*CS 558: Computer Systems Lab*
*(January-May 2026)*

# *Assignment – 3:* Network Simulation using NS-3

*Submission deadline: 11:55 PM, Wednesday, 23rd February 2026*

The objective of this assignment is to deepen understanding of **network protocol behavior, congestion control, fairness, QoS, and wireless dynamics** using NS-3. This assignment builds upon concepts explored in earlier assignments but introduces **new scenarios, metrics, and design-oriented questions**.

Students are expected to design simulations, justify parameter choices, analyze results statistically, and relate observations to networking theory.

## General Instructions

1. Each group is required to **simulate only one assigned application** and make a **single consolidated submission** through the Google Form provided below. Submission should be made by **any one member of the group**. The mapping between **groups and applications** is specified in **Table 1**.
2. Students must **install the ns-3 network simulator** on their system, develop the required simulation programs, and conduct all experiments as specified in the assigned application. All questions associated with the application must be answered based on the simulation results.
3. **Performance data must be collected using the ns-3 FlowMonitor module only**. The use of **PCAP files and Wireshark for trace collection is strictly prohibited**, and submissions using PCAP-based analysis will receive **zero marks**.
4. Each group must submit a **compressed archive (ZIP/RAR/TAR.GZ)** containing:
    - All source code files used for the simulations
    - A **detailed report** describing the experimental setup, observations, explanations, graphs, and answers to all questions

   The archive file must be named using the group number only (e.g., Group_3.zip). **Submissions without a report will not be evaluated.**

   Google Form link for submission:
   **https://forms.gle/eJN1VATPZ6RjBwsh6**

   Students must write **original source code**. Any form of **plagiarism, code reuse, or unfair means** will be dealt with strictly and may result in **negative marking equivalent to the maximum marks of the assignment**.

# Application 1

Compare the effect of **router buffer size** on the performance of **TCP and UDP flows** in a shared bottleneck network.

Create a **dumbbell topology** consisting of two routers **R1** and **R2** connected by a wired bottleneck link of **10 Mbps bandwidth** and **100 ms propagation delay**. Router **R1** is connected to three hosts **H1**, **H2**, and **H3**, while router **R2** is connected to three hosts **H4**, **H5**, and **H6**. All host-to-router links have a bandwidth of **100 Mbps** and a propagation delay of **10 ms**.

Configure both routers to use **DropTail queues** with **equal queue sizes**, initially set according to the **bandwidth–delay product (BDP)** of the bottleneck link. Use a **packet size of 1.5 KB** for all flows. Make appropriate assumptions wherever necessary.

At the sender side (hosts **H1–H3**), configure:

- **Four TCP NewReno flows** destined for hosts **H4–H6**
- **Two CBR flows over UDP**, each initially transmitting at a rate of **20 Mbps**, destined for hosts **H4–H6**

The flows are scheduled as follows:

- TCP flows start at **0 seconds** and continue until the end of the simulation
- UDP flows start after TCP flows have reached steady state
- The rate of one UDP flow is gradually increased from **20 Mbps up to 100 Mbps**

Repeat the experiment by varying the **router buffer size** from **10 packets to 800 packets**.

## Tasks

1. Plot the **throughput versus time** for all TCP and UDP flows for different buffer sizes.
2. Analyze the effect of increasing UDP sending rate on:
   - TCP throughput
   - Throughput of the competing UDP flow
3. Plot **average throughput versus buffer size** for TCP and UDP flows.
4. Compute and plot **Jain's Fairness Index versus buffer size**.
5. Comment on the impact of buffer sizing on:
   - Fair bandwidth sharing
   - Congestion behavior
   - Queue buildup and packet loss

# Application 2

Create a point-to-point network topology consisting of two nodes **N0** and **N1** connected by a wired link of **1 Mbps bandwidth** and **10 ms propagation delay**. Configure a **DropTail queue** at the link. The queue size should be set appropriately based on the **bandwidth–delay product (BDP)** of the link.

At node **N0**, configure:

- One **TCP agent** (type specified in the tasks below) generating **FTP traffic** destined for **N1**
- Five **CBR traffic sources over UDP**, each transmitting at a rate of **300 Kbps**, also destined for **N1**

Make appropriate assumptions wherever necessary.

## Flow Timing Configuration

- FTP (TCP) flow starts at **0 seconds** and continues until the end of the simulation
- CBR1 starts at **200 ms** and continues till the end
- CBR2 starts at **400 ms** and continues till the end
- CBR3 starts at **600 ms** and stops at **1200 ms**
- CBR4 starts at **800 ms** and stops at **1400 ms**
- CBR5 starts at **1000 ms** and stops at **1600 ms**
- Total simulation time is **1800 ms**

## Tasks

1. **TCP Congestion Window Analysis**
   Plot the **TCP congestion window (cwnd) versus time** for the following TCP congestion control algorithms. Clearly explain the observed congestion control behavior in each case.
   - Case 1: TCP Reno
   - Case 2: TCP Tahoe
   - Case 3: TCP Westwood
   - Case 4: TCP NewReno
   - Case 5: TCP FACK
2. **Packet Drop Analysis**
   Draw a graph showing the **cumulative number of TCP packets dropped versus time**, comparing all five TCP implementations.
3. **Throughput Analysis**
   Draw a graph showing the **cumulative bytes successfully transferred versus time** for all five TCP implementations and compare their performance.

# Application 3

Analyze and compare the performance of **TCP Reno**, **TCP Westwood**, and **TCP FACK (Forward Acknowledgment)** under shared bottleneck conditions.

Create a **dumbbell topology** consisting of two routers **R1** and **R2** connected by a wired bottleneck link of **10 Mbps bandwidth** and **50 ms propagation delay**. Router **R1** is connected to three sender hosts **H1**, **H2**, and **H3**, while router **R2** is connected to three receiver hosts **H4**, **H5**, and **H6**. All host-to-router links have a bandwidth of **100 Mbps** and a propagation delay of **20 ms**.

Configure both routers to use **DropTail queues** with queue size set according to the **bandwidth–delay product (BDP)** of the bottleneck link. Choose a **packet size of 1.2 KB** for all TCP flows. Make appropriate assumptions wherever necessary.

Attach the following TCP variants at the sender hosts:

- **H1** uses **TCP Reno**
- **H2** uses **TCP Westwood**
- **H3** uses **TCP FACK**

Each sender communicates with a corresponding receiver at **R2**.

## Tasks

1. **Single Flow Analysis**
   Activate only **one TCP flow at a time** and run the simulation for a sufficiently long duration to reach steady state. Clearly justify how the simulation duration is selected. For each TCP variant:
   - Measure and plot the **throughput versus time**
   - Plot the **congestion window (cwnd) versus time**
   - Analyze the congestion control behavior
2. **Multiple Flow Analysis**
   Start one TCP flow and, while it is in progress, activate the remaining two TCP flows so that all flows share the bottleneck link.
   - Measure the **throughput (in Kbps)** of each flow
   - Plot **throughput versus time** and **congestion window versus time** for each flow at steady state
   - Determine the **maximum achievable throughput** for each flow
3. **Loss and Goodput Evaluation**
   For each TCP variant:
   - Measure the **congestion loss** over the duration of the experiment
   - Measure the **goodput** (useful data delivered to the receiver per unit time)

- Compare and analyze the efficiency of the three TCP variants

## Application 4

Compare the effect of **CBR traffic over UDP** and **FTP traffic over TCP** in a shared bottleneck network.

Create a **dumbbell topology** consisting of two routers **R1** and **R2** connected by a wired bottleneck link of **30 Mbps bandwidth** and **100 ms propagation delay**. Configure both routers to use **DropTail queues** with queue size set according to the **bandwidth–delay product (BDP)** of the bottleneck link.

Router **R1** is connected to two sender hosts **H1** and **H2**, while router **R2** is connected to two receiver hosts **H3** and **H4**. All host-to-router links have a bandwidth of **80 Mbps** and a propagation delay of **20 ms**.

Configure:

- A **CBR application over UDP** originating from **H1** and destined for **H3**
- An **FTP application over TCP** originating from **H2** and destined for **H4**

Choose an appropriate **packet size** for all experiments. Make appropriate assumptions wherever necessary.

### Tasks

1. **Single Flow Performance Analysis**
   Run the simulation with **only one flow active at a time**:
   - Only CBR over UDP
   - Only FTP over TCP

   For each case, measure and compare:
   - **Average end-to-end delay (in ms)**
   - **Throughput (in Kbps)**
2. **Concurrent Flow Performance Analysis**
   Run the simulation with **both CBR and FTP flows active** under the following conditions:
   - Both flows start at the **same time**
   - Flows start at **different time instants**

   For each scenario, measure and compare:
   - **Average end-to-end delay (in ms)** of CBR and FTP flows
   - **Throughput (in Kbps)** of CBR and FTP flows

3. **Comparative Analysis**
   Analyze the impact of UDP traffic on TCP performance and vice versa. Comment on:
   - Fairness
   - Congestion behavior
   - Delay sensitivity of UDP and TCP traffic

# Application 5

Compare the performance of **TCP over wired and wireless networks** in a heterogeneous network topology.

Consider a network consisting of two TCP sources **Node0** and **Node2**, and their corresponding TCP destinations **Node1** and **Node3**, respectively. **Node0** communicates with **Node1** through a **wireless domain**, while **Node2** communicates with **Node3** through a **wired domain**.

The wireless communication is facilitated through two base stations:

- **Node0** lies in the coverage area of **Base Station BS1**
- **Node1** lies in the coverage area of **Base Station BS2**

Base stations **BS1** and **BS2** are interconnected via a wired link of **10 Mbps bandwidth** and **100 ms propagation delay**.

For the wired domain, **Node2** and **Node3** communicate through two intermediate routers **R1** and **R2**. All wired links are configured with identical bandwidth and delay parameters unless otherwise specified.

All TCP sources use **TCP Reno** as the congestion control algorithm. Make appropriate assumptions wherever necessary.

## Tasks

1. **Packet Size Variation Study**
   Conduct simulations by varying the **TCP packet size** while keeping all other network parameters constant. Use the following TCP packet size values (in KB) for the experiments:
   - 40, 44, 48, 52, 60, 552, 576, 628, 1420, 1500
2. **Throughput Analysis**
   For each packet size:
   - Measure the **steady-state throughput (in Kbps)** of both TCP flows
   - Plot **throughput versus packet size** for wired and wireless TCP connections
3. **Fairness Analysis**
   For each packet size:
   - Compute **Jain’s Fairness Index** between the two TCP flows
   - Plot **fairness index versus packet size**

4. **Comparative Evaluation**
   Analyze and compare:
   - Performance of TCP over wired versus wireless links
   - Impact of packet size on throughput efficiency
   - Fairness behavior under heterogeneous network conditions

| Application Number | Group Number |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |