DataRateValue (DataRate (5000000)));
```

```
  csma.SetChannelAttribute ("Delay", TimeValue (MilliSeconds (2)));
  csma.SetDeviceAttribute ("Mtu", UintegerValue (1400));
  NetDeviceContainer d = csma.Install (n);

//
// We've got the "hardware" in place.  Now we need to add IP addresses.
//
  NS_LOG_INFO ("Assign IP Addresses.");
  if (useV6 == false)
    {
      Ipv4AddressHelper ipv4;
      ipv4.SetBase ("10.1.1.0", "255.255.255.0");
      Ipv4InterfaceContainer i = ipv4.Assign (d);
      serverAddress = Address(i.GetAddress (1));
    }
  else
    {
      Ipv6AddressHelper ipv6;
      ipv6.SetBase ("2001:0000:f00d:cafe::", Ipv6Prefix (64));
      Ipv6InterfaceContainer i6 = ipv6.Assign (d);
      serverAddress = Address(i6.GetAddress (1,1));
    }

  NS_LOG_INFO ("Create Applications.");
//
// Create a UdpEchoServer application on node one.
//
```

```
  uint16_t port = 9;  // well-known echo port number
  UdpEchoServerHelper server (port);
  ApplicationContainer apps = server.Install (n.Get (1));
  apps.Start (Seconds (1.0));
  apps.Stop (Seconds (10.0));

//
// Create a UdpEchoClient application to send UDP datagrams from node zero to
// node one.
//
  uint32_t packetSize = 1024;
  uint32_t maxPacketCount = 1;
  Time interPacketInterval = Seconds (1.);
  UdpEchoClientHelper client (serverAddress, port);
  client.SetAttribute ("MaxPackets", UintegerValue (maxPacketCount));
  client.SetAttribute ("Interval", TimeValue (interPacketInterval));
  client.SetAttribute ("PacketSize", UintegerValue (packetSize));
  apps = client.Install (n.Get (0));
  apps.Start (Seconds (2.0));
  apps.Stop (Seconds (10.0));

#if 0
//
// Users may find it convenient to initialize echo packets with actual data;
// the below lines suggest how to do this
//
  client.SetFill (apps.Get (0), "Hello World");
```

```
  client.SetFill (apps.Get (0), 0xa5, 1024);

  uint8_t fill[] = { 0, 1, 2, 3, 4, 5, 6};
  client.SetFill (apps.Get (0), fill, sizeof(fill), 1024);
#endif

  AsciiTraceHelper ascii;
  csma.EnableAsciiAll (ascii.CreateFileStream ("udp-echo.tr"));
  csma.EnablePcapAll ("udp-echo", false);

//
// Now, do the actual simulation.
//
  NS_LOG_INFO ("Run Simulation.");
  Simulator::Run ();
  Simulator::Destroy ();
  NS_LOG_INFO ("Done.");
}
```

**OutPut:**

C

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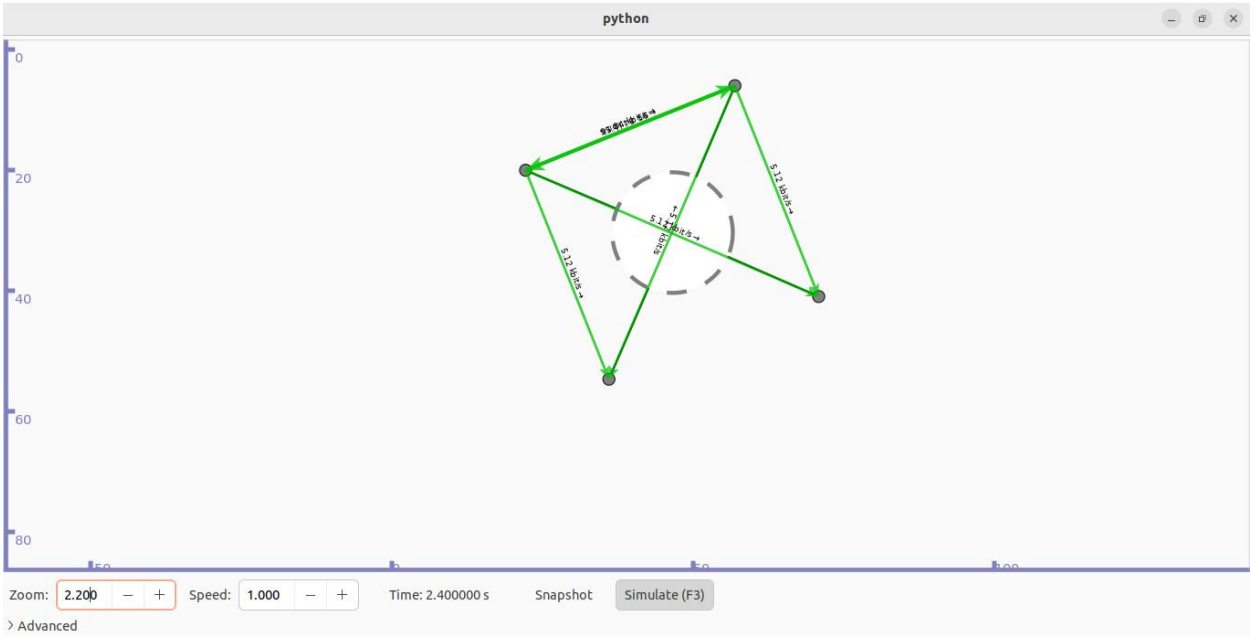


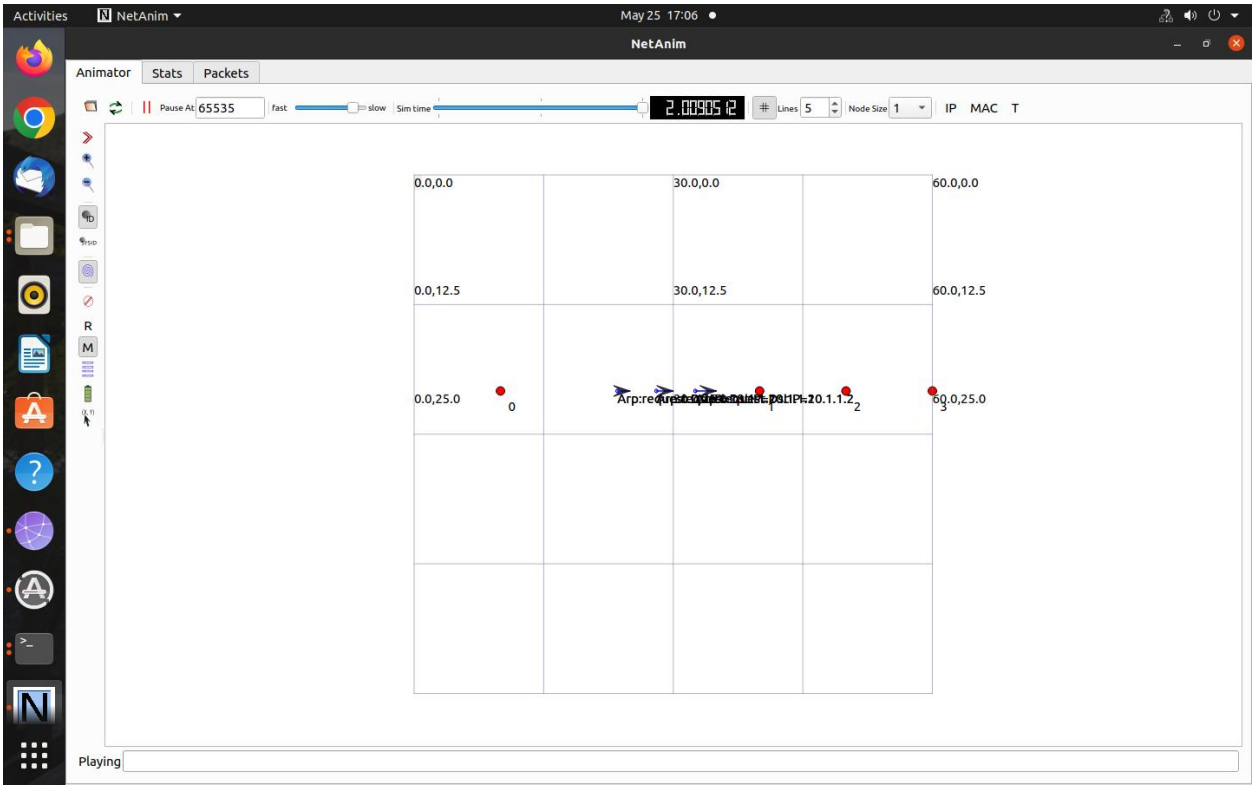

C

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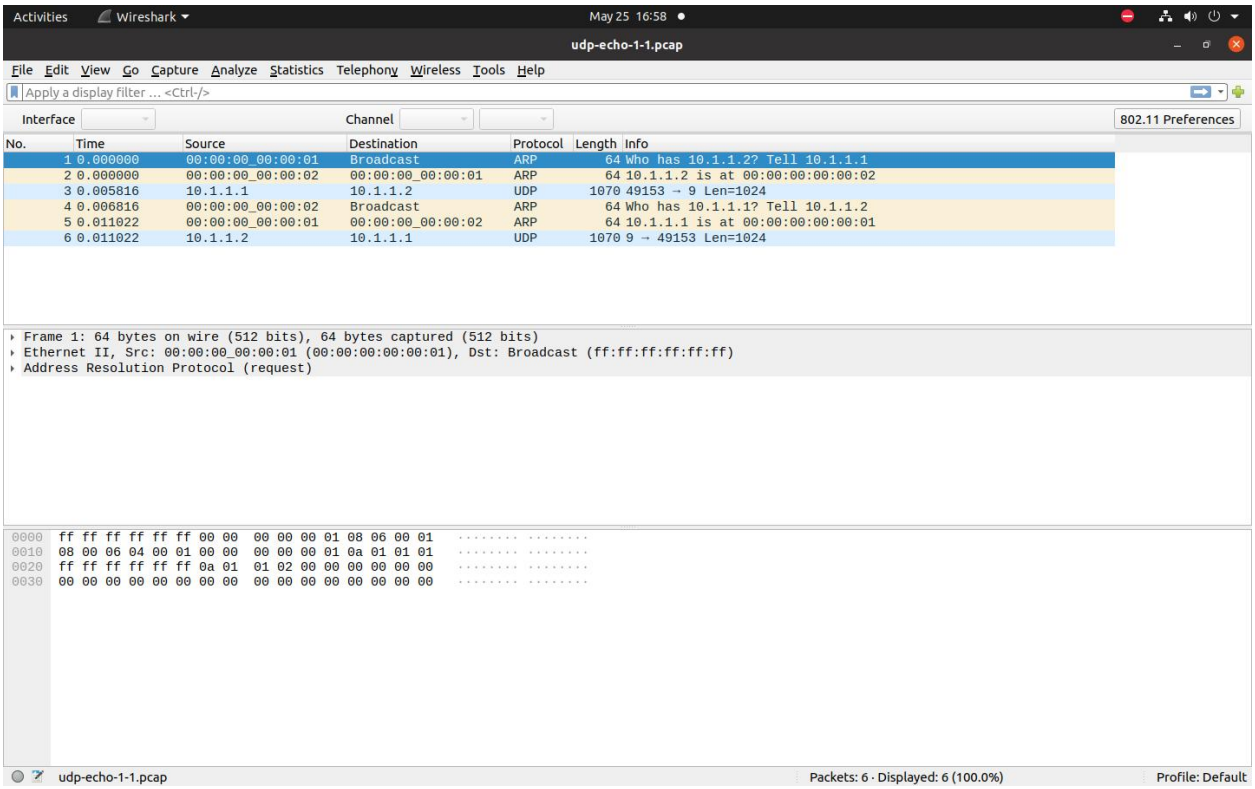


## Practical 10:Program to simulate UDP server client

### Code:

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * Copyright (c) 2009 INRIA
 *
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 *
 * Author: Mohamed Amine Ismail <amine.ismail@sophia.inria.fr>
 */

// Network topology
//
//       n0    n1
//       |     |
```

```
//      =======
//        LAN (CSMA)
//
// - UDP flow from n0 to n1 of 1024 byte packets at intervals of 50 ms
//   - maximum of 320 packets sent (or limited by simulation duration)
//   - option to use IPv4 or IPv6 addressing
//   - option to disable logging statements

#include <fstream>
#include "ns3/core-module.h"
#include "ns3/csma-module.h"
#include "ns3/applications-module.h"
#include "ns3/internet-module.h"
#include "ns3/point-to-point-module.h"
//netanimation
#include "ns3/netanim-module.h"
#include "ns3/mobility-module.h"




using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("UdpClientServerExample");

int
main (int argc, char *argv[])
{
```

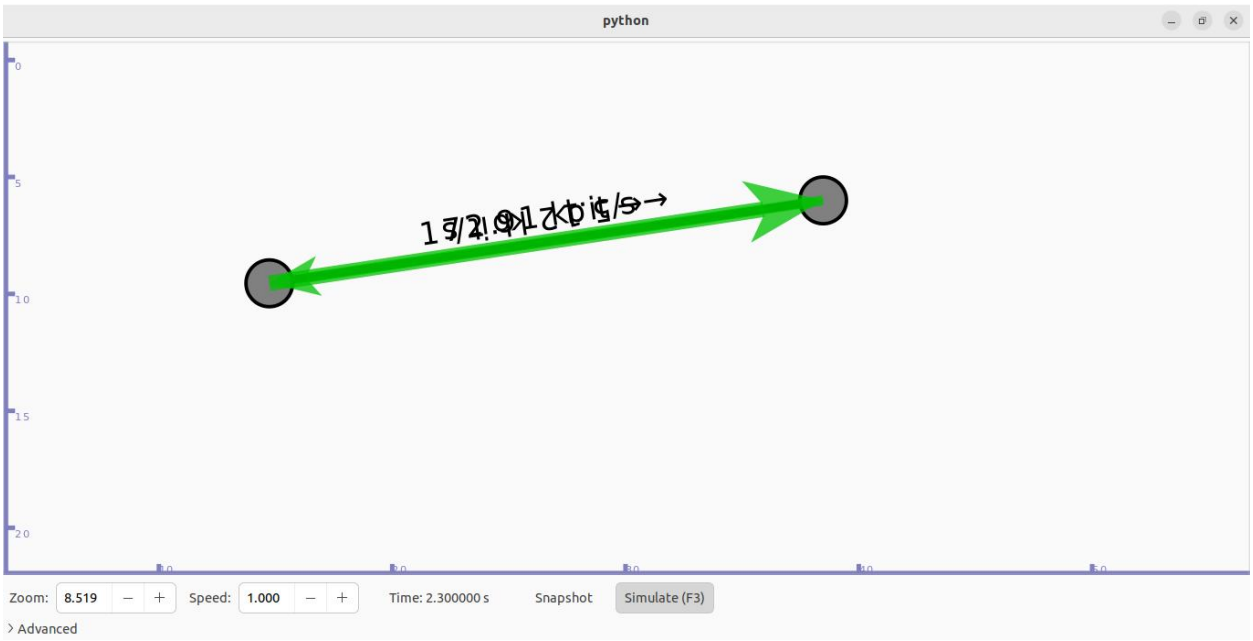
```
// Declare variables used in command-line arguments
bool useV6 = false;
bool logging = true;
Address serverAddress;

CommandLine cmd (__FILE__);
cmd.AddValue ("useIpv6", "Use Ipv6", useV6);
cmd.AddValue ("logging", "Enable logging", logging);
cmd.Parse (argc, argv);

if (logging)
  {
    LogComponentEnable ("UdpClient", LOG_LEVEL_INFO);
    LogComponentEnable ("UdpServer", LOG_LEVEL_INFO);
  }

NS_LOG_INFO ("Create nodes in above topology.");
NodeContainer n;
n.Create (2);


  PointToPointHelper pointToPoint;
pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));

NetDeviceContainer devices;
devices = pointToPoint.Install (n);
```

```
InternetStackHelper internet;
internet.Install (n);

NS_LOG_INFO ("Create channel between the two nodes.");
CsmaHelper csma;
csma.SetChannelAttribute ("DataRate", DataRateValue (DataRate (5000000)));
csma.SetChannelAttribute ("Delay", TimeValue (MilliSeconds (2)));
csma.SetDeviceAttribute ("Mtu", UintegerValue (1400));
NetDeviceContainer d = csma.Install (n);

NS_LOG_INFO ("Assign IP Addresses.");
if (useV6 == false)
  {
    Ipv4AddressHelper ipv4;
    ipv4.SetBase ("10.1.1.0", "255.255.255.0");
    Ipv4InterfaceContainer i = ipv4.Assign (d);
    serverAddress = Address (i.GetAddress (1));
  }
else
  {
    Ipv6AddressHelper ipv6;
    ipv6.SetBase ("2001:0000:f00d:cafe::", Ipv6Prefix (64));
    Ipv6InterfaceContainer i6 = ipv6.Assign (d);
    serverAddress = Address(i6.GetAddress (1,1));
  }
```

```
NS_LOG_INFO ("Create UdpServer application on node 1.");
uint16_t port = 4000;
UdpServerHelper server (port);
ApplicationContainer apps = server.Install (n.Get (1));
apps.Start (Seconds (1.0));
apps.Stop (Seconds (10.0));

NS_LOG_INFO ("Create UdpClient application on node 0 to send to node 1.");
uint32_t MaxPacketSize = 1024;
Time interPacketInterval = Seconds (0.05);
uint32_t maxPacketCount = 320;
UdpClientHelper client (serverAddress, port);
client.SetAttribute ("MaxPackets", UintegerValue (maxPacketCount));
client.SetAttribute ("Interval", TimeValue (interPacketInterval));
client.SetAttribute ("PacketSize", UintegerValue (MaxPacketSize));
apps = client.Install (n.Get (0));
apps.Start (Seconds (2.0));
apps.Stop (Seconds (10.0));

NS_LOG_INFO ("Run Simulation.");



MobilityHelper mobility;
mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
mobility.Install(n);

AnimationInterface anim("udp-client-server.xml");
```

```
AnimationInterface::SetConstantPosition(n.Get(0),10,25);
AnimationInterface::SetConstantPosition(n.Get(1),40,25);
anim.EnablePacketMetadata(true);

pointToPoint.EnablePcapAll("udp-client-server");

Simulator::Run ();
Simulator::Destroy ();
NS_LOG_INFO ("Done.");
}
```

**Output:**



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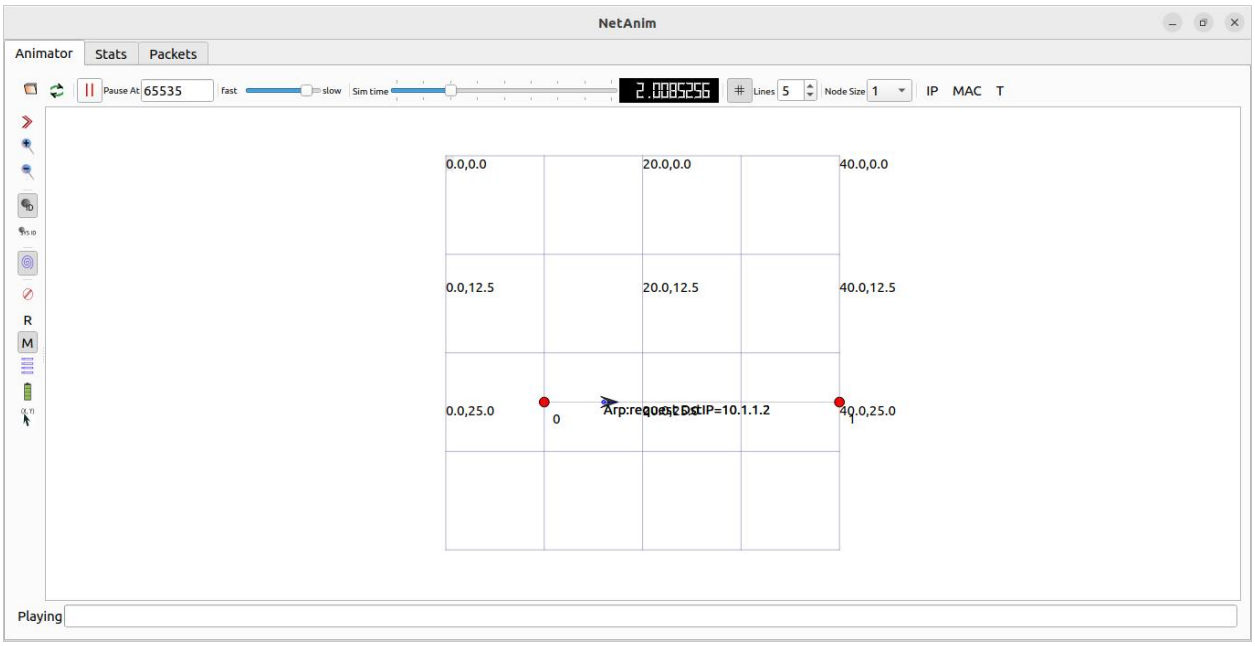


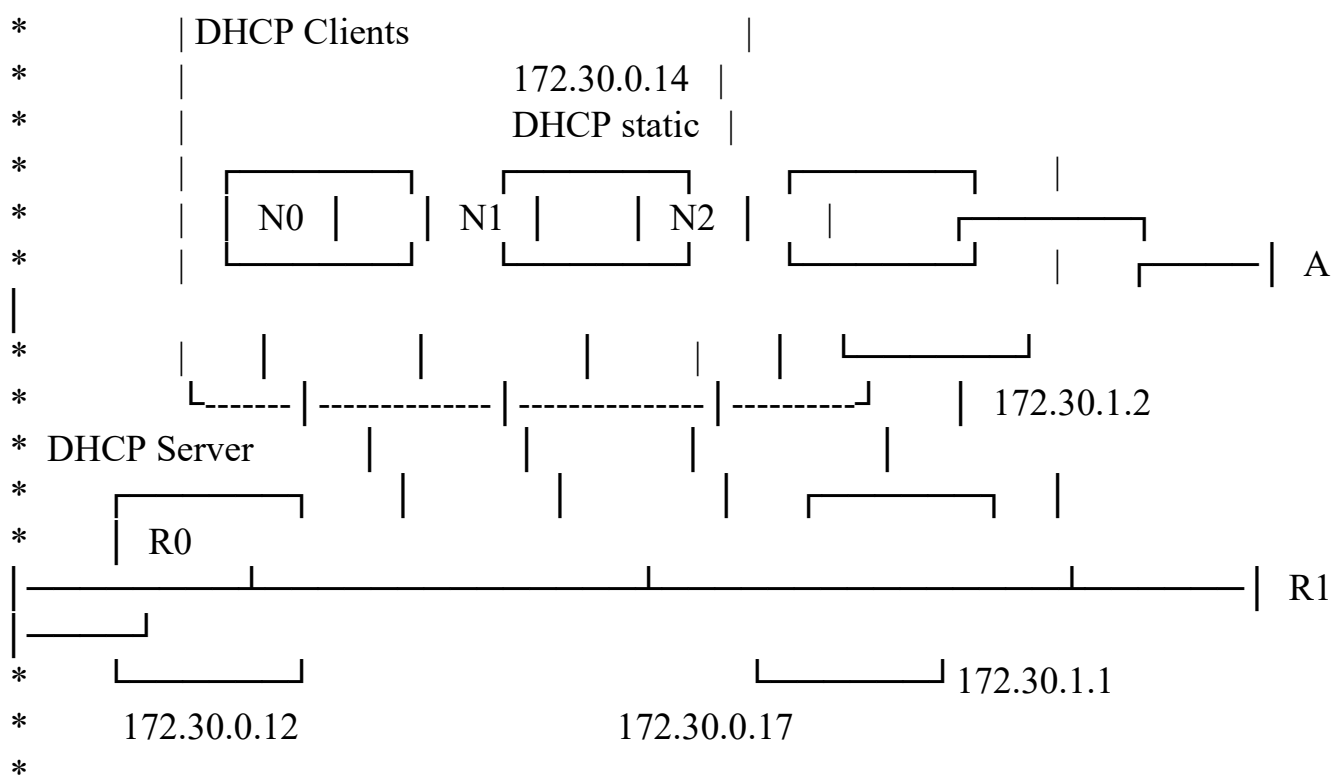
## Practical 11: Program to simulate DHCP server and n clients

DHCP stands for Dynamic Host Configuration Protocol. It is the critical feature on which the users of an enterprise network communicate. DHCP helps enterprises to smoothly manage the allocation of IP addresses to the end-user clients' devices such as desktops, laptops, cellphones.

### Code:

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */
/*
 * Copyright (c) 2011 UPB
 * Copyright (c) 2017 NITK Surathkal
 *
 * This program is free software; you can redistribute it and/or modify
 * it under the terms of the GNU General Public License version 2 as
 * published by the Free Software Foundation;
 *
 * This program is distributed in the hope that it will be useful,
 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 * GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program; if not, write to the Free Software
 * Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA  02111-1307  USA
 *
 * Author: Radu Lupu <rlupu@elcom.pub.ro>
 *         Ankit Deepak <adadeepak8@gmail.com>
 *         Deepti Rajagopal <deeptir96@gmail.com>
 *
 */

/*
 * Network layout:
 *
 * R0 is a DHCP server. The DHCP server announced R1 as the default router.
 * Nodes N1 will send UDP Echo packets to node A.
 *
 *
 *              ┌----------------------------------------------┐
```




```
 *
 * Things to notice:
 * 1) The routes in A are manually set to have R1 as the default router,
 *    just because using a dynamic outing in this example is an overkill.
 * 2) R1's address is set statically though the DHCP server helper interface.
 *    This is useful to prevent address conflicts with the dynamic pool.
 *    Not necessary if the DHCP pool is not conflicting with static addresses.
 * 3) N2 has a dynamically-assigned, static address (i.e., a fixed address assigned via
DHCP).
 *
 */

#include "ns3/core-module.h"
#include "ns3/internet-apps-module.h"
#include "ns3/csma-module.h"
#include "ns3/internet-module.h"
#include "ns3/point-to-point-module.h"
#include "ns3/applications-module.h"

//netanim code
#include "ns3/netanim-module.h"
#include "ns3/mobility-module.h"
```

```
using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("DhcpExample");

int
main (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);

  bool verbose = false;
  bool tracing = false;
  cmd.AddValue ("verbose", "turn on the logs", verbose);
  cmd.AddValue ("tracing", "turn on the tracing", tracing);

  cmd.Parse (argc, argv);

  // GlobalValue::Bind ("ChecksumEnabled", BooleanValue (true));

  if (verbose)
    {
      LogComponentEnable ("DhcpServer", LOG_LEVEL_ALL);
      LogComponentEnable ("DhcpClient", LOG_LEVEL_ALL);
      LogComponentEnable ("UdpEchoServerApplication", LOG_LEVEL_INFO);
      LogComponentEnable ("UdpEchoClientApplication", LOG_LEVEL_INFO);
    }

  Time stopTime = Seconds (20);

  NS_LOG_INFO ("Create nodes.");
  NodeContainer nodes;
  NodeContainer router;
  nodes.Create (3);
  router.Create (2);

  NodeContainer net (nodes, router);

  NS_LOG_INFO ("Create channels.");
  CsmaHelper csma;
```

```
  csma.SetChannelAttribute ("DataRate", StringValue ("5Mbps"));
  csma.SetChannelAttribute ("Delay", StringValue ("2ms"));
  csma.SetDeviceAttribute ("Mtu", UintegerValue (1500));
  NetDeviceContainer devNet = csma.Install (net);

  NodeContainer p2pNodes;
  p2pNodes.Add (net.Get (4));
  p2pNodes.Create (1);

  PointToPointHelper pointToPoint;
  pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
  pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));

  NetDeviceContainer p2pDevices;
  p2pDevices = pointToPoint.Install (p2pNodes);

  InternetStackHelper tcpip;
  tcpip.Install (nodes);
  tcpip.Install (router);
  tcpip.Install (p2pNodes.Get (1));

  Ipv4AddressHelper address;
  address.SetBase ("172.30.1.0", "255.255.255.0");
  Ipv4InterfaceContainer p2pInterfaces;
  p2pInterfaces = address.Assign (p2pDevices);

  // manually add a routing entry because we don't want to add a dynamic routing
  Ipv4StaticRoutingHelper ipv4RoutingHelper;
  Ptr<Ipv4> ipv4Ptr = p2pNodes.Get (1)->GetObject<Ipv4> ();
  Ptr<Ipv4StaticRouting> staticRoutingA = ipv4RoutingHelper.GetStaticRouting
(ipv4Ptr);
  staticRoutingA->AddNetworkRouteTo (Ipv4Address ("172.30.0.0"), Ipv4Mask ("/24"),
                                     Ipv4Address ("172.30.1.1"), 1);

  NS_LOG_INFO ("Setup the IP addresses and create DHCP applications.");
  DhcpHelper dhcpHelper;

  // The router must have a fixed IP.
```

```
  Ipv4InterfaceContainer fixedNodes = dhcpHelper.InstallFixedAddress (devNet.Get (4),
Ipv4Address ("172.30.0.17"), Ipv4Mask ("/24"));
  // Not really necessary, IP forwarding is enabled by default in IPv4.
  fixedNodes.Get (0).first->SetAttribute ("IpForward", BooleanValue (true));

  // DHCP server
  ApplicationContainer dhcpServerApp = dhcpHelper.InstallDhcpServer (devNet.Get (3),
Ipv4Address ("172.30.0.12"),
                                                     Ipv4Address ("172.30.0.0"), Ipv4Mask
("/24"),
                                                     Ipv4Address ("172.30.0.10"), Ipv4Address
("172.30.0.15"),
                                                     Ipv4Address ("172.30.0.17"));

  // This is just to show how it can be done.
  DynamicCast<DhcpServer> (dhcpServerApp.Get (0))->AddStaticDhcpEntry
(devNet.Get (2)->GetAddress (), Ipv4Address ("172.30.0.14"));

  dhcpServerApp.Start (Seconds (0.0));
  dhcpServerApp.Stop (stopTime);

  // DHCP clients
  NetDeviceContainer dhcpClientNetDevs;
  dhcpClientNetDevs.Add (devNet.Get (0));
  dhcpClientNetDevs.Add (devNet.Get (1));
  dhcpClientNetDevs.Add (devNet.Get (2));

  ApplicationContainer dhcpClients = dhcpHelper.InstallDhcpClient
(dhcpClientNetDevs);
  dhcpClients.Start (Seconds (1.0));
  dhcpClients.Stop (stopTime);

  UdpEchoServerHelper echoServer (9);

  ApplicationContainer serverApps = echoServer.Install (p2pNodes.Get (1));
  serverApps.Start (Seconds (0.0));
  serverApps.Stop (stopTime);

  UdpEchoClientHelper echoClient (p2pInterfaces.GetAddress (1), 9);
```

```
 echoClient.SetAttribute ("MaxPackets", UintegerValue (100));
 echoClient.SetAttribute ("Interval", TimeValue (Seconds (1.0)));
 echoClient.SetAttribute ("PacketSize", UintegerValue (1024));

 ApplicationContainer clientApps = echoClient.Install (nodes.Get (1));
 clientApps.Start (Seconds (10.0));
 clientApps.Stop (stopTime);


 MobilityHelper mobility;
 mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
 mobility.Install(nodes);

 AnimationInterface anim("pranay.xml");
 AnimationInterface::SetConstantPosition(nodes.Get(0),10,25);
 AnimationInterface::SetConstantPosition(nodes.Get(1),40,25);
 anim.EnablePacketMetadata(true);



 Simulator::Stop (stopTime + Seconds (10.0));

 if (tracing)
   {
    csma.EnablePcapAll ("dhcp-csma");
    pointToPoint.EnablePcapAll ("dhcp-p2p");
   }

 NS_LOG_INFO ("Run Simulation.");
 Simulator::Run ();
 Simulator::Destroy ();
 NS_LOG_INFO ("Done.");
}
```

**Output:**

C

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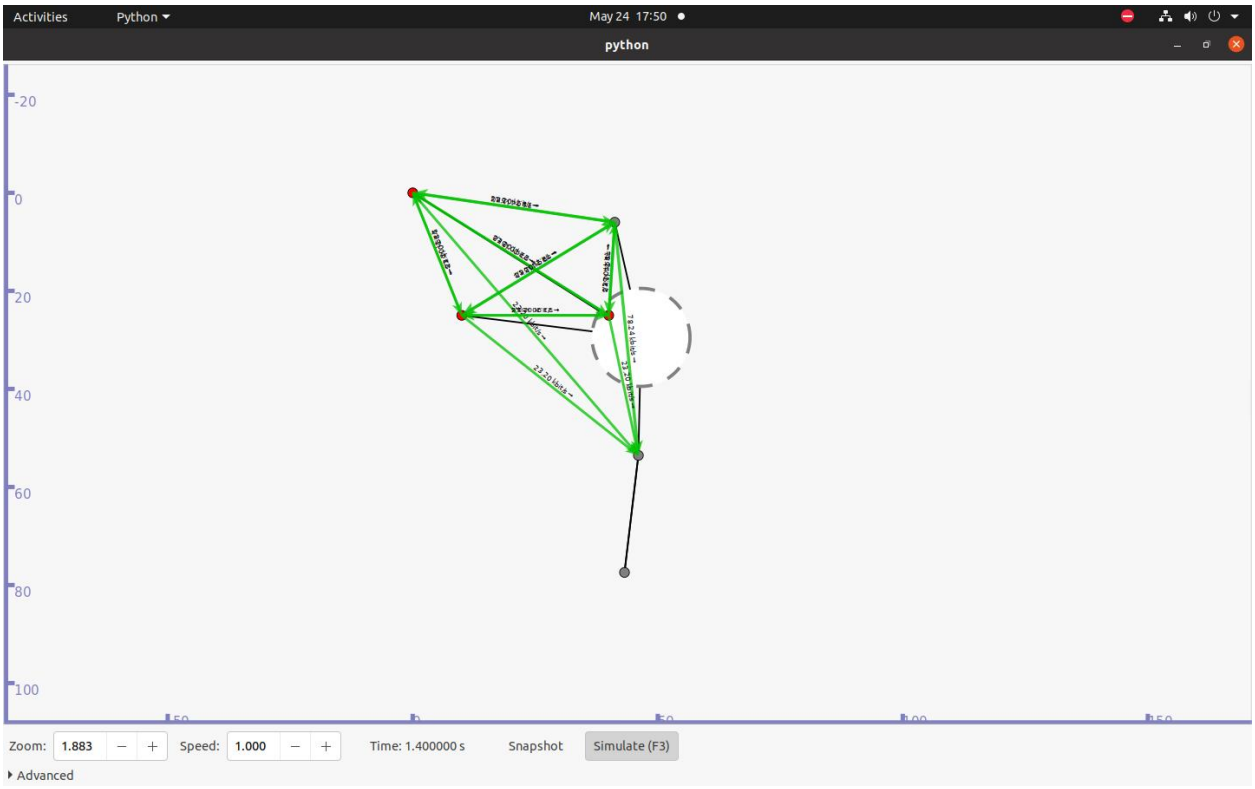


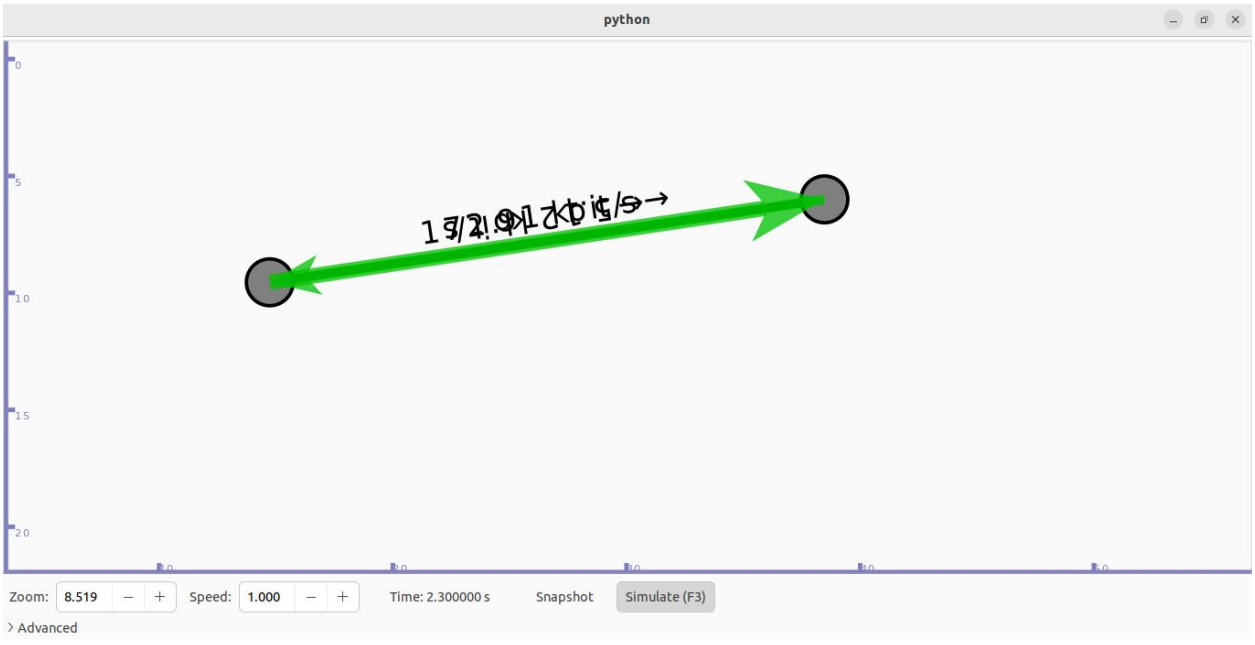

C

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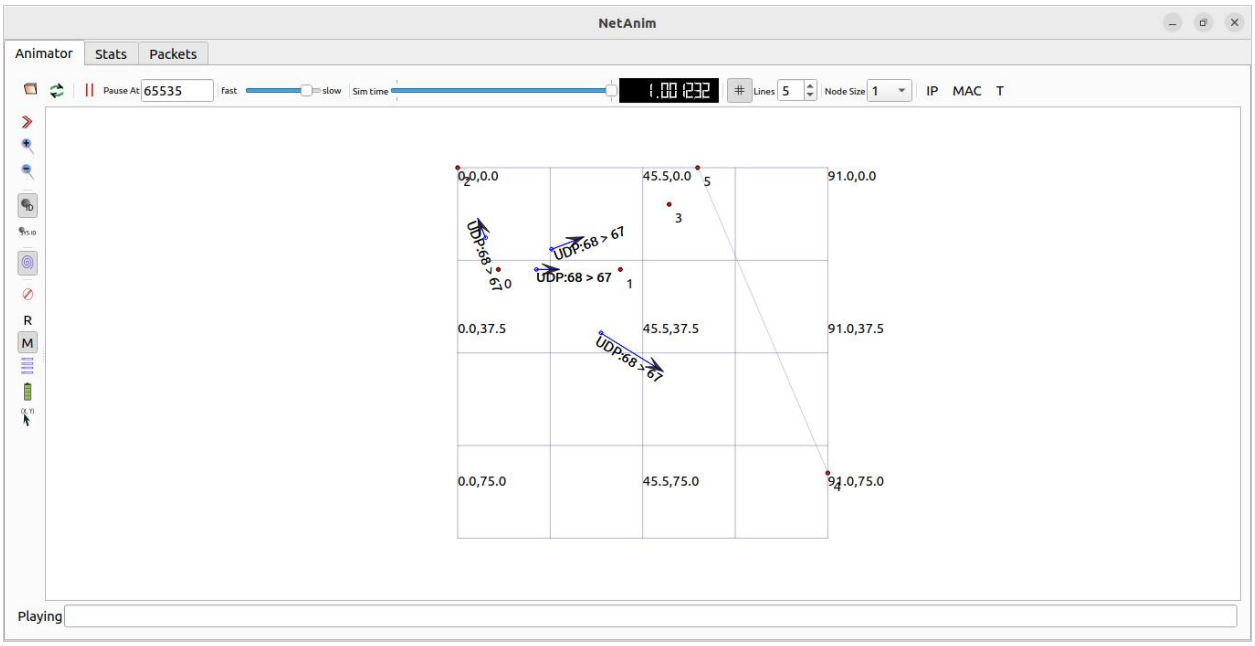
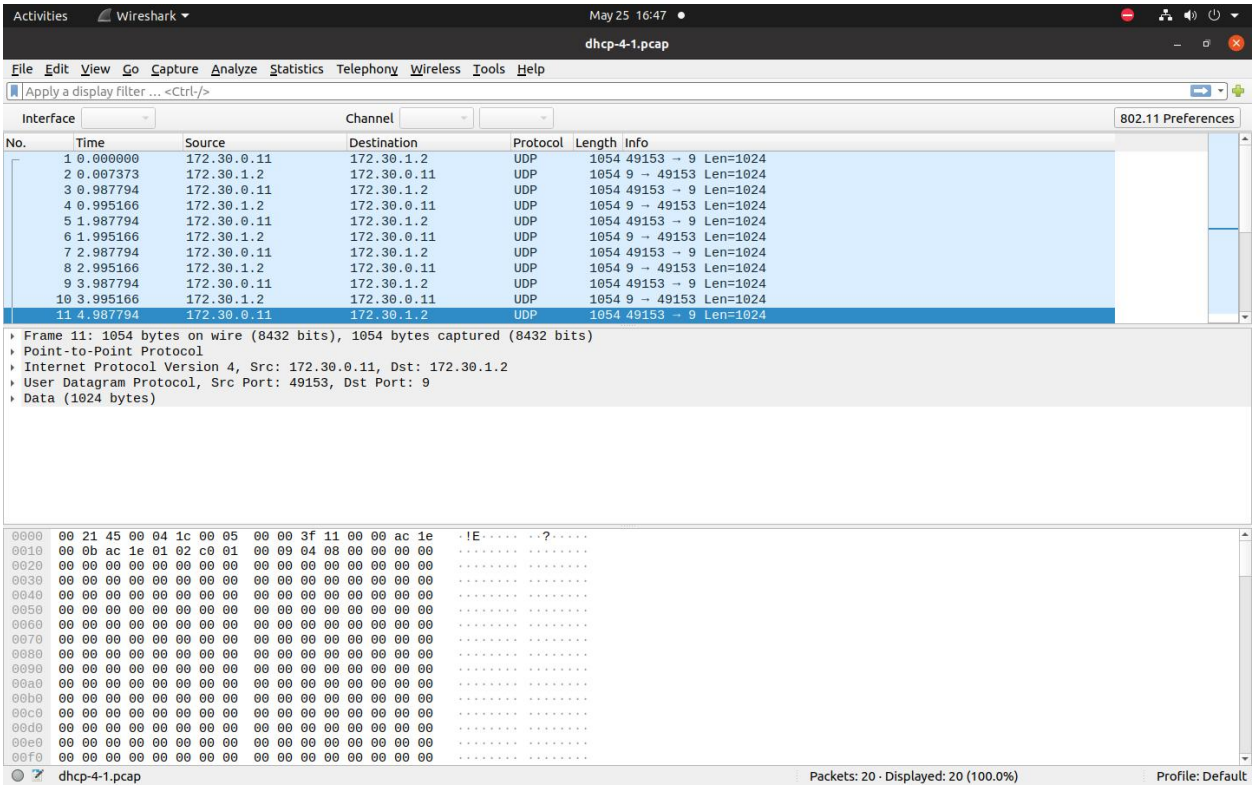


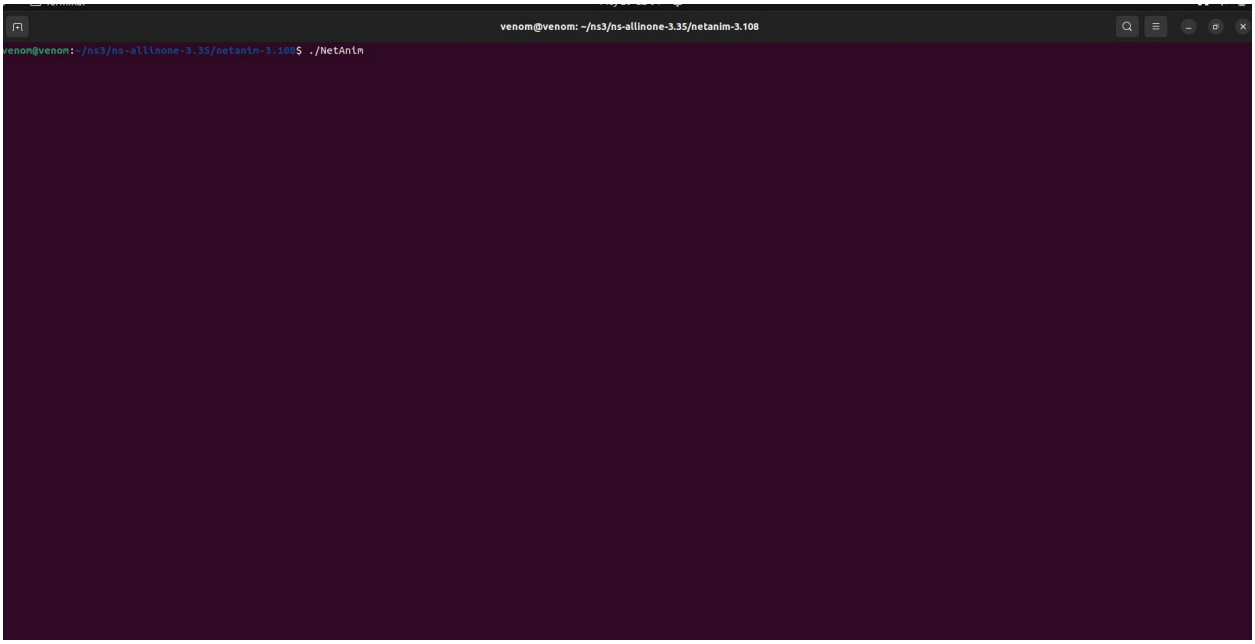
# Practical 12: Animate a simple Network using NetAnim in Network Stimulator

**Step 1:** Generate the XML file using Mobility helper in first.cc and the code below to create the XML file

```
MobilityHelper mobility;
mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
mobility.Install(nodes);

AnimationInterface anim("first.xml");
AnimationInterface::SetConstantPosition(nodes.Get(0),10,25);
AnimationInterface::SetConstantPosition(nodes.Get(1),40,25);
anim.EnablePacketMetadata(true);

pointToPoint.EnablePcapAll("first");

Simulator::Run ();
Simulator::Destroy ();
return 0;
}
```

C++ Tab Width: 8 Ln 89, Col 39 INS

**Step 2:** Then change directory to NetAnim folder and open terminal and enter ./NetAnim to start NetAnim




**Step 3:** Open the XML File that was just generated now and click the play button to start the stimulation

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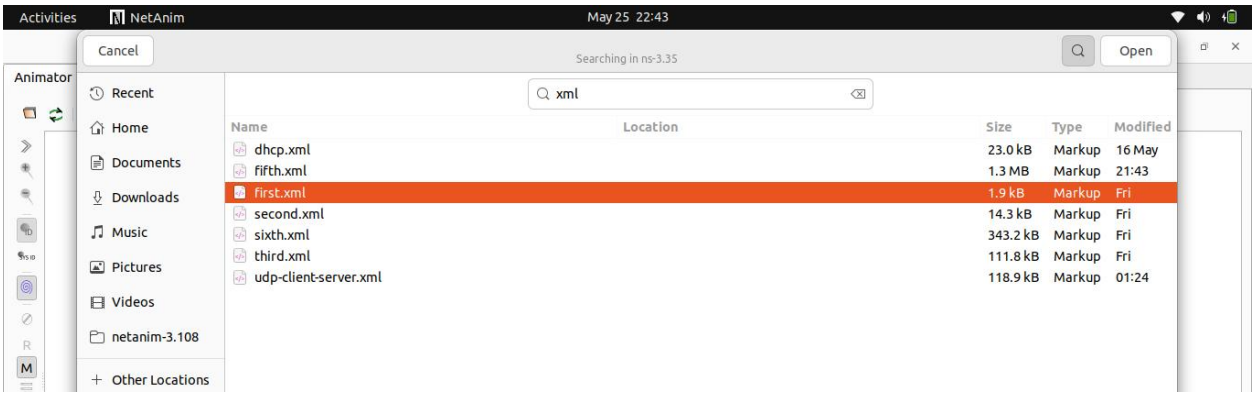


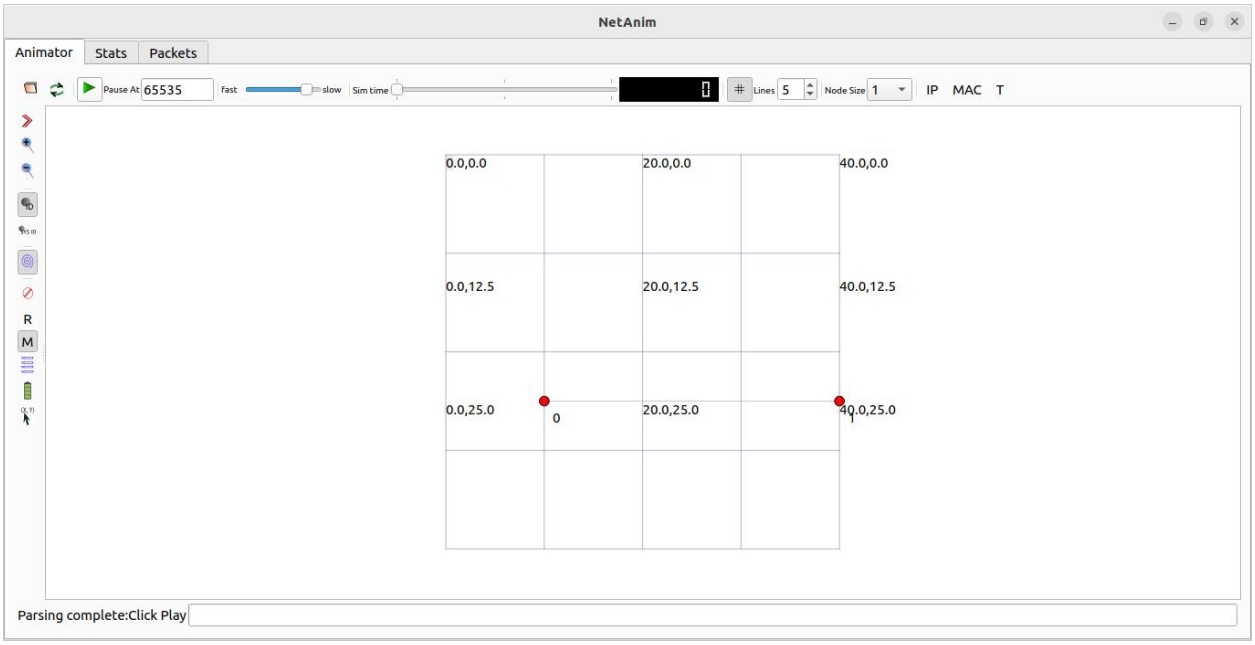

C

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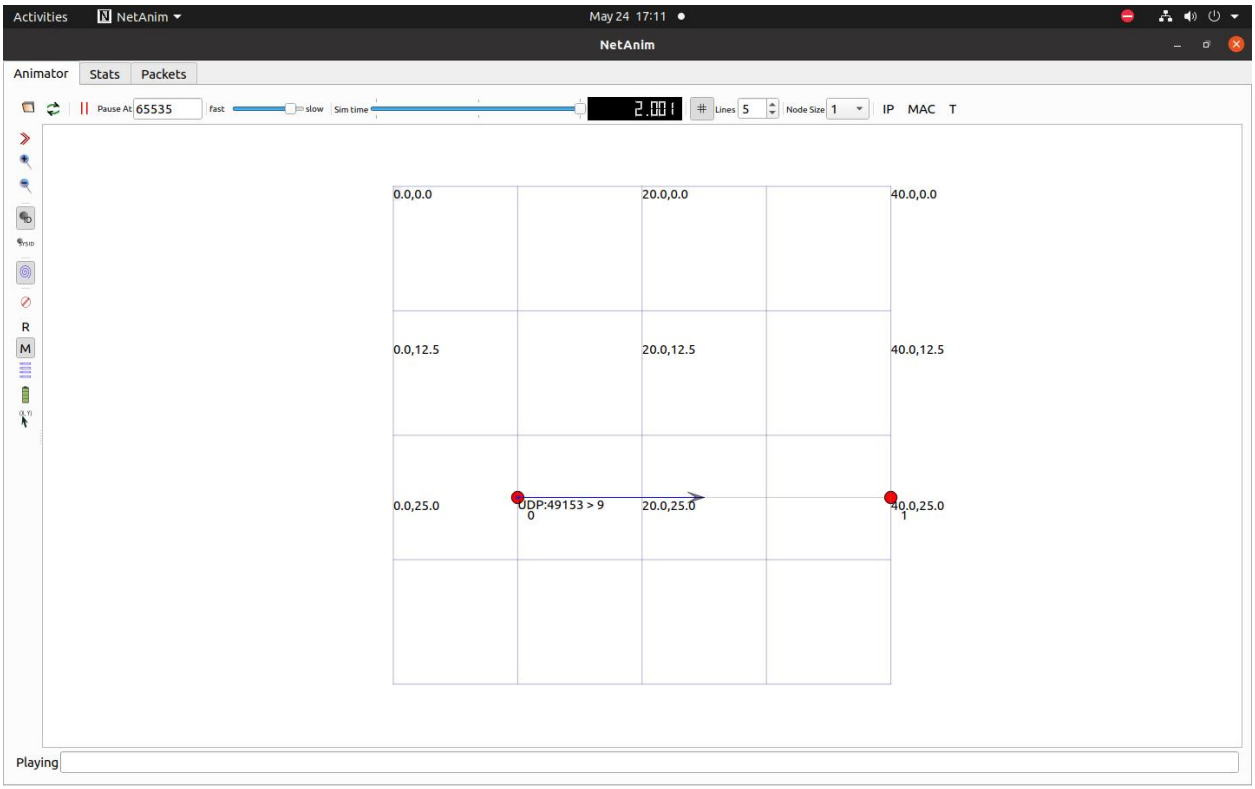


# Practical 13: Network Traffic Analysis using WireShark

Wireshark is a network protocol analyzer, or an application that captures packets from a networkconnection, such as from your computer to your home office or the internet. Packet is the name given to a discrete unit of data in a typical Ethernet network.

Wireshark is the most often-used packet sniffer in the world. Like any other packet sniffer,Wireshark does three things:

1. **Packet Capture:** Wireshark listens to a network connection in real time and then grabsentire streams of traffic – quite possibly tens of thousands of packets at a time.
2. **Filtering:** Wireshark is capable of slicing and dicing all of this random live data usingfilters. By applying a filter, you can obtain just the information you need to see.
3. **Visualization:** Wireshark, like any good packet sniffer, allows you to dive right into the verymiddle of a network packet. It also allows you to visualize entire conversations and network streams.

## How to Install Wireshark on Linux

To install Wireshark using the following sequence (notice that you'll need to have root permissions):

**$ sudo apt-get install wireshark**

**$ sudo dpkg-reconfigure wireshark-common**

**$ sudo usermod -a -G wireshark $USER**

**$ newgrp wireshark**

Once you have completed the above steps, you then log out and log back in, and then startWireshark:

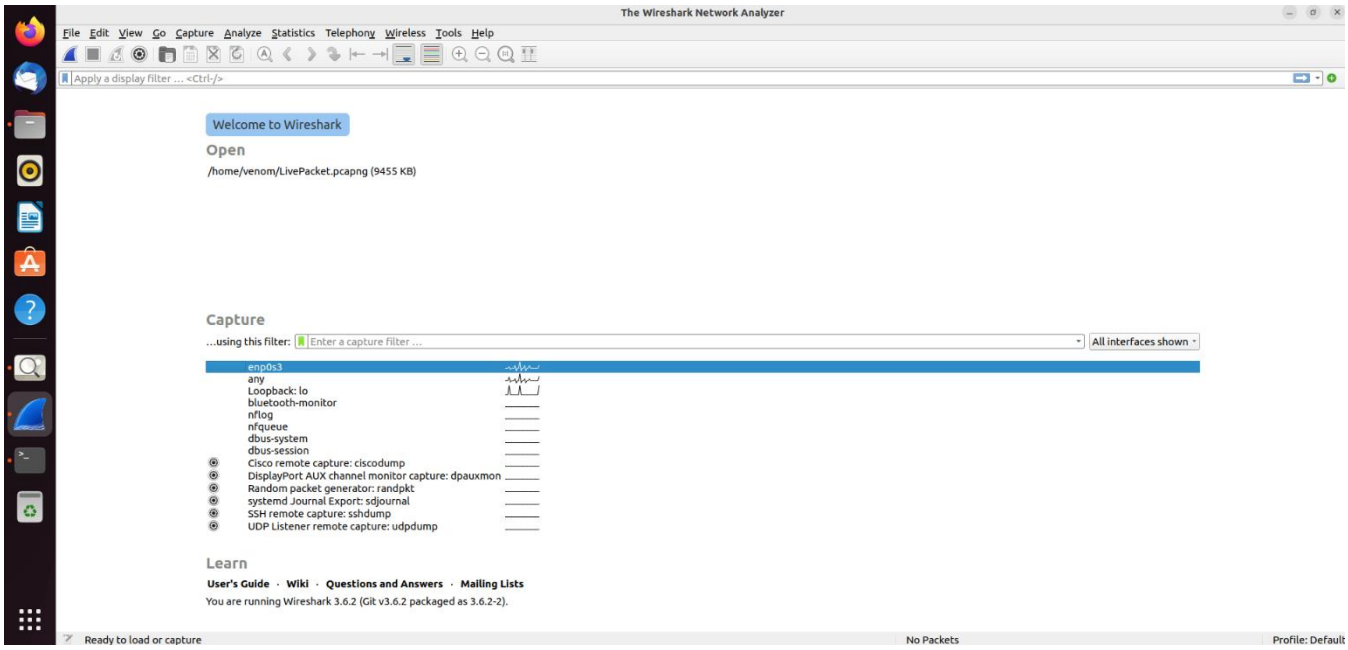
$ sudo wireshark

## How to Capture Packets Using Wireshark

Once you've installed Wireshark, you can start grabbing network traffic. But remember: To captureany packets, you need to have proper permissions on your computer to put Wireshark into promiscuous mode.

- In a Linux system, it usually means that you have root access.

As long as you have the right permissions, you have several options to actually start the capture.Perhaps the best is to select Capture >> Options from the main window. This will bring up the Capture Interfaces window, as shown below




This window will list all available interfaces. In this case, Wireshark provides several to choosefrom.

For this example, we'll select the wlp interface, which is the most active interface. Wiresharkvisualizes the traffic by showing a moving line, which represents the packets on the network.

Once the network interface is selected, you simply click the Start button to begin your capture. Asthe capture begins, it's possible to view the packets that appear on the screen, as shown in image below

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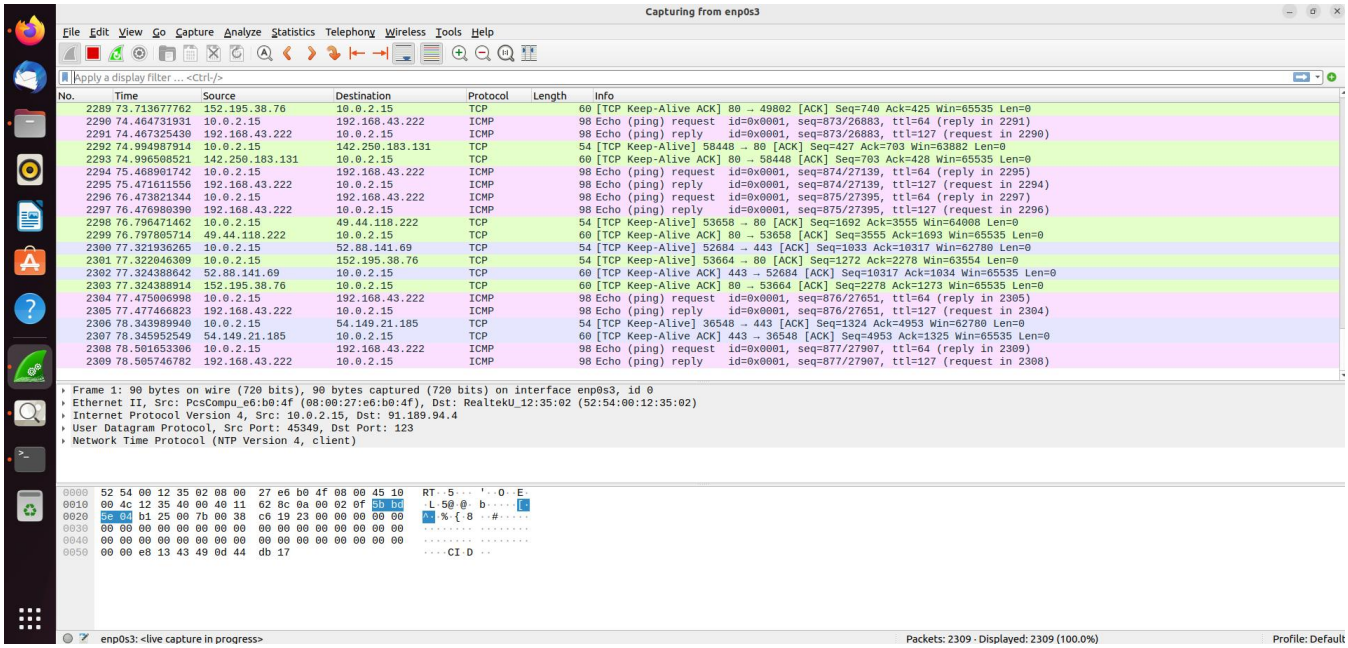


In the above image we can see all the packets that are tranferred using the current network.

## What the Color Coding Means in Wireshark

Now that you have some packets, it's time to figure out what they mean. Wireshark tries to help youidentify packet types by applying common-sense color coding. The table below describes the default colors given to major packet types.

| Color in Wireshark | Packet Type |
|---|---|
| Light purple | TCP |
| Light blue | UDP |
| Black | Packets with errors |
| Light green | HTTP traffic |
| Light yellow | Windows-specific traffic, including Server Message Blocks (SMB) andNetBIOS |
| Dark yellow | Routing |
| Dark gray | TCP SYN, FIN and ACK traffic |

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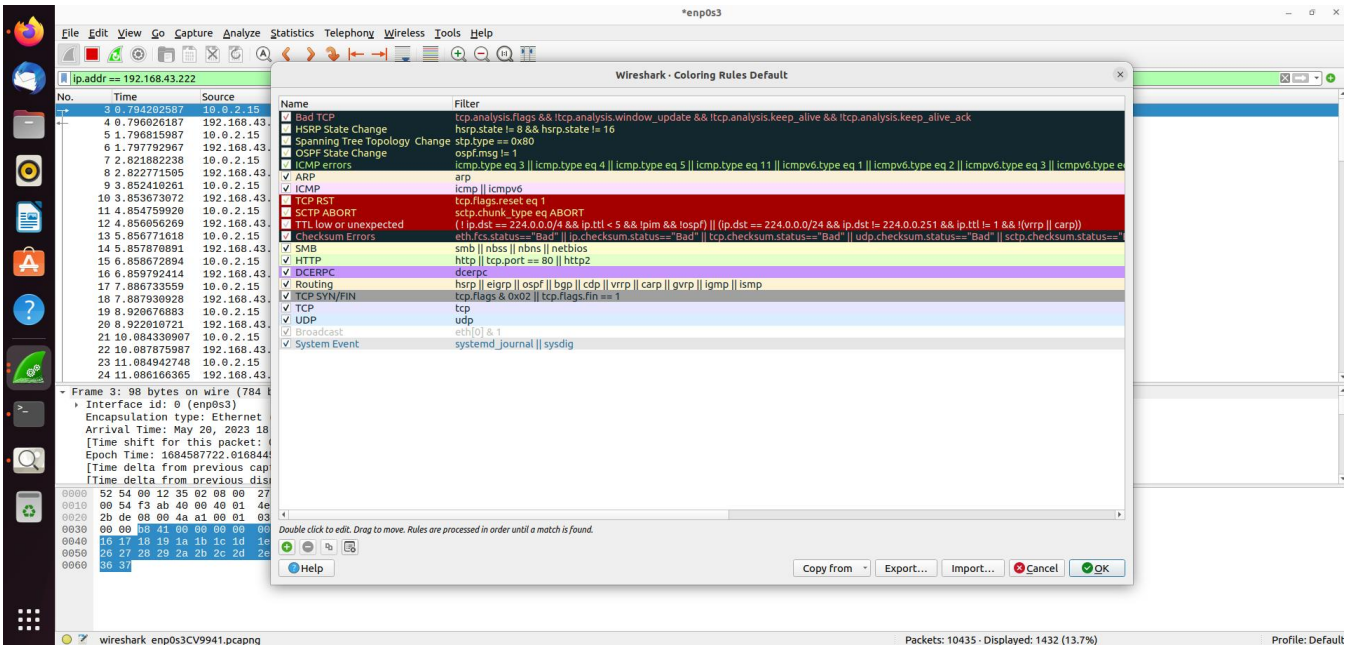
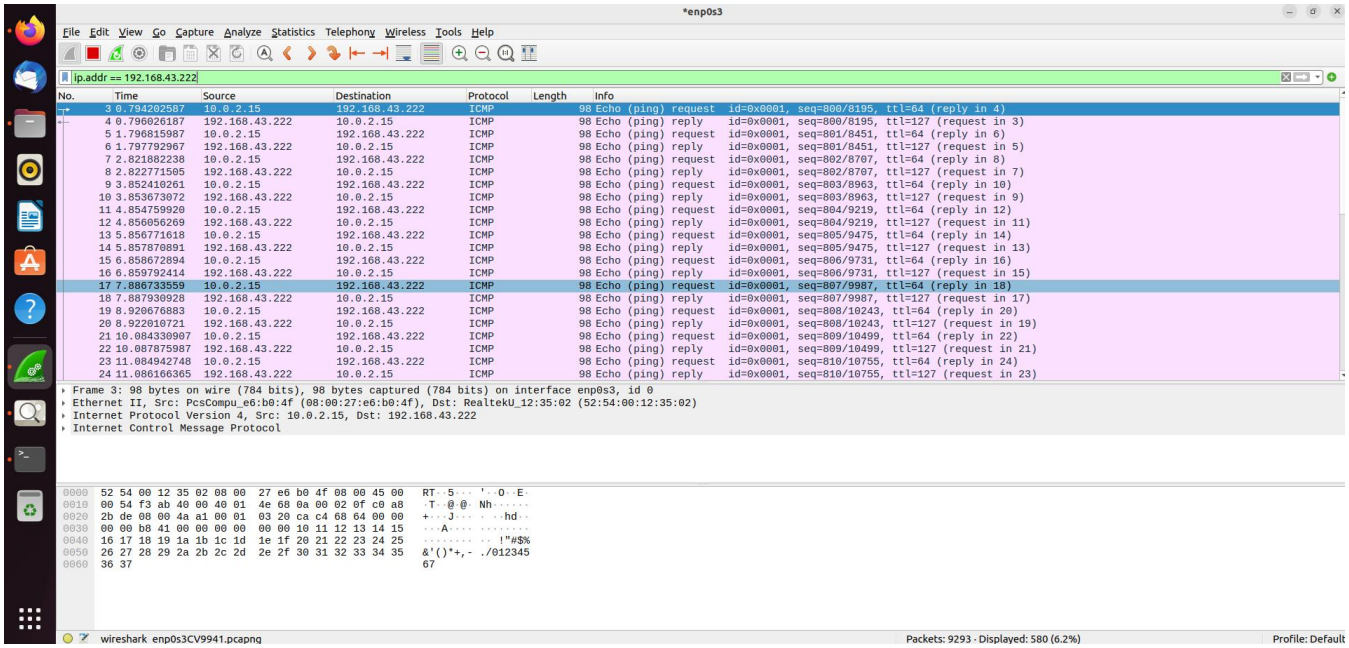
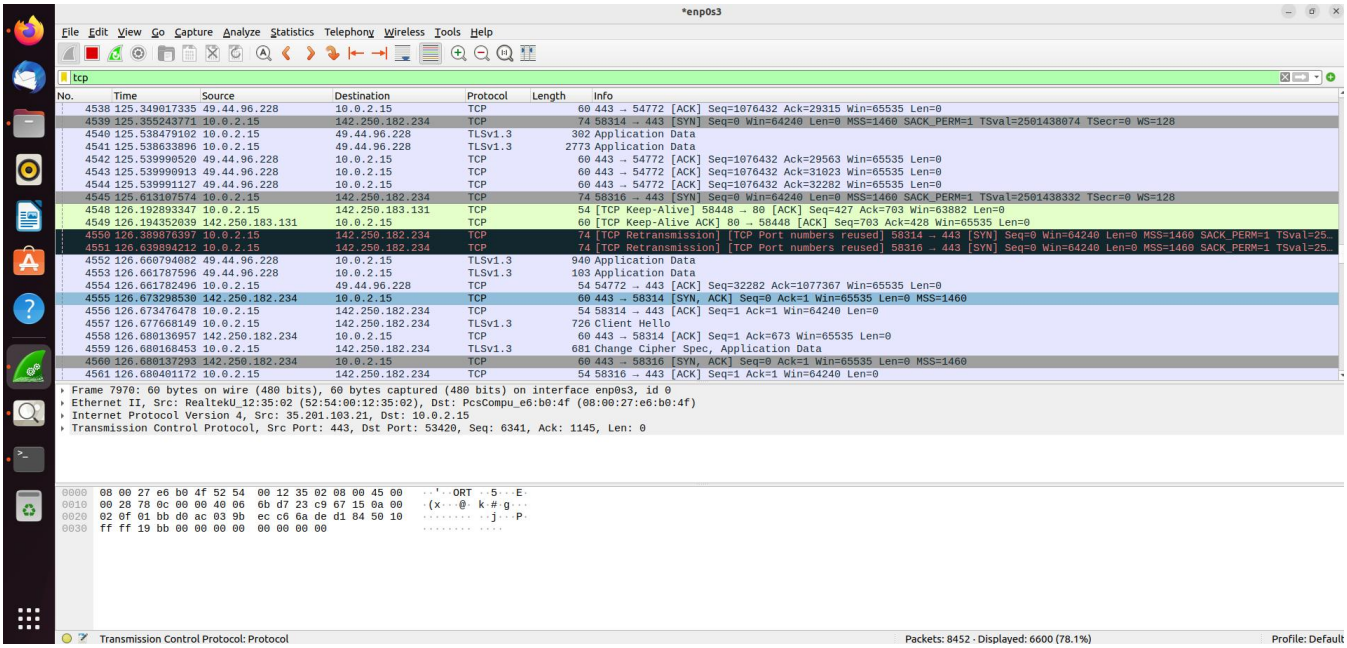
The default coloring scheme is shown below in image below. You can view this by going toView >> Coloring Rules.




You can even change the defaults or apply a custom rule. If you don't want any coloring at all, go toView, then click Colorize Packet List. It's a toggle, so if you want the coloring back, simply go backand click Colorize Packet List again. It's possible, even, to colorize specific conversations between computers.

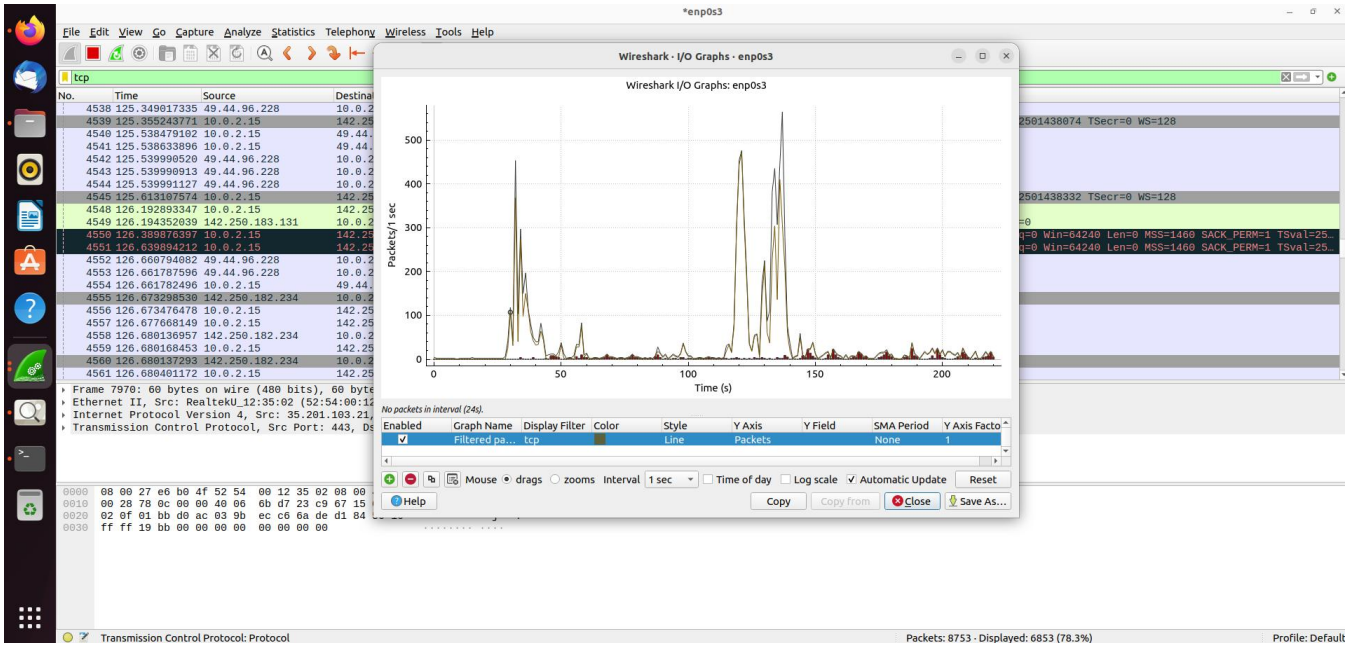


In the above screenshot we can see that there are light blue which indicate TPC protocols, UDP(light blue), TCP (light purple), TCP handshake (dark gray), HTTP (Green), Bad TCP(Black)




However, you're not limited to just interpreting by color. It's possible to view the input/output (I/O)statistics of an entire packet capture.

In Wireshark, just go to Statistics >> I/O Graph, and you'll see a graph similar to the one shown inImage below



## How to Filter and Inspect Packets in Wireshark

You can apply Wireshark filters in two ways:

1. In the Display Filter window, at the top of the screen
2. By highlighting a packet (or a portion of a packet) and right-clicking

on the packetWireshark filters use key phrases, such as the following:

| | |
|---|---|
| ip.addr | Specifies an IPv4 address |
| ipv6.addr | Specifies an IPv6 address |
| src | Source - where the packet came from |
| dst | Destination - where the packet is going |

You can also use the following values:

| | |
|---|---|
| & | Means “and,” as in, “Choose the IP address of 192.168.2.1 and 192.168.2.2” |
| & | |
| == | Means “equals,” as in “Choose only IP address 192.168.2.1” |
| ! | Means “not,” as in, do not show a particular IP address or source port |

Valid filter rules are always colored green. If you make a mistake on a filter rule, the box will turn avivid pink.

Let’s start with a couple of basic rules. For example, let’s say you want to see packets that have only the IP address of 192.168.53.216 somewhere inside. You would create the following commandline, and put it into the Filter window:

ip.addr == 192.168.43.222

The image below shows the results of adding that filter:

C

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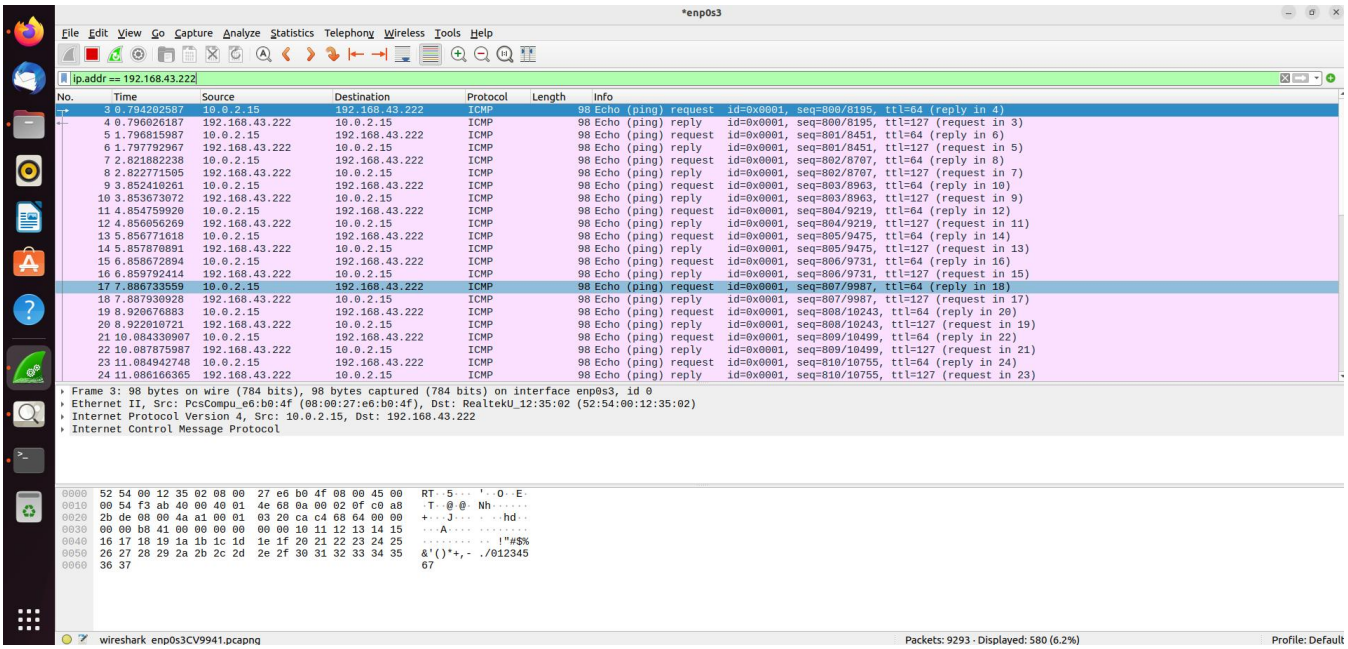
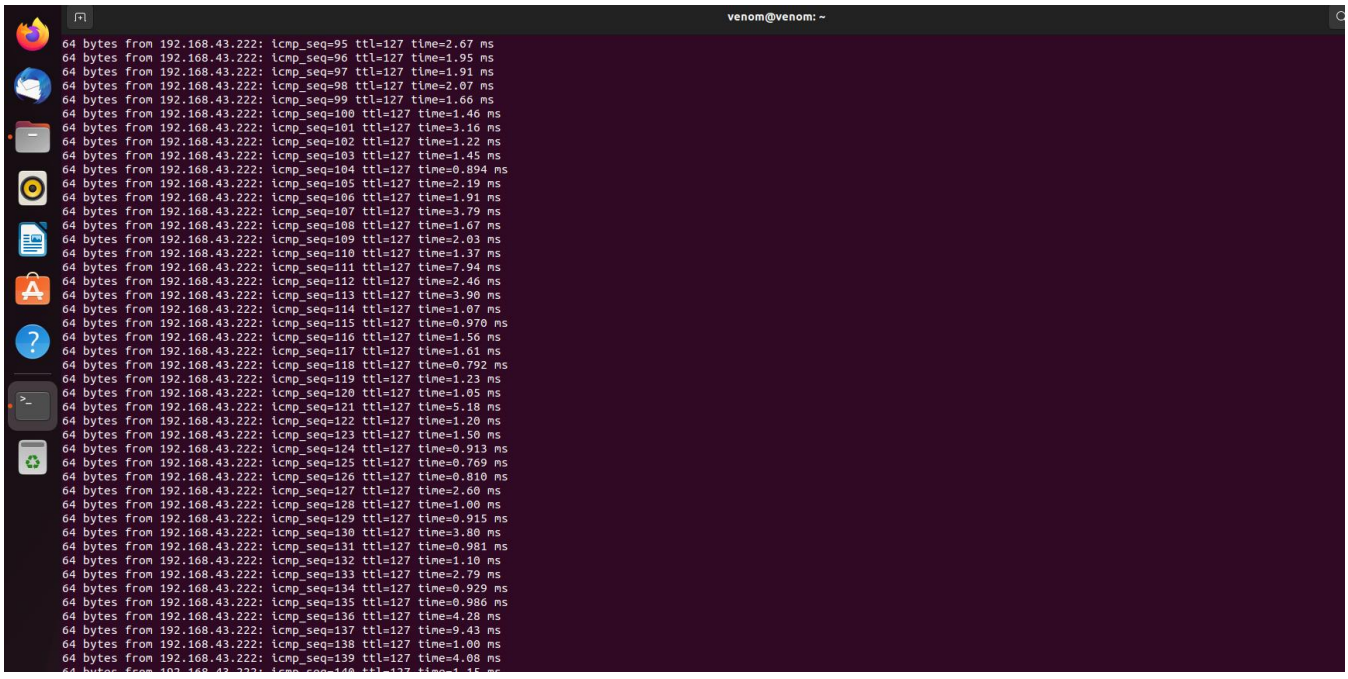



In this example we have tried to make a connection between two devices using

ping commandping 192.168.43.222

this allows us to send ping request to the device with the IP address 192.168.42.1

In the screenshot below we can observe that the connection have successfully achived using ping



C

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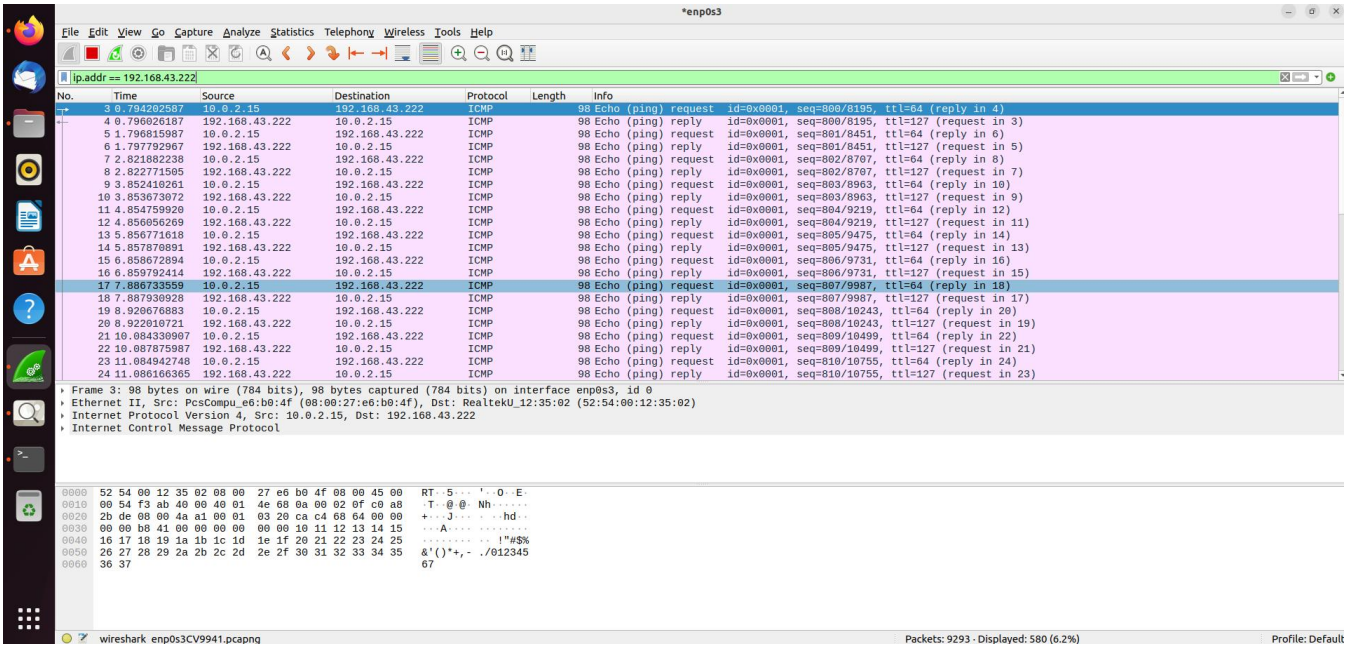
Now we analyze the ping request using wireshark. In the below image we can now filter using ip.addr == 192.168.42.1 here we can now see all he packets that are getting transfered between thetwo devices.

Here there are requests and responses that we can now use to minitor the connection between thesetwo devices.




## Request

The below image is the visual representation of the request that was generated.Here we can see the following data

1. Source IP: 192.168.42.222

2. Destination IP: 192.168.42.1

3. Length of the packet: 98 bytes
4. Type of the message: Echo (ping) request
5. Frame number: 2

C

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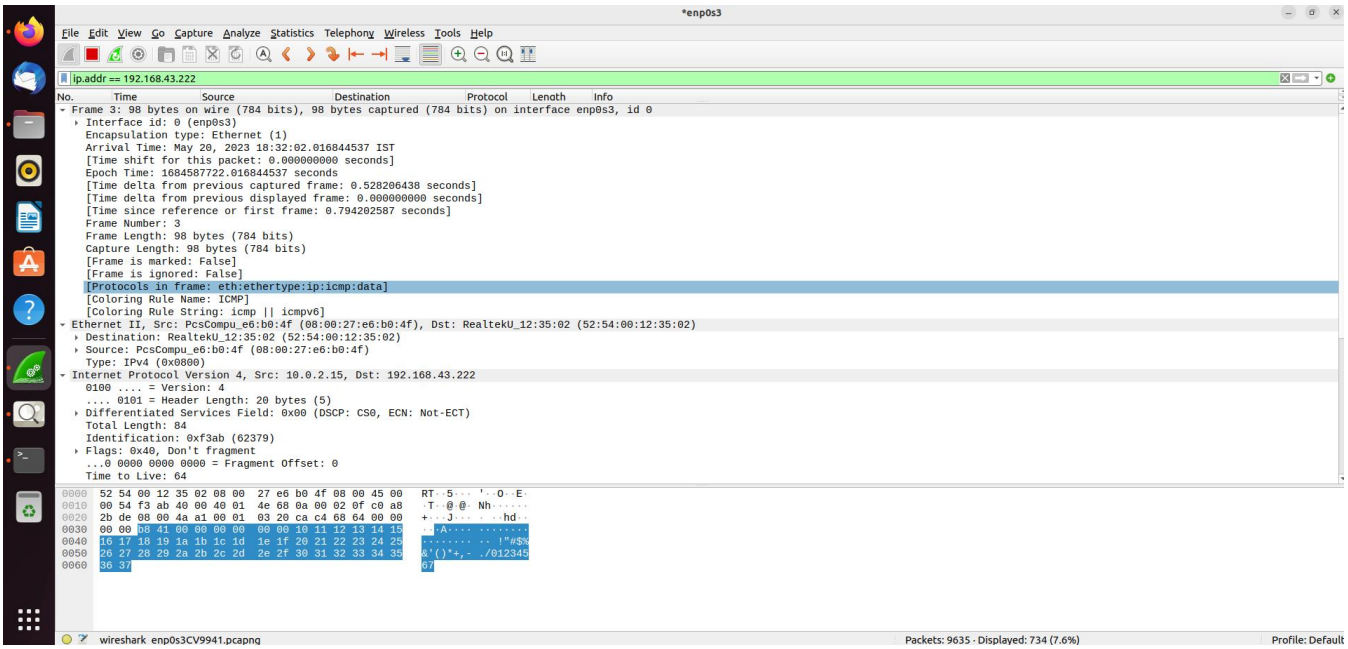

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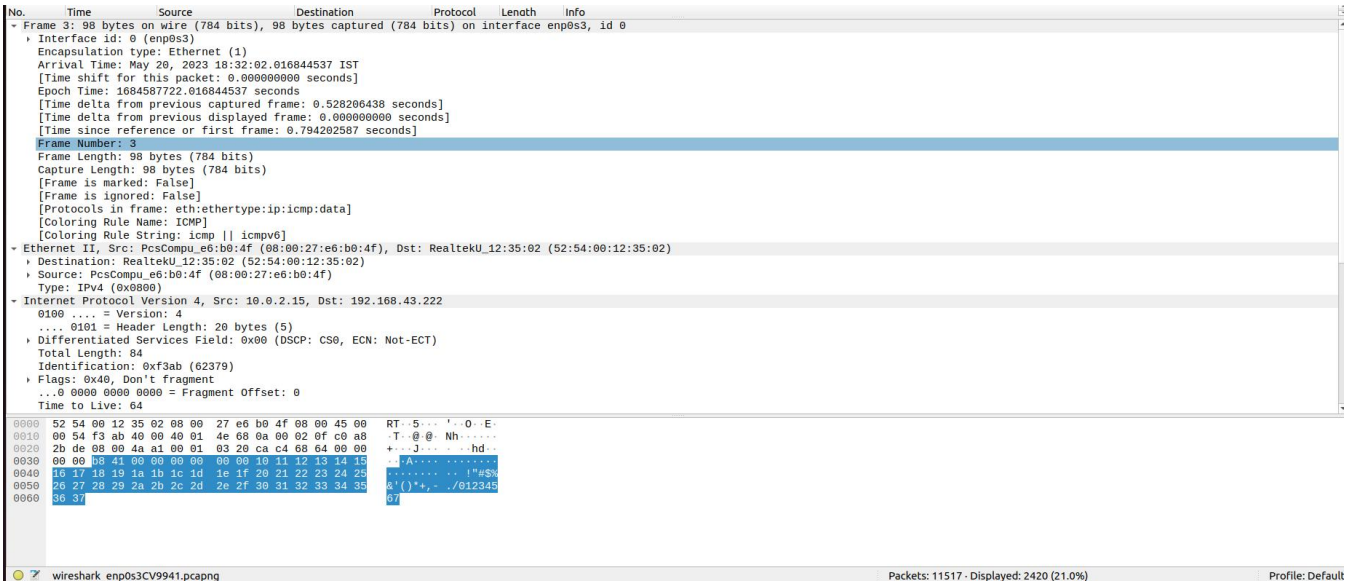
## Response

The below image is the visual representation of the response that was generated.Here we can see the following data

1. Source IP: 192.168.53.85
2. Destination IP: 192.168.53.216
3. Length of the packet: 98 bytes
4. Type of the message: Echo (ping) response
5. Request frame: 3
6. Response time: 206.677 ms



## 14. Mini Project of Write a program to demonstrate Hybrid Topology in ns3

- Hybrid topology refers to a network configuration that combines multiple types of network topologies. It is a combination of two or more basic network topologies, such as star, ring, bus, mesh, or tree topologies. The aim of using a hybrid topology is to leverage the advantages of different topologies and create a network that suits specific requirements.
- In a hybrid topology, different sections of the network may be connected using different topologies, resulting in a more flexible and scalable network infrastructure. For example, a network might have a star topology in one area, a ring topology in another, and a bus topology connecting these sections. This allows for efficient use of resources, better fault tolerance, improved performance, and increased network capacity.
- Some of the benefits of a hybrid topology include:
- Scalability: Hybrid topologies can be easily expanded by adding or modifying specific sections of the network without affecting the entire infrastructure. This flexibility allows for growth and adaptation to changing network needs.
- Fault tolerance: By combining different topologies, a hybrid network can provide redundancy and fault tolerance. If one section of the network fails, the remaining sections can continue to function, minimizing downtime and improving reliability.
- Performance optimization: Different topologies excel in different aspects. By combining them strategically, a hybrid topology can optimize network performance. For example, a star topology can provide centralized management and easy connectivity, while a mesh topology can offer robust communication between nodes.
- Segmentation: Hybrid topologies allow for network segmentation, enabling specific sections of the network to have their own topologies suited to their requirements. This can enhance security, isolate network issues, and improve overall network management.

- Hybrid topologies are commonly used in large-scale networks, such as enterprise networks, data centers, and telecommunications infrastructure. They provide a versatile and adaptable network architecture that can meet diverse needs and support various applications and services.

**Tools used:** Ns3 , NetAnim,Wireshark

## Code:

```
#include "ns3/core-module.h"
#include "ns3/point-to-point-module.h"
```

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```
#include "ns3/network-module.h"
#include "ns3/applications-module.h"
#include "ns3/csma-module.h"
#include "ns3/internet-module.h"
#include "ns3/yans-wifi-helper.h"
#include "ns3/ssid.h"
#include "ns3/netanim-module.h"
#include "ns3/mobility-module.h"

using namespace ns3;

NS_LOG_COMPONENT_DEFINE ("ThirdScriptExample");

int
main (int argc, char *argv[])
{
 bool verbose = true;
 uint32_t nCsma = 3;
 uint32_t nWifi = 3;
 bool tracing = false;

 CommandLine cmd (__FILE__);
 cmd.AddValue ("nCsma", "Number of \"extra\" CSMA nodes/devices", nCsma);
 cmd.AddValue ("nWifi", "Number of wifi STA devices", nWifi);
 cmd.AddValue ("verbose", "Tell echo applications to log if true", verbose);
 cmd.AddValue ("tracing", "Enable pcap tracing", tracing);

 cmd.Parse (argc,argv);

 // The underlying restriction of 18 is due to the grid position
 // allocator's configuration; the grid layout will exceed the
 // bounding box if more than 18 nodes are provided.
 if (nWifi > 18)
   {
    std::cout << "nWifi should be 18 or less; otherwise grid layout exceeds the bounding box" << std::endl;
    return 1;
   }

 if (verbose)
   {
    LogComponentEnable ("UdpEchoClientApplication", LOG_LEVEL_INFO);
    LogComponentEnable ("UdpEchoServerApplication", LOG_LEVEL_INFO);
   }

 NodeContainer p2pNodes;
 p2pNodes.Create (2);

 PointToPointHelper pointToPoint;
 pointToPoint.SetDeviceAttribute ("DataRate", StringValue ("5Mbps"));
 pointToPoint.SetChannelAttribute ("Delay", StringValue ("2ms"));

 NetDeviceContainer p2pDevices;
```

```
p2pDevices = pointToPoint.Install (p2pNodes);

NodeContainer csmaNodes;
csmaNodes.Add (p2pNodes.Get (1));
csmaNodes.Create (nCsma);

CsmaHelper csma;
csma.SetChannelAttribute ("DataRate", StringValue ("100Mbps"));
csma.SetChannelAttribute ("Delay", TimeValue (NanoSeconds (6560)));

NetDeviceContainer csmaDevices;
csmaDevices = csma.Install (csmaNodes);

NodeContainer wifiStaNodes;
wifiStaNodes.Create (nWifi);
NodeContainer wifiApNode = p2pNodes.Get (0);

YansWifiChannelHelper channel = YansWifiChannelHelper::Default ();
YansWifiPhyHelper phy;
phy.SetChannel (channel.Create ());

WifiHelper wifi;
wifi.SetRemoteStationManager ("ns3::AarfWifiManager");

WifiMacHelper mac;
Ssid ssid = Ssid ("ns-3-ssid");
mac.SetType ("ns3::StaWifiMac",
             "Ssid", SsidValue (ssid),
             "ActiveProbing", BooleanValue (false));

NetDeviceContainer staDevices;
staDevices = wifi.Install (phy, mac, wifiStaNodes);

mac.SetType ("ns3::ApWifiMac",
             "Ssid", SsidValue (ssid));

NetDeviceContainer apDevices;
apDevices = wifi.Install (phy, mac, wifiApNode);

MobilityHelper mobility;

mobility.SetPositionAllocator ("ns3::GridPositionAllocator",
                               "MinX", DoubleValue (0.0),
                               "MinY", DoubleValue (0.0),
                               "DeltaX", DoubleValue (5.0),
                               "DeltaY", DoubleValue (10.0),
                               "GridWidth", UintegerValue (3),
                               "LayoutType", StringValue ("RowFirst"));

mobility.SetMobilityModel ("ns3::RandomWalk2dMobilityModel",
                           "Bounds", RectangleValue (Rectangle (-50, 50, -50, 50)));
mobility.Install (wifiStaNodes);
```

```
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
mobility.Install (wifiApNode);

InternetStackHelper stack;
stack.Install (csmaNodes);
stack.Install (wifiApNode);
stack.Install (wifiStaNodes);

Ipv4AddressHelper address;

address.SetBase ("10.1.1.0", "255.255.255.0");
Ipv4InterfaceContainer p2pInterfaces;
p2pInterfaces = address.Assign (p2pDevices);

address.SetBase ("10.1.2.0", "255.255.255.0");
Ipv4InterfaceContainer csmaInterfaces;
csmaInterfaces = address.Assign (csmaDevices);

address.SetBase ("10.1.3.0", "255.255.255.0");
address.Assign (staDevices);
address.Assign (apDevices);

UdpEchoServerHelper echoServer (9);

ApplicationContainer serverApps = echoServer.Install (csmaNodes.Get (nCsma));
serverApps.Start (Seconds (1.0));
serverApps.Stop (Seconds (10.0));

UdpEchoClientHelper echoClient (csmaInterfaces.GetAddress (nCsma), 9);
echoClient.SetAttribute ("MaxPackets", UintegerValue (1));
echoClient.SetAttribute ("Interval", TimeValue (Seconds (1.0)));
echoClient.SetAttribute ("PacketSize", UintegerValue (1024));

ApplicationContainer clientApps =
  echoClient.Install (wifiStaNodes.Get (nWifi - 1));
clientApps.Start (Seconds (2.0));
clientApps.Stop (Seconds (10.0));


mobility.SetMobilityModel("ns3::ConstantPositionMobilityModel");
mobility.Install(csmaNodes);

AnimationInterface anim("ram.xml");
AnimationInterface::SetConstantPosition (csmaNodes.Get(0),10,25);
AnimationInterface::SetConstantPosition (csmaNodes.Get(1),40,25);
anim.EnablePacketMetadata(true);

PcapHelper pcapHelper;
Ptr<PcapFileWrapper> file = pcapHelper.CreateFile ("ram.pcap", std::ios::out, PcapHelper::DLT_PPP);
```

```
Ipv4GlobalRoutingHelper::PopulateRoutingTables ();

Simulator::Stop (Seconds (10.0));

if (tracing)
  {
   phy.SetPcapDataLinkType (WifiPhyHelper::DLT_IEEE802_11_RADIO);
   pointToPoint.EnablePcapAll ("ram");
   phy.EnablePcap ("ram", apDevices.Get (0));
   csma.EnablePcap ("ram", csmaDevices.Get (0), true);
  }

Simulator::Run ();
Simulator::Destroy ();
return 0;
}
```

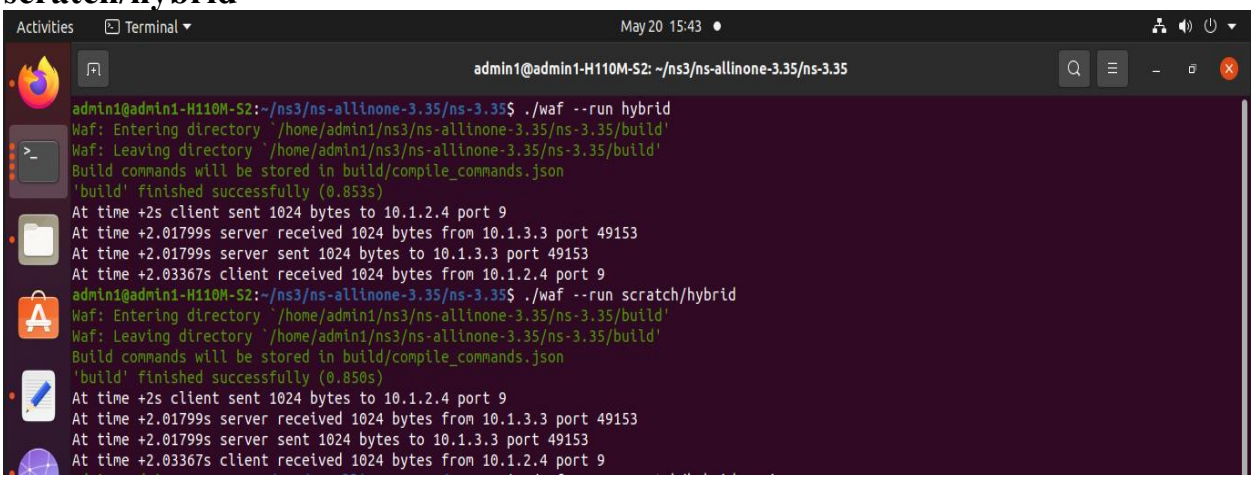
---

## Step1: Open terminal and type the following command

## ./waf –run hybrid

## Step2: After successful build the file needs to be run using the following command:

## ./waf –run scratch/hybrid




## Setp 3: In order to activate the pyvis the following command needs to be entered

## “./waf –run scratch/filename --vis”

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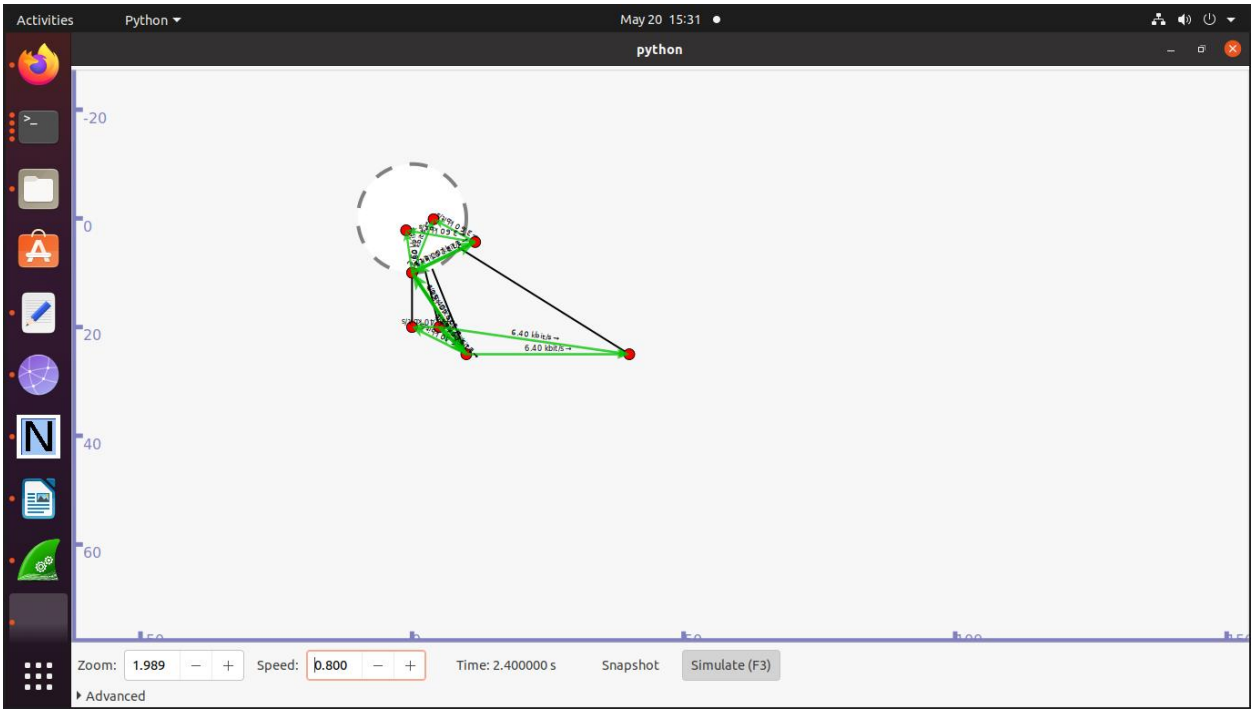
```
admin1@admin1-H110M-S2:~/ns3/ns-allinone-3.35/ns-3.35$ ./waf --run scratch/hybrid --vis
Waf: Entering directory `/home/admin1/ns3/ns-allinone-3.35/ns-3.35/build'
Waf: Leaving directory `/home/admin1/ns3/ns-allinone-3.35/ns-3.35/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (0.989s)
```




**Step 4 : Move to netanim folder and type following command and open hybrid.xml**

**./NetAnim**

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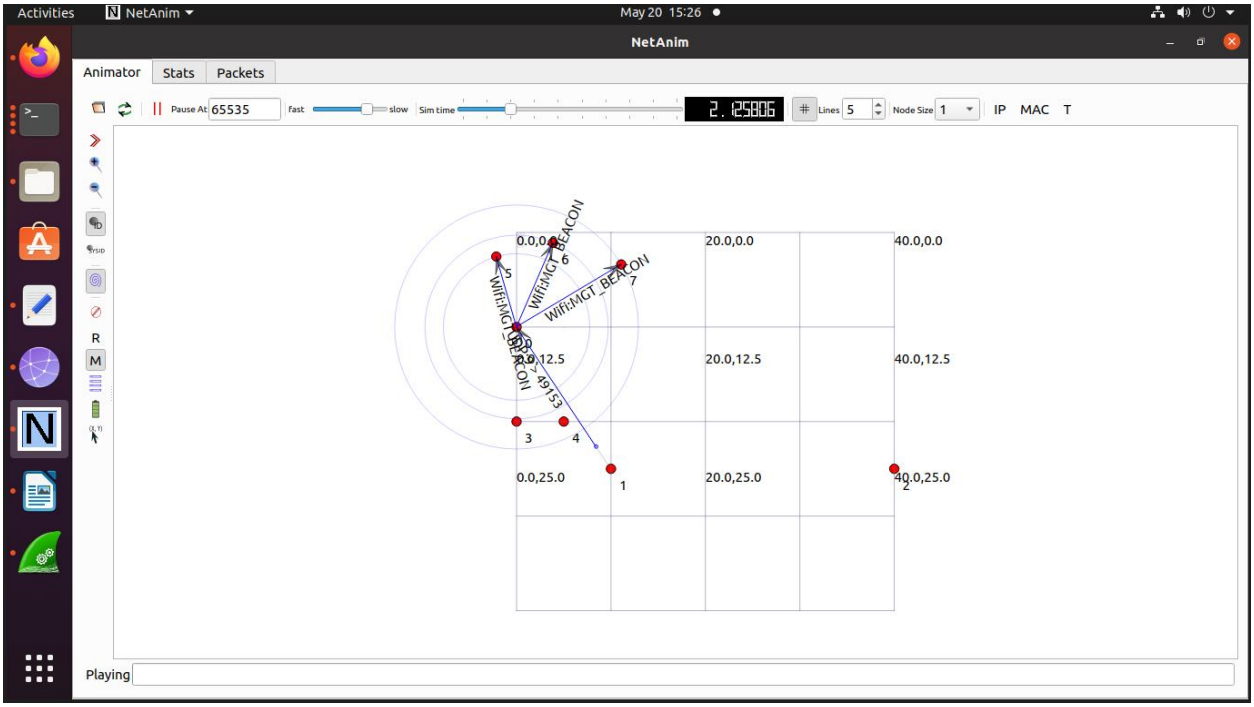


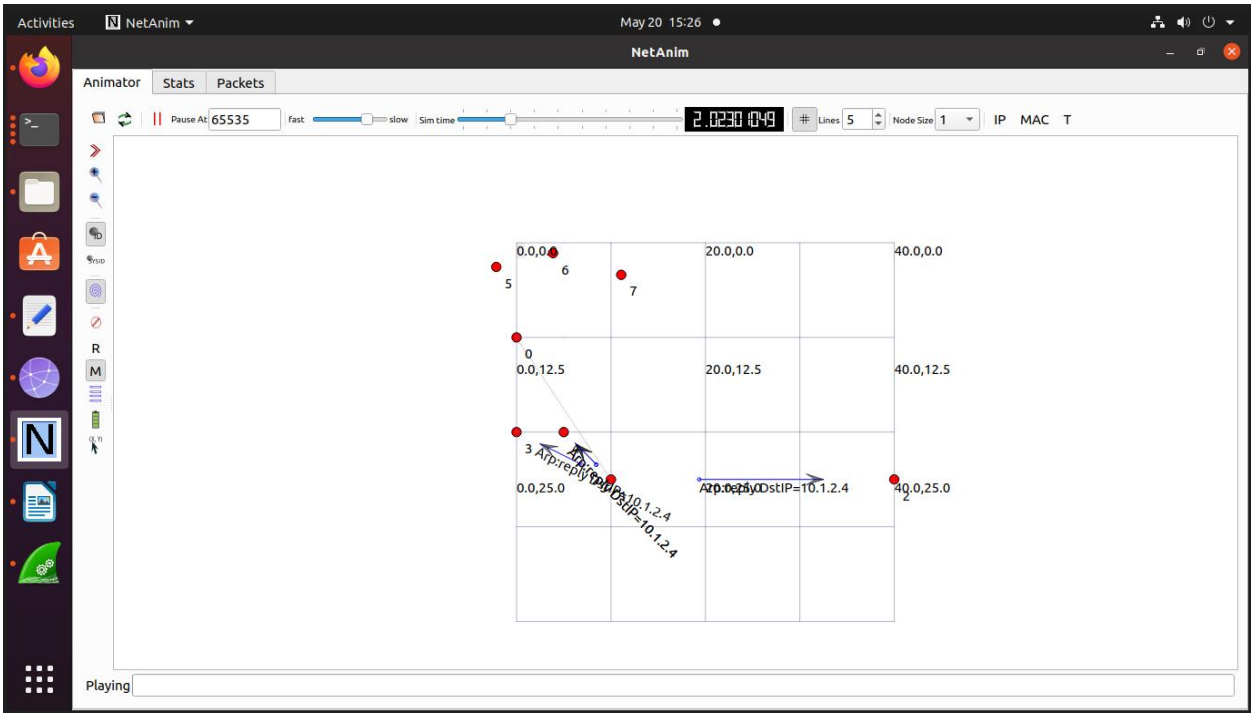

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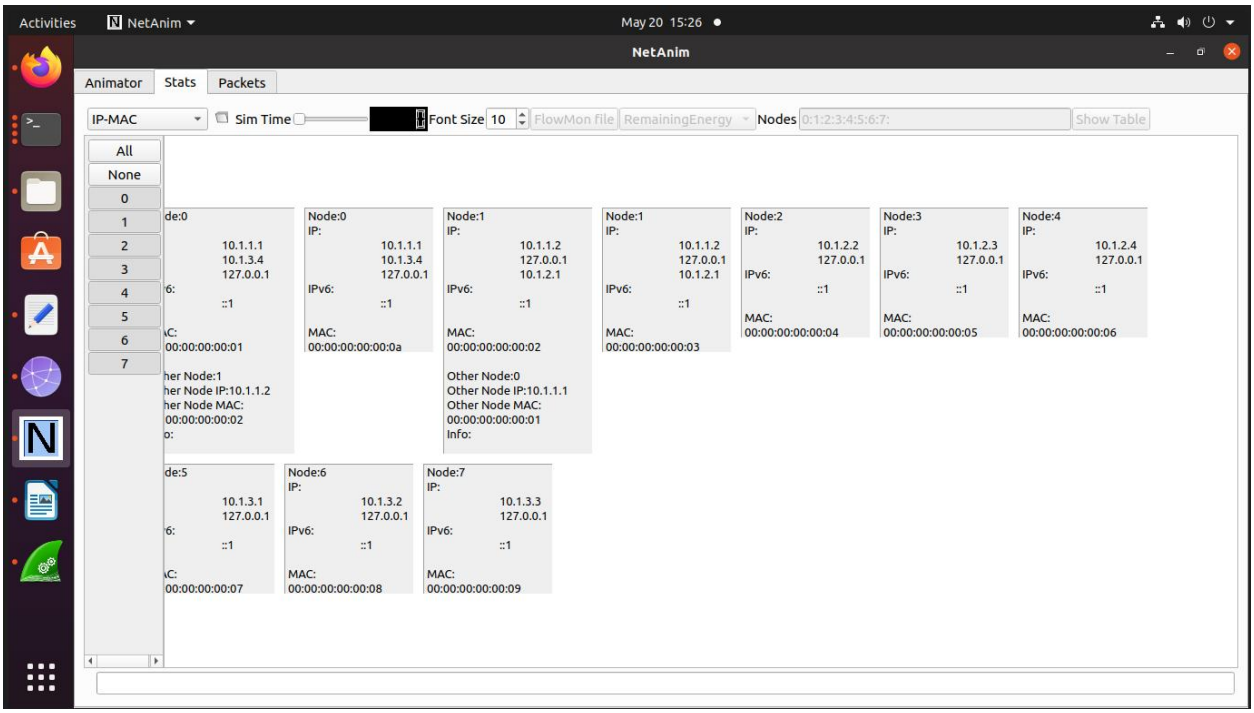
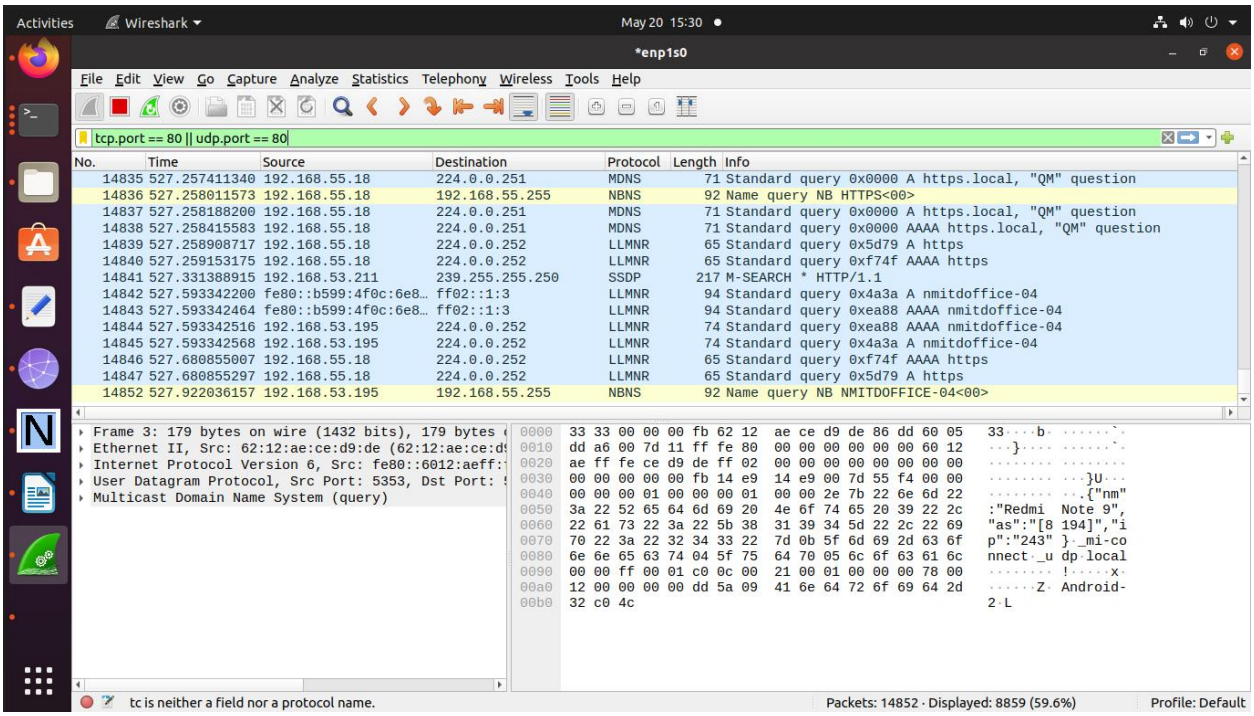



## Step5: In Terminal Type wireshark and open pcap file generated

And Click On Start Capturing




## Network throughput:

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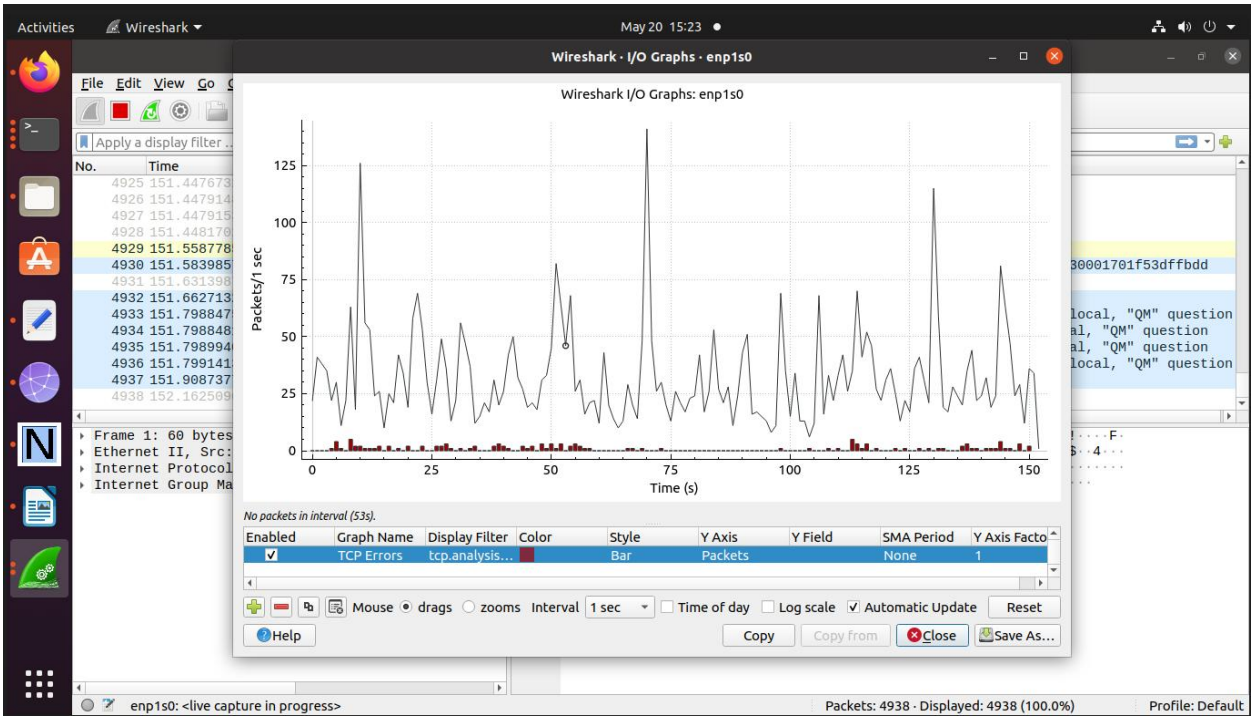


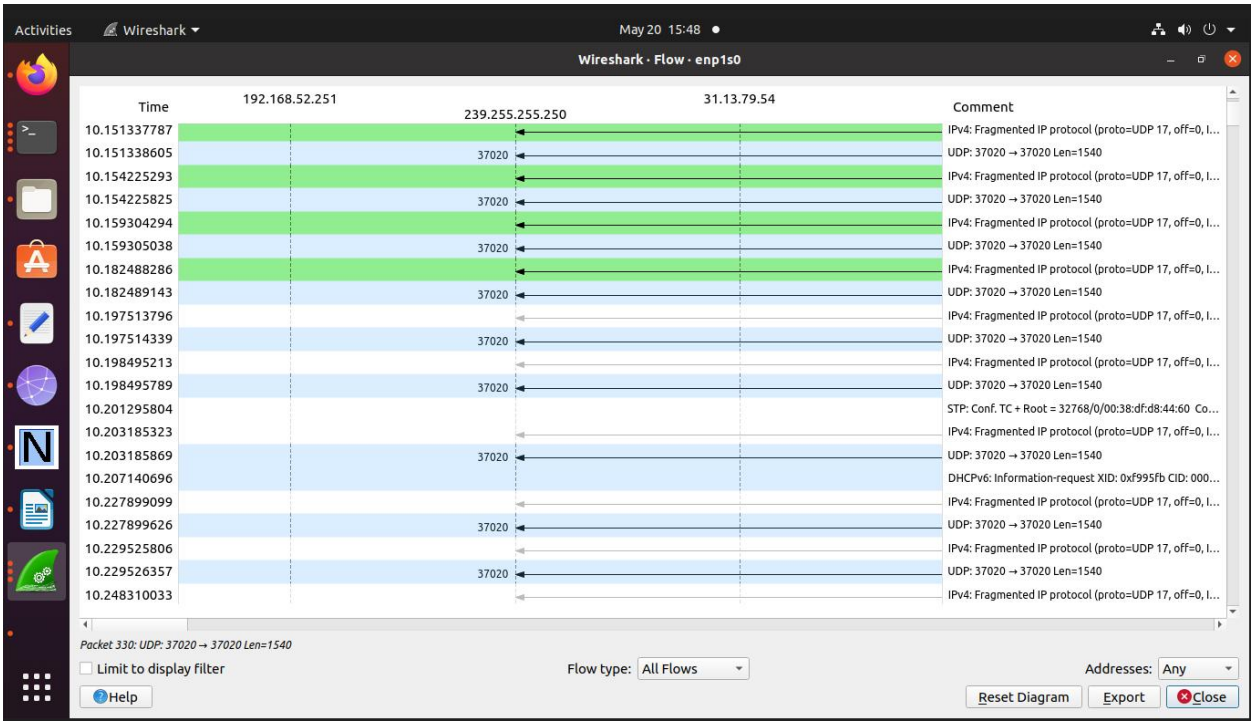


# Conclusion

It proves to be more flexible, reliable, effective and scalable than other networking topologies but at the same time difficult to manage and

costly also. Although its complex structure can create hazards due to its robust and effective features gained a lot of popularity.