Wireless Ad Hoc Networks
Lab 1

Network Simulator

NS3 Experiment (I) - CBR & Queue

Introduction

- Lab Purpose
  - Introducing network simulator tools
  - Getting familiar with NS-3
- Equipments
  - PC / NB (Root Password : **ImBun**)
  - Network Simulators : NS-3 (Network Simulator version 3)

Introduction

- Network Simulator
  - NS : NS-2 & NS-3
    - a discrete event simulator targeted at networking research
    - NS-3 is not backward compatible with NS-2
    - NS-2 is implemented using a combination of oTCL (for scripts describing the network topology) and C++ (The core of the simulator) ; However, NS-3 is written in C++ only.
  - NS-3
    - Written in C++
    - Bindings in Python
    - Uses waf build system
      - (waf = python-based framework for compiling/installing application)
    - Simulations programs are in C++ executables or python scripts

NS-3 Installation

- Install prerequisites
  - sudo apt-get install gcc g++ python python-dev mercurial bzr gdb valgrind gsl-bin libgsl0-dev libgsl0ldbl flex bison tcpdump sqlite sqlite3 libsqlite3-dev libxml2 libxml2-dev libgtk2.0-0 libgtk2.0-dev uncrustify doxygen graphviz imagemagick texlive texlive-latex-extra texlive-generic-extra texlive-generic-recommended texinfo dia texlive texlive-latex-extra texlive-extra-utils texlive-generic-recommended texi2html python-pygraphviz python-kiwi python-pygoocanvas libgoocanvas-dev python-pygccxml
- Download source code
  - wget http://www.nsnam.org/release/ns-allinone-3.24.tar.bz2
  - tar –xvjf ns-allinone-3.24.tar.bz2
  - cd ns-allinone-3.24/
- Build
  - ./build.py --enable-examples --enable-tests
- Configure with waf (build tools)
  - ./waf -d debug --enable-examples --enable-tests configure
- Test everything
  - ./test.py

Run NS-3 Program

- Build all your scripts
  - ./waf
- you can build and run a specific program/script
  - ./waf --run <***ns3-program***>

Substitute <***ns3-program***> with your own program name

- Run the script with an argument
  - ./waf --run <***ns3-program***> --command-template="%s <***args***>"

Substitute <***args***> with the arguments

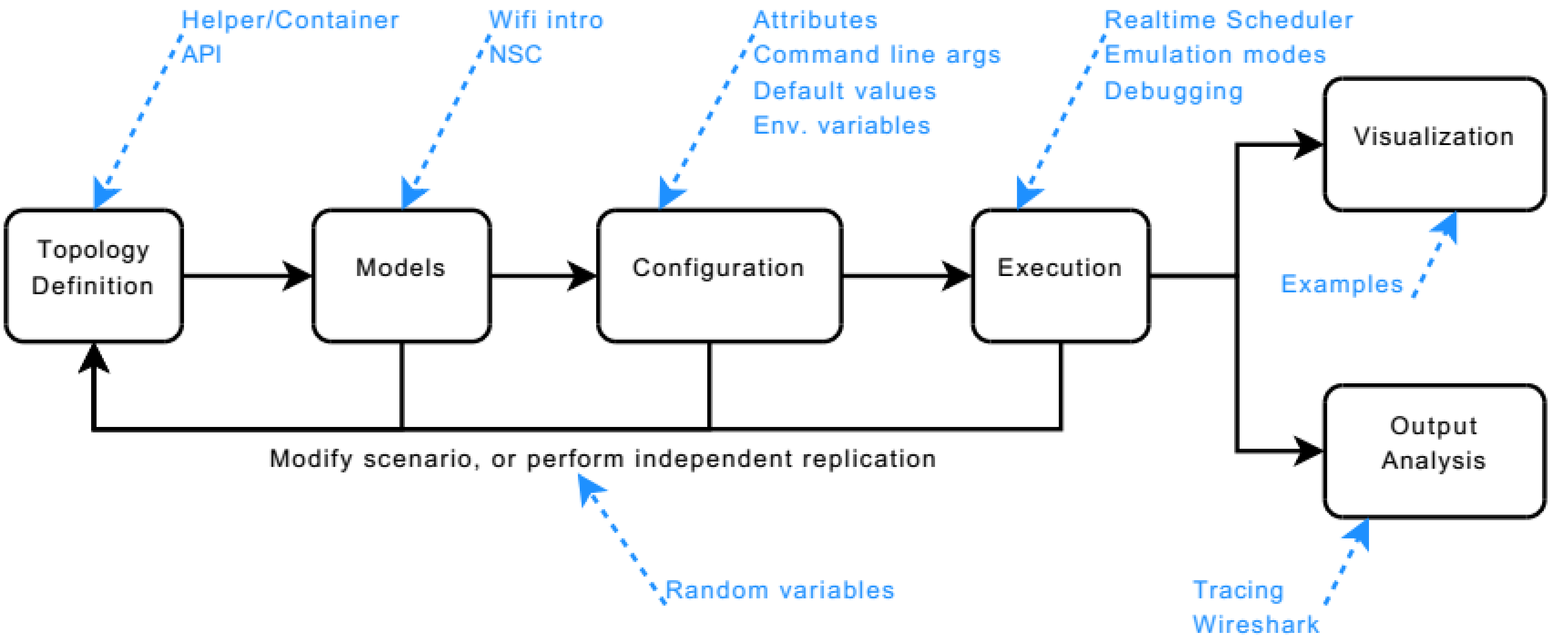
NS-3 Simulation Basics

- Simulation time moves discretely from event to event
- C++ functions schedule events to occur at specific simulation times
- A simulation scheduler orders the event execution
- Simulation::Run gets it all started
- Simulation stops at specific time or when events end
-

Scheduling Events

```
static void random_function (MyModel *model)
{
  // print some stuff
}
int main (int argc, char **argv)
{
  MyModel model;
  Simulator::Schedule (Seconds (10.0),
                       &random_function, &model);
  Simulator::Run ();
  Simulator::Destroy ();
}
```

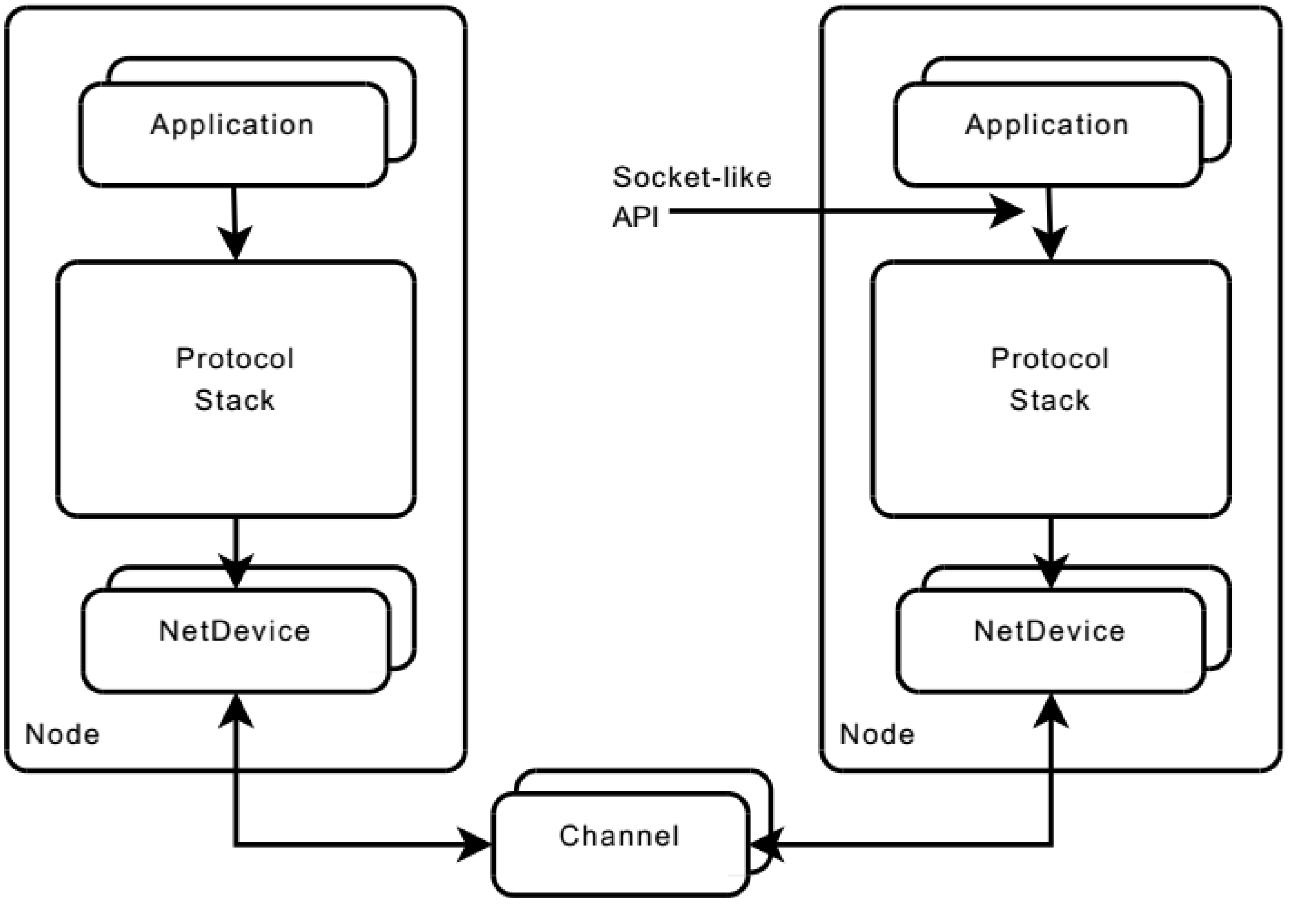
Typical Simulation Structure



What the source code look like

```
NodeContainer csmaNodes;
csmaNodes.Create (2);
...
NetDeviceContainer csmaDevices;
CsmaHelper csma;
csma.SetChannelAttribute ("DataRate",
                          StringValue ("5Mbps"));
csma.SetChannelAttribute ("Delay",
                          StringValue ("2ms"));
csmaDevices = csma.Install (csmaNodes);
```

The Basic Model



NS-3 Fundamental Objects

- **Node**
  - motherboard of a computer with RAM, CPU, and IO interfaces
- **Application**
  - A packet generator and consumer, run on a Node
- **NetDevice**
  - A network card which can be plugged in an IO interface of a Node
- **Channel**
  - A physical connector between a set of NetDevice objects

The helper/container API (I)

- Make it easy to build topologies with repeating patterns
- Make the the topology description more high-level (easier to read and understand)

- Sets of objects are stored in **Containers**
- One operation is encoded in a **Helper** object and applies on a **Container**
- Different helpers provide different operations

The helper/container API (II)

- Example containers
  - NodeContainer
  - NetDeviceContainer
  - IPvAddressContainer
- Example helper classes
  - InternetStackHelper
  - WifiHelper
  - MobilityHelper
  - etc. (Each model provides a helper class)

The helper/container API - Nodes & Devices

- Create the nodes

```
NodeContainer csmaNodes;
csmaNodes.Create (2);
NodeContainer wifiNodes;
wifiNodes.Add (csmaNodes.Get (1));
wifiNodes.Create (3);
```

Create empty node container
Create two nodes

Create empty node container
Add existing node to it

- Create the network device

```
NetDeviceContainer csmaDevices;
CsmaHelper csma;
csma.SetChannelAttribute ("DataRate",
                StringValue ("5Mbps"));
csma.SetChannelAttribute ("Delay",
                StringValue ("2ms"));
csmaDevices = csma.Install (csmaNodes);
```

Create empty device container
Create csma helper
Set data rate
Set delay

Create csma devices

The helper/container API - Channel & Device

- Setup wifi channel

```
YansWifiChannelHelper wifiChannel = YansWifiChannelHelper::Default ();
YansWifiPhyHelper wifiPhy = YansWifiPhyHelper::Default ();
wifiPhy.SetChannel (wifiChannel.Create ());
```

- Create wifi devices

```
NetDeviceContainer wifiDevices;
WifiHelper wifi = WifiHelper::Default ();
wifiDevices = wifi.Install (wifiPhy, wifiNodes);
```

The helper/container API - Mobility models

- Setup initial position

```
MobilityHelper mobility;
mobility.SetPositionAllocator ("ns3::RandomDiscPositionAllocator",
                               "X", StringValue ("100.0"),
                               "Y", StringValue ("100.0"),
                               "Rho", StringValue ("Uniform:0:30"));
```

- Setup mobility model during simulation

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

The helper/container API - Protocol stacks

- Install ipv4, udp, tcp stacks

```
InternetStackHelper internet;
internet.Install (NodeContainer::GetGlobal ());
```

- Assign ipv4 addresses

```
Ipv4InterfaceContainer csmaInterfaces;
Ipv4InterfaceContainer wifiInterfaces;
Ipv4AddressHelper ipv4;
ipv4.SetBase ("10.1.1.0", "255.255.255.0");
csmaInterfaces = ipv4.Assign (csmaDevices);
ipv4.SetBase ("10.1.2.0", "255.255.255.0");
wifiInterfaces = ipv4.Assign (wifiDevices);
```

- Setup routing tables

```
GlobalRouteManager::PopulateRoutingTables ();
```

The helper/container API - Application (I)

- Create a traffic generator

```
OnOffHelper onoff ("ns3::UdpSocketFactory",
                   InetSocketAddress ("10.1.2.2", 1025));
onoff.SetAttribute ("OnTime", StringValue ("Constant:1.0"));
onoff.SetAttribute ("OffTime", StringValue ("Constant:0.0"));
```

- Install the traffic generator

```
ApplicationContainer apps;
apps = onoff.Install (csmaNodes.Get (0));
```

- Start it

```
apps.Start (Seconds (1.0));
apps.Stop (Seconds (4.0));
```

Example

```
OnOffHelper onoff( "ns3::UdpSocketFactory" , InetSocketAddress( address , Port ) );
onoff.SetConstantRate(DataRate( your_rate ), packetsize );
appcontainer.Add(onff.Install(nodecontainer.Get(0)));
appcontainer.Start(starttime);
appcontainer.Stop(stoptime);
```

You can obtain Address from Ipv4interfacecontainer by method GetAddress(i,j).
For example, Ipv4interfacecontainer.GetAddress(i,j) will return the IPv4 address of the j'th address of the interface corresponding to index i.

The helper/container API - Application (II)

- Setup a traffic sink

```
PacketSinkHelper sink ("ns3::UdpSocketFactory",
                       InetSocketAddress ("10.1.2.2", 1025));
apps = sink.Install (wifiNodes.Get (1));
apps.Start (Seconds (0.0));
apps.Stop (Seconds (4.0));
```

Tracing in NS-3 vs NS-2

- Tracing is a structured form of simulation output
- When you open .tr file in NS-2

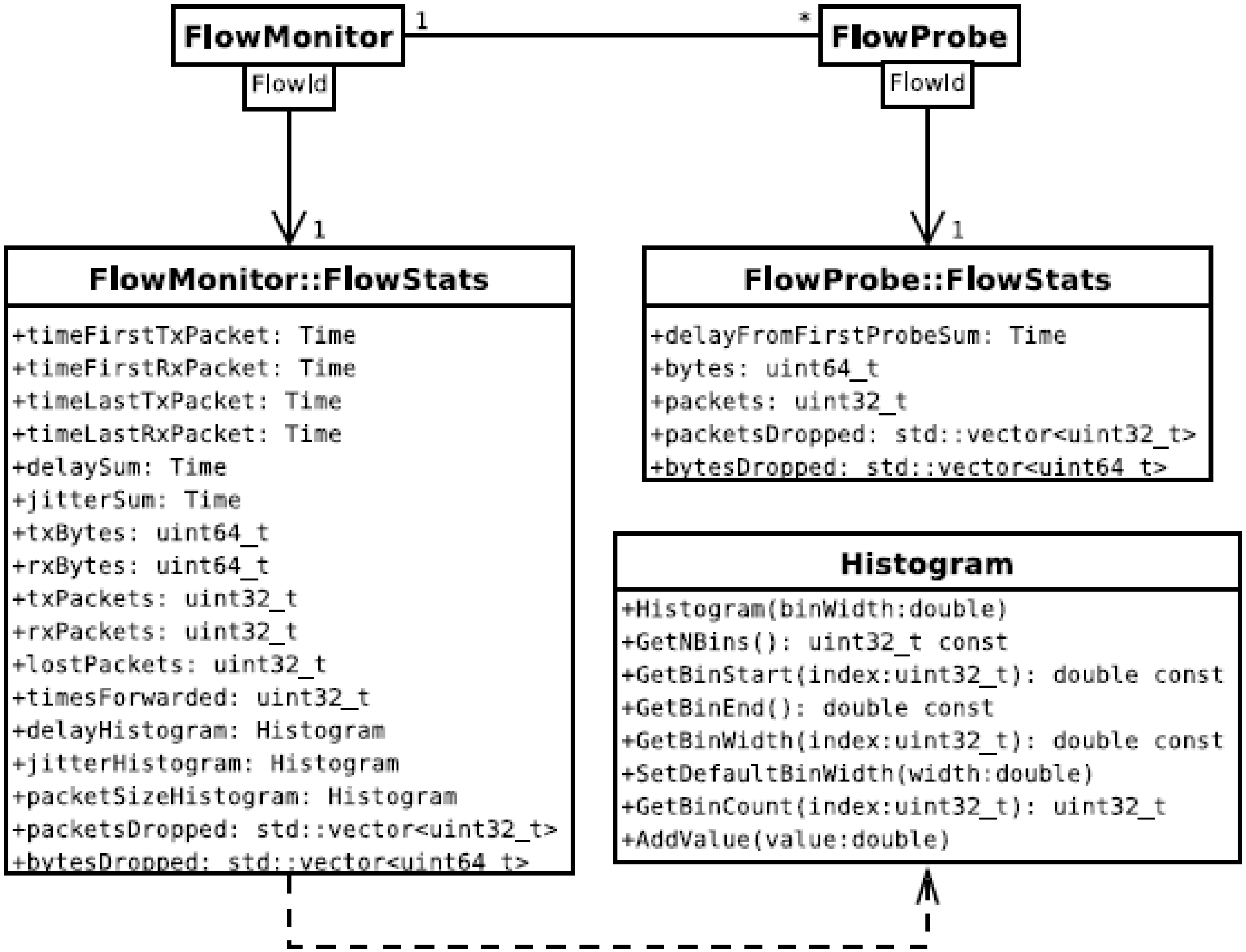
wireless1-out.tr

```
s 0.053360000 _0_ AGT  --- 2 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [1] 0 0
r 0.053360000 _0_ RTR  --- 2 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [1] 0 0
s 0.054411734 _0_ RTR  --- 1 DSR 32 [0 0 0 0] ------- [0:255 1:255 32 0] 1 [1 1] [0 1 0 0->0] [0 0 0 0->0]
s 0.054486734 _0_ MAC  --- 1 DSR 84 [0 ffffffff 0 800] ------- [0:255 1:255 32 0] 1 [1 1] [0 1 0 0->0] [0 0 0 0->0]
r 0.055159205 _1_ MAC  --- 1 DSR 32 [0 ffffffff 0 800] ------- [0:255 1:255 32 0] 1 [1 1] [0 1 0 0->0] [0 0 0 0->0]
r 0.055184205 _1_ RTR  --- 1 DSR 32 [0 ffffffff 0 800] ------- [0:255 1:255 32 0] 1 [1 1] [0 1 0 0->0] [0 0 0 0->0]
s 0.056720000 _0_ AGT  --- 5 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [2] 0 0
r 0.056720000 _0_ RTR  --- 5 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [2] 0 0
s 0.060080000 _0_ AGT  --- 7 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [3] 0 0
r 0.060080000 _0_ RTR  --- 7 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [3] 0 0
s 0.063348966 _1_ RTR  --- 4 DSR 44 [0 0 0 0] ------- [1:255 0:255 254 0] 2 [0 1] [1 1 2 0->1] [0 0 0 0->0]
s 0.063440000 _0_ AGT  --- 13 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [4] 0 0
r 0.063440000 _0_ RTR  --- 13 cbr 210 [0 0 0 0] ------- [0:0 1:0 32 0] [4] 0 0
s 0.063763966 _1_ MAC  --- 0 ARP 80 [0 ffffffff 1 806] ------- [REQUEST 1/1 0/0]
r 0.064404437 _0_ MAC  --- 0 ARP 28 [0 ffffffff 1 806] ------- [REQUEST 1/1 0/0]
```

NS-3 FlowMonitor

- Detect all flows passing through network
- Stores metrics for analysis
  - bitrates, duration, delays, packet sizes, packet loss ratios
- Solves the problem
  - Less programming time than callback-based tracing
  - More efficient than ascii tracing

Flow Data Structures (I)



Flow Data Structures (II)

- **timeFirstTxPacket, timeLastTxPacket, timeFirstRxPacket, timeLastRxPacket**
  - begin and end times of the flow from the point of view of the transmitter/receiver
- **delaySum, jitterSum**
  - sum of delay and jitter values
- **txBytes, txPackets, rxBytes, rxPackets**
  - number of transmitted/received bytes and packets

Flow Data Structures (III)

- **lostPackets**
  - number of definitely lost packets
- **packetsDropped, bytesDropped**
  - discriminates the losses by a *reason code*
    - **DROP NO ROUTE** no IPv4 route found for a packet
    - **DROP TTL EXPIRE** a packet was dropped due to an
    - IPv4 TTL field decremented and reaching zero
    - **DROP BAD CHECKSUM** a packet had a bad IPv4
    - header checksum and had to be dropped
    -

FlowMonitor - Example

- Install FlowMonitor

```
FlowMonitorHelper flowmon;
Ptr<FlowMonitor> monitor = flowmon.InstallAll ();
```

- Print per flow statistics

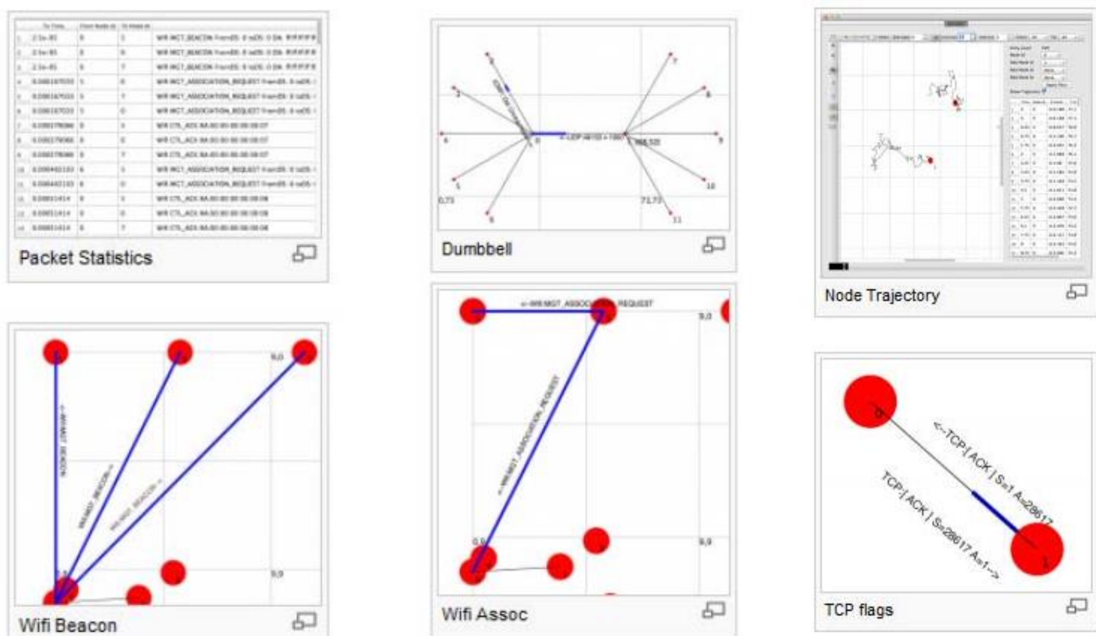
Output

```
Flow 1 (10.0.0.1 -> 10.0.0.2)
  Tx Bytes:   3847500
  Rx Bytes:   316464
  Throughput: 0.241443 Mbps
Flow 2 (10.0.0.3 -> 10.0.0.2)
  Tx Bytes:   3848412
  Rx Bytes:   336756
  Throughput: 0.256924 Mbps
```

```
monitor->CheckForLostPackets ();
Ptr<Ipv4FlowClassifier> classifier = DynamicCast<Ipv4FlowClassifier> (flowmon.GetClassifier ());
std::map<FlowId, FlowMonitor::FlowStats> stats = monitor->GetFlowStats ();
for (std::map<FlowId, FlowMonitor::FlowStats>::const_iterator i = stats.begin (); i != stats.end (); ++i)
  {
    // first 2 FlowIds are for ECHO apps, we don't want to display them
    if (i->first > 2)
      {
        Ipv4FlowClassifier::FiveTuple t = classifier->FindFlow (i->first);
        std::cout << "Flow " << i->first - 2 << " (" << t.sourceAddress << " -> " << t.destinationAddress << ")\n";
        std::cout << "  Tx Bytes:   " << i->second.txBytes << "\n";
        std::cout << "  Rx Bytes:   " << i->second.rxBytes << "\n";
        std::cout << "  Throughput: " << i->second.rxBytes * 8.0 / 10.0 / 1024 / 1024  << " Mbps\n";
      }
  }
```

Visualization: NetAnim

- Animate packets over wired or wireless links
- Node position statistics with node trajectory plotting (path of a mobile node)



NS-3 Lab1 Experiment

- [Step 1] Install NS-3. (Done For You)
- [Step 2] Open the terminal and edit the NS3 source file with following settings:
  - 2 nodes placed apart 100 [m]
  - CBR packet size = 1000 [Byte]
  - CBR rate = **20 [kbps] to 30 [kbps] , 40 [kbps] , 50 [kbps]**
  - ifqlen = **860 to 960, 1060, 1160**
  - CBR traffic
    - start at 1 [sec]
    - stop at 15 [sec]
  - Simulation Time = 30 [sec]

- [Step 3] Modify the FlowMonitor section to analyze and get the following results :
  - average end-to-end delay
  - packet delivery ratio
  - total received data size

Note for NS-3 Lab1 Experiment

- average end-to-end delay = $\dfrac{\text{total e2e delay}}{\text{\#total packets}}$
  - Total e2e delay = the summation end-to-end delay per packet
  - (received time – sent time)
- packet delivery ratio = $\dfrac{\text{\#total packets received}}{\text{\#total packets sent}}$
- total received data size
  - 1 kbits = 1024 bits
  - 1 mbits = 1024 kbits = 1024*1024 bits

Questions & Report

- Draw three figures with
  - X-axis : ifqlen settings
  - Y-axis : the three network performance metrics, respectively
    - average end-to-end delay
    - packet delivery ratio
    - total received data size
  - In each figure, show the curves for the four CBR values
    - 4 curves in each figure
- You need to answer these works and then write a full report with your thoughts or analyses.
  - Deadline : **2019 / 11 / 26**