CN-LAB ASSIGNMENT-6

Code, ReadMe file and Makefile and detailed description in the github repository. Click on CN Lab to get the link.

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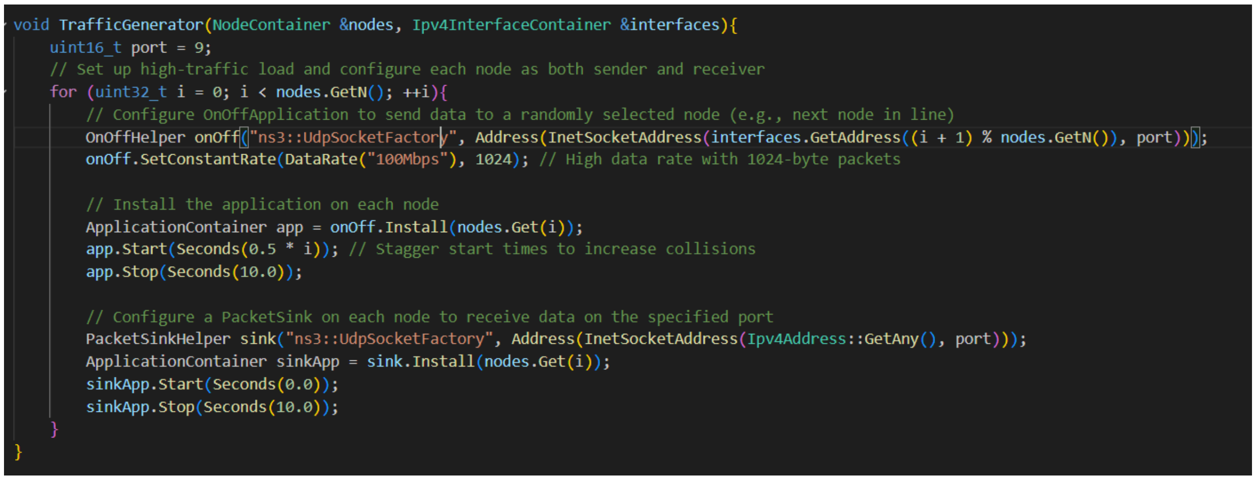
Part A

`TrafficGenerator() ->function :-`

This function sets up the network traffic between nodes, where each node acts as both a sender and receiver. Here's a breakdown of its responsibilities:

- **Traffic Setup:** Each node is configured to send data to another node in a "round-robin" fashion, creating a high-traffic load.
- **On-Off Application:** An `OnOffApplication` is set up to generate UDP packets from each node, sending them to the next node in the container. The transmission rate and packet size are set to `100Mbps` and `1024` bytes, respectively.
- **Staggered Starts:** Each `OnOffApplication` is configured to start at staggered times (`0.5 * i` seconds), helping to increase potential collisions.

● **Packet Sink Application:** A `PacketSink` is installed on each node to receive incoming packets. This application runs for the full duration of the simulation (from 0.0 to 10.0 seconds).



```
void TrafficGenerator(NodeContainer &nodes, Ipv4InterfaceContainer &interfaces){
    uint16_t port = 9;
    // Set up high-traffic load and configure each node as both sender and receiver
    for (uint32_t i = 0; i < nodes.GetN(); ++i){
        // Configure OnOffApplication to send data to a randomly selected node (e.g., next node in line)
        OnOffHelper onOff("ns3::UdpSocketFactory", Address(InetSocketAddress(interfaces.GetAddress((i + 1) % nodes.GetN()), port)));
        onOff.SetConstantRate(DataRate("100Mbps"), 1024); // High data rate with 1024-byte packets

        // Install the application on each node
        ApplicationContainer app = onOff.Install(nodes.Get(i));
        app.Start(Seconds(0.5 * i)); // Stagger start times to increase collisions
        app.Stop(Seconds(10.0));

        // Configure a PacketSink on each node to receive data on the specified port
        PacketSinkHelper sink("ns3::UdpSocketFactory", Address(InetSocketAddress(Ipv4Address::GetAny(), port)));
        ApplicationContainer sinkApp = sink.Install(nodes.Get(i));
        sinkApp.Start(Seconds(0.0));
        sinkApp.Stop(Seconds(10.0));
    }
}
```

`LogMetrics()`

This function logs network performance metrics at regular intervals and adds them to a CSV file for analysis. Here's a breakdown of its tasks:

● **Flow Statistics Collection**: Flow statistics like throughput, packet loss, and delay are collected for each active flow using the `FlowMonitor`.

● **Metric Calculation**:

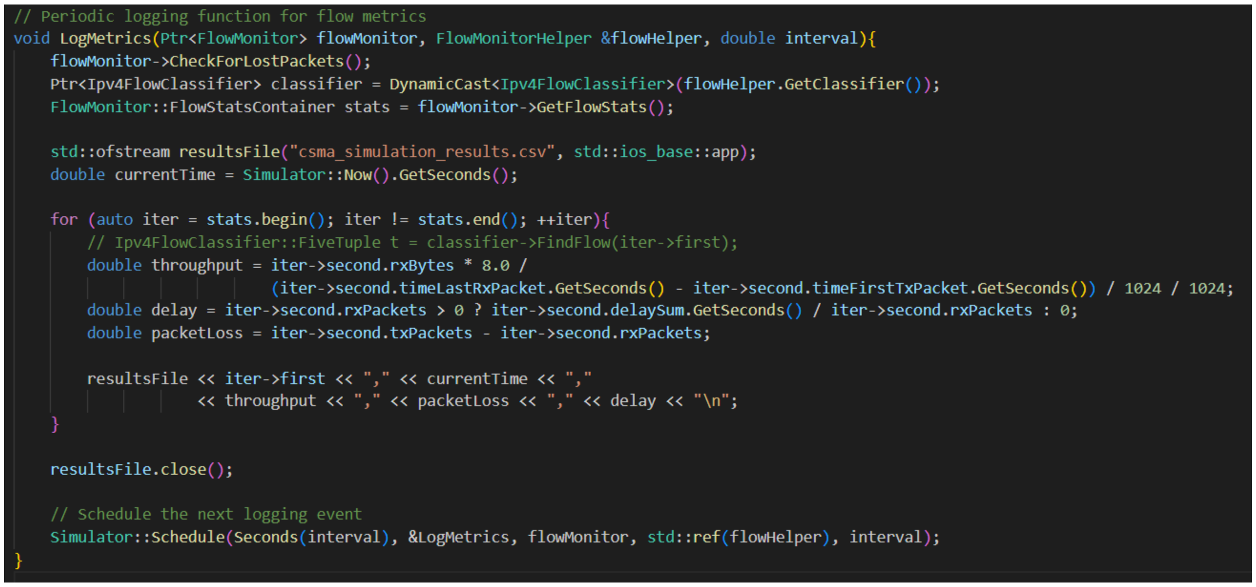
  ○ **Throughput** is calculated by taking the total number of received bytes and dividing by the flow duration in seconds, with the result converted to Mbps.

  ○ **Delay** is averaged over the received packets.

  ○ **Packet Loss** is calculated as the difference between the transmitted packets and received packets.

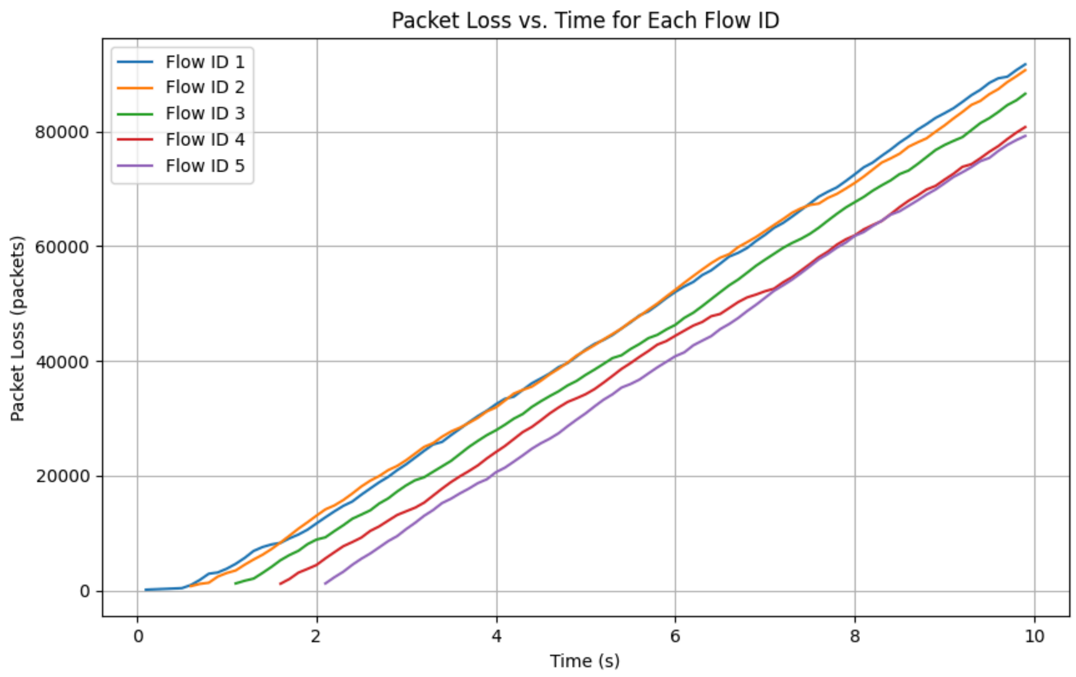
● **Logging to File**: These metrics are written to `csma_simulation_results.csv` with the format: `FlowId, Time, Throughput, PacketLoss, Delay`.

● **Scheduling**: This function schedules itself to run again after the specified interval (`interval`), continuously logging metrics throughout the simulation.

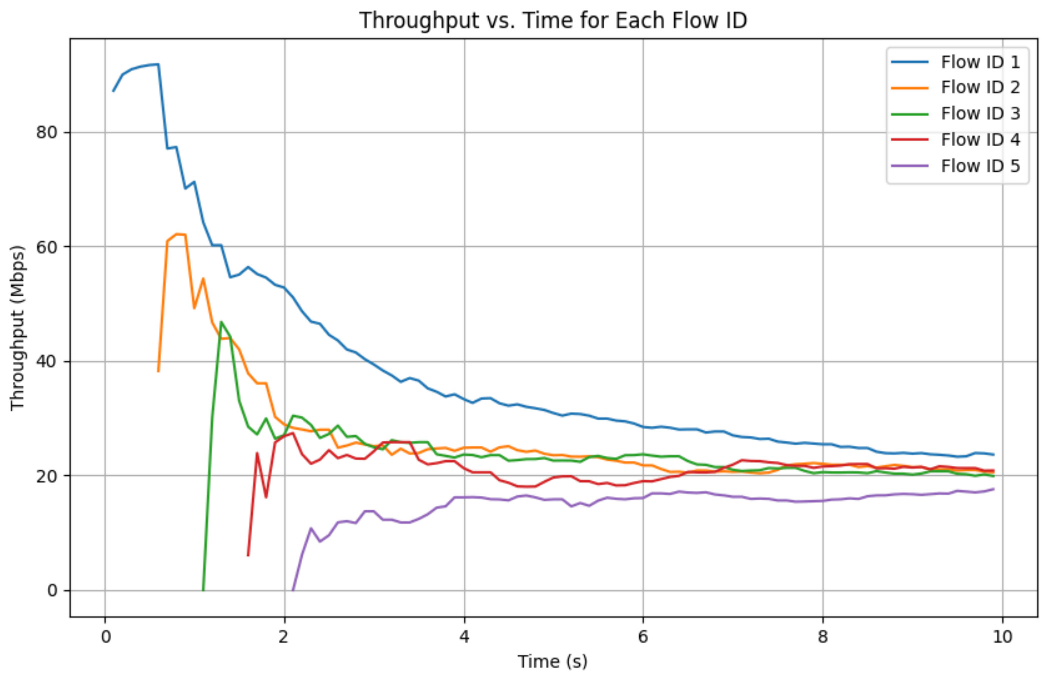


```
// Periodic logging function for flow metrics
void LogMetrics(Ptr<FlowMonitor> flowMonitor, FlowMonitorHelper &flowHelper, double interval){
    flowMonitor->CheckForLostPackets();
    Ptr<Ipv4FlowClassifier> classifier = DynamicCast<Ipv4FlowClassifier>(flowHelper.GetClassifier());
    FlowMonitor::FlowStatsContainer stats = flowMonitor->GetFlowStats();

    std::ofstream resultsFile("csma_simulation_results.csv", std::ios_base::app);
    double currentTime = Simulator::Now().GetSeconds();

    for (auto iter = stats.begin(); iter != stats.end(); ++iter){
        // Ipv4FlowClassifier::FiveTuple t = classifier->FindFlow(iter->first);
        double throughput = iter->second.rxBytes * 8.0 /
                            (iter->second.timeLastRxPacket.GetSeconds() - iter->second.timeFirstTxPacket.GetSeconds()) / 1024 / 1024;
        double delay = iter->second.rxPackets > 0 ? iter->second.delaySum.GetSeconds() / iter->second.rxPackets : 0;
        double packetLoss = iter->second.txPackets - iter->second.rxPackets;

        resultsFile << iter->first << "," << currentTime << ","
                    << throughput << "," << packetLoss << "," << delay << "\n";
    }

    resultsFile.close();

    // Schedule the next logging event
    Simulator::Schedule(Seconds(interval), &LogMetrics, flowMonitor, std::ref(flowHelper), interval);
}
```

Packet loss vs time graph for various flows



Throughput vs time for various flows



Part 3

i. How CSMA/CD Detects a Collision in a Shared Medium?

Ans -:

In a shared medium like Ethernet, CSMA/CD (Carrier Sense Multiple Access with Collision Detection) works by detecting collisions as follows:

- **Carrier Sensing:** Each node first listens to the medium (carrier sensing) to check if any other device is transmitting. If the medium is free, the node begins its transmission.
- **Collision Detection:** While transmitting, the node simultaneously monitors the signal on the medium. If the transmitted signal differs from what the node sent (indicating another node is transmitting), the node detects a collision. Collision Handling: Upon detecting a collision, the node stops transmission immediately, sends a jamming signal to notify other nodes of the collision, and initiates a backoff procedure.

ii. How the Exponential Backoff Algorithm Works

Ans-:

Ethernet receives datagram from network layer. Ethernet

- if senses channel: creates frame
- if idle: start frame transmission.
- if busy: wait until channel idle, then transmit
- If entire frame transmitted without collision - done!

If another transmission detected while sending: abort, send jam signal
After aborting, enter binary (exponential) backoff:
after mth collision, chooses K at random from {0,1,2, …, 2m-1}. Ethernet
waits K·512 bit times, returns to Step 2
more collisions: longer backoff interval

Part 4

i. Why CSMA/CD works well in wired networks but may not be as effective in wireless scenarios.

Ans-:

CSMA/CD (Carrier Sense Multiple Access with Collision Detection) is effective in wired networks because:

- **Collision Detection**: Wired networks allow each node to monitor (or "listen to") the shared channel for collisions as they transmit. This is possible because electrical signals travel through the cable, and nodes can sense any disturbances or interference caused by a collision.
- **Direct, Reliable Sensing**: Wired nodes have direct access to the shared medium and can reliably detect when it is free or busy.

In wireless networks, CSMA/CD is less effective due to:

- **Hidden Terminal Problem**: In wireless networks, two devices may not "see" each other (due to obstacles or distance) even though both are within range of the receiver. This lack of awareness can lead both devices to transmit simultaneously, causing a collision.
- **Difficult Collision Detection**: Wireless devices cannot easily detect collisions because the transmission and reception use the same frequency

range. While a device is transmitting, it cannot "listen" to the channel to check for collisions effectively.

- **Signal Fading and Interference**: Wireless signals weaken over distance and can be affected by obstacles, which can lead to missed detections of active transmissions.

Due to these limitations, **CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)** is used in wireless networks, where devices aim to avoid collisions rather than detect them, typically by using acknowledgment packets and waiting periods to verify successful transmissions.

ii. How the protocol detects collisions and how exponential backoff helps mitigate them.

Ans-:

Collision Detection:

- In CSMA/CD, when a device transmits data, it also "listens" to the channel to verify that its transmission is the only signal on the medium.
- If another device transmits at the same time, the two signals interfere, causing a change in the voltage level on the wire that is easily detected as a collision.
- When a collision is detected, all transmitting devices immediately stop sending data.

Exponential Backoff:

- After a collision, each device involved waits a random amount of time before attempting to retransmit. The waiting time is calculated using an exponential backoff algorithm, where the wait time doubles with each consecutive collision (up to a limit).
- For example, if two devices collide, each device chooses a random number of time slots (from a range that doubles after each collision) to wait before retransmitting.
- This backoff strategy reduces the probability that the same devices will collide repeatedly, which is especially useful when the network is busy.

Part B

1. Network Setup

a. Create a 5x5 wireless ad-hoc network in a grid layout

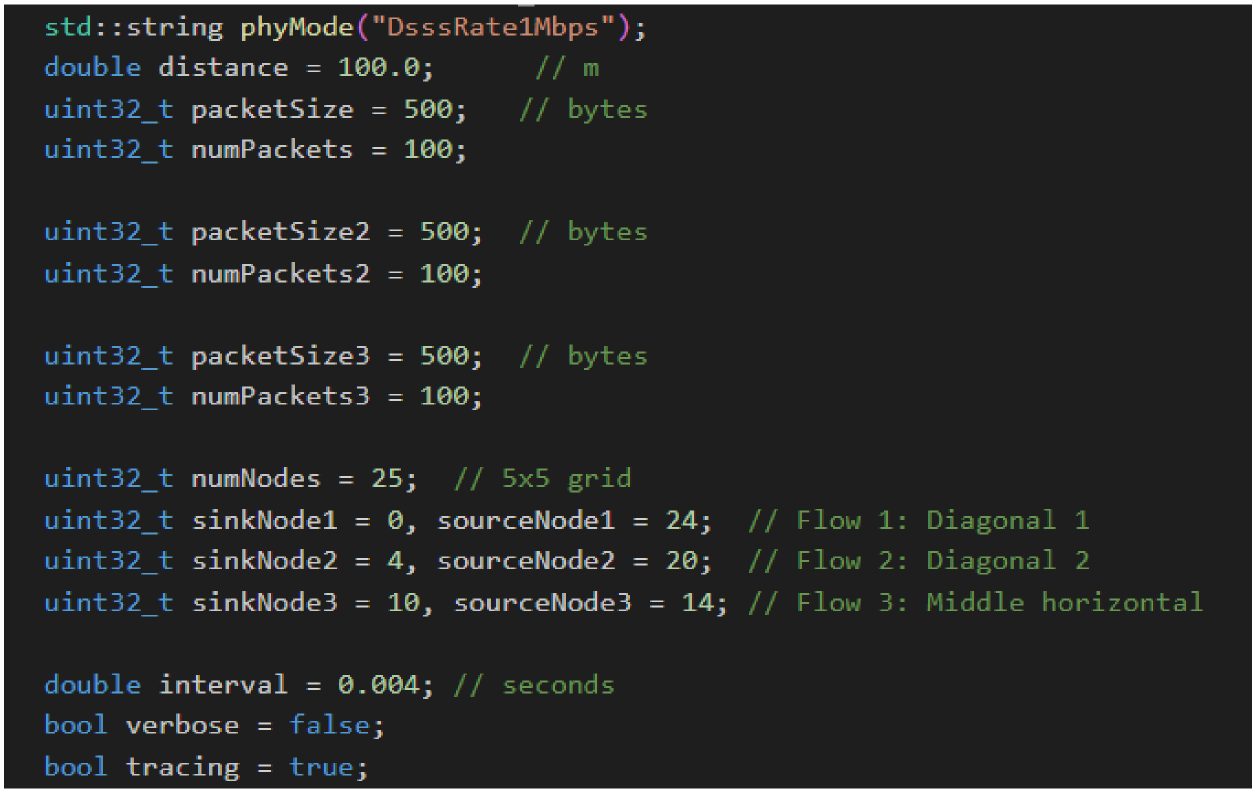
- **Node Creation:** The `NodeContainer` named `c` creates 25 nodes, representing the 5x5 grid.
- **Wifi Setup:**
  - The `WifiHelper` and `WifiMacHelper` objects configure each node with Wi-Fi settings using the `WIFI_STANDARD_80211b` standard.
  - The `YansWifiPhyHelper` sets up physical layer attributes such as `RxGain`, and connects nodes to a `YansWifiChannel` configured with `ConstantSpeedPropagationDelayModel` and `FriisPropagationLossModel` to simulate realistic signal loss and delay.
- **Grid Positioning:**
  - `MobilityHelper` arranges nodes in a grid layout, with `MinX` and `MinY` set to zero and `DeltaX` and `DeltaY` set to 100 meters (the `distance` variable), creating a grid with 5 columns (`GridWidth = 5`) and row-first layout.

b. Use `wifi-simple-adhoc-grid.cc` as a starting point

- The code structure follows that of `wifi-simple-adhoc-grid.cc`, implementing a similar Wi-Fi ad-hoc configuration, grid layout, and traffic flows.

c. Install OLSR for routing

- **Routing Protocol:** OLSR (Optimized Link State Routing) is enabled using `OlsrHelper` and added to `Ipv4ListRoutingHelper` to handle routing within the network. This protocol helps nodes dynamically find and maintain routes to each other in the ad-hoc network.



```
std::string phyMode("DsssRate1Mbps");
double distance = 100.0;      // m
uint32_t packetSize = 500;   // bytes
uint32_t numPackets = 100;

uint32_t packetSize2 = 500;  // bytes
uint32_t numPackets2 = 100;

uint32_t packetSize3 = 500;  // bytes
uint32_t numPackets3 = 100;

uint32_t numNodes = 25;  // 5x5 grid
uint32_t sinkNode1 = 0, sourceNode1 = 24;  // Flow 1: Diagonal 1
uint32_t sinkNode2 = 4, sourceNode2 = 20;  // Flow 2: Diagonal 2
uint32_t sinkNode3 = 10, sourceNode3 = 14; // Flow 3: Middle horizontal

double interval = 0.004; // seconds
bool verbose = false;
bool tracing = true;
```

2. Traffic Configuration

a. Establish three UDP traffic flows

- **Flow 1**: From `n0` to `n24` along one diagonal.
- **Flow 2**: From `n4` to `n20` along the other diagonal.
- **Flow 3**: From `n10` to `n14` along the middle row.
- **Socket Configuration**: Each flow is set up with a source and a sink socket. For example, `source1` transmits from `n0` to `n24` on port 80 for Flow 1, with separate sockets set up for Flow 2 and Flow 3 on unique ports (81 and 82).

b. Set traffic flows to operate at high transmission rates

- **Traffic Rate and Packet Size**: Each flow is configured with a high transmission rate by scheduling `GenerateTraffic` to send 1000-byte packets at a 0.004-second interval.

3. Flow Monitoring

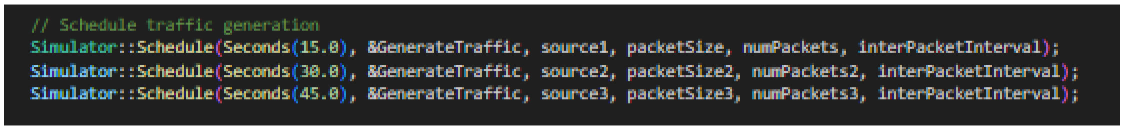
a. Implement `FlowMonitor` to track UDP flow performance

- **Flow Monitor**: `FlowMonitorHelper` and `FlowMonitor` are configured to track each flow's performance, enabling detailed analysis of transmission statistics, such as throughput and packet loss.

4. Scheduling

a. Schedule the initiation of each traffic flow at staggered times

- **Scheduling Traffic Generation**: Flow 1 is scheduled to start at 15.0 seconds, Flow 2 at 15.5 seconds, and Flow 3 at 16.0 seconds. These staggered start times allow observation of how different flows interact with each other in the network.



```
// Schedule traffic generation
Simulator::Schedule(Seconds(15.0), &GenerateTraffic, source1, packetSize, numPackets, interPacketInterval);
Simulator::Schedule(Seconds(30.0), &GenerateTraffic, source2, packetSize2, numPackets2, interPacketInterval);
Simulator::Schedule(Seconds(45.0), &GenerateTraffic, source3, packetSize3, numPackets3, interPacketInterval);
```

5. Data Collection

a. Record throughput for each UDP flow

- **Throughput Measurement:** Throughput for each flow is calculated from `FlowMonitor` statistics as `rxBytes * 8.0 / (timeLastRxPacket - timeFirstTxPacket)` in Kbps. This data is printed in the console for each flow, providing an overview of transmission efficiency.

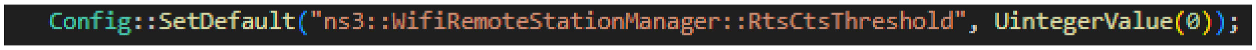
b. Monitor packet collisions and drops at intermediary nodes

- **Packet Drop and Collision Analysis**: The `FlowMonitor` also tracks metrics like transmitted (`txPackets`) and received packets (`rxPackets`), lost packets (`lostPackets`), and times forwarded (`timesForwarded`), which indicate potential areas of congestion or collision in the network.
- **Tracing**: ASCII and PCAP tracing is enabled with `AsciiTraceHelper` and `wifiPhy.EnablePcap`, allowing for a detailed record of packet-level events for offline analysis.

6. RTS/CTS Experimentation

a. Repeat the experiment with RTS/CTS enabled

- **Enabling RTS/CTS**: To enable RTS/CTS, configure the `RtsCtsThreshold` parameter in `Config::SetDefault` to a value that triggers RTS/CTS for all packets (typically set to a small packet size threshold, such as 0).



```
Config::SetDefault("ns3::WifiRemoteStationManager::RtsCtsThreshold", UintegerValue(0));
```

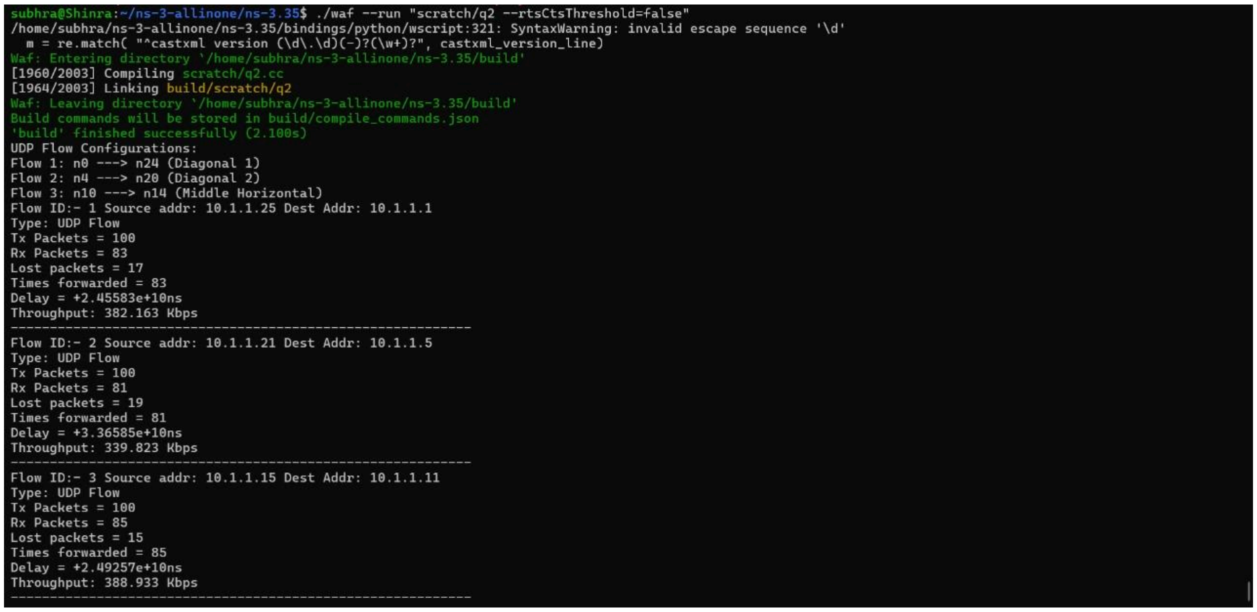
b. Comparison:

The experiment should be repeated with RTS/CTS enabled, and results, such as throughput and packet drops, can be compared to those from the scenario without RTS/CTS.

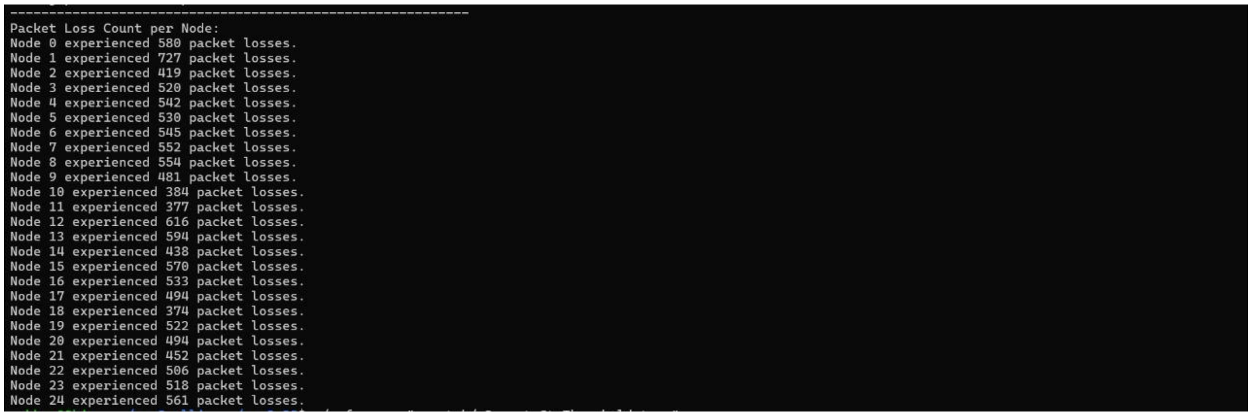
Analysis and Reporting

● **Data Analysis**: We simulated the network for different packet sizes and observed that smaller the packet size lesser the packet loss.
● **Observations**: We simulated the network with and without RTS/CTS and saw a slight increase in the number of packets successfully received.

Without RTS/CTS

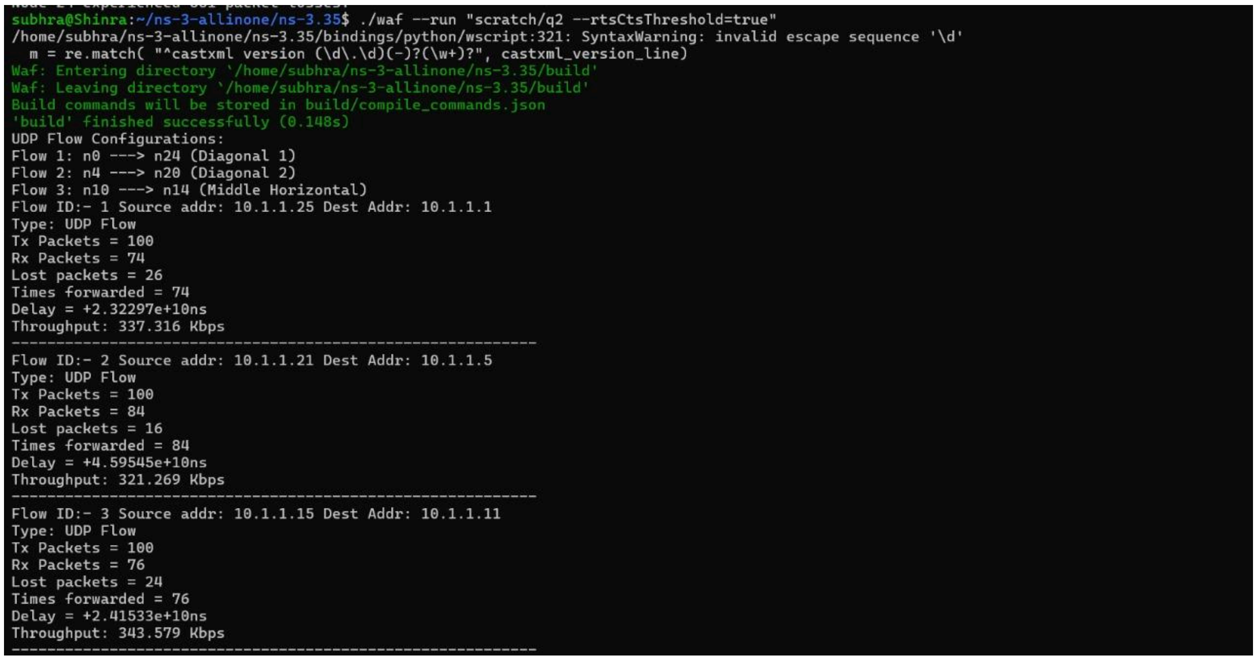


```
subhra@Shinra:~/ns-3-allinone/ns-3.35$ ./waf --run "scratch/q2 --rtsCtsThreshold=false"
/home/subhra/ns-3-allinone/ns-3.35/bindings/python/wscript:321: SyntaxWarning: invalid escape sequence '\d'
  m = re.match( "^castxml version (\d\.\d)(-)?(\w+)?", castxml_version_line)
Waf: Entering directory `/home/subhra/ns-3-allinone/ns-3.35/build'
[1960/2003] Compiling scratch/q2.cc
[1964/2003] Linking build/scratch/q2
Waf: Leaving directory `/home/subhra/ns-3-allinone/ns-3.35/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (2.100s)
UDP Flow Configurations:
Flow 1: n0 ---> n24 (Diagonal 1)
Flow 2: n4 ---> n20 (Diagonal 2)
Flow 3: n10 ---> n14 (Middle Horizontal)
Flow ID:- 1 Source addr: 10.1.1.25 Dest Addr: 10.1.1.1
Type: UDP Flow
Tx Packets = 100
Rx Packets = 83
Lost packets = 17
Times forwarded = 83
Delay = +2.45583e+10ns
Throughput: 382.163 Kbps
-----------------------------------------------------------
Flow ID:- 2 Source addr: 10.1.1.21 Dest Addr: 10.1.1.5
Type: UDP Flow
Tx Packets = 100
Rx Packets = 81
Lost packets = 19
Times forwarded = 81
Delay = +3.36585e+10ns
Throughput: 339.823 Kbps
-----------------------------------------------------------
Flow ID:- 3 Source addr: 10.1.1.15 Dest Addr: 10.1.1.11
Type: UDP Flow
Tx Packets = 100
Rx Packets = 85
Lost packets = 15
Times forwarded = 85
Delay = +2.49257e+10ns
Throughput: 388.933 Kbps
-----------------------------------------------------------
```

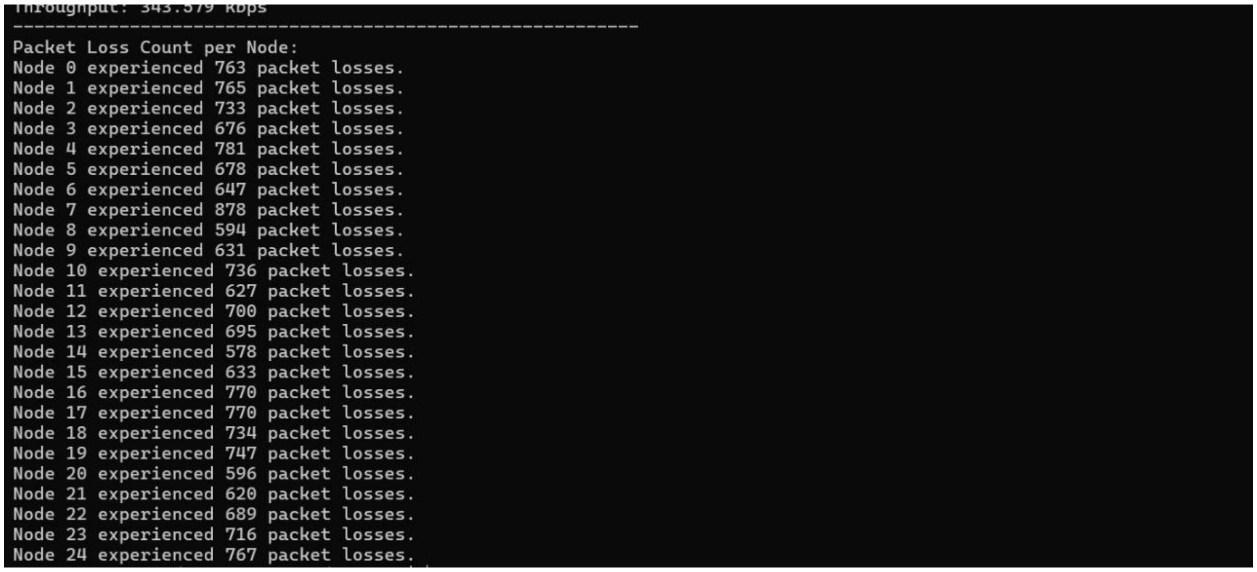


```
-----------------------------------------------------------
Packet Loss Count per Node:
Node 0 experienced 580 packet losses.
Node 1 experienced 727 packet losses.
Node 2 experienced 419 packet losses.
Node 3 experienced 520 packet losses.
Node 4 experienced 542 packet losses.
Node 5 experienced 530 packet losses.
Node 6 experienced 545 packet losses.
Node 7 experienced 552 packet losses.
Node 8 experienced 554 packet losses.
Node 9 experienced 481 packet losses.
Node 10 experienced 384 packet losses.
Node 11 experienced 377 packet losses.
Node 12 experienced 616 packet losses.
Node 13 experienced 594 packet losses.
Node 14 experienced 438 packet losses.
Node 15 experienced 570 packet losses.
Node 16 experienced 533 packet losses.
Node 17 experienced 494 packet losses.
Node 18 experienced 374 packet losses.
Node 19 experienced 522 packet losses.
Node 20 experienced 494 packet losses.
Node 21 experienced 452 packet losses.
Node 22 experienced 506 packet losses.
Node 23 experienced 518 packet losses.
Node 24 experienced 561 packet losses.
```

With RTS/CTS



```
subhra@Shinra:~/ns-3-allinone/ns-3.35$ ./waf --run "scratch/q2 --rtsCtsThreshold=true"
/home/subhra/ns-3-allinone/ns-3.35/bindings/python/wscript:321: SyntaxWarning: invalid escape sequence '\d'
  m = re.match( "^castxml version (\d\.\d)(-)?(\w+)?", castxml_version_line)
Waf: Entering directory `/home/subhra/ns-3-allinone/ns-3.35/build'
Waf: Leaving directory `/home/subhra/ns-3-allinone/ns-3.35/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (0.148s)
UDP Flow Configurations:
Flow 1: n0 ---> n24 (Diagonal 1)
Flow 2: n4 ---> n20 (Diagonal 2)
Flow 3: n10 ---> n14 (Middle Horizontal)
Flow ID:- 1 Source addr: 10.1.1.25 Dest Addr: 10.1.1.1
Type: UDP Flow
Tx Packets = 100
Rx Packets = 74
Lost packets = 26
Times forwarded = 74
Delay = +2.32297e+10ns
Throughput: 337.316 Kbps
------------------------------------------------------------
Flow ID:- 2 Source addr: 10.1.1.21 Dest Addr: 10.1.1.5
Type: UDP Flow
Tx Packets = 100
Rx Packets = 84
Lost packets = 16
Times forwarded = 84
Delay = +4.59545e+10ns
Throughput: 321.269 Kbps
------------------------------------------------------------
Flow ID:- 3 Source addr: 10.1.1.15 Dest Addr: 10.1.1.11
Type: UDP Flow
Tx Packets = 100
Rx Packets = 76
Lost packets = 24
Times forwarded = 76
Delay = +2.41533e+10ns
Throughput: 343.579 Kbps
------------------------------------------------------------
```



```
Throughput: 343.579 Kbps
------------------------------------------------------------
Packet Loss Count per Node:
Node 0 experienced 763 packet losses.
Node 1 experienced 765 packet losses.
Node 2 experienced 733 packet losses.
Node 3 experienced 676 packet losses.
Node 4 experienced 781 packet losses.
Node 5 experienced 678 packet losses.
Node 6 experienced 647 packet losses.
Node 7 experienced 878 packet losses.
Node 8 experienced 594 packet losses.
Node 9 experienced 631 packet losses.
Node 10 experienced 736 packet losses.
Node 11 experienced 627 packet losses.
Node 12 experienced 700 packet losses.
Node 13 experienced 695 packet losses.
Node 14 experienced 578 packet losses.
Node 15 experienced 633 packet losses.
Node 16 experienced 770 packet losses.
Node 17 experienced 770 packet losses.
Node 18 experienced 734 packet losses.
Node 19 experienced 747 packet losses.
Node 20 experienced 596 packet losses.
Node 21 experienced 620 packet losses.
Node 22 experienced 689 packet losses.
Node 23 experienced 716 packet losses.
Node 24 experienced 767 packet losses.
```